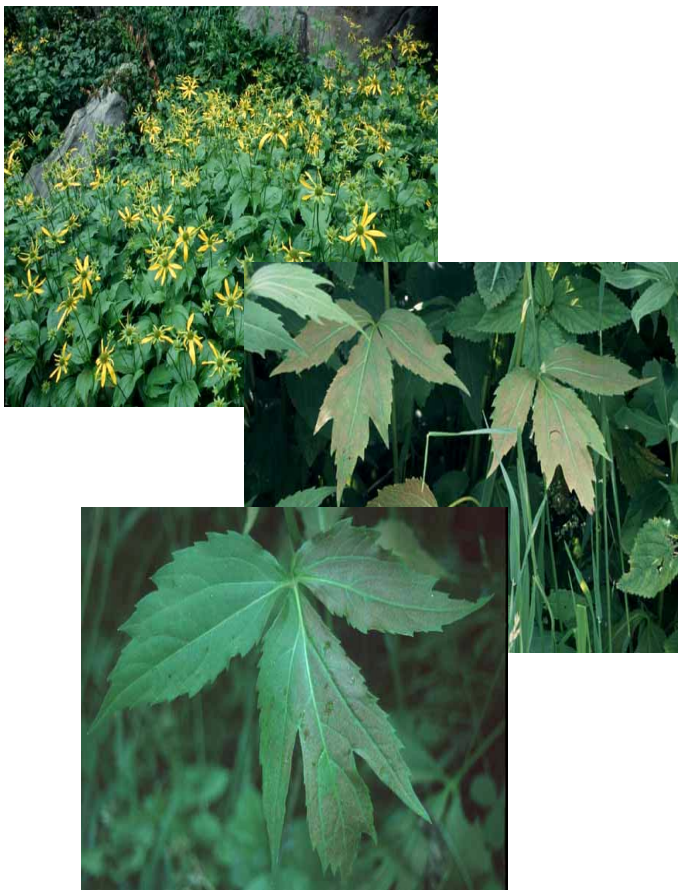
National Park Service
U.S. Department of the Interior

Natural Resource Program Center
Fort Collins, Colorado

Ozone Risk Assessment for Vital Signs Monitoring Networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail

Natural Resource Technical Report NPS/NRPC/ARD/NRTR—2007/001



ON THE COVER
Ozone injury to cutleaf coneflower (*Rudbeckia lacinata var. digitata*) at Great Smoky Mountains National Park
Photographs by: Dr. Art Chappelka, Auburn University, and Dr. Howie Neufeld, Appalachian State University

Ozone Risk Assessment for Vital Signs Monitoring Networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail

Natural Resource Report NPS/NRPC/ARD/NRTR—2007/001

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February 2007

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

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This report was originally written and distributed in February 2005, but was reformatted and published in the Natural Resources Technical Reports series in February 2007 under the new National Park Service report standards. This report is available from the Air Resources Division website (http://www2.nature.nps.gov/air/) on the internet.

Please cite this publication as:

Kohut, R.J., 2007. Ozone risk assessment for Vital Signs Monitoring Networks, Appalachian National Scenic Trail, and Natchez Trace National Scenic Trail. NPS/NRPC/ARD/NRTR—2007/001. National Park Service, Fort Collins, Colorado.

NPS D-566, February 2007

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Introduction

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003; available at http://www2.nature.nps.gov/air/Pubs/pdf/BaltFinalReport1.pdf). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels

of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from the National Park Service Biodiversity Database, NPSpecies, with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus,

the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hour's ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

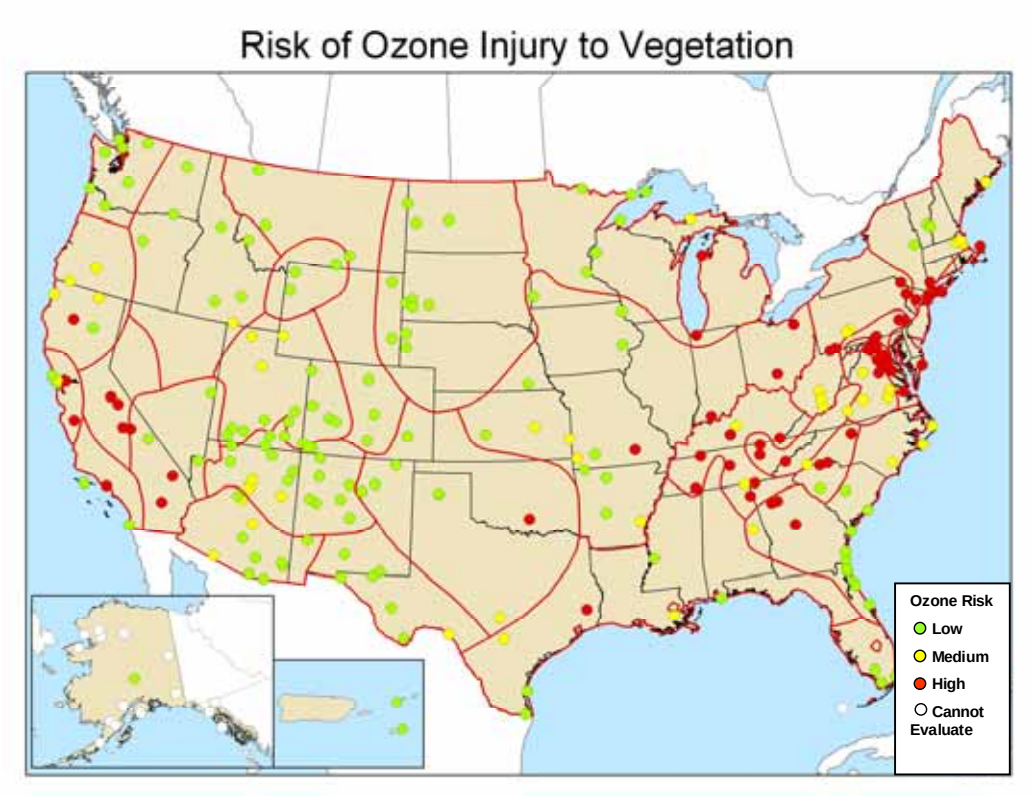
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The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Summary of Results

The Appendix contains a summary table of the risk assessments for 32 Vital Signs Networks, the Appalachian National Scenic Trail, and the Natchez Trace National Scenic Trail. The following map shows the geographic distribution of park units and networks with high, medium, and low risk of ozone injury to vegetation.



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Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. Environmental Management. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. Atmospheric Environment 31(11):1695-1708.

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APPALACHIAN HIGHLANDS NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE APPALACHIAN HIGHLANDS NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

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significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

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Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

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Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. Environmental Management. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. Atmospheric Environment 31(11):1695-1708.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE APPALACHIAN HIGHLANDS NETWORK

Park	Code	State	Risk	O3 Data
Big South Fork NRRA	BISO	TN	high	kriged
Blue Ridge PKWY	BLRI	NC	low	kriged
Great Smoky Mountains NP	GRSM	TN	high	monitored
Obed Wild and Scenic River	OBRI	TN	high	kriged

A portion of the Appalachian National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Appalachian Trail.

BIG SOUTH FORK NATIONAL RIVER AND RECREATION AREA (BISO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BISO					
	1995	1996	1997	1998	1999
Sum06	26	21	26	37	41
W126	38.4	34.1	39.2	56.6	61.3
N60	695	616	709	1004	1112
N80	120	101	116	226	249
N100	17	8	10	34	24

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BISO					
	1995	1996	1997	1998	1999
Month 1	1.05	-0.16	-3.06	0.23	3.52
Month 2	-1.28	0.98	-0.75	0.33	0.07
Month 3	-0.50	0.82	0.66	-2.51	-1.87

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BISO					
	1995	1996	1997	1998	1999
April	-1.05	0.28	0.06	4.35	-1.14
May	2.31	0.46	2.10	-0.31	0.18
June	1.05	-0.16	5.90	6.93	3.52
July	-1.28	0.98	-3.06	0.23	0.07
August	-0.50	0.82	-0.75	0.33	-1.87
September	0.81	2.45	0.66	-2.51	-2.48
October	3.77	-0.93	0.25	-1.30	-1.25

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during the 90-day Sum06 accumulation periods were generally normal and favored the uptake of ozone. In the five-year assessment period there was one month of mild to severe drought in each of four years, with normal soil moisture in the fifth year. There is no apparent relationship between the Sum06 exposure index and soil moisture conditions. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone years, 1999 and 1998, there were four and two months, respectively, of mild and moderate drought. The two mid-ozone years,

1995 and 1997, had two months of mild and one month of severe drought, respectively. In the lowest ozone year, 1996, soil moisture conditions were normal.

The risk of foliar ozone injury at Big South Fork National River and Recreation Area is high. While the levels of ozone exposure create the potential for injury each year, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds and soil moisture is normal, and in 1998 when exposures are high and drought occurs late in the growing season.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

BLUE RIDGE PARKWAY (BLRI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Krigia montana	Mountain dandelion	Asteraceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in

cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BLRI					
	1995	1996	1997	1998	1999
Sum06	7	18	12	20	19
W126	22.6	33.7	23.9	38.9	33.9
N60	235	544	340	736	576
N80	8	20	5	21	16
N100	0	0	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BLRI					
	1995	1996	1997	1998	1999
Month 1	-0.22	-0.70	2.84	-2.57	1.24
Month 2	3.12	0.26	-1.17	-2.52	-0.91
Month 3	-1.62	-0.32	-3.35	-3.01	-2.64

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BLRI					
	1995	1996	1997	1998	1999
April	-2.81	0.22	2.05	3.84	-0.96
May	-0.22	-0.70	-0.13	-1.65	-0.39
June	3.12	0.26	2.84	0.73	1.24
July	-1.62	-0.32	-1.17	-2.57	-0.91
August	1.98	1.36	-3.35	-2.52	-2.64
September	-0.16	2.86	1.59	-3.01	-1.75
October	3.09	-1.80	0.65	-1.32	-0.37

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb, and only one year in which the concentration reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Although the year with the highest Sum06 and W126 index of exposure, 1998, also had the most months of drought stress, there is no overall association between ozone and drought for either index of exposure. The three highest Sum06 indices in 1998, 1999 and 1996 were similar in magnitude, but accompanied by three months of moderate and severe drought, one month of moderate drought, and normal moisture conditions, respectively. The highest W126 index occurred in 1998 and was associated with five months of mild to severe drought. The two mid-exposure years, 1996 and 1999, experienced one and two months of mild and moderate drought, respectively. There were two

months of mild to severe drought in each of the two lowest exposure years, 1997 and 1995. Overall, there is no apparent association between the W126 index of exposure and drought stress.

The low levels of ozone exposure at Blue Ridge Parkway make the risk of foliar ozone injury to plants low. The Sum06 exposure threshold is generally satisfied, but the W126 criteria are not. While there are some hours with concentrations of ozone above 80 ppb, the numbers are not high and concentrations of 100 ppb are rare. Soil moisture conditions and ozone exposure levels are not related, and conditions constraining uptake can occur at any level of ozone exposure.

If a program to assess the incidence of foliar ozone injury on plants at the site is initiated at some point in the future, one or more of the following bioindicator species could be used: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, common snowberry and crownbeard.

GREAT SMOKY MOUNTAINS NATIONAL PARK (GRSM)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Krigia montana	Mountain dandelion	Asteraceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in

cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Lookout Rock

Ozone air quality data for GRSM – Lookout Rock					
	1995	1996	1997	1998	1999
Sum06	33	35	47	46	54
W126	66.9	76.6	92.8	120.6	128.8
N60	1270	1490	1686	2102	2240
N80	218	175	374	558	617
N100	24	5	42	105	82

Cade's Cove

Ozone air quality data for GRSM – Cade's Cove					
	1995	1996	1997	1998	1999
Sum06	16	18	22	27	36
W126	23.6	24.3	30.6	42.2	47.4
N60	410	452	570	742	877
N80	33	21	56	131	159
N100	4	0	1	5	8

Cove Mountain

Ozone air quality data for GRSM – Cove Mountain					
	1995	1996	1997	1998	1999
Sum06	36	38	44	55	57
W126	95.7	98.7	106.2	142.6	141.3
N60	1856	1990	2019	2566	2511
N80	247	248	368	680	680
N100	18	8	15	107	54

Clingman's Dome

Ozone air quality data for GRSM – Clingman's Dome					
	1995	1996	1997	1998	1999
Sum06	18	31	35	51	51
W126	65.9	74.2	90.0	136.2	133.9
N60	1300	1489	1786	2577	2568
N80	127	124	188	617	510
N100	5	3	5	57	29

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRSM					
	1995	1996	1997	1998	1999
Month 1	1.37	-0.09	-0.80	-0.89	1.52
Month 2	-2.96	1.38	-1.53	-1.71	-2.38
Month 3	-1.51	1.32	1.39	-2.87	-1.82

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRSM					
	1995	1996	1997	1998	1999
April	-2.42	0.78	1.59	7.53	-0.78
May	2.15	1.14	2.08	-0.33	0.42
June	1.37	-0.09	3.01	3.96	2.45
July	-2.96	1.38	-0.80	-0.89	1.52
August	-1.51	1.32	-1.53	-1.71	-2.38
September	0.24	2.32	1.39	-2.87	-1.82
October	1.38	-0.86	0.51	-2.35	-0.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury at each of the sites. The W126 accumulative value significantly exceeds the threshold at each site, however the N100 count is highly variable both among sites and years. The number of hours above 100ppb ozone often, but not consistently, meets the threshold for injury under the W126 criterion for injury to vegetation.

- The N-values for concentrations of 60 and 80 ppb are very high and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone. While the N100 index is highly variable, site-years with 10 hours of concentrations greater than 100 ppb are common and there are five site-years with over 50 hours of ozone greater than 100 ppb.

- Relationships between levels of ozone exposure and soil moisture were assessed using data for Lookout Rock and Cove Mountain sites since they generally had the highest levels of exposure. There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The highest exposure years, 1998 and 1999, and the lowest year, 1995, each experienced two months of mild and moderate drought. Soil moisture levels

associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone years, 1998 and 1999, there were three and two months, respectively, of mild and moderate drought. The two mid-ozone years, 1997 and 1996, had one month of mild drought and normal moisture conditions. In the lowest ozone year, 1995, there were three months of mild and moderate drought.

The risk of foliar ozone injury to plants at Great Smoky Mountains National Park is high. The threshold for the Sum06 index is consistently exceeded at all sites, while the threshold for the W126 index is consistently exceeded at some sites and occasionally at others. Hours of exposure at 80 and 100 ppb vary widely among sites and years. Although the levels of ozone exposure create the potential for injury, dry soil conditions may reduce the likelihood of injury developing in high exposure years. Since the park is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1997 and 1999 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone. While all four Smoky Mountain sites have a high risk for ozone injury, the Cade's Cove site shows levels of ozone distinctly lower than those at the other three sites. Exposure trends among the four sites are similar with the highest exposures occurring in the same years at all sites and the lowest exposures in the same years. Thus it is likely that the level of risk of ozone injury will be similar among all four sites in any given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and crownbeard.

OBED WILD AND SCENIC RIVER (OBRI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for OBRI					
	1995	1996	1997	1998	1999
Sum06	17	17	15	18	24
W126	40.9	41.1	47.0	63.6	63.6
N60	727	750	845	1118	1147
N80	140	129	154	270	267
N100	22	11	13	42	31

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at OBRI					
	1995	1996	1997	1998	1999
Month 1	1.05	-0.16	-3.06	6.93	0.07
Month 2	-1.28	0.98	-0.75	0.23	-1.87
Month 3	-0.50	0.82	0.66	0.33	-2.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at OBRI					
	1995	1996	1997	1998	1999
April	-1.05	0.28	0.06	4.35	-1.14
May	2.31	0.46	2.10	-0.31	0.18
June	1.05	-0.16	5.90	6.93	3.52
July	-1.28	0.98	-3.06	0.23	0.07
August	-0.50	0.82	-0.75	0.33	-1.87
September	0.81	2.45	0.66	-2.51	-2.48
October	3.77	-0.93	0.25	-1.30	-1.25

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant numbers of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- There is no relationship between the 90-day Sum06 accumulation period index of ozone and soil. The highest exposure year, 1999, had two months of mild and moderate drought, while the lowest year, 1997, had one month of severe drought. There was one month of mild drought in the remaining three mid-exposure years. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is inconsistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The highest

ozone years, 1998 and 1999, experienced two and four months of mild to moderate drought. The mid-exposure year 1997 had one month of severe drought. Soil moisture in the two lowest years, 1995 and 1996, consisted of two months of mild drought and normal moisture conditions, respectively.

The risk of foliar ozone injury to plants at Obed Wild and Scenic River is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury, particularly in a high exposure year. Levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

APPALACHIAN NATIONAL SCENIC TRAIL (APPL)

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION AT SITES ALONG THE APPALACHIAN NATIONAL SCENIC TRAIL
October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers to better understand the risk of ozone injury to vegetation and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used, and how they were applied and modified to meet the requirements of producing an assessment for the 2174-mile long Appalachian Trail. It also provides a summary of the results of risk assessments for sites along the Trail.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Due to its linear configuration and length, the Appalachian Trail is represented by 30 sub-sites with a risk assessment for each. The sub-sites consist of US National Park sites on and near the Appalachian Trail and EPA AIRS ozone monitoring sites located near the Trail. Plant species and ozone exposure data are not complete for each site, and therefore the quality of the risk assessment varies among sites.

Appalachian National Scenic Trail Assessment Sites and Data Availability

State	Location	County	AIRS ID #	Sum06 yrs	W126 yrs	N-value yrs
GA	Dawsonville	Dawson	130850001	95-99	95-99	95-99
	Great Smokey Mtn		NPS	95-99	95-99	95-99
NC	Bryson City	Swain	371730002	95-99	95-99	95-99
	Mount Mitchell	Yancey	371990003	95-99	95,97-99	95,97-99
	Lenoir	Caldwell	370270003	95,97-99	95,97-99	95,97-99
TN	Kingsport	Sullivan	471632003	---	95-99	95-99
	Blountville	Sullivan	471632002	---	95-99	95-99
VA	Rural Retreat	Wythe	511970002	95-99	95-99	95-99
WV	Bluestone NSR		NPS	95-99	95-99	95-99
VA	Vinton	Roanoke	511611004	95-99	95-99	95-99
	Glenwood-Pedlar	Rockbridge	511630003	99	99	99
	Shenandoah NP		NPS	95-99	95-99	95-99
	Rest	Frederick	510690010	95-99	95-99	95-99
WV	Harpers Ferry		NPS	95-99	95-99	95-99
MD	Catoctin Mtn Park		NPS	95-99	95-99	95-99
PA	Gettysburg		NPS	95-99	95-99	95-99
	Little Buffalo SP	Perry	420990301	---	95-99	95-99
	Kutztown Univ	Berks	420110001	95-99	95-99	95-99
	Kunkletown	Monroe	420890001	97-99	98-99	98-99
	Del Water Gap		NPS	95-99	95-99	95-99
NY	Montgomery	Orange	360715001	95-99	95-99	95-99
	Roosevelt NHS		NPS	95-99	95-99	95-99
CT	Torrington	Litchfield	090050006	---	95-99	95-99
MA	Mount Greylock	Berkshire	250034002	---	95-96,98-99	95-96,98-99
VT	Bennington	Bennington	500030004	95-99	95-99	95-99
	Marsh-Billings		NPS	95-99	95-99	95-99
	Saint-Gaudens		NPS	95-99	95-99	95-99
NH	Haverhill	Grafton	330090008	---	97-99	97-99
	Mt Washington	Coos	330074001	---	95	95
ME	Greenville	Piscataquis	230210002	---	95-96	95-96

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone.

Ozone-sensitive and bioindicator plant species at each National Park Service site along the Appalachian Trail were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop. Since there are no floral lists for the EPA AIRS monitoring sites used in the assessment, another approach had to be adopted for them. The database maintained by the US Forest Service for the Forest Inventory/Forest Health Monitoring program (FIA/FHM) was consulted. Data on all FIA/FHM assessment plots within 25 miles of the AIRS monitoring site were evaluated to identify ozone-sensitive tree species occurring there. Since the FIA/FHM assessments currently examine only trees, it was not possible to identify ozone-sensitive herbaceous or understory species associated with the AIRS sites.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 were obtained either from on-site monitoring or by kriging, a statistical interpolation process. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the

assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Ozone exposure values for the sites along the Appalachian Trail were provided by the Air Resources Division of the National Park Service using hourly data either from their own or from the EPA AIRS database. Exposure values for the National Park Service sites were produced using hourly data either from on-site monitoring or estimated by kriging. Hourly monitoring data from EPA AIRS were used to generate exposure values for the non-Park Service sites in the assessment.

Although the assessment period is five years, 1995 through 1999, not all sites have the complete suite of data for the exposure indices. This limits the understanding of the exposure regimes at some sites and constrains their risk assessments. Sites with limited ozone data were included in the Appalachian Trail assessment to both identify them for use future evaluation and to provide an initial look at their ozone environments.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not

available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

The collection of 30 National Park Service and AIRS sites provides a reasonable spatial distribution of assessment points from Georgia to Maine along the Appalachian Trail. However, there are several factors that need to be considered when relating the risk assessments for the sites to that of the Trail. Except where the Appalachian Trail passes through a national park, the species lists represent those found in the vicinity of the assessment site and not those actually on the Trail. A second consideration is that since the Park Service and AIRS monitoring sites are generally at elevations different from those of the Trail in that area, the ozone regimes at the monitoring sites may not be representative of those on the Trail. The magnitudes of the differences between the sites cannot be accurately assessed except to note that ozone exposures generally increase with increasing elevation. Lastly, the Palmer Z data used for the monitoring sites may not

accurately represent soil moisture conditions on the Trail due to differences in soil type, physiography, and precipitation that occur with elevation. As a consequence of these factors, the assessments should be viewed as providing insight to the levels of risk that exist at selected points along the Appalachian Trail, and used as guidance in determining either whether a field injury survey is appropriate, or whether additional ozone exposure and species information should be collected and evaluated before a decision about risk can be made.

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SUMMARY OF RISK ASSESSMENTS FOR SITES ALONG THE APPALACHIAN NATIONAL SCENIC TRAIL

Site / Park		State	Risk
Dawsonville		GA	moderate
Great Smokey Mountain NP	GRSM	NC	high
Bryson City		NC	low
Mount Mitchell		NC	moderate
Lenoir		NC	moderate
Kingsport		TN	high
Blountville		TN	moderate
Rural Retreat		VA	low
Bluestone NSR	BLUE	WV	moderate
Vinton		VA	low
Glenwood-Pedlar Ranger Station		VA	low
Shenandoah NP	SHEN	VA	moderate
Rest		VA	low
Harpers Ferry NHP	HAFE	WV	high
Catoctin Mountain Park	CATO	MD	high
Gettysburg NMP	GETT	PA	high
Little Buffalo State Park		PA	moderate
Kutztown University		PA	moderate
Kunkletown		PA	moderate
Delaware Water Gap NRA	DEWA	PA	high
Montgomery		NY	high
Roosevelt-Vanderbilt Headquarters	ROVA	NY	high
Torrington		CT	high
Mount Greylock		MA	low
Bennington		VT	low
Marsh-Billings NHP	MABI	VT	low
Saint-Gaudens NHS	SAGA	VT	low
Haverhill		NH	low
Mount Washington		NH	low
Greenville		ME	low

GEORGIA

Dawsonville, Dawson County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus spp.	Ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Dawsonville, Dawson County					
	1995	1996	1997	1998	1999
Sum06	16	17	16	34	32
W126	25.7	23.5	23.7	49.5	49.5
N60	452	420	412	889	903
N80	22	45	38	167	183
N100	3	3	1	21	6

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since it was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Dawsonville					
	1995	1996	1997	1998	1999
Month 1	-2.01	-0.95	-1.66	-2.60	-1.21
Month 2	-1.49	0.22	0.76	0.21	-0.59
Month 3	-1.24	-1.17	0.75	-1.53	0.96

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Dawsonville					
	1995	1996	1997	1998	1999
April	-1.49	0.22	0.76	4.22	-1.77
May	-1.24	-0.95	0.75	-0.96	0.17
June	2.87	0.22	1.93	-0.84	1.82
July	-2.11	-1.17	0.62	-2.60	-0.23
August	2.84	0.23	-1.40	0.21	-1.21
September	0.01	1.70	2.65	-1.53	-0.59
October	4.86	-1.23	3.20	-2.04	0.96

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at these concentrations was significantly lower. In the higher ozone years, the levels of exposure could injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. In 1998 when the Sum06 index was high there were two months of drought stress, and in 1995 when the index was the lowest there were three months of drought. The intermediate exposure years each had one month of drought. The two years with the highest W126 indices of exposure, 1998 and 1999, had three and two months

of drought stress respectively. The remaining three years had similar and significantly lower levels of exposure and exposure had from one to three months of drought. Collectively, there are no consistent relationships between the Sum06 and W126 levels of ozone and soil moisture conditions.

The risk of foliar ozone injury to plants in the vicinity of Dawsonville is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index is satisfied in two years. The N-values indicate that exposure to concentrations of ozone greater than 80 and 100 ppb is highly variable with elevated levels in two years. There are no associations between the levels of ozone exposure and soil moisture, and the uptake of ozone may be fostered or constrained in any year. It is anticipated that the risk of injury may be greatest in years such as 1999 when ambient levels of ozone exceed thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Great Smokey Mountains National Park (GRSM)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Aster umbellatus	Flat-topped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Krigia montana	Mountain dandelion	Asteraceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae

Sambucus canadensis	American elder	Caprifoliaceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Lookout Rock

Ozone air quality data for GRSM – Lookout Rock					
	1995	1996	1997	1998	1999
Sum06	33	35	47	46	54
W126	66.9	76.6	92.8	120.6	128.8
N60	1270	1490	1686	2102	2240
N80	218	175	374	558	617
N100	24	5	42	105	82

Cade's Cove

Ozone air quality data for GRSM – Cade's Cove					
	1995	1996	1997	1998	1999
Sum06	16	18	22	27	36
W126	23.6	24.3	30.6	42.2	47.4
N60	410	452	570	742	877
N80	33	21	56	131	159
N100	4	0	1	5	8

Cove Mountain

Ozone air quality data for GRSM – Cove Mountain					
	1995	1996	1997	1998	1999
Sum06	36	38	44	55	57
W126	95.7	98.7	106.2	142.6	141.3
N60	1856	1990	2019	2566	2511
N80	247	248	368	680	680
N100	18	8	15	107	54

Clingman's Dome

Ozone air quality data for GRSM – Clingman's Dome					
	1995	1996	1997	1998	1999
Sum06	18	31	35	51	51
W126	65.9	74.2	90.0	136.2	133.9
N60	1300	1489	1786	2577	2568
N80	127	124	188	617	510
N100	5	3	5	57	29

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil

moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRSM					
	1995	1996	1997	1998	1999
Month 1	1.37	-0.09	-0.80	-0.89	1.52
Month 2	-2.96	1.38	-1.53	-1.71	-2.38
Month 3	-1.51	1.32	1.39	-2.87	-1.82

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRSM					
	1995	1996	1997	1998	1999
April	-2.42	0.78	1.59	7.53	-0.78
May	2.15	1.14	2.08	-0.33	0.42
June	1.37	-0.09	3.01	3.96	2.45
July	-2.96	1.38	-0.80	-0.89	1.52
August	-1.51	1.32	-1.53	-1.71	-2.38
September	0.24	2.32	1.39	-2.87	-1.82
October	1.38	-0.86	0.51	-2.35	-0.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury at each of the sites. The W126 accumulative value significantly exceeds the threshold at each site, however the N100 count is highly variable both among sites and years. The number of hours above 100ppb ozone often, but not consistently, meets the threshold for injury under the W126 criterion for injury to vegetation.

- The N-values for concentrations of 60 and 80 ppb are very high and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone. While the N100 index is highly variable,

site-years with 10 hours of concentrations greater than 100 ppb are common and there are five site-years with over 50 hours of ozone greater than 100 ppb.

- Relationships between levels of ozone exposure and soil moisture were assessed using data for Lookout Rock and Cove Mountain sites since they generally had the highest levels of exposure. There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The highest exposure years, 1998 and 1999, and the lowest year, 1995, each experienced two months of mild and moderate drought. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone years, 1998 and 1999, there were three and two months, respectively, of mild and moderate drought. The two mid-level ozone years, 1997 and 1996, had one month of mild drought and normal moisture conditions. In the lowest ozone year, 1995, there were three months of mild and moderate drought.

The risk of foliar ozone injury to plants at Great Smoky Mountains National Park is high. The threshold for the Sum06 index is consistently exceeded at all sites, while the threshold for the W126 index is consistently exceeded at some sites and occasionally at others. Hours of exposure at 80 and 100 ppb vary widely among sites and years. Although the levels of ozone exposure create the potential for injury, dry soil conditions may reduce the likelihood of injury developing in high exposure years. Since the park is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1997 and 1999 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone. While all four Smoky Mountain sites have a high risk for ozone injury, the Cade's Cove site shows levels of ozone distinctly lower than those at the other three sites. Exposure trends among the four sites are similar with the highest exposures occurring in the same years at all sites and the lowest exposures in the same years. Thus it is likely that the level of risk of ozone injury will be similar among all four sites in any given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and crownbeard.

NORTH CAROLINA

Bryson City, Swain County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus spp.	Ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
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W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and

100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Bryson City, Swain County					
	1995	1996	1997	1998	1999
Sum06	8	5	11	22	22
W126	12.2	9.0	16.2	30.7	31.0
N60	180	120	259	588	649
N80	1	0	5	43	16
N100	0	0	0	0	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Bryson City					
	1995	1996	1997	1998	1999
Month 1	-1.62	0.26	1.58	-2.57	-0.96
Month 2	1.98	-0.32	2.05	-2.52	-0.39
Month 3	-0.16	1.36	-0.13	-3.01	1.24

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Bryson City					
	1995	1996	1997	1998	1999
April	-2.81	-0.22	2.05	3.84	-0.96
May	-0.22	-0.70	-0.13	-1.65	-0.39
June	3.12	0.26	2.84	0.73	1.24
July	-1.62	-0.32	-1.17	-2.57	-0.91
August	1.98	1.36	-3.35	-2.52	-2.64
September	-0.16	2.86	1.59	-3.01	-1.75
October	3.09	-1.80	0.65	-1.32	-0.37

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and generally exceeded 80 ppb for a few hours each year. Ozone exceeded 100 ppb for only one hour over the five-year assessment period. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture status. Both 1998 and 1999 had the highest level of ozone exposure, but 1998 had three months of moderate to severe drought while 1999 had favorable conditions throughout. There was only one month of mild drought in the remaining three years. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher

exposures in producing foliar injury. In the two highest ozone years, 1998 and 1999, there were five months of mild to severe drought and two months of mild and moderate drought, respectively. There was one month of mild drought in 1996, the year with the lowest ozone. The remaining years were intermediate in exposure and each experienced two months of drought.

The low level of ozone exposure and soil moisture conditions make the risk of foliar ozone injury to plants in the vicinity of Bryson City low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are few hours with concentrations of ozone above 80 ppb, and only one hour of exposure to 100 ppb ozone. The inverse relationship between exposure and soil moisture constrains uptake during high exposures and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, yellow-poplar, American sycamore, and black cherry.

Mount Mitchell, Yancey County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus spp.	Ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to

give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Mount Mitchell, Yancey County					
	1995	1996	1997	1998	1999
Sum06	34	10	14	7	35
W126	82.1	-	32.8	-	82.1
N60	1639	-	559	-	1621
N80	210	-	13	-	234
N100	13	-	0	-	6

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Mount Mitchell					
	1995	1996	1997	1998	1999
Month 1	-1.62	0.26	-1.17	-2.57	-0.91
Month 2	1.98	-0.32	-3.35	-2.52	-2.64
Month 3	-0.16	1.36	1.59	-3.01	-1.75

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Mount Mitchell					
	1995	1996	1997	1998	1999
April	-2.81	-0.22	2.05	3.84	-0.96
May	-0.22	-0.70	-0.13	-1.65	-0.39
June	3.12	0.26	2.84	0.73	1.24
July	-1.62	-0.32	-1.17	-2.57	-0.91
August	1.98	1.36	-3.35	-2.52	-2.64
September	-0.16	2.86	1.59	-3.01	-1.75
October	3.09	-1.80	0.65	-1.32	-0.37

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. Only three years of data are available to assess the W126 index of exposure. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the three years. The criteria for injury under the W126 exposure index are generally satisfied.

- Three years of data are available to assess N-values. In two of the years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining year, the number of hours at 80 ppb was significantly lower and there were no hours above 100 ppb. In the two high ozone years the levels of exposure could injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The year with the highest Sum06 exposure index, 1999, had two months of drought while the year with the lowest index, 1998, had three. The intermediate years experienced two, one, and no months of drought. Three years of W126 ozone data are available to assess relationships with soil moisture; two years have high and similar exposures and the remaining year a significantly lower level of exposure. All three years experienced two months of mild to severe drought. No association is apparent between ozone exposure and soil moisture.

The risk of foliar ozone injury to plants in the vicinity of Mount Mitchell is moderate. The threshold for injury is consistently satisfied by the Sum06 index, while the W126 index is satisfied in two years. The N-values indicate that exposure to concentrations of ozone greater than 80 and 100 ppb is highly variable. There are no apparent associations between the levels of ozone exposure and soil moisture, and the uptake of ozone may be fostered or constrained in any year. The limited data available indicate exposures vary considerably among years and levels of risk vary accordingly. It is anticipated that the risk of injury may be greatest in years such as 1995 when ambient levels of ozone are moderately high and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, yellow-poplar, American sycamore, and black cherry.

Lenoir, Caldwell County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus spp.	Ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae

Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Lenoir, Caldwell County					
	1995	1996	1997	1998	1999
Sum06	30	-	24	43	42
W126	41.2	-	31.0	53.6	63.2
N60	813	-	603	957	1145
N80	70	-	41	208	264
N100	1	-	0	30	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Lenoir					
	1995	1996	1997	1998	1999
Month 1	-3.30	-	0.95	-2.14	-0.39
Month 2	-0.22	-	-2.65	-0.80	-0.09
Month 3	4.71	-	0.20	-2.27	-1.29

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Lenoir					
	1995	1996	1997	1998	1999
April	-3.30	-1.02	2.01	3.87	-0.58
May	-0.22	-0.52	-1.28	0.86	-1.37
June	4.71	0.48	1.47	0.17	-0.39
July	-1.55	-0.32	0.95	-2.14	-0.09
August	0.08	4.24	-2.65	-0.80	-1.29
September	-0.43	1.81	0.20	-2.27	0.31
October	3.36	-1.41	-0.87	-1.46	-1.09

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- Four years of data are available to assess the Sum06 and W126 indices of exposure. The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the requirement in two of the four years, and thus the criteria for injury under the W126 exposure index are frequently satisfied.

- In two of the four years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at these concentrations was significantly lower. In the high ozone years, the levels of exposure could injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Of the four years of data available, the two highest exposure years, 1998 and 1999, experienced two and one month of drought, respectively, while each of the two lower exposure years had one month of drought. Soil moisture levels associated with the seasonal W126 index appear unrelated to the levels of exposure. Four years of exposure data are available for assessment. The two years with highest exposures, 1999 and 1998, each had three months of mild and moderate drought, while the two lowest years, 1995 and 1997, each had two months of mild to severe drought. No clear relationship between exposure and soil moisture is evident even though the levels of exposure cover a considerable range.

The risk of foliar ozone injury to plants in the vicinity of Lenoir is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index is satisfied in two years. The N-values indicate that exposure to concentrations of

ozone greater than 80 and 100 ppb is highly variable with elevated levels in two years. No association is apparent between the level of ozone exposure and soil moisture, however some constraint on the uptake of ozone occurs each year. Variation in the annual level of exposure and the occurrence of two or three months of drought each year produce significant differences in the annual level of risk. It is anticipated that the risk of injury could be greatest in years such as 1999 when ambient levels of ozone are high and months of mild drought are scattered over the year and do not create long-term constraints on uptake.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

TENNESSEE

Kingsport, Sullivan County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Kingsport, Sullivan County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	41.6	34.0	35.7	52.9	45.5
N60	739	606	624	915	835
N80	154	112	133	273	190
N100	19	11	11	42	7

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Kingsport					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Kingsport					
	1995	1996	1997	1998	1999
April	-2.42	0.78	1.59	7.53	-0.78
May	2.15	1.14	2.08	-0.33	0.42
June	1.37	-0.09	3.01	3.96	2.45
July	-2.96	1.38	-0.80	-0.89	1.52
August	-1.51	1.32	-1.53	-1.71	-2.38
September	0.24	2.32	1.39	-2.87	-1.82
October	1.38	-0.86	0.51	-2.35	-0.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, but the association is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The year with the highest exposure index, 1998, had three months of mild to moderate drought. The intermediate exposure years 1999 and 1995 had two and three months of drought, respectively. The years with the two lowest exposures, 1996 and 1997, had none and one month of drought.

The risk of foliar ozone injury to plants in the vicinity of Kingsport is high. The W126 levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in a high exposure year. Exposures capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Blountville, Sullivan County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Blountville, Sullivan County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	39.5	32.3	34.8	48.9	32.2
N60	719	597	620	843	587
N80	137	91	107	232	116
N100	23	3	9	34	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil

moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Blountville					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Blountville					
	1995	1996	1997	1998	1999
April	-2.42	0.78	1.59	7.53	-0.78
May	2.15	1.14	2.08	-0.33	0.42
June	1.37	-0.09	3.01	3.96	2.45
July	-2.96	1.38	-0.80	-0.89	1.52
August	-1.51	1.32	-1.53	-1.71	-2.38
September	0.24	2.32	1.39	-2.87	-1.82
October	1.38	-0.86	0.51	-2.35	-0.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for concentrations of 60 and 80 ppb are elevated in each year. In two years the N-value for 100 ppb is high, but considerably lower in the

remaining years. These data indicate that in some years plants are exposed to levels of ozone likely to produce foliar injury.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two years with the highest exposure indices, 1998 and 1995, each had three months of mild to moderate drought. The intermediate exposure year 1997 had one month of drought. The two years with the lowest exposures, 1996 and 1999, had no and two months of drought, respectively.

The risk of foliar ozone injury to plants in the vicinity of Blountville is moderate. The W126 index criteria are generally satisfied, and the N80 and N100 counts are high in two years and significantly lower in others. The inverse relationship between ozone exposure and soil moisture constrains uptake in high exposure years and reduces the likelihood the exposures will produce foliar injury. The probability of foliar injury developing may greatest during years such as 1997 when ozone exposures exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone, or like1998 and 1999 when drought occurs only at the end of the growing season after an extended period of conditions favorable for the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

VIRGINIA

Rural Retreat, Wythe County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Rural Retreat, Wythe County					
	1995	1996	1997	1998	1999
Sum06	27	22	29	41	38
W126	35.3	29.7	41.2	49.3	52.9
N60	721	567	769	958	1088
N80	39	10	65	107	98
N100	1	0	0	0	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Rural Retreat					
	1995	1996	1997	1998	1999
Month 1	3.70	-0.59	0.49	-2.35	-0.69
Month 2	-3.27	0.01	-1.56	-0.49	-2.14
Month 3	-3.30	2.52	-2.59	-2.72	-1.40

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Rural Retreat					
	1995	1996	1997	1998	1999
April	-2.46	-0.76	-0.24	4.16	-0.52
May	1.56	2.78	-0.14	2.21	-0.69
June	3.70	-0.59	0.49	1.94	-2.14
July	-3.27	0.01	-1.56	-2.35	-1.40
August	-3.30	2.52	-2.59	-0.49	-2.02
September	-0.51	2.56	-0.91	-2.72	-0.06
October	-0.02	0.07	-2.15	-2.14	-1.38

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and 80 ppb in most years. No year had more than two hours in which the concentration exceeded 100 ppb and most years had none. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. For the Sum06 index, four of the five years had two months of drought, and the lowest ozone year had favorable soil moisture conditions. A similar pattern existed with the W126 index. Four years each had three or four months of drought, and the lowest year had favorable moisture conditions throughout. While this may appear to be an inverse relationship, there is no pattern of decreasing incidence of drought over a range of decreasing levels of ozone exposure.

The low level of ozone exposure and soil moisture make the risk of foliar ozone injury to plants in the vicinity of Rural Retreat low. The W126 exposures do not exceed the threshold since the N100 criterion is not satisfied. There are a moderate number of hours with concentrations of ozone above 80 ppb in some years, but exposure to 100 ppb is rare. Most years experience three or four months of drought and the uptake of ozone during these years would be constrained and the likelihood of foliar injury reduced.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

WEST VIRGINIA

Bluestone National Scenic River (BLUE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanacea
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BLUE					
	1995	1996	1997	1998	1999
Sum06	27	19	24	36	37
W126	45.9	30.3	46.8	64.8	59.9
N60	892	554	897	1217	1163
N80	92	46	86	215	161
N100	6	3	3	21	9

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BLUE					
	1995	1996	1997	1998	1999
Month 1	-2.22	-0.66	0.82	2.42	-1.03
Month 2	-2.76	4.73	0.50	-1.48	-2.58
Month 3	0.76	0.41	0.30	-1.56	-2.18

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BLUE					
	1995	1996	1997	1998	1999
April	-1.98	-0.66	-0.84	2.50	0.47
May	2.67	4.73	0.82	3.09	-1.03
June	3.62	0.41	0.50	2.42	-2.58
July	-2.22	-0.59	0.30	-1.48	-2.18
August	-2.76	2.36	-0.72	-1.56	-1.45
September	0.76	3.75	-0.74	-2.96	1.05
October	0.65	-0.17	-1.99	-2.14	-0.07

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in some years. The higher levels of exposure can injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126

accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1999 and 1998, had, respectively, three and two months of mild and moderate drought. The two intermediate ozone years, 1995 and 1997, had two months of moderate drought stress and normal soil moisture, respectively. Soil moisture was normal in 1996, the year with the lowest ozone exposure. Soil moisture levels associated with the W126 index also appear to be inversely related to ozone concentrations, although the pattern is not consistent. The two highest ozone years, 1998 and 1999, each had four months of mild and moderate drought. The two mid-level exposure years, 1997 and 1995, had one month of mild drought, and three months of mild and moderate drought, respectively. The year with the lowest ozone exposure, 1996, had normal soil moisture conditions.

The risk of foliar ozone injury to plants at Bluestone National Scenic River is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in two years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is reduced. The two years that have favorable soil moisture conditions, 1996 and 1997, also have ozone exposures that are lower. These years, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may be greatest during years when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, Allegheny blackberry, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

VIRGINIA

Vinton, Roanoke County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Vinton, Roanoke County					
	1995	1996	1997	1998	1999
Sum06	28	16	30	46	40
W126	34.1	19.9	37.6	59.1	35.3
N60	674	357	669	1033	658
N80	52	8	97	238	130
N100	0	0	2	34	8

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Vinton					
	1995	1996	1997	1998	1999
Month 1	-1.02	2.58	1.17	-3.15	-2.90
Month 2	-2.36	2.01	-0.68	-1.29	-2.57
Month 3	-0.81	-0.30	-1.22	-3.04	-1.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Vinton					
	1995	1996	1997	1998	1999
April	-1.80	-1.51	0.43	2.32	-1.41
May	0.81	2.58	-1.01	1.11	-1.18
June	7.17	2.01	1.17	0.61	-2.90
July	-1.02	-0.30	-0.68	-3.15	-2.57
August	-2.36	1.46	-1.22	-1.29	-1.52
September	-0.81	6.31	-0.25	-3.04	3.79
October	0.52	-0.84	-1.56	-2.23	-0.77

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years. The criteria for injury under the W126 exposure index are not satisfied.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at these concentrations was significantly lower. In the higher ozone years, the levels of exposure could injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest and second highest ozone exposure values, 1998 and 1999, experienced three months of mild to severe drought. The two intermediate ozone years had similar levels of exposure and one and two months of drought each. The year with the lowest ozone

exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone year, 1998, there were four months of mild to severe drought, while the lowest ozone year, 1996, had one month of mild drought. The three mid-level ozone years had similar exposures and each had three to four months of mild to moderate drought.

The risk of foliar ozone injury to plants in the vicinity of Vinton is low. The threshold level for injury is satisfied by the Sum06 index, while the W126 index is satisfied in two years. The N-values indicate exposure to concentrations of ozone greater than 80 and 100 ppb is highly variable with elevated levels in two years. Multiple months of mild to severe drought during years with high levels of exposure significantly constrain the uptake of ozone by plants and greatly reduce the likelihood of foliar injury being produced.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Glenwood-Pedlar Ranger District, Rockbridge County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus pungens	Table-mountain pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Glenwood-Pedlar Ranger District					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	34
W126	-	-	-	-	36.8
N60	-	-	-	-	713
N80	-	-	-	-	87
N100	-	-	-	-	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it

represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Glenwood-Pedlar					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-2.90
Month 2	-	-	-	-	-2.57
Month 3	-	-	-	-	-1.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Glenwood-Pedlar					
	1995	1996	1997	1998	1999
April	-1.80	-1.51	0.43	2.32	-1.41
May	0.81	2.58	-1.01	1.11	-1.18
June	7.17	2.01	1.17	0.61	-2.90
July	-1.02	-0.30	-0.68	-3.15	-2.57
August	-2.36	1.46	-1.22	-1.29	-1.52
September	-0.81	6.31	-0.25	-3.04	3.79
October	0.52	-0.84	-1.56	-2.23	-0.77

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- Only one year of ozone monitoring data is available for analysis of injury thresholds. The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The limited data do not provide insight to the long-term ozone exposure regime at the site.

- The N-values for the one year of monitoring data show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. There were three hours in which the concentration exceeded 100 ppb. This level of exposure is not likely to injure vegetation.

- Soil moisture levels for 1999 indicate there were three months of mild and moderate drought during the Sum06 accumulation period, and five months of mild and moderate drought during the seasonal W126 accumulation period. These soil moisture regimes would constrain the uptake of ozone and reduce the likelihood of foliar injury. Soil moisture data for the four years without ozone data indicate three of the years experienced at least three months of mild to severe drought, while one year had one month of mild drought. In general, it appears that soil moisture conditions at the site can reduce the uptake of ozone.

The risk of foliar ozone injury to plants in the vicinity the Glenwood-Pedlar Ranger District is low. However, risk is difficult to assess from only one year of monitoring data. The Sum06 index is above its threshold while the W126 is not. The N-values for 60 and 80 ppb are elevated with three hours above 100 ppb. During the year there are five months of drought that significantly constrain the uptake of ozone. This assessment is very preliminary since limited ozone monitoring data are available, and additional data must be evaluated to provide a comprehensive assessment of risk.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Shenandoah National Park (SHEN)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SHEN					
	1995	1996	1997	1998	1999
Sum06	33	31	29	57	43
W126	73.1	63.7	65.5	118.3	69.4
N60	1454	1268	1239	2321	1307
N80	134	55	123	387	231
N100	1	0	4	67	11

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SHEN					
	1995	1996	1997	1998	1999
Month 1	-0.52	2.64	0.60	-2.56	-2.03
Month 2	-1.56	1.73	0.15	-2.57	-1.60
Month 3	-0.68	3.13	-1.30	-2.87	6.55

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SHEN					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only two years, and thus the criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a few hours most years and for a significant number of hours in one year. The higher levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest Sum06 exposure year, 1998, there were three months of moderate drought stress, and two months of drought in the second highest ozone year, 1999. The three lowest ozone years had similar levels of exposure, with two of the years

each having one month of mild drought. Soil moisture levels associated with the W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. There were four months of moderate drought in the highest ozone year, 1998, and two months of mild drought in the second highest year, 1995. The median exposure year, 1999, had five months of mild and moderate drought. The lowest ozone year, 1996, had favorable soil moisture conditions, while the second lowest year, 1997, had four months of mild drought.

The risk of foliar ozone injury at Shenandoah National Park is moderate. The threshold for injury is consistently satisfied for the Sum06 and occasionally the W126 indices. The N-values indicate that there are frequent exposures to concentrations of ozone greater than 80 ppb. There are several hours of exposure to 100 ppb in most years, and a significant number of hours of exposure in some years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the higher exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

Rest, Frederick County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Rest, Frederick County					
	1995	1996	1997	1998	1999
Sum06	25	27	30	42	34
W126	30.3	25.2	33.7	46.8	39.0
N60	524	483	616	834	712
N80	98	41	94	195	123
N100	1	1	7	23	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it

represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Rest					
	1995	1996	1997	1998	1999
Month 1	3.57	1.73	0.60	-2.56	-2.42
Month 2	-0.52	3.13	0.15	-2.57	-2.03
Month 3	-1.56	1.41	-1.30	-2.87	-1.60

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Rest					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at 80 ppb was often high, while the hours at 100 ppb was lower. In the higher ozone years, the levels of exposure could injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1998 and 1999, each experienced three months of mild and moderate drought. The year with the lowest ozone exposure, 1995, had one month of mild drought, while the two intermediate ozone years had one month of drought and favorable soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and five months, respectively, of mild and moderate drought. The two mid-level ozone years, 1995 and 1997, had two and four months of mild drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants in the vicinity of the Rest monitoring site is low. The threshold level for injury is satisfied by the Sum06 index, while the W126 criteria are satisfied in two years. The N-values indicate that exposure to concentrations of ozone greater than 80 and 100 ppb is highly variable. Years in which exposures exceed the injury thresholds are also ones in which there are four months of mild and moderate drought. These moisture conditions significantly constrain the uptake of ozone and reduce the likelihood that the higher exposures will produce foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

WEST VIRGINIA

Harpers Ferry National Historical Park (HAFE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HAFE					
	1995	1996	1997	1998	1999
Sum06	17	17	19	31	36
W126	35.4	29.2	37.4	51.2	44.8
N60	596	532	647	869	760
N80	144	74	128	232	187
N100	22	5	15	35	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HAFE					
	1995	1996	1997	1998	1999
Month 1	2.31	0.42	0.35	-2.15	-3.10
Month 2	-0.03	5.12	-0.60	-1.60	-2.86
Month 3	-0.30	3.15	-1.05	-2.04	-1.57

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HAFE					
	1995	1996	1997	1998	1999
April	-1.18	-1.33	-1.57	1.67	-0.41
May	0.41	4.74	-1.10	-0.45	-2.03
June	2.31	0.42	0.35	1.63	-3.10
July	-0.03	5.12	-0.60	-2.15	-2.86
August	-0.30	3.15	-1.05	-1.60	-1.57
September	-1.22	7.78	0.87	-2.04	2.85
October	1.33	0.72	-1.80	-2.56	-0.75

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two years with the highest Sum06 index of exposure, 1999 and 1998, each had three years of mild to severe drought. The mid-level exposure year 1997 had one year of mild drought, while the two years with the lowest exposure had normal soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In both of the highest ozone years, 1998 and 1999, there were four months of mild to severe drought. The two mid-level ozone years, 1997 and 1995, had four and two months of mild drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Harper's Ferry National Historic Park is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone in most years, the probability of foliar injury developing may be greatest during years such as 1995 when ozone levels exceed the thresholds, and soil moisture levels are under mild drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

MARYLAND

Catoctin Mountain Park (CATO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CATO					
	1995	1996	1997	1998	1999
Sum06	32	27	33	38	36
W126	39.4	32.1	43.8	59.3	48.9
N60	652	576	749	1009	825
N80	168	87	156	269	200
N100	23	6	20	33	21

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CATO					
	1995	1996	1997	1998	1999
Month 1	-0.53	5.30	-1.78	-0.67	-1.97
Month 2	-0.74	0.32	-2.91	-1.64	-3.63
Month 3	-2.32	3.39	-1.29	-2.31	-0.40

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CATO					
	1995	1996	1997	1998	1999
April	-1.72	0.10	-1.68	-0.04	-0.91
May	0.22	1.67	-1.83	0.71	-2.45
June	-0.53	3.05	-1.78	0.86	-1.97
July	-0.74	5.30	-2.91	-0.67	-3.63
August	-2.32	0.32	-1.29	-1.64	-0.40
September	-0.58	3.39	-0.90	-2.31	5.70
October	2.48	2.34	-1.84	-1.12	0.33

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of

ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 exposures, 1998 and 1999, had two months of mild and moderate drought and two months of mild and severe drought, respectively. In the mid-level exposure years, there were three months of mild and moderate drought in 1997, and one month of moderate drought in 1995. Soil moisture was normal in 1996, the lowest exposure year. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. The year with the highest exposure index, 1998, had three months of mild and moderate drought. The two years with next highest levels of exposure, 1999 and 1997, had three and six months of mild to severe drought, respectively. There were two months of mild and moderate drought in 1995, the second lowest exposure year, and normal soil moisture conditions in 1996, the lowest year.

The risk of foliar ozone injury at Catoctin Mountain Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 or 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or not under periods of prolonged drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and northern fox grape.

PENNSYLVANIA

Gettysburg National Military Park
(GETT)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GETT					
	1995	1996	1997	1998	1999
Sum06	21	21	26	32	33
W126	39.5	32.1	43.7	57.9	47.5
N60	648	571	734	977	791
N80	172	90	165	266	199
N100	26	7	24	32	25

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GETT					
	1995	1996	1997	1998	1999
Month 1	2.52	4.42	-1.49	0.10	-2.02
Month 2	2.25	4.57	-0.64	-0.64	-2.40
Month 3	-2.09	0.38	-0.21	-2.42	-2.98

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GETT					
	1995	1996	1997	1998	1999
April	-1.43	0.35	-2.05	1.39	0.68
May	0.05	1.37	-0.52	1.00	-2.02
June	2.52	4.42	-1.49	1.01	-2.40
July	2.25	4.57	-0.64	0.10	-2.98
August	-2.09	0.38	-0.21	-0.64	-0.41
September	-0.55	5.89	1.42	-2.42	4.11
October	2.22	2.17	-1.37	-0.89	0.19

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone

concentrations: when ozone is high, soil moisture is low, but the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two highest Sum06 ozone years had similar levels of exposure, but different soil moisture regimes. The year with the highest exposure, 1999, had three months of moderate drought, while the second highest year, 1998, had one month of moderate drought. The three years with lower ozone exposure had two months of drought among them. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, and the pattern is again not consistent. The highest ozone year, 1998, experienced one month of moderate drought. The next two highest ozone years, 1999 and 1997, had three months of mild and moderate drought each. There were two months of drought in the second lowest year, and the lowest ozone year, 1996, had favorable soil moisture conditions.

The risk of foliar ozone injury to plants at Gettysburg National Military Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the largely inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under limited drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

Little Buffalo State Park, Perry County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Little Buffalo State Park, Perry County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	24.8	20.7	24.4	32.8	35.4
N60	405	372	371	555	582
N80	86	37	84	137	161
N100	3	0	8	11	16

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Little Buffalo SP					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Little Buffalo SP					
	1995	1996	1997	1998	1999
April	-0.86	1.73	2.42	3.42	-1.94
May	-0.96	-0.65	-0.17	1.02	-1.24
June	0.64	2.60	-0.36	0.49	-1.99
July	-1.56	2.30	-1.19	-1.86	2.31
August	-4.60	-1.12	2.01	-0.76	8.01
September	-2.65	6.25	0.78	-2.26	-0.57
October	4.22	2.63	-2.13	-0.48	-1.94

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- In three years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at these concentrations was significantly lower. In the higher ozone years, the levels of exposure could injure vegetation.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In 1999, the highest exposure year, there were four months of mild drought while the second highest year, 1998, which had slightly lower exposure, had two months of mild and moderate drought. The two mid-exposure years, 1995 and 1997, had three and two months, respectively, of mild and moderate drought, and the lowest exposure year, 1996, had one month of mild drought.

The risk of foliar ozone injury to plants at Little Buffalo State Park is moderate. The threshold for injury is consistently satisfied by the Sum06 index, while the W126 threshold is satisfied in three years. The N-values indicate that exposure to concentrations of ozone greater than 80 and 100 ppb is highly variable. The years in which exposures are the highest are also ones in which there are two to four months of drought. These moisture conditions constrain the uptake of ozone and reduce the

likelihood the exposures will produce foliar injury. It is anticipated that the risk of injury may be greatest in years such as 1997 and 1998 when ambient levels of ozone exceed thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, yellow-poplar, American sycamore, and black cherry.

Kutztown University, Berks County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Kutztown University, Berks County					
	1995	1996	1997	1998	1999
Sum06	27	22	25	30	35
W126	30.8	24.0	28.8	42.6	43.9
N60	490	413	450	684	721
N80	136	67	117	224	204
N100	11	2	13	9	38

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil

moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Kutztown Univ					
	1995	1996	1997	1998	1999
Month 1	-1.51	1.51	-1.33	1.69	-2.41
Month 2	0.10	3.68	-0.12	-1.18	-4.16
Month 3	-3.35	0.21	-0.50	-1.24	-0.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Kutztown Univ					
	1995	1996	1997	1998	1999
April	-1.83	1.58	-1.67	1.26	-0.39
May	0.13	0.02	-0.25	0.98	-1.74
June	-1.51	1.51	-1.33	1.69	-2.41
July	0.10	3.68	-0.12	-1.18	-4.16
August	-3.35	0.21	-0.50	-1.24	-0.58
September	-0.49	1.93	-0.77	-2.27	7.56
October	4.01	4.32	-1.32	0.10	1.08

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for concentrations of 60 and 80 ppb are elevated while exposures over 100 ppb are variable. In the higher ozone years, the levels of exposure could injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1999 and 1998, each experienced two months of mild to severe drought. The year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. The two years with intermediate levels of ozone had one and two months of drought. Soil moisture levels associated with the W126 index also appear inversely related to exposure. The two highest ozone years, 1998 and 1999, each had three continuous months of mild to severe drought. The two mid-level ozone years, 1995 and 1997, each had three scattered months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants in the vicinity of Kutztown University is moderate. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone almost annually, the probability of foliar injury developing may be greatest during years such as 1997 when ozone levels exceed the thresholds, and months of mild drought occur scattered over the year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, white ash, yellow-poplar, American sycamore, and black cherry.

Kunkletown, Monroe County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Kunkletown, Monroe County					
	1995	1996	1997	1998	1999
Sum06	-	-	22	32	40
W126	-	-	-	45.6	50.1
N60	-	-	-	787	804
N80	-	-	-	191	248
N100	-	-	-	7	41

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it

represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Kunkletown					
	1995	1996	1997	1998	1999
Month 1	-	-	-1.37	-1.19	-2.14
Month 2	-	-	-1.72	-2.13	-3.15
Month 3	-	-	1.36	-0.66	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Kunkletown					
	1995	1996	1997	1998	1999
April	-1.53	1.90	-1.44	1.60	-1.41
May	-1.22	-0.18	-0.32	0.78	-1.13
June	-1.94	0.86	-1.37	3.26	-2.14
July	-0.56	2.84	-1.72	-1.19	-3.15
August	-3.49	-1.70	1.36	-2.13	-1.97
September	-0.99	1.26	0.11	-0.66	6.14
October	3.91	2.89	-1.41	-0.17	-0.10

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation in the three years of data available. In two years of data, the W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- In both years, the N-values for concentrations of 60 and 80 ppb are elevated while exposures over 100 ppb are variable. The levels of exposure in the two years could injure vegetation.

- Since data on Sum06 and W126 exposures are available for only two and three years respectively, no firm conclusions can be drawn regarding relationships between the levels of ozone exposure and soil moisture. However, for both indices there is some indication of an inverse relationship: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. Additional exposure and soil moisture data must be assessed to confirm any relationship.

The risk of foliar ozone injury to plants in the vicinity of Kunkletown is moderate. In the few years assessed, the Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. However, the year with the highest exposure, 1999, experienced five months of mild to severe drought. These conditions greatly constrain the uptake of ozone and reduce the likelihood of foliar injury. The probability of foliar injury developing may be greater during years such as 1998 when ozone levels are somewhat lower but still exceed the thresholds, and there are fewer months of drought to reduce the uptake of ozone. This assessment of risk is hampered by the limited availability of ozone monitoring data, and additional data need to be evaluated to develop a comprehensive assessment.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, yellow-poplar, quaking aspen, and black cherry.

Delaware Water Gap National Recreation Area (DEWA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less

weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DEWA					
	1995	1996	1997	1998	1999
Sum06	21	16	20	23	28
W126	32.8	25.3	29.1	36.4	39.9
N60	511	397	452	608	630
N80	160	96	128	160	184
N100	29	13	21	14	41

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DEWA					
	1995	1996	1997	1998	1999
Month 1	-1.94	0.86	-1.37	-1.19	-2.14
Month 2	-0.56	2.84	-1.72	-2.13	-3.15
Month 3	-3.49	-1.70	1.36	-0.66	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DEWA					
	1995	1996	1997	1998	1999
April	-1.53	1.90	-1.44	1.60	-1.41
May	-1.22	-0.18	-0.32	0.78	-1.13
June	-1.94	0.86	-1.37	3.26	-2.14
July	-0.56	2.84	-1.72	-1.19	-3.15
August	-3.49	-1.70	1.36	-2.13	-1.97
September	-0.99	1.26	0.11	-0.66	6.14
October	3.91	2.89	-1.41	-0.17	-0.10

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels

of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest ozone exposure value, 1999, had three months of mild to moderate drought, while the lowest ozone year, 1996, had one month of mild drought. The three intermediate years each had two months of mild to severe drought. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, but the pattern is not consistent. The highest ozone year, 1999, had five months of mild to severe drought and the lowest year, 1996, had one month of mild drought. However, the second highest ozone year, 1998, had two months of drought, while the second lowest year, 1997, had four months of mild drought.

The risk of foliar ozone injury to plants at Delaware Water Gap National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, common snowberry, and northern fox grape.

NEW YORK

Montgomery, Orange County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Prunus virginiana	Chokecherry	Roseaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Montgomery, Orange County					
	1995	1996	1997	1998	1999
Sum06	30	23	22	23	25
W126	28.2	23.9	23.6	28.3	28.8
N60	469	377	366	477	437
N80	120	96	104	114	120
N100	24	21	2	7	18

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Montgomery					
	1995	1996	1997	1998	1999
Month 1	-3.26	1.08	-2.31	-1.72	-2.93
Month 2	-0.79	6.42	-0.42	-1.75	-2.40
Month 3	-2.62	-1.18	0.84	-2.05	-0.75

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Montgomery					
	1995	1996	1997	1998	1999
April	-1.05	3.59	0.89	0.02	-3.01
May	-1.59	0.56	-0.23	1.03	-0.22
June	-3.26	1.08	-2.31	5.16	-2.93
July	-0.79	6.42	-0.42	-1.72	-2.40
August	-2.62	-1.18	0.84	-1.75	-0.75
September	-1.04	2.19	-0.39	-2.05	5.84
October	5.01	1.56	-1.26	0.04	0.73

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours several years. These levels of exposure can injure vegetation.

- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture. Relationships between the Sum06 ozone levels and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. Soil moisture levels show that each year had one to three months of mild to severe drought without any association to the level of ozone. The seasonal W126 exposure indices fell into two groups each having similar concentrations. The years with higher indices, 1995, 1998, and 1999, experienced three or five months of mild to severe drought, while the years with lower indices, 1996 and 1997, experienced one or two months of mild and moderate drought. The limited range and distribution of levels of ozone exposure

hamper the assessment of relationships between exposure and soil moisture, however there appear to be greater levels of drought at higher levels of ozone exposure.

The risk of foliar ozone injury to plants in the vicinity of Montgomery is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, white ash, yellow-poplar, American sycamore, quaking aspen, and black cherry.

Roosevelt-Vanderbilt Headquarters (ROVA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ROVA					
	1995	1996	1997	1998	1999
Sum06	20	15	19	18	21
W126	25.9	21.8	24.7	28.4	29.7
N60	408	340	373	469	452
N80	97	66	89	92	114
N100	18	12	13	11	25

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ROVA					
	1995	1996	1997	1998	1999
Month 1	-3.26	1.08	-2.31	-1.72	-2.93
Month 2	-0.79	6.42	-0.42	-1.75	-2.40
Month 3	-2.62	-1.18	0.84	-2.05	-0.75

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ROVA					
	1995	1996	1997	1998	1999
April	-1.05	3.59	0.89	0.02	-3.01
May	-1.59	0.56	-0.23	1.03	-0.22
June	-3.26	1.08	-2.31	5.16	-2.93
July	-0.79	6.42	-0.42	-1.72	-2.40
August	-2.62	-1.18	0.84	-1.75	-0.75
September	-1.04	2.19	-0.39	-2.05	5.84
October	5.01	1.56	-1.26	0.04	0.73

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The Sum06 indices of exposure were relatively similar over the five-year period, and the inverse relationship with soil moisture is not consistent. The two years with the highest ozone exposures, 1999 and 1995, both had two months of moderate and severe drought. The two next highest years, 1997 and 1998, respectively experienced one and three months of mild to moderate drought, while the year with the lowest ozone, 1996, has one month of mild drought. Annual ozone levels associated with the seasonal W126 index were similar in value, and also appear to be inversely related to soil moisture. The two highest ozone years, 1999 and 1998, each had three months of mild to severe drought. Two years with mid-level exposures, 1995 and 1997, had five and two months of mild to severe drought, respectively, and the year with lowest ozone, 1996, has one month of mild drought.

The risk of foliar ozone injury to plants at Roosevelt-Vanderbilt Headquarters is high.

While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in higher exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest in years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under drought conditions that do not extensively constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

CONNECTICUT

Torrington, Litchfield County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus rigida	Pitch pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Torrington, Litchfield County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	28.6	23.8	27.2	36.1	40.7
N60	436	372	384	581	628
N80	98	70	103	122	162
N100	25	13	17	19	45

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Torrington					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Torrington					
	1995	1996	1997	1998	1999
April	-1.35	3.14	2.07	-0.40	-3.04
May	-0.54	0.31	0.05	-0.01	1.19
June	-3.11	-1.82	-2.28	1.98	-2.55
July	-0.01	4.79	0.62	-1.50	-2.33
August	-1.31	-0.88	2.15	-2.41	-1.61
September	-0.63	2.46	-1.85	-1.24	6.64
October	5.95	4.25	-1.65	1.39	0.18

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The year with the highest exposure index, 1999, had four months of mild to severe drought, and the year with the second highest index, 1998, had three months of mild and moderate drought. The year with the lowest index, 1996, had one month of mild drought, and the two intermediate years each had three months of drought.

The risk of foliar ozone injury to plants in the vicinity of Torrington is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in high exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, yellow-poplar, quaking aspen, and black cherry.

MASSACHUSETTS

Mount Greylock Summit, Berkshire County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Prunus virginiana	Chokecherry	Roseaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Mount Greylock Summit, Berkshire County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	13.9	19.4	-	13.0	16.8
N60	217	305	-	199	267
N80	13	40	-	2	20
N100	0	4	-	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Mt Greylock					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Mt Greylock					
	1995	1996	1997	1998	1999
April	-1.58	3.76	0.96	-1.43	-3.12
May	-1.57	0.82	0.93	-0.73	0.88
June	-1.88	-0.39	-3.17	5.38	-0.81
July	-1.35	4.53	1.10	-0.52	-1.68
August	-2.35	-1.22	0.60	-2.85	-1.33
September	-0.77	3.28	-1.63	-2.34	3.27
October	7.54	2.53	-1.21	0.52	1.50

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. The four years of monitoring data indicate that while the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had four hours in which the concentration exceeded 100 ppb while the rest had none. These levels of exposure are not likely to injure vegetation.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. The relatively uniform W126 indices of ozone exposure during the four years make it difficult to assess relationships between the levels of ozone and soil moisture. Levels of drought varied widely among years and ranged from five months of mild and moderate stress in 1995 to a single month of mild stress in 1996. The remaining two years, 1998 and 1999, each had three months of mild to severe stress. No association between the W126 levels of ozone and soil moisture is apparent from these

observations.

The low level of ozone exposure makes the risk of foliar injury to plants in the vicinity of Mount Greylock summit low. The W126 exposures indices do not exceed the threshold levels for injury, the number of hours of exposure greater than 80 ppb is low, and only four hours of exposure greater than 100 ppb occurred during the four-year data period.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, quaking aspen, and black cherry.

VERMONT

Bennington, Bennington County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Fraxinus americana	White ash	Oleaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Bennington, Bennington County					
	1995	1996	1997	1998	1999
Sum06	12	11	14	14	19
W126	18.5	19.6	21.0	21.4	26.7
N60	282	292	332	386	432
N80	33	38	41	20	65
N100	0	3	4	0	8

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Bennington					
	1995	1996	1997	1998	1999
Month 1	-1.57	2.91	-2.27	-2.21	-1.00
Month 2	-3.80	0.73	0.20	6.95	-2.82
Month 3	-0.85	4.57	1.54	5.13	-1.44

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Bennington					
	1995	1996	1997	1998	1999
April	-0.60	4.85	-0.45	-1.32	-3.75
May	-1.57	2.91	0.50	-2.21	-1.00
June	-3.80	0.73	-2.27	6.95	-2.82
July	-0.85	4.57	0.20	5.13	-1.44
August	0.06	-1.93	1.54	2.96	-2.45
September	0.10	-0.34	0.05	1.91	5.38
October	4.91	1.33	-0.95	0.45	2.22

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb and two years had none. These levels of exposure are unlikely to injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest exposure index, 1999, had three months of mild and moderate drought while the year with the lowest index, 1996, had favorable conditions. The three intermediate exposure years had either one or two months of drought. Soil moisture levels also appear to be inversely

related to the seasonal W126 exposure index, but similar levels of exposure among the years make it difficult to fully assess and confirm the relationship. There were four months of mild to severe drought in the highest exposure year, 1999. The remaining four years had lower and similar levels of exposure and each experienced either one or two months of mild or severe drought.

The low level of ozone exposure makes the risk of foliar ozone injury to plants in the vicinity of Bennington low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. The highest ozone exposures occur in years with months of mild to severe drought that constrain the uptake of ozone and reduce the likelihood of foliar ozone injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, white ash, quaking aspen, and black cherry.

Marsh-Billings National Historic Park (MABI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MABI					
	1995	1996	1997	1998	1999
Sum06	8	5	7	8	9
W126	14.2	11.5	11.7	13.5	16.4
N60	216	145	158	203	245
N80	22	21	20	12	33
N100	1	1	2	0	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to

foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MABI					
	1995	1996	1997	1998	1999
Month 1	-3.75	1.22	-0.57	-1.63	-1.63
Month 2	1.84	6.51	3.81	6.56	6.56
Month 3	2.48	-0.80	5.10	4.22	4.22

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MABI					
	1995	1996	1997	1998	1999
April	-0.49	6.44	0.18	-1.30	-1.30
May	-0.28	3.19	2.28	-1.63	-1.63
June	-3.75	1.22	-0.57	6.56	6.56
July	1.84	6.51	3.81	4.22	4.22
August	2.48	-0.80	5.10	2.57	2.57
September	1.53	-0.28	0.61	2.55	2.55
October	5.79	2.29	-0.07	0.26	0.26

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury at a marginal level. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposures were low and relatively similar over the five-year period. No relationships were apparent between the Sum06 levels of ozone and soil moisture conditions. In general, soil moisture conditions were favorable for the uptake of ozone with only two months of mild and one of severe drought stress over the five-year period. With the seasonal W126 index there were few months of drought during the five-year period, however there is some indication of an inverse relationship: when ozone is high, soil moisture is low, but the relationship is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the three years with the highest ozone, there were two months of mild drought in both 1999 and 1998, and one month of severe drought in 1995. Soil moisture conditions were favorable in the remaining two years with lower levels of ozone.

The risk of foliar ozone injury to plants at Marsh-Billings Historic Park is low. The Sum06 and W126 exposure indices are either marginally attained or not satisfied. The N-values indicate that exposure to ozone greater than 80 ppb is uncommon and exposure to 100 ppb is rare. While soil moisture conditions generally favor the uptake of ozone, periods of drought constrain uptake in higher exposure years and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, American sycamore, quaking aspen, black cherry, Allegheny blackberry, and American elder.

Saint-Gaudens National Historic Site (SAGA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAGA					
	1995	1996	1997	1998	1999
Sum06	7	5	7	7	9
W126	13.0	10.9	11.2	12.4	15.0
N60	198	134	149	183	221
N80	21	22	23	12	32
N100	1	1	3	1	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAGA					
	1995	1996	1997	1998	1999
Month 1	-2.43	-1.03	-2.37	-0.70	-0.28
Month 2	0.51	4.24	0.24	8.48	-2.02
Month 3	-1.60	-3.39	1.24	-1.14	-1.13

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAGA					
	1995	1996	1997	1998	1999
April	-1.75	4.73	2.08	-1.97	-4.13
May	-0.59	1.79	-0.30	-0.70	-0.28
June	-2.43	-1.03	-2.37	8.48	-2.02
July	0.51	4.24	0.24	-1.14	-1.13
August	-1.60	-3.39	1.24	-1.21	-1.16
September	-1.27	0.48	-1.38	-1.76	5.80
October	4.81	7.22	-2.06	0.91	1.32

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between both the 90-day Sum06 and the seasonal W126 indices of ozone exposure and soil moisture are difficult to assess because the levels of exposure for both were low and similar over the five-year period. There does not appear to be any association between the Sum06 levels of ozone exposure and the incidence of drought. Soil moisture levels show that each year had one or two months of mild to severe drought. The relatively uniform levels of ozone exposure for the W126 index also make it difficult to assess relationships between exposure and soil moisture. Months of mild, moderate, and severe drought stress were distributed throughout the five-year period with each year having two to four months of drought. No associations between the W126 levels of ozone and soil moisture are apparent in the distribution.

The low levels of ozone exposure at Saint-Gaudens National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 and W126 exposures indices do not exceed the threshold levels for injury, the number of hours of exposure greater than 80 ppb is low, and exposure to concentrations greater than 100 ppb are rare. Months of mild to severe drought throughout the assessment period limit the uptake of ozone and serve to reduce the effectiveness of the ozone exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, and American elder.

NEW HAMPSHIRE

Haverhill, Grafton County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus americana	White ash	Oleaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Prunus virginiana	Chokecherry	Roseaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Haverhill, Grafton County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	-	-	7.1	15.8	11.6
N60	-	-	87	240	169
N80	-	-	0	18	9
N100	-	-	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Haverhill					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Haverhill					
	1995	1996	1997	1998	1999
April	-1.51	4.02	-0.40	-1.92	-3.65
May	-0.95	2.76	0.55	-1.92	-0.75
June	-3.85	0.31	-0.83	5.71	-0.93
July	-0.96	5.21	1.38	1.97	0.37
August	-2.02	-2.37	1.96	0.17	-0.80
September	-1.23	-1.98	-0.95	-0.15	5.79
October	4.26	2.11	-1.56	0.32	2.22

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. While the W126 accumulative value exceeds the threshold in the three years of data, the N100 count shows that the one-hour concentration of ozone never reaches 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. Only three years of W126 data are available limiting the ability to assess relationships between exposure and soil moisture. The year with the highest exposure, 1998, had two months of mild drought. There was one month of mild drought in the lowest ozone year, 1997, and a month of severe drought in the middle ozone year. No association between levels of exposure and soil moisture is apparent from these observations.

The low level of ozone exposure makes the risk of foliar ozone injury to plants in the vicinity of Haverhill low. The W126 exposure indices do not exceed the threshold levels for injury, the number of hours of exposure greater than 80 ppb is very low, and there are no exposures greater than 100 ppb during the three-year assessment period.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, quaking aspen, and black cherry.

Mount Washington, Coos County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Prunus virginiana	Chokecherry	Roseaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Mount Washington, Coos County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	22.1	-	-	-	-
N60	349	-	-	-	-
N80	17	-	-	-	-
N100	0	-	-	-	-

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Mt Washington					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Mt Washington					
	1995	1996	1997	1998	1999
April	-1.51	4.02	-0.40	-1.92	-3.65
May	-0.95	2.76	0.55	-1.92	-0.75
June	-3.85	0.31	-0.83	5.71	-0.93
July	-0.96	5.21	1.38	1.97	0.37
August	-2.02	-2.37	1.96	0.17	-0.80
September	-1.23	-1.98	-0.95	-0.15	5.79
October	4.26	2.11	-1.56	0.32	2.22

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. Only one year of data are available to assess the W126 index. The W126 accumulative value did not exceed the threshold level and there were no hourly exposure above 100 ppb, thus the W126 threshold criteria are not satisfied.

- In the year of monitoring data available, the N-values show only a few hours in which concentrations exceeded 80 ppb and no hours above 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. In the year for which W126 data were available, there were four months of mild to severe drought. No relationships can be discerned form these limited data.

The low level of ozone exposure makes the risk of foliar ozone injury to plants in the vicinity of Mount Washington low. Drought stress during the year for which data are available serves to limit the uptake of ozone and further reduce the risk of foliar injury.

This assessment is significantly constrained by the limited ozone monitoring data available, and additional data need to be evaluated.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, white ash, quaking aspen, and black cherry.

MAINE

Greenville, Piscataquis County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were monitored on-site and hourly concentrations of ozone used to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Greenville, Piacataquis County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	-	-
W126	11.6	9.5	-	-	-
N60	140	63	-	-	-
N80	9	1	-	-	-
N100	0	0	-	-	-

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Greenville					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-	-
Month 2	-	-	-	-	-
Month 3	-	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Greenville					
	1995	1996	1997	1998	1999
April	-0.76	2.14	-1.09	-0.58	-3.13
May	0.98	2.59	2.65	-1.74	-2.13
June	-2.69	1.23	-0.36	2.85	-0.99
July	-1.03	5.69	-0.65	2.58	-1.08
August	-2.57	-1.63	1.69	-0.44	-0.92
September	-1.91	1.14	-0.61	-0.06	6.08
October	2.12	0.84	-2.02	-0.58	2.08

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- No data are available to assess the Sum06 exposure thresholds. In the two years of data, the W126 accumulative value is above the threshold, but the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no hours in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the Sum06 exposures and soil moisture cannot be assessed since exposure data for the index are not available. In the two years for which W126 data were available, there were four months of mild to moderate drought in the higher ozone exposure year, and one month of mild drought in the lower year. No relationships can be discerned form these limited data.

The low level of ozone exposure makes the risk of foliar ozone injury to plants in the vicinity of Greenville low. Drought stress during one of the years for which data are available serves to limit the uptake of ozone and further reduce the risk of foliar injury.

This assessment is significantly constrained by the limited ozone monitoring data available, and additional data need to be evaluated.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, quaking aspen, and black cherry.

ARCTIC ALASKA NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE ARCTIC ALASKA NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

It was not possible to assess risk for sites in the Arctic Alaska Network since ozone was neither monitored nor kriged for them, and Palmer Z values are not calculated for the state.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE ARCTIC ALASKA NETWORK

Park	Code	State	Risk	O3 Data
Bering Land Bridge N PRES	BELA	AK	cannot eval	no data
Cape Krusenstern NM	CAKR	AK	cannot eval	no data
Gates of the Arctic NP & PRES	GAAR	AK	cannot eval	no data
Kobuk Valley NP	KOVA	AK	cannot eval	no data
Noatak N PRES	NOAT	AK	cannot eval	no data

BERING LAND BRIDGE NATIONAL PRESERVE (BELA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Populus tremuloides	Quaking aspen	Salicaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Bering Land Bridge National Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

CAPE KRUSENSTERN NATIONAL MONUMENT (CAKR)

Plant Species Sensitive to Ozone

No species are listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation Cape Krusenstern National Monument cannot be assessed due to the lack of information on ozone exposure at the site.

GATES OF THE ARCTIC NATIONAL PARK AND PRESERVE (GAAR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Gates of the Arctic National Park and Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

KOBUK VALLEY NATIONAL PRESERVE (KOVA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Populus tremuloides	Quaking aspen	Salicaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Kobuk Valley National Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

NOATAK NATIONAL PRESERVE (NOAT)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Populus tremuloides	Quaking aspen	Salicaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Noatak National Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

CENTRAL ALASKA NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE CENTRAL ALASKA NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

It was not possible to assess risk for all sites in the Central Alaska Network since ozone was neither monitored nor kriged for them, and Palmer Z values are not calculated for the state.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. Environmental Management. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. Atmospheric Environment 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE CENTRAL ALASKA NETWORK

Park	Code	State	Risk	O3 Data
Denali NP & Preserve	DENA	AK	low	monitored
Wrangell-St Elias NP & PRES	WRST	AK	cannot eval	no data
Yukon-Charley Rivers N PRES	YUCH	AK	cannot eval	no data

DENALI NATIONAL PARK AND PRESERVE (DENA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DENA					
	1995	1996	1997	1998	1999
Sum06	0	0	0	0	0
W126	3.0	4.1	4.0	6.0	4.7
N60	0	2	2	0	0
N80	0	0	1	0	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer data are not calculated for Alaska, and therefore cannot be used in the assessment of risk at Denali National Park.

Risk Analysis

- There are a few ozone-sensitive species at the site, two of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. Since the W126 accumulative value did not exceed the threshold level and there were no hourly concentrations above 100 ppb, the W126 threshold criteria are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only one hour of ozone at a concentration greater than 60 ppb. These levels of exposure are unlikely to injure vegetation.

- Since soil moisture data are not available for the site, the relationship between the Sum06 and W126 levels of ozone concentration and soil moisture status cannot be assessed.

The low level of ozone exposure at Denali National Park make the risk of foliar ozone injury to plants low.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use quaking aspen and Scouler's willow.

WRANGELL-ST ELIAS NATIONAL PARK AND PRESERVE (WRST)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Wrangell-St. Elias National Park and Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

YUKON-CHARLEY RIVERS NATIONAL PRESERVE (YUCH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Yukon-Charlie Rivers National Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

CHIHUAHUAN DESERT NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE CHIHUAHUAN DESERT NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its

determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be

a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. Environmental Management. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. Atmospheric Environment 31(11):1695-1708.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE CHIHUAHUAN DESERT NETWORK

Park	Code	State	Risk	O3 Data
Amistad NRA	AMIS	TX	moderate	kriged
Big Bend NP	BIBE	TX	low	monitored
Carlsbad Caverns NP	CAVE	NM	low	kriged
Chamizal NM	CHAM	TX	low	monitored
Fort Davis NHS	FODA	TX	low	kriged
Guadalupe Mountains NP	GUMO	TX	low	kriged
White Sands NM	WHSA	NM	low	kriged

AMISTAD NATIONAL RECREATION AREA (AMIS)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for AMIS

	1995	1996	1997	1998	1999
Sum06	11	5	7	15	14
W126	31.1	15.5	16.0	21.9	23.4
N60	497	233	245	372	378
N80	119	40	40	40	73
N100	19	7	3	5	8

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at AMIS					
	1995	1996	1997	1998	1999
Month 1	0.33	-0.94	1.64	1.91	-2.41
Month 2	-1.28	-1.15	-1.51	-1.77	-2.94
Month 3	-0.98	-3.47	-2.24	-3.70	-1.22

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at AMIS					
	1995	1996	1997	1998	1999
April	0.27	-1.15	2.93	-1.77	-0.71
May	1.74	-3.47	0.74	-3.70	-1.45
June	0.33	-2.73	5.60	-2.31	0.28
July	-1.28	-2.09	1.64	-2.72	-0.80
August	-0.98	2.96	-1.51	6.87	-2.41
September	0.39	1.06	-2.24	-1.81	-2.94
October	-1.98	0.14	-0.54	0.45	-1.22

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index intermittently exceeds the threshold for injury. The W126 accumulative value exceeds the threshold each year and the N100 count intermittently meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had numbers of hours above 80 and 100 ppb that were significantly greater than those in the other years. Most years had eight or fewer hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Three of the Sum06 years, including the highest and lowest years, had two months of mild to severe drought. The remaining two years had one and three months of drought. With the W126 index, the highest ozone year, 1995, had two months of mild drought, and the lowest year, 1996, four months of mild to severe drought. The second highest year, 1999, had four months of mild and moderate drought while the two intermediate years had five and two months of drought. Overall, no associations between ozone exposure and drought are apparent for either index.

The risk of foliar ozone injury at Amistad National Recreation Area is moderate. The threshold levels for the Sum06 and W126 indices are intermittently satisfied. The N-values indicate that exposures to concentrations of ozone greater than 80 and 100 ppb vary widely among years. Since there is no association between levels of ozone and soil moisture, conditions favorable for the uptake of ozone can occur at all levels of exposure. This creates the opportunity for reaching the threshold for injury at both high and more moderate levels of ambient ozone. The risk of injury is greatest in years such as 1995 when the ambient level of ozone is high, and soil moisture conditions favor uptake by plants. No ozone-sensitive species have been identified at the site, and any risk remains

potential until such species are found.

No ozone-sensitive or bioindicator species are identified for the site.

BIG BEND NATIONAL PARK (BIBE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BIBE					
	1995	1996	1997	1998	1999
Sum06	6	10	3	16	4
W126	16.2	17.8	11.7	26.9	14.4
N60	196	235	90	395	132
N80	4	11	0	1	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BIBE					
	1995	1996	1997	1998	1999
Month 1	1.09	-0.51	-0.10	-1.65	-0.14
Month 2	-3.09	-3.37	-0.70	-3.51	-1.49
Month 3	-2.36	1.19	-1.92	-3.00	-0.78

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BIBE					
	1995	1996	1997	1998	1999
April	-0.22	-0.51	2.00	-1.65	-1.49
May	-0.44	-3.37	0.12	-3.51	-0.78
June	1.09	1.19	1.13	-3.00	2.38
July	-3.09	-1.02	-0.10	-1.01	1.94
August	-2.36	2.96	-0.70	0.70	-1.93
September	0.78	0.93	-1.92	-3.25	-2.20
October	-2.01	-2.27	-1.69	1.05	-2.16

Risk Analysis

- There are a few ozone-sensitive species at the site, both of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 index exceeds the accumulative value for injury to vegetation, the N100 count shows that one-hour concentrations of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure conditions are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.

- The N-values for the site show no concentrations of 100 ppb and relatively few greater than 80 ppb. These levels of exposure are unlikely to injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In 1998 when the Sum06 exposure index was highest, there were three months of low and severe drought. There were two months of moderate and severe drought in 1995, the mid-level exposure year, while the remaining three years each had one month of drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but the pattern is again not consistent. The year with the highest exposure, 1998, had five months of mild and severe drought. The two mid-level exposure years, 1996 and 1995, each experienced three months of mild to severe drought. The second lowest exposure year, 1999, had four months of mild and moderate drought, while the lowest year, 1997, had two months of mild drought.

The levels of ozone exposure and the relatively dry soil moisture conditions at Big Bend National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 exposure thresholds are satisfied. Exposure to concentrations greater than 80 ppb is rare, and concentrations never exceed 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposure levels and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: ponderosa pine and skunkbush.

CARLSBAD CAVERNS NATIONAL PARK (CAVE)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CAVE

	1995	1996	1997	1998	1999
Sum06	13	16	6	23	14
W126	21.2	21.8	20.6	31.5	24.2
N60	318	331	304	604	402
N80	41	41	29	24	14
N100	8	7	3	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CAVE					
	1995	1996	1997	1998	1999
Month 1	0.62	-4.12	-0.02	0.97	1.45
Month 2	-3.05	2.02	-0.15	-0.33	2.22
Month 3	-2.40	-0.15	0.61	-2.83	1.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CAVE					
	1995	1996	1997	1998	1999
April	-1.24	-1.24	4.28	-0.33	1.45
May	-0.69	-4.12	1.34	-2.83	2.22
June	0.62	2.02	1.05	-3.04	1.48
July	-3.05	-0.15	-0.02	-1.86	0.02
August	-2.40	3.22	-0.15	-0.48	-1.26
September	2.58	0.26	0.61	-2.85	-1.47
October	-2.08	-1.59	0.83	3.28	-1.74

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation in the highest years.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. During the Sum06 accumulation periods, four months of drought were distributed over three years without any association with the level of ozone exposure. With the W126 indices, four of the five years experienced three or four months of mild to severe drought. The year with the lowest exposure had normal soil moisture conditions.

The risk of foliar ozone injury to plants at Carlsbad Caverns National Park is low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone occasionally exceeded 80 ppb, but exposure to 100 ppb is rare. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often three or four months of mild to severe drought in a year. These levels of soil moisture significantly constrain the uptake of ozone and reduce the likelihood of foliar injury being produced.

No ozone-sensitive or bioindicator species are identified for the site.

CHAMIZAL NATIONAL MEMORIAL (CHAM)

Plant Species Sensitive to Ozone

No ozone-sensitive species are listed.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHAM					
	1995	1996	1997	1998	1999
Sum06	13	9	10	28	8
W126	19.6	13.7	15.4	-	17.9
N60	270	166	232	-	245
N80	66	44	33	-	31
N100	14	14	9	-	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHAM					
	1995	1996	1997	1998	1999
Month 1	-3.09	1.19	0.12	-1.01	-1.93
Month 2	-2.36	-1.02	1.13	0.70	-2.20
Month 3	0.78	2.96	-0.10	-3.25	-2.16

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHAM					
	1995	1996	1997	1998	1999
April	-0.22	-0.51	2.00	-1.65	-1.49
May	-0.44	-3.37	0.12	-3.51	-0.78
June	1.09	1.19	1.13	-3.00	2.38
July	-3.09	-1.02	-0.10	-1.01	1.94
August	-2.36	2.96	-0.70	0.70	-1.93
September	0.78	0.93	-1.92	-3.25	-2.20
October	-2.01	-2.27	-1.69	1.05	-2.16

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index generally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. Thus the Sum06 and the W126 criteria were often satisfied in the four years of data presented.
- The N-values for the site show concentrations frequently exceed 60 and 80 ppb, and exceed 100 ppb every year. These levels of exposure may possibly injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels associated with the seasonal Sum06 index show that three of the years, with the highest, second highest and lowest levels of exposure, had two or three months of drought. Two mid-level exposure years had one month of drought between them. No association is apparent between the W126 index of exposure and soil moisture, although only four years of data are available for the assessment. The two highest exposure years, 1995 and 1999, experienced three and four months of mild to severe drought, respectively. The lower exposure years 1996 and 1997 had three and two months of drought, respectively.

The risk of foliar ozone injury to plants at Chamizal National Memorial is low. Both the Sum06 and W126 indices satisfy the threshold criteria and there are frequent exposures at concentrations greater than 80 and 100 ppb. However, most years experience three or more months of mild to severe drought that significantly constrain the uptake of ozone and reduce the effectiveness of the exposure. Since levels of exposure and soil moisture are not associated, the level of risk could increase if higher exposures and normal soil moisture conditions occur in the same year. Exposure and moisture levels in 1997

illustrate how these conditions can occur at thee site. No ozone-sensitive species have been identified at the site.

FORT DAVIS NATIONAL HISTORIC SITE (FODA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Prunus serotina	Black cherry	Rosaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FODA					
	1995	1996	1997	1998	1999
Sum06	7	10	7	18	10
W126	21.0	20.7	18.6	28.8	20.9
N60	308	306	259	500	316
N80	38	37	24	29	20
N100	7	6	3	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FODA					
	1995	1996	1997	1998	1999
Month 1	1.09	-1.19	-0.10	-0.76	-1.93
Month 2	-3.09	-0.51	-0.70	-1.65	-2.20
Month 3	-2.36	-3.37	-1.92	-3.51	-2.16

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FODA					
	1995	1996	1997	1998	1999
April	-0.22	-0.51	2.00	-1.65	-1.49
May	-0.44	-3.37	0.12	-3.51	-0.78
June	1.09	1.19	1.13	-3.00	2.38
July	-3.09	-1.02	-0.10	-1.01	1.94
August	-2.36	2.96	-0.70	0.70	-1.93
September	0.78	0.93	-1.92	-3.25	-2.20
October	-2.01	-2.27	-1.69	1.05	-2.16

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. The highest levels of exposure may injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The highest ozone year, 1998, had two months of mild and moderate drought. The intermediate exposure years 1996 and 1999 had two and three months of drought, respectively. Two years with the lowest and same ozone exposure, 1995 and 1997, had two months of moderate and severe drought and one month of mild drought, respectively. Soil moisture levels associated with the seasonal W126 index appear inversely related

to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. There were five months of mild and severe drought in the highest ozone year, 1998, and four, three and three months of mild to severe drought in 1999, 1996 and 1995 the next three highest years of exposure. There were two months of mild drought in the lowest year, 1997.

The low levels of ozone exposure and the frequent dry soil moisture conditions at Fort Davis National Historic Site make the risk of foliar ozone injury to plants low. While the Sum06 exposures intermittently exceed the threshold levels for injury, the W126 do not since the N100 criterion is not generally satisfied. Frequent months of mild to severe drought constrain the uptake of ozone and further reduce the effectiveness of the exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use black cherry and skunkbush.

GUADALUPE MOUNTAINS NATIONAL PARK (GUMO)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GUMO

	1995	1996	1997	1998	1999
Sum06	6	8	8	20	13
W126	21.8	21.8	20.9	30.2	23.5
N60	330	332	312	561	386
N80	44	43	30	31	21
N100	9	7	4	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GUMO					
	1995	1996	1997	1998	1999
Month 1	1.09	-3.37	-0.10	-1.65	-1.49
Month 2	-3.09	1.19	-0.70	-3.51	-0.78
Month 3	-2.36	-1.02	-1.92	-3.00	2.38

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GUMO					
	1995	1996	1997	1998	1999
April	-0.22	-0.51	2.00	-1.65	-1.49
May	-0.44	-3.37	0.12	-3.51	-0.78
June	1.09	1.19	1.13	-3.00	2.38
July	-3.09	-1.02	-0.10	-1.01	1.94
August	-2.36	2.96	-0.70	0.70	-1.93
September	0.78	0.93	-1.92	-3.25	-2.20
October	-2.01	-2.27	-1.69	1.05	-2.16

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than nine hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The highest ozone year, 1998, had three months of mild and severe drought and the second highest year, 1999, one month of mild drought. The intermediate years 1997 and 1996 had one and two months of drought each, while the lowest year, 1995, had two months of moderate and severe drought. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. There were five months of mild and severe drought in the highest ozone year, 1998, and four months of mild and moderate drought in 1999, the second highest year. The intermediate ozone years 1995 and 1996 each had three months of drought, and there were two months of mild drought in the lowest year, 1997.

The low levels of ozone exposure and the frequent dry soil moisture conditions at Guadalupe Mountains National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is generally not satisfied. Frequent months of mild to severe drought

constrain the uptake of ozone and further reduce the effectiveness of the exposures.

No ozone-sensitive or bioindicator species are identified for the site.

WHITE SANDS NATIONAL MONUMENT (WHSA)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WHSA

	1995	1996	1997	1998	1999
Sum06	7	15	10	17	15
W126	20.3	22.2	19.7	27.6	23.8
N60	303	341	272	484	381
N80	34	30	20	27	19
N100	7	4	2	3	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WHSA					
	1995	1996	1997	1998	1999
Month 1	-0.62	-3.01	1.48	6.08	0.26
Month 2	-2.13	4.94	3.46	-2.03	-0.16
Month 3	-1.16	0.20	-0.19	-3.45	-0.02

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WHSA					
	1995	1996	1997	1998	1999
April	0.52	-1.99	2.85	2.65	0.26
May	-0.67	-3.01	-0.27	-0.51	-0.16
June	-0.62	4.94	1.48	-0.78	-0.02
July	-2.13	0.20	3.46	6.08	3.60
August	-1.16	0.20	-0.19	-2.03	4.47
September	1.08	2.33	3.14	-3.45	-0.84
October	-2.50	2.01	-1.15	3.01	-1.49

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The years with the highest and lowest Sum06 exposures, 1998 and 1995, each experienced two months of mild to severe drought. One month of mild drought occurred over the remaining three years. The highest and second highest W126 exposure years, 1998 and 1999, had two months of moderate and severe drought and one month of mild drought, respectively. The lowest and second lowest years, 1997 and 1995, had one month of mild and three months of mild and moderate drought. No association is apparent between the W126 level of ozone exposure and soil moisture.

The low levels of ozone exposure and the frequent dry soil moisture conditions at White Sands National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures generally exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Months of mild to severe drought in most years constrain the uptake of ozone and further reduce the effectiveness of the exposures.

There are no ozone-sensitive or bioindicator species listed for the site.

CUMBERLAND / PIEDMONT NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE CUMBERLAND/PIEDMONT NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its

determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be

a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE CUMBERLAND/PIEDMONT NETWORK

Park	Code	State	Risk	O3 Data
Abraham Lincoln Birthplace NHS	ABLI	KY	moderate	kriged
Carl Sandburg Home NHS	CARL	NC	moderate	kriged
Chickamauga & Chattanooga NMP	CHCH	GA	high	kriged
Cowpens NB	COWP	SC	high	monitored
Cumberland Gap NHP	CUGA	KY	high	kriged
Fort Donelson NB	FODO	TN	high	kriged
Guilford Courthouse NMP	GUCO	NC	high	kriged
Kings Mountain NMP	KIMO	SC	high	kriged
Little River Canyon NPRES	LIRI	AL	high	kriged
Mammoth Cave NP	MACA	KY	high	monitored
Ninety Six NHS	NISI	SC	low	kriged
Russell Cave NM	RUCA	AL	moderate	kriged
Shiloh NMP	SHIL	TN	high	kriged
Stones River NB	STRI	TN	high	kriged

A portion of the Natchez Trace National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Natchez Trace Trail.

ABRAHAM LINCOLN BIRTHPLACE NATIONAL HISTORIC SITE (ABLI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ABLI					
	1995	1996	1997	1998	1999
Sum06	28	22	20	29	34
W126	37.0	29.0	28.3	46.7	58.1
N60	674	519	514	836	1049
N80	118	77	72	168	245
N100	16	7	9	24	19

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ABLI					
	1995	1996	1997	1998	1999
Month 1	0.28	1.29	-2.99	0.19	1.06
Month 2	-1.38	1.76	-0.28	-2.05	-3.13
Month 3	-0.71	-0.84	-0.97	-2.56	-3.05

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ABLI					
	1995	1996	1997	1998	1999
April	-0.17	1.99	-1.38	3.52	-0.94
May	5.59	1.30	1.57	-0.54	-1.03
June	0.28	1.29	4.08	4.83	1.06
July	-1.38	1.76	-2.99	0.19	-3.13
August	-0.71	-0.84	-0.28	-2.05	-3.05
September	-0.96	4.08	-0.97	-2.56	-2.17
October	3.29	0.65	-1.02	-0.59	-0.57

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in three years. These levels of ozone can injure vegetation during high exposure years.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1998 and 1999, each had two months of moderate to severe drought. The year with a slightly lower ozone exposure, 1995, had one month of mild drought, while the two years with the lowest exposures experienced normal conditions and one month of moderate drought between them. Soil moisture levels associated with the W126 indices of exposure appear to be inversely related to ozone concentrations, although the pattern is not consistent. In the year with highest exposure, 1999, there were four months of mild to severe drought. The two mid-exposure years, 1998 and 1995, experienced two months of moderate and one month of mild drought, respectively. The second lowest year had normal soil moisture and the lowest year, 1997, experienced three months of mild and moderate drought.

The risk of foliar ozone injury to plants at Abraham Lincoln Birthplace National Historic Site is moderate. While the levels of ozone exposure consistently create the potential for

injury, dry soil conditions may reduce the likelihood of injury developing in years with the highest levels of exposure. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry and northern fox grape.

CARL SANDBURG HOME NATIONAL HISTORIC SITE (CARL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CARL					
	1995	1996	1997	1998	1999
Sum06	23	22	26	33	34
W126	39.7	35.9	42.5	59.2	64.7
N60	747	649	794	1078	1215
N80	95	69	85	223	217
N100	9	4	3	27	15

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CARL					
	1995	1996	1997	1998	1999
Month 1	3.12	-0.70	-1.17	-2.57	1.24
Month 2	-1.62	0.26	-3.35	-2.52	-0.91
Month 3	1.98	-0.32	1.59	-3.01	-2.64

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CARL					
	1995	1996	1997	1998	1999
April	-2.81	-0.22	2.05	3.84	-0.96
May	-0.22	-0.70	-0.13	-1.65	-0.39
June	3.12	0.26	2.84	0.73	1.24
July	-1.62	-0.32	-1.17	-2.57	-0.91
August	1.98	1.36	-3.35	-2.52	-2.64
September	-0.16	2.86	1.59	-3.01	-1.75
October	3.09	-1.80	0.65	-1.32	-0.37

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two years. The higher levels of exposure can injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two years with the highest Sum06 values, 1999 and 1998, had one and three months of moderate to severe levels of drought, respectively. The mid-level exposure year, 1997, had two months of mild and severe drought. The two lowest exposure years, 1995 and 1996, had one month of mild drought and normal soil moisture, respectively. Relationships between the W126 index of exposure and soil

moisture also appear to be inverse, and are also inconsistent. Soil moisture levels associated with the highest exposure in 1999 showed two months of mild and moderate drought, while the second highest ozone year, 1998, had five months of mild to severe drought. The mid-exposure year 1997 had two months of mild and severe drought while the two lowest ozone years, 1995 and 1996, had two months of mild and moderate drought and normal soil moisture, respectively.

The risk of foliar ozone injury at the Carl Sandburg Home National Historic Site is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in three years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to five months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. One year, 1996, has favorable soil moisture conditions, but ozone exposures are lower. These conditions, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought, such as 1995, or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

CHICKAMAUGA AND CHATTANOOGA NATIONAL MILITARY PARK (CHCH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHCH					
	1995	1996	1997	1998	1999
Sum06	19	22	23	27	27
W126	33.6	36.0	35.6	53.5	52.8
N60	598	655	626	894	933
N80	103	108	109	244	219
N100	18	12	8	51	31

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHCH					
	1995	1996	1997	1998	1999
Month 1	0.00	-1.78	0.34	-1.00	0.88
Month 2	-1.57	-0.26	-0.88	-1.27	-2.13
Month 3	-0.82	-0.92	3.13	-3.01	-1.99

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHCH					
	1995	1996	1997	1998	1999
April	-1.26	0.00	0.93	2.39	-2.06
May	-1.09	-1.78	0.86	-1.50	0.49
June	0.00	-0.26	3.08	0.32	2.92
July	-1.57	-0.92	0.34	-1.00	0.88
August	-0.82	0.94	-0.88	-1.27	-2.13
September	0.97	2.01	3.13	-3.01	-1.99
October	5.38	-1.07	2.59	-2.08	0.33

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated. The N100 values are highly variable and ranges from 8 to 51. The higher levels of exposure can injure vegetation

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture levels during two years with the highest Sum06 values, 1998 and 1999, showed three and two months of moderate to severe drought, respectively. Two years with the lowest indices each had one month of mild drought, while in 1997, a

mid-exposure year, soil moisture was normal. Soil moisture levels associated with the W126 index also appear to be inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone years, 1998 and 1999, soil moisture conditions were at moderate to severe drought levels for five and three months, respectively. In the two mid-exposure years, 1996 and 1997, there were two months of mild drought and normal moisture conditions, respectively. There were three months of mild drought in 1995, the year with the lowest exposure.

The risk of foliar ozone injury to plants at Chickamauga and Chattanooga National Military Park is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in a particular year. High levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

COWPENS NATIONAL BATTLEFIELD (COWP)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Platanus occidentalis	American sycamore	Platanaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for COWP					
	1995	1996	1997	1998	1999
Sum06	24	30	40	39	36
W126	33.1	33.7	54.6	55.4	51.4
N60	581	647	963	942	913
N80	112	72	199	236	171
N100	11	2	8	30	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil

moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at COWP					
	1995	1996	1997	1998	1999
Month 1	2.99	0.27	0.56	-0.35	0.81
Month 2	-1.49	-1.13	1.14	-2.35	-1.78
Month 3	6.28	-1.04	1.34	-1.05	-2.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at COWP					
	1995	1996	1997	1998	1999
April	-2.28	0.40	1.64	5.34	-0.13
May	-1.05	0.27	0.07	-0.90	-1.54
June	2.99	-1.13	1.43	-0.35	0.81
July	-1.49	-1.04	1.12	-2.35	-1.78
August	6.28	0.64	-2.38	-1.05	-2.36
September	0.42	1.78	0.56	-0.13	-0.49
October	2.61	-0.65	1.14	-0.96	1.53

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value is significantly greater than the threshold and the N100 count exceeded its threshold value in four of five years, thus the criteria for injury under the W126 index are satisfied. Both the Sum06 and W126 indices exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. During the highest Sum06 exposure in 1997, soil moisture was normal. In each of three other years, 1996, 1998 and 1999, there were two months of mild and moderate drought, and there was one month of mild drought in 1995, the lowest exposure year. There also does not appear to be any association between the W126 index of exposure and soil moisture. Four of the five years had two or three months of mild and moderate drought with one month of moderate drought in the remaining year 1997.

The risk of foliar ozone injury to plants at Cowpens National Battlefield is high. Both the Sum06 and W126 exposure thresholds are satisfied. The number of hours of exposure to 80 ppb and 100 ppb is generally high, but variable. Levels of ozone exposure and soil moisture are not related and moisture conditions fostering or constraining the uptake of ozone can occur at any exposure. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1997 and 1998 when ozone levels exceed the thresholds, and soil moisture levels are under comparatively short-term drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

CUMBERLAND GAP NATIONAL HISTORICAL PARK (CUGA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CUGA					
	1995	1996	1997	1998	1999
Sum06	22	17	23	27	27
W126	37.6	33.3	35.3	48.6	49.5
N60	682	595	627	842	903
N80	117	104	105	200	184
N100	15	9	9	38	20

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CUGA					
	1995	1996	1997	1998	1999
Month 1	0.54	2.73	-1.33	-0.54	-0.84
Month 2	-2.95	1.04	0.35	-1.49	-3.26
Month 3	-1.97	2.03	-0.03	-2.85	-1.42

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CUGA					
	1995	1996	1997	1998	1999
April	-0.39	1.39	-1.65	5.46	-0.97
May	4.43	2.73	1.41	1.07	-1.87
June	0.54	1.04	4.17	4.96	-0.84
July	-2.95	2.03	-1.33	-0.54	-3.26
August	-1.97	0.46	0.35	-1.49	-1.42
September	0.29	3.08	-0.03	-2.85	-2.31
October	1.85	1.33	-0.83	-1.62	-0.23

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in some years. These levels of exposure can injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture in the two years with the highest Sum06 values, 1998 and 1999, showed two months of mild to severe drought each year. The two mid-exposure years, 1997 and 1995, experienced one and two months of mild and moderate drought,

respectively. The lowest exposure year, 1996, had normal soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. When ozone exposures were highest in 1999 and 1998, there were four and three months of mild to severe drought, respectively. The remaining three years had lower and similar levels of exposure. Two years had two months of mild and moderate drought each, and the lowest exposure year, 1996, had normal levels of soil moisture.

The risk of foliar ozone injury to plants at Cumberland Gap National Historical Park is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in the highest exposure years. High levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and crownbeard.

FORT DONELSON NATIONAL BATTLEFIELD (FODO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FODO					
	1995	1996	1997	1998	1999
Sum06	12	16	16	15	25
W126	39.3	31.4	32.6	48.9	63.7
N60	710	556	581	884	1145
N80	106	60	83	153	249
N100	9	4	8	17	32

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FODO					
	1995	1996	1997	1998	1999
Month 1	0.33	0.49	-1.50	3.31	-1.23
Month 2	-2.06	3.03	0.61	-0.93	-2.01
Month 3	-0.95	-0.02	1.74	-2.50	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FODO					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two years. The higher levels of exposure can injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture in the year with the highest index, 1999, showed three months of mild and moderate drought. The three mid-exposure years had lower and similar Sum06 indices; two years had one month of mild or moderate drought and one year had conditions favorable for ozone uptake. The lowest ozone year, 1995, had one month of moderate drought. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone year, 1999, soil moisture conditions were at mild to moderate drought levels for four months, while the second highest year, 1998, had one month of moderate drought. The three lower exposure years had one month of mild drought among them.

The risk of foliar ozone injury to plants at Fort Donelson National Battlefield is high. The levels of ozone exposure are variable, but create the potential for injury in most years. However, dry soil conditions may reduce the likelihood of injury in the highest exposure years. Levels of ozone capable of producing foliar injury also occur under conditions of

minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1995, 1997 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under short-term drought conditions that do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

GUILFORD COURTHOUSE NATIONAL MILITARY PARK (GUCO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GUCO					
	1995	1996	1997	1998	1999
Sum06	22	27	31	32	29
W126	31.9	36.5	46.5	54.1	42.5
N60	581	663	826	929	736
N80	86	99	161	232	166
N100	9	10	12	32	24

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GUCO					
	1995	1996	1997	1998	1999
Month 1	6.39	0.82	0.50	-1.83	-1.05
Month 2	-0.69	-0.78	-0.72	-1.68	-1.19
Month 3	-0.12	-0.29	-2.21	-1.58	-0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GUCO					
	1995	1996	1997	1998	1999
April	-2.96	0.57	3.47	1.37	1.13
May	-0.11	0.82	-1.76	0.24	-1.54
June	6.39	-0.78	0.50	-1.11	-1.05
July	-0.69	-0.29	-0.72	-1.83	-1.19
August	-0.12	1.36	-2.21	-1.68	-0.86
September	-1.21	6.90	0.02	-1.58	9.76
October	3.91	1.31	-0.49	-2.37	0.69

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours most years. These levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1998, had three months of mild drought. The next two highest years, 1997 and 1999, had one and two months of moderate and mild drought, respectively. The two years with the lowest exposures experienced normal conditions. Soil moisture levels associated with

the W126 index also appear inversely related to ozone exposure, although the relationship is not consistent. In the highest ozone year, 1998, soil moisture conditions were at mild to moderate drought levels for five months. In two years with mid-level exposure, 1997 and 1999, soil moisture conditions exhibited two and three months of drought respectively. The year with the lowest ozone, 1995, had two months of drought, while the second lowest year, 1996, had normal conditions.

The risk of foliar ozone injury to plants at Guilford Courthouse National Military Park is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in a high exposure year. Levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under short-term drought conditions that do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, crownbeard and northern fox grape.

KINGS MOUNTAIN NATIONAL MILITARY PARK (KIMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for KIMO					
	1995	1996	1997	1998	1999
Sum06	24	27	30	37	34
W126	35.6	33.8	40.4	51.6	47.8
N60	646	607	728	891	829
N80	118	98	122	220	189
N100	16	10	12	32	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at KIMO					
	1995	1996	1997	1998	1999
Month 1	2.99	-1.13	1.12	-0.35	0.81
Month 2	-1.49	-1.04	-2.38	-2.35	-1.78
Month 3	6.28	0.64	0.56	-1.05	-2.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at KIMO					
	1995	1996	1997	1998	1999
April	-2.28	0.40	1.64	5.34	-0.13
May	-1.05	0.27	0.07	-0.90	-1.54
June	2.99	-1.13	1.43	-0.35	0.81
July	-1.49	-1.04	1.12	-2.35	-1.78
August	6.28	0.64	-2.38	-1.05	-2.36
September	0.42	1.78	0.56	-0.13	-0.49
October	2.61	-0.65	1.14	-0.96	1.53

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. In the Sum06 assessment there were three years, 1998, 1999 and 1996, representing the highest, second highest and second lowest exposures, respectively, each of which experienced two months of mild and moderate drought. Years with mid-level and the lowest exposure, 1997 and 1995, each had one month of moderate or mild drought. There also does not appear to be any association between the W126 level of exposure and soil moisture. Four of the five years experienced two or

three months of mild to moderate drought, and only 1997 had one month of moderate drought.

The risk of foliar ozone injury to plants at Kings Mountain National Military Park is high. The levels of ozone exposure consistently create the potential for injury although dry conditions can reduce the uptake from one to several months in any particular year. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 in which exposures exceed injury thresholds and there are few months of mild or moderate drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

LITTLE RIVER CANYON NATIONAL PRESERVE (LIRI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Aster acuminatus	Whorled aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LIRI					
	1995	1996	1997	1998	1999
Sum06	22	25	19	32	35
W126	39.2	35.9	33.2	60.9	64.3
N60	710	645	588	1030	1095
N80	124	107	92	273	299
N100	22	13	7	49	43

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LIRI					
	1995	1996	1997	1998	1999
Month 1	0.38	-1.24	-0.72	0.21	-3.29
Month 2	-1.23	2.63	1.77	-2.97	-2.34
Month 3	-1.24	0.43	2.98	-2.44	-0.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LIRI					
	1995	1996	1997	1998	1999
April	-0.61	-0.12	0.49	1.87	-1.50
May	-1.01	-1.20	3.02	-1.50	0.56
June	0.38	-1.24	6.25	-0.52	4.76
July	-1.23	2.63	-0.54	-0.69	-1.00
August	-1.24	0.43	-0.72	0.21	-3.29
September	1.12	2.88	1.77	-2.97	-2.34
October	6.30	-0.29	2.98	-2.44	-0.36

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold and the N100 count meets the threshold requirement each year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant numbers of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture during the years with the highest Sum06 ozone values, 1999 and 1998, showed two months of moderate to severe drought each year. Years with mid-level exposures, 1996 and 1995, had one and two months of mild drought, and the year with the lowest exposure, 1997, had normal soil moisture conditions. Soil moisture levels associated with the seasonal W126

index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, soil moisture conditions were at moderate to severe drought levels for four and three months, respectively. In the years with mid-level exposures, 1995 and 1996, there were three and two months of mild drought, respectively. The lowest exposure year 1997 had normal soil moisture conditions.

The risk of foliar ozone injury to plants at Little River Canyon National Preserve is high. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions may reduce the likelihood of injury developing in the highest exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, redbud, white ash, yellow-poplar, American sycamore, black cherry, American elder and crownbeard.

MAMMOTH CAVE NATIONAL PARK (MACA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MACA					
	1995	1996	1997	1998	1999
Sum06	29	27	11	-	-
W126	34.5	33.5	30.6	60.6	80.8
N60	673	631	567	1118	1493
N80	63	75	79	198	328
N100	14	4	10	23	26

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MACA					
	1995	1996	1997	1998	1999
Month 1	-1.38	1.29	-1.38	-	-
Month 2	-0.71	1.76	1.57	-	-
Month 3	-0.96	-0.84	4.08	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MACA					
	1995	1996	1997	1998	1999
April	-0.17	1.99	-1.38	3.52	-0.94
May	5.59	1.30	1.57	-0.54	-1.03
June	0.28	1.29	4.08	4.83	1.06
July	-1.38	1.76	-2.99	0.19	-3.13
August	-0.71	-0.84	-0.28	-2.05	-3.05
September	-0.96	4.08	-0.97	-2.56	-2.17
October	3.29	0.65	-1.02	-0.59	-0.57

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. Both the Sum06 and W126 indices exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone.

- Only three years of data are available for the 90-day Sum06 exposure index limiting the ability to assess relationships between exposure levels and soil moisture. There were only two months of mild drought during the three years, and ozone uptake was generally fostered. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the relationship is inconsistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal

exposure in producing foliar injury. The two highest exposure years, 1999 and 1998, had four and two months of mild to severe drought, respectively. Two years with intermediate and similar levels of exposure had one month of drought and normal moisture conditions. The year with the lowest exposure, 1997, had three months of drought.

The risk of foliar ozone injury to plants at Mammoth Cave National Park is high. Threshold levels for both the Sum06 and W126 indices are satisfied and hours of exposure to 80 and 100 ppb are generally high. The levels of ozone exposure consistently create the potential for injury during years with both normal soil moisture and drought. Due to the inverse relationship between ozone and soil moisture levels, dry soil conditions constrain the uptake of ozone and reduce the likelihood of injury in higher exposure years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and crownbeard.

NINETY SIX NATIONAL HISTORIC SITE (NISI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NISI					
	1995	1996	1997	1998	1999
Sum06	20	19	26	38	32
W126	25.9	23.6	31.7	50.7	43.4
N60	477	424	583	917	780
N80	59	40	77	195	155
N100	5	2	3	24	13

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NISI					
	1995	1996	1997	1998	1999
Month 1	2.82	-0.79	1.59	-0.05	-0.41
Month 2	-0.74	-1.08	-1.81	-1.76	-2.25
Month 3	4.32	-1.27	1.46	-1.77	0.14

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NISI					
	1995	1996	1997	1998	1999
April	-2.53	0.66	0.73	2.78	-1.10
May	-1.27	-0.79	-0.37	1.03	-0.96
June	2.82	-1.08	1.58	-0.05	2.67
July	-0.74	-1.27	1.59	-1.76	-0.41
August	4.32	1.31	-1.81	-1.77	-2.25
September	1.83	0.81	1.46	1.57	0.14
October	2.06	1.45	1.93	-1.09	-0.16

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years although concentrations exceeded 100 ppb every year. The Sum06 threshold was satisfied each year and the W126 criteria in two of the five years.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods do not appear to be related to the level of ozone exposure. Soil moisture levels in the two highest Sum06 ozone years, 1998 and 1999, showed two months of mild and one month of moderate drought, respectively. There was one month of mild drought in 1997 a mid-exposure year. The lowest exposure year, 1996, experienced two months of mild drought, and the second lowest year had normal soil moisture. Similarly, no relationships are apparent between the W126 index of exposure and soil moisture. Four of the five years experienced two or three months of mild to moderate drought, and only 1997, a mid-exposure year, had one month of mild drought.

The risk of foliar ozone injury at Ninety Six National Historical Site is low. The threshold level for injury is satisfied mainly by the Sum06 index, the W126 index is satisfied in two years, and N-values indicate that in some years there are frequent exposures to concentrations of ozone greater than 80 ppb and a several hours of exposure to 100 ppb. The levels of exposure vary significantly among the years. There is no

association between the level of ozone and soil moisture however there are two or more months of mild and moderate drought in most years that constrain the uptake of ozone and reduce the exposure.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, yellow-poplar, American sycamore, cut-leaf coneflower and crownbeard.

RUSSELL CAVE NATIONAL MONUMENT (RUCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for RUCA					
	1995	1996	1997	1998	1999
Sum06	23	25	18	27	24
W126	33.2	37.0	34.7	51.3	55.4
N60	611	682	617	886	986
N80	82	98	100	205	223
N100	11	8	7	34	27

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at RUCA					
	1995	1996	1997	1998	1999
Month 1	0.38	-1.24	-0.72	0.21	-3.29
Month 2	-1.23	2.63	1.77	-2.97	-2.34
Month 3	-1.24	0.43	2.98	-2.44	-0.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at RUCA					
	1995	1996	1997	1998	1999
April	-0.61	-0.12	0.49	1.87	-1.50
May	-1.01	-1.20	3.02	-1.50	0.56
June	0.38	-1.24	6.25	-0.52	4.76
July	-1.23	2.63	-0.54	-0.69	-1.00
August	-1.24	0.43	-0.72	0.21	-3.29
September	1.12	2.88	1.77	-2.97	-2.34
October	6.30	-0.29	2.98	-2.44	-0.36

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.

- Relationships between the 90-day Sum06 accumulation period index of ozone exposure and soil moisture are difficult to assess because ozone exposure was high and similar in four of the five years. However, they appear to be inversely related: when ozone is high, soil moisture is low, although the pattern is not consistent. In the highest exposure year 1998 there were two months of moderate drought. In each of the three mid-level exposure years, 1996, 1999 and 1995, there were one or two years of drought, while in 1997, the year with the lowest exposure, soil moisture conditions were normal. Soil moisture levels associated with the W126 index also appear inversely related to exposure, although the pattern is again not consistent. In the two highest exposure years, 1999 and 1998, there were four and three months, respectively, of mild to severe drought. The mid-exposure year 1997 had two months of mild drought. The years 1995 and 1997 had the lowest levels of ozone and experienced three months of mild drought and normal moisture conditions, respectively. Overall, most years experienced two or three months of drought with moderate and severe drought occurring in the highest W126 exposure years.

The risk of foliar ozone injury to plants at Russell Cave National Monument is moderate. While the levels of ozone exposure generally create the potential for injury, dry soil conditions may significantly reduce the likelihood of injury in the highest exposure years. However, levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

SHILOH NATIONAL MILITARY PARK (SHIL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SHIL					
	1995	1996	1997	1998	1999
Sum06	15	28	24	31	43
W126	34.7	36	32.7	48.7	62
N60	621	648	603	884	1100
N80	95	81	69	158	261
N100	10	6	5	19	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SHIL					
	1995	1996	1997	1998	1999
Month 1	-2.06	0.49	-1.50	-0.93	-1.23
Month 2	-0.95	3.03	0.61	-2.50	-2.01
Month 3	-0.25	-0.02	1.74	-0.88	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SHIL					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and the W126 criteria were satisfied in two the five years of data presented.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because of the limited number of months of drought. Soil moisture levels during the year with the highest exposure, 1999, show three months of mild to moderate drought. There were only three months of drought in the remaining four years and no associations between the Sum06 index of exposure and soil moisture were apparent. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five and one month, respectively. In the remaining three years, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997, the lowest exposure year.

The risk of foliar ozone injury at Shiloh National Military Park is high. The Sum06 threshold for injury is consistently satisfied, and W126 threshold is satisfied

intermittently. The N-values indicate that exposures to 80 to 100 ppb vary considerably among years, and in some years exposure to 100 ppb is significant. In the highest exposure years, low soil moisture levels reduce the uptake of ozone, however exposure thresholds are also satisfied in years with more normal soil moisture conditions. It is anticipated that the risk of foliar injury developing may be greatest during years such as 1995, 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

STONES RIVER NATIONAL BATTLEFIELD (STRI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for STRI					
	1995	1996	1997	1998	1999
Sum06	24	25	21	25	27
W126	31.9	34.8	36.7	41.0	54.2
N60	590	650	680	744	969
N80	92	101	118	128	211
N100	12	11	14	17	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at STRI					
	1995	1996	1997	1998	1999
Month 1	0.98	0.49	-1.50	3.31	1.61
Month 2	0.14	3.03	0.61	-0.93	-1.23
Month 3	0.59	-0.02	1.74	-2.50	-2.01

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at STRI					
	1995	1996	1997	1998	1999
April	0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because ozone exposure was relatively similar in all five years. However, soil moisture levels associated with the Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture levels during the year with the highest Sum06 value, 1999, show three months of mild to moderate levels of drought. There were only two months of drought in the remaining four years. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five months and one month, respectively. In the three years when ozone exposures were lower, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997.

The risk of foliar ozone injury to plants at Stones River National Battlefield is high. While the levels of ozone exposure consistently create the potential for injury, dry soil

conditions may reduce the likelihood of injury developing in the highest exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995, 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, American sycamore, black cherry and American elder.

EASTERN RIVERS AND MOUNTAINS NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE EASTERN RIVERS AND MOUNTAINS NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE EASTERN RVERS AND MOUNTAINS NETWORK

Park	Code	State	Risk	O3 Data
Allegheny Portage Railroad NHS	ALPO	PA	moderate	kriged
Bluestone NSR	BLUE	WV	moderate	kriged
Delaware Water Gap NRA	DEWA	PA	high	kriged
Fort Necessity NB	FONE	PA	high	kriged
Friendship Hill NHS	FRHI	PA	high	kriged
Gauley River NRA	GARI	WV	moderate	kriged
Johnstown Flood N MEM	JOFL	PA	moderate	kriged
New River Gorge NR	NERI	WV	moderate	kriged
Upper Delaware SRR	UPDE	PA	high	kriged

A portion of the Appalachian National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Appalachian Trail.

ALLEGHENY PORTAGE RAILROAD NATIONAL HISTORIC SITE (ALPO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ALPO					
	1995	1996	1997	1998	1999
Sum06	20	18	23	26	31
W126	30.9	23.9	32.2	44.0	38.2
N60	505	422	514	744	655
N80	117	55	111	183	133
N100	16	4	21	33	14

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ALPO					
	1995	1996	1997	1998	1999
Month 1	2.57	0.66	-0.37	-0.89	-2.67
Month 2	-1.29	4.22	-1.75	-1.19	-1.70
Month 3	-3.25	-0.22	1.54	-2.03	-3.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ALPO					
	1995	1996	1997	1998	1999
April	-1.10	-0.91	-2.49	2.93	2.21
May	0.38	1.41	1.81	-0.20	-2.67
June	2.57	0.66	-0.37	1.02	-1.70
July	-1.29	4.22	-1.75	-0.89	-3.36
August	-3.25	-0.22	1.54	-1.19	0.72
September	-1.88	8.51	1.49	-2.03	0.68
October	2.69	2.10	-1.30	-1.36	-0.79

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1999 and 1998, show three and two months of mild to severe drought, respectively. The two mid-level exposure years, 1997 and 1995 , had one month of mild drought and two months of mild and severe drought, respectively, while the year with the lowest exposure, 1996, experienced favorable conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. The four highest ozone years each experienced three or four months of mild to severe drought. In the lowest exposure year, 1996, soil moisture conditions were favorable.

The risk of foliar ozone injury to plants at Allegheny Portage Railroad National Historic Site is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. One year, 1996, has favorable soil moisture conditions, but ozone exposures are lower. This year, however, suggests that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

BLUESTONE NATIONAL SCENIC RIVER (BLUE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanacea
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BLUE					
	1995	1996	1997	1998	1999
Sum06	27	19	24	36	37
W126	45.9	30.3	46.8	64.8	59.9
N60	892	554	897	1217	1163
N80	92	46	86	215	161
N100	6	3	3	21	9

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BLUE					
	1995	1996	1997	1998	1999
Month 1	-2.22	-0.66	0.82	2.42	-1.03
Month 2	-2.76	4.73	0.50	-1.48	-2.58
Month 3	0.76	0.41	0.30	-1.56	-2.18

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BLUE					
	1995	1996	1997	1998	1999
April	-1.98	-0.66	-0.84	2.50	0.47
May	2.67	4.73	0.82	3.09	-1.03
June	3.62	0.41	0.50	2.42	-2.58
July	-2.22	-0.59	0.30	-1.48	-2.18
August	-2.76	2.36	-0.72	-1.56	-1.45
September	0.76	3.75	-0.74	-2.96	1.05
October	0.65	-0.17	-1.99	-2.14	-0.07

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in some years. The higher levels of exposure can injure vegetation.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone

concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1999 and 1998, had, respectively, three and two months of mild and moderate drought. The two intermediate ozone years, 1995 and 1997, had two months of moderate drought stress and normal soil moisture, respectively. Soil moisture was normal in 1996, the year with the lowest ozone exposure. Soil moisture levels associated with the W126 index also appear to be inversely related to ozone concentrations, although the pattern is not consistent. The two highest ozone years, 1998 and 1999, each had four months of mild and moderate drought. The two mid-level exposure years, 1997 and 1995, had one month of mild drought, and three months of mild and moderate drought, respectively. The year with the lowest ozone exposure, 1996, had normal soil moisture conditions.

The risk of foliar ozone injury to plants at Bluestone National Scenic River is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in two years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is reduced. The two years that have favorable soil moisture conditions, 1996 and 1997, also have ozone exposures that are lower. These years, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may be greatest during years when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, Allegheny blackberry, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

DELAWARE WATER GAP NATIONAL RECREATION AREA (DEWA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to

give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DEWA					
	1995	1996	1997	1998	1999
Sum06	21	16	20	23	28
W126	32.8	25.3	29.1	36.4	39.9
N60	511	397	452	608	630
N80	160	96	128	160	184
N100	29	13	21	14	41

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil

moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DEWA					
	1995	1996	1997	1998	1999
Month 1	-1.94	0.86	-1.37	-1.19	-2.14
Month 2	-0.56	2.84	-1.72	-2.13	-3.15
Month 3	-3.49	-1.70	1.36	-0.66	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DEWA					
	1995	1996	1997	1998	1999
April	-1.53	1.90	-1.44	1.60	-1.41
May	-1.22	-0.18	-0.32	0.78	-1.13
June	-1.94	0.86	-1.37	3.26	-2.14
July	-0.56	2.84	-1.72	-1.19	-3.15
August	-3.49	-1.70	1.36	-2.13	-1.97
September	-0.99	1.26	0.11	-0.66	6.14
October	3.91	2.89	-1.41	-0.17	-0.10

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb,

and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest ozone exposure value, 1999, had three months of mild to moderate drought, while the lowest ozone year, 1996, had one month of mild drought. The three intermediate years each had two months of mild to severe drought. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, but the pattern is not consistent. The highest ozone year, 1999, had five months of mild to severe drought and the lowest year, 1996, had one month of mild drought. However, the second highest ozone year, 1998, had two months of drought, while the second lowest year, 1997, had four months of mild drought.

The risk of foliar ozone injury to plants at Delaware Water Gap National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, common snowberry, and northern fox grape.

FORT NECESSITY NATIONAL BATTLEFIELD (FONE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FONE					
	1995	1996	1997	1998	1999
Sum06	21	18	22	29	32
W126	32.5	27.2	30.8	43.5	40.7
N60	544	488	494	741	711
N80	130	74	112	191	148
N100	21	7	17	36	19

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FONE					
	1995	1996	1997	1998	1999
Month 1	-0.52	1.23	-0.80	-1.48	-1.07
Month 2	-1.84	1.41	-2.79	-0.83	-3.31
Month 3	-3.07	-0.63	1.58	-2.13	-1.30

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FONE					
	1995	1996	1997	1998	1999
April	-1.16	0.57	-2.08	1.97	1.42
May	0.64	1.19	2.81	-2.20	-1.07
June	-0.52	1.23	-0.80	1.33	-3.31
July	-1.84	1.41	-2.79	-1.48	-1.30
August	-3.07	-0.63	1.58	-0.83	-1.86
September	-2.15	4.21	0.69	-2.13	-0.86
October	0.25	1.76	-1.71	-1.24	-1.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest and second highest Sum06 ozone exposure values, 1999 and 1998, experienced three and two months of mild to severe drought, respectively. The two intermediate ozone years, 1997 and 1995, had similar levels of exposure and one and two months of drought each. The year with the lowest ozone

exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and five months, respectively, of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had four and three months of mild to severe drought, while the lowest ozone year, 1996, had favorable soil moisture conditions throughout.

The risk of foliar ozone injury to plants at Fort Necessity National Battlefield is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, white ash, yellow-poplar, black cherry, Allegheny blackberry, and American elder.

FRIENDSHIP HILL NATIONAL HISTORIC SITE (FRHI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FRHI					
	1995	1996	1997	1998	1999
Sum06	20	18	24	32	34
W126	32.2	28.2	30.8	45.2	45.9
N60	540	505	501	772	815
N80	128	78	107	201	163
N100	20	8	15	36	19

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FRHI					
	1995	1996	1997	1998	1999
Month 1	-0.52	1.23	-0.80	-1.48	-1.07
Month 2	-1.84	1.41	-2.79	-0.83	-3.31
Month 3	-3.07	-0.63	1.58	-2.13	-1.30

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FRHI					
	1995	1996	1997	1998	1999
April	-1.16	0.57	-2.08	1.97	1.42
May	0.64	1.19	2.81	-2.20	-1.07
June	-0.52	1.23	-0.80	1.33	-3.31
July	-1.84	1.41	-2.79	-1.48	-1.30
August	-3.07	-0.63	1.58	-0.83	-1.86
September	-2.15	4.21	0.69	-2.13	-0.86
October	0.25	1.76	-1.71	-1.24	-1.58

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1999 and 1998, experienced three and two months of mild to severe drought, respectively. The two intermediate ozone years, 1997 and 1995, had one and two months of drought each. The year with the lowest ozone exposure, 1996, had favorable soil

moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, there were five and four months, respectively, of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had four and three months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Friendship Hill National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

GAULEY RIVER NATIONAL RECREATION AREA (GARI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GARI					
	1995	1996	1997	1998	1999
Sum06	19	15	15	23	29
W126	40.3	27.0	36.2	52.3	48.4
N60	757	485	673	955	889
N80	100	53	72	195	150
N100	11	4	4	26	18

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GARI					
	1995	1996	1997	1998	1999
Month 1	0.96	-1.05	-1.13	-1.91	-3.46
Month 2	-3.09	4.40	0.91	-1.51	-3.38
Month 3	-1.88	1.51	0.44	-2.06	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GARI					
	1995	1996	1997	1998	1999
April	-1.89	-0.78	-1.11	1.15	-1.35
May	2.18	6.67	1.50	0.09	-1.66
June	0.96	-1.05	-0.50	5.38	-3.46
July	-3.09	4.40	-1.13	-1.91	-3.38
August	-1.88	1.51	0.91	-1.51	-1.56
September	-1.84	5.53	0.44	-2.06	-1.10
October	-0.55	0.45	-1.49	-2.48	-0.28

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb. The N-value for 100 ppb was highly variable, but reached a significant number of hours in three of the years. The higher levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest ozone exposure values, 1999 and 1998, each experienced three months of mild to severe drought. The mid-level exposure year 1995 had two months of mild and severe drought while the two years with the same and lowest ozone exposure, 1996 and 1997, each had one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and six months, respectively, of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had four and three months of mild to severe drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Gauley River National Recreation Area is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in two years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are four to six months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. Two years, 1996 and 1997, have favorable to generally favorable soil moisture conditions, but ozone exposures are lower. These years, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and crownbeard.

JOHNSTOWN FLOOD NATIONAL MEMORIAL (JOFL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JOFL					
	1995	1996	1997	1998	1999
Sum06	20	18	20	25	30
W126	30.6	23.4	30.4	40.7	36.2
N60	497	413	482	684	618
N80	123	58	107	173	133
N100	19	5	20	33	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JOFL					
	1995	1996	1997	1998	1999
Month 1	2.57	0.66	-0.37	-0.89	-2.67
Month 2	-1.29	4.22	-1.75	-1.19	-1.70
Month 3	-3.25	-0.22	1.54	-2.03	-3.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JOFL					
	1995	1996	1997	1998	1999
April	-1.10	-0.91	-2.49	2.93	2.21
May	0.38	1.41	1.81	-0.20	-2.67
June	2.57	0.66	-0.37	1.02	-1.70
July	-1.29	4.22	-1.75	-0.89	-3.36
August	-3.25	-0.22	1.54	-1.19	0.72
September	-1.88	8.51	1.49	-2.03	0.68
October	2.69	2.10	-1.30	-1.36	-0.79

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. The levels of high exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1999 and 1998, experienced three and two months of mild to severe drought, respectively.. The two intermediate ozone years, 1997 and 1995, had one and two months of drought each, and the year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The highest ozone years,

1998 and 1999, each had three months of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had four and three months of mild to severe drought. The lowest ozone year, 1996, had favorable soil moisture conditions.

The risk of foliar ozone injury to plants at Johnstown Flood National Memorial is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. One year, 1996, has favorable soil moisture conditions, but ozone exposures are lower. This year, however, suggests that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, white ash, yellow-poplar, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

NEW RIVER GORGE NATIONAL RIVER (NERI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NERI					
	1995	1996	1997	1998	1999
Sum06	19	14	16	25	29
W126	44.3	28.7	40.8	59.7	53.3
N60	848	520	771	1109	1001
N80	100	48	79	209	157
N100	9	3	4	24	15

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NERI					
	1995	1996	1997	1998	1999
Month 1	0.96	-1.05	-1.13	-1.91	-3.46
Month 2	-3.09	4.40	0.91	-1.51	-3.38
Month 3	-1.88	1.51	0.44	-2.06	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NERI					
	1995	1996	1997	1998	1999
April	-1.89	-0.78	-1.11	1.15	-1.35
May	2.18	6.67	1.50	0.09	-1.66
June	0.96	-1.05	-0.50	5.38	-3.46
July	-3.09	4.40	-1.13	-1.91	-3.38
August	-1.88	1.51	0.91	-1.51	-1.56
September	-1.84	5.53	0.44	-2.06	-1.10
October	-0.55	0.45	-1.49	-2.48	-0.28

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours most years. The high levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1999 and 1998, each experienced three months of mild to severe drought, and the intermediate ozone year, 1995, had two months of drought. The years with the lowest and second lowest ozone exposure, 1996 and 1997, each experienced one month of mild drought. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and six months, respectively, of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had four and three months of drought, respectively, and the lowest ozone year, 1996, had one month of mild drought.

The risk of foliar ozone injury to plants at New River Gorge National River is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in two years. The inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are three to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. When drought is moderate and severe in high ozone years, the uptake of ozone is significantly diminished, and, in spite of the high levels of exposure, the risk of injury is greatly reduced. Two years, 1996 and 1997, have favorable or generally favorable soil moisture conditions, but ozone exposures are lower. These years, however, suggest that levels of exposure capable of producing foliar injury may also occur at the site under conditions of minor drought or normal soil moisture. The probability of foliar injury developing may greatest during years in which ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, Allegheny blackberry, cut-leaf coneflower, American elder, common snowberry, crownbeard, and northern fox grape.

UPPER DELAWARE SCENIC AND RECREATIONAL RIVER (UPDE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for UPDE					
	1995	1996	1997	1998	1999
Sum06	21	15	20	19	26
W126	28.9	23	25.4	31.2	33.6
N60	461	362	401	530	540
N80	112	68	90	108	127
N100	14	9	9	8	19

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at UPDE					
	1995	1996	1997	1998	1999
Month 1	-1.94	0.86	-1.37	-1.19	-1.13
Month 2	-0.56	2.84	-1.72	-2.13	-2.14
Month 3	-3.49	-1.70	1.36	-0.66	-3.15

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at UPDE					
	1995	1996	1997	1998	1999
April	-1.53	1.90	-1.44	1.60	-1.41
May	-1.22	-0.18	-0.32	0.78	-1.13
June	-1.94	0.86	-1.37	3.26	-2.14
July	-0.56	2.84	-1.72	-1.19	-3.15
August	-3.49	-1.70	1.36	-2.13	-1.97
September	-0.99	1.26	0.11	-0.66	4.14
October	3.91	2.89	-1.41	-0.17	-0.10

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, experienced three months of mild to severe drought. The three intermediate ozone years had similar levels of exposure and each had two months of drought. The year with the lowest ozone exposure, 1996, had one month of mild drought. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone year, 1999, there were five months of mild to severe drought. The

three mid-level ozone years, 1998, 1995 and 1997, had two, four and three months of drought, respectively, and the lowest ozone year, 1996, had one month of mild drought.

The risk of foliar ozone injury to plants at Upper Delaware Scenic and Recreational River is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

GREAT LAKES NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE GREAT LAKES NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE GREAT LAKES NETWORK

Park	Code	State	Risk	O3 Data
Apostle Islands NL	APIS	WI	low	kriged
Grand Portage NM	GRPO	MN	low	kriged
Indiana Dunes NL	INDU	IN	high	monitored
Isle Royale NP	ISRO	MI	low	kriged
Mississippi NRRA	MISS	MN	low	kriged
Missouri NRA	MNRR	NB/SD	low	kriged
Pictured Rocks NL	PIRO	MI	moderate	kriged
Saint Croix/Lower St. Croix NSR	SACN	WI	low	kriged
Sleeping Bear Dunes NL	SLBE	MI	high	kriged
Voyageurs NP	VOYA	MN	low	monitored

APOSTLE ISLANDS NATIONAL LAKESHORE (APIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for APIS					
	1995	1996	1997	1998	1999
Sum06	7	3	5	7	9
W126	12.1	10.0	10.0	15.2	17.8
N60	168	106	122	217	268
N80	11	5	4	12	36
N100	1	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at APIS					
	1995	1996	1997	1998	1999
Month 1	0.50	1.01	0.90	2.33	-0.94
Month 2	-3.55	1.47	-2.25	-2.44	3.50
Month 3	-0.08	-2.02	0.55	-1.69	-1.23

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at APIS					
	1995	1996	1997	1998	1999
April	0.74	1.47	-2.25	-2.44	-0.94
May	0.50	-2.02	0.55	-1.69	3.50
June	-3.55	1.06	-0.86	1.38	-1.23
July	-0.08	3.36	1.41	-3.24	5.56
August	3.63	-1.04	0.69	-2.72	-0.70
September	-0.61	-0.85	-0.41	-3.22	-1.70
October	5.08	2.86	1.14	-1.74	-0.90

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than one hour in which the concentration exceeded 100 ppb and in most years ambient ozone did not reach this concentration. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. Soil moisture levels show that each year generally had one month of mild or moderate drought, and there does not appear to be any association between the levels of ozone and drought over the five-year period. The relatively uniform levels of ozone exposure also make it difficult to assess

relationships between the W126 ozone exposure index and soil moisture. Levels of drought varied widely among years and ranged from five months of mild to severe stress in 1998, the year with the second highest level of ozone, to single months of severe and moderate moisture stress in 1995 and 1997, years of moderate and low ozone respectively. Two months of drought stress occurred in 1996, a low ozone year, and 1999, the highest ozone year. No associations between the W126 levels of ozone and soil moisture are apparent in these observations.

The low level of ozone exposure at Apostle Islands National Lakeshore makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposure to levels greater than 100 ppb are rare. Months of drought stress are distributed over the five-year period, and are at times severe or numerous. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, quaking aspen, Allegheny blackberry, and cut-leaf coneflower.

GRAND PORTAGE NATIONAL MONUMENT (GRPO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GRPO					
	1995	1996	1997	1998	1999
Sum06	5	3	5	5	7
W126	10.4	9.9	10.4	13.9	14.8
N60	134	100	123	190	214
N80	9	5	7	9	25
N100	1	0	1	1	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRPO					
	1995	1996	1997	1998	1999
Month 1	0.01	0.33	-1.13	2.95	0.14
Month 2	-0.64	-0.74	-0.28	0.44	1.16
Month 3	-5.16	1.35	0.86	-2.07	-0.41

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRPO					
	1995	1996	1997	1998	1999
April	0.01	0.33	-1.13	-2.07	0.14
May	-0.64	-0.74	-0.28	-1.01	1.16
June	-5.16	1.35	0.86	0.68	-0.41
July	2.98	2.98	-0.87	-1.38	7.86
August	1.51	-1.22	-2.44	-2.41	1.22
September	0.84	0.75	-2.18	-0.70	4.08
October	4.84	3.03	0.07	3.83	0.94

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and a few years in which concentrations reached 100 ppb for one hour. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was low and similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought over the five-year period. Soil moisture levels show that several years had one month of mild to severe drought, and the years with the highest and lowest exposures, 1999 and 1996 respectively, had favorable soil moisture conditions. The relatively uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture. No associations are apparent between the

W126 indices of exposure and soil moisture. Soil moisture was normal in 1999, the highest ozone year, and there were four months of mild and moderate drought in 1998, the second highest exposure year. Of the three remaining years, two had the same level of exposure and had one and three months of drought, and the lowest exposure year, 1996, had one month of mild drought.

The low level of ozone exposure at Grand Portage National Monument makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposure to levels greater than 100 ppb are rare. Months of drought stress are distributed over the five-year period, and are at times severe or numerous. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen, and black cherry.

INDIANA DUNES NATIONAL LAKESHORE (INDU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus banksiana	Jack pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for INDU					
	1995	1996	1997	1998	1999
Sum06	28	22	24	19	22
W126	25.8	-	-	38.1	39.2
N60	415	-	-	681	641
N80	111	-	-	138	182
N100	21	-	-	17	36

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at INDU					
	1995	1996	1997	1998	1999
Month 1	-1.34	1.98	2.01	-1.04	-2.28
Month 2	-0.91	5.70	1.31	2.26	-0.71
Month 3	-2.70	-1.48	2.15	1.10	-1.04

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at INDU					
	1995	1996	1997	1998	1999
April	1.82	0.48	-1.83	0.19	2.04
May	1.68	3.28	1.67	-1.04	-2.28
June	-0.23	1.98	2.01	2.26	-0.71
July	-1.34	5.70	1.31	1.10	-1.04
August	-0.91	-1.48	2.15	0.44	-0.74
September	-2.70	0.10	-0.26	-1.78	-2.26
October	-0.61	0.19	-0.17	-0.58	-2.20

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- There are no associations between the 90-day Sum06 accumulation period levels of ozone and soil moisture conditions. Soil moisture levels during year with the highest level of ozone, 1995, showed two months of mild and moderate drought, while the lowest ozone year, 1998, had one month of mild drought. The second highest ozone year, 1997, had favorable conditions, and the remaining two years had one and two months of mild and moderate drought. Assessment of relationships between the seasonal W126 level of exposure and soil moisture is

difficult since only three years of ozone data are available. However, there is no clear association between the level of ozone exposure and drought stress. Ozone exposures in 1999 and 1998 were high and similar in value, while the exposure in 1995 was considerably lower. There were four months of mild and moderate drought in 1999, and two of mild drought in 1998. The lowest ozone year, 1995, had two months of mild and moderate drought.

The risk of foliar ozone injury to plants at Indiana Dunes National Lakeshore is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture reduces the likelihood of injury developing in any particular year. Although only three years of complete ozone data are available, the site is subject to potentially harmful levels of ozone annually, and there is no relationship between the level of ozone exposure and drought stress. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

ISLE ROYALE NATIONAL PARK (ISRO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ISRO					
	1995	1996	1997	1998	1999
Sum06	7	4	6	6	9
W126	12.9	11.9	11.7	16.6	18.9
N60	184	136	146	243	282
N80	17	13	14	19	52
N100	3	1	3	3	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ISRO					
	1995	1996	1997	1998	1999
Month 1	0.87	4.11	-2.12	-1.59	-1.41
Month 2	1.25	-1.43	1.15	2.06	3.61
Month 3	-3.39	1.56	-2.13	-3.00	-1.08

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ISRO					
	1995	1996	1997	1998	1999
April	0.87	4.11	-2.12	-3.00	-1.41
May	1.25	-1.43	1.15	-3.03	3.61
June	-3.39	1.56	-2.13	0.04	-1.08
July	0.27	3.07	-0.59	-1.62	4.19
August	-0.79	-0.98	-0.40	-2.47	-0.18
September	-0.26	-1.03	-1.76	-2.36	-0.67
October	3.69	0.99	-1.33	-2.81	0.21

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought over the five-year period. Soil moisture levels show that each year had one or two months of mild to severe drought. The relatively uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture, however no

associations between the indices of ozone exposure and soil moisture is apparent. The highest exposure year, 1999, had two months of mild drought. The second highest year, 1998, and the lowest year, 1997, had six and four months of mild to severe drought respectively. The remaining two years mid-level exposure years had one and two months of drought each.

The low level of ozone exposure at Isle Royale National Park makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposures to levels greater than 100 ppb are rare. Months of drought stress are distributed over the five-year period, and are at times severe or numerous. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, quaking aspen, and black cherry.

MISSISSIPPI NATIONAL RIVER AND RECREATION AREA (MISS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MISS					
	1995	1996	1997	1998	1999
Sum06	10	4	8	9	10
W126	13.5	10.2	11.2	15.3	14.6
N60	186	123	152	225	238
N80	33	8	14	13	13
N100	4	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MISS					
	1995	1996	1997	1998	1999
Month 1	-0.36	-0.17	-1.85	-1.52	3.14
Month 2	-2.38	-0.49	-0.69	-0.60	0.74
Month 3	2.68	0.58	5.48	1.75	2.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MISS					
	1995	1996	1997	1998	1999
April	0.71	-0.73	-1.98	-1.52	0.51
May	-0.36	-0.17	-1.85	-0.60	3.14
June	-2.38	-0.49	-0.69	1.75	0.74
July	2.68	0.58	5.48	-1.01	2.58
August	4.10	-3.09	0.55	0.07	1.21
September	-0.36	-1.45	-0.56	-2.59	0.24
October	4.08	1.65	0.24	0.22	-0.50

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was low and similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought. In the highest ozone years, 1995 and 1999, there was one month of mild drought and normal soil moisture, respectively. Each of the mid-level exposure years, 1998 and 1997, had one month of mild drought, and the lowest exposure year, 1996, had normal soil moisture. The uniform levels of ozone also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture, and no association is apparent between the two. There were three months of mild and moderate drought in 1998, the highest ozone year, no drought in the second highest year 1999, and two months of mild and severe drought in 1996, the lowest ozone year.

The low level of ozone exposure at Mississippi National River and Recreation Area makes the risk of foliar ozone injury to plants low. The Sum06 exposure threshold is satisfied, while the W126 threshold is not. Exposure to levels of ozone greater than 80 ppb is infrequent and exposure to 100 ppb is rare. Months of mild to severe drought are distributed over the five-year period. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

MISSOURI NATIONAL RECREATION AREA (MNRR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MNRR					
	1995	1996	1997	1998	1999
Sum06	2	0	4	3	5
W126	9.9	6.0	9.9	10.1	10.2
N60	139	60	141	141	133
N80	17	5	5	10	7
N100	2	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MNRR					
	1995	1996	1997	1998	1999
Month 1	-1.96	-0.28	1.22	-1.50	0.29
Month 2	-1.14	-1.13	-0.94	3.45	4.93
Month 3	2.70	3.33	-0.69	1.81	2.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MNRR					
	1995	1996	1997	1998	1999
April	3.32	-1.13	1.75	3.14	4.46
May	4.84	3.33	1.22	-1.50	0.29
June	-1.96	-0.75	-0.94	3.45	4.93
July	-1.14	1.47	-0.69	1.81	2.36
August	2.70	2.57	-0.85	3.32	0.15
September	2.45	2.17	0.87	-2.45	-1.87
October	2.92	-0.47	1.41	3.82	-1.78

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and two years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was low and similar over the five years. There does not appear to be any association between the Sum06 levels of ozone and drought over the five-year period. Soil moisture levels show that three years had one or two months of mild drought. The uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone exposure index and soil moisture. No association is apparent between the W126 level of ozone exposure and soil moisture. Levels of drought were scattered and consisted mainly of one or two months of mild drought each

year; in one year, 1997, soil moisture was normal.

The low level of ozone exposure at Missouri National Recreation Area makes the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 indices of exposure are satisfied, and exposure to levels greater than 100 ppb are rare. Months of drought stress are mild and scattered over the five-year period. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed and cut-leaf coneflower.

PICTURED ROCKS NATIONAL LAKESHORE (PIRO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PIRO					
	1995	1996	1997	1998	1999
Sum06	12	8	9	10	16
W126	23.1	18.9	19.0	25.3	28.9
N60	365	267	273	410	441
N80	74	48	57	61	124
N100	16	9	12	11	18

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PIRO					
	1995	1996	1997	1998	1999
Month 1	0.10	-0.21	-2.66	-2.79	-0.26
Month 2	-3.37	5.18	-1.08	0.00	-1.29
Month 3	0.77	-0.23	-0.46	-2.11	4.41

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PIRO					
	1995	1996	1997	1998	1999
April	2.43	4.17	-1.99	-1.86	-1.46
May	0.10	-2.38	2.02	-2.79	-0.26
June	-3.37	-0.21	-2.66	0.00	-1.29
July	0.77	5.18	-1.08	-2.11	4.41
August	-0.28	-0.23	-0.46	-1.30	-0.05
September	0.04	2.20	-1.98	-2.03	-0.70
October	4.37	2.86	-2.26	-2.09	1.50

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposure was relatively similar over the five-year period. The pattern in which months of drought appeared during the five-year period appears unrelated to the Sum06 levels of ozone. The year with the highest ozone, 1999, had one month of mild stress while the next highest year, 1995, had one month of severe stress. The year with the lowest ozone, 1996, had normal soil moisture, but the next lowest year, 1997, had a month of mild and one of moderate stress. The relatively uniform levels of ozone also make it difficult to

assess relationships between the W126 exposure index and soil moisture. There are no apparent associations between the W126 levels of exposure and soil moisture. The two highest ozone years, 1999 and 1998, had two and six months of mild to moderate stress, respectively. The two years with the lowest ozone levels, 1996 and 1997, experienced one month of moderate stress and six months of mild and moderate stress, respectively.

The risk of foliar ozone injury to plants at Pictured Rocks National Lakeshore is moderate. The levels of ozone exposure consistently create the potential for injury, however consecutive months of low soil moisture may reduce the likelihood of injury developing in a particular year. Since there are no apparent relationships between the levels of ozone exposure and soil moisture conditions, and since entire growing seasons appear to be characterized by either largely favorable or unfavorable soil moisture conditions, the levels of risk vary considerably among years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995, 1996 and 1999 when soil moisture levels are under limited drought that does not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

SAINT CROIX/LOWER ST. CROIX NATIONAL SCENIC RIVER (SACN)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SACN					
	1995	1996	1997	1998	1999
Sum06	11	4	7	8	11
W126	13.4	8.8	9.7	15.7	16.8
N60	193	98	124	229	271
N80	28	5	6	16	20
N100	3	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SACN					
	1995	1996	1997	1998	1999
Month 1	-0.12	-0.42	-1.52	-2.14	1.63
Month 2	-2.60	-0.24	2.51	-1.41	0.74
Month 3	0.76	0.91	-0.11	0.74	5.23

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SACN					
	1995	1996	1997	1998	1999
April	1.20	-0.42	-2.57	-2.14	0.15
May	-0.12	-0.24	-1.20	-1.41	1.63
June	-2.60	0.91	-1.52	0.74	0.74
July	0.76	2.55	2.51	-2.39	5.23
August	3.95	-2.56	-0.11	-1.36	1.39
September	-0.86	-0.23	-0.74	-2.74	0.00
October	4.52	3.21	-0.10	-0.38	-0.71

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb and in most years there were no hours at this level. These levels of exposure are not likely to injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposure was low and relatively similar over the five-year period. The pattern in which drought occurred during the five-year period appears unrelated to the Sum06 levels of ozone. The two years with the highest exposure, 1995 and 1999, had one month of moderate stress and normal soil moisture, respectively. The years with mid-level exposures, 1998 and 1997, had two months of mild and moderate drought and one month of mild drought, while the year with the lowest ozone, 1996, had favorable soil moisture. The relatively uniform levels of ozone also make it difficult to assess relationships between the W126 exposure index and soil moisture. Overall, there are no apparent associations between the W126 levels of exposure and soil moisture. The two highest ozone years, 1999 and 1998, had favorable moisture conditions and five months of mild and moderate stress, respectively. The year with the lowest ozone, 1996, experienced one month of moderate stress, while the two years with intermediate levels of ozone had one and three months of moderate and mild stress.

The low level of ozone exposure at Saint Croix/Lower St. Croix National Scenic River makes the risk of foliar ozone injury to plants low. The Sum06 threshold is intermittently satisfied while the W126 threshold is not. Exposure to ozone greater than 80 ppb is uncommon and exposure to100 ppb is rare. Months of drought are distributed over the five-year period, reach moderate levels of stress and occur for several consecutive months. These levels of drought limit the uptake of ozone and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and northern fox grape.

SLEEPING BEAR DUNES NATIONAL LAKESHORE (SLBE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SLBE					
	1995	1996	1997	1998	1999
Sum06	9	6	6	6	15
W126	30.4	20.4	21.4	27.0	27.1
N60	487	312	322	441	419
N80	116	55	58	71	114
N100	20	12	8	9	12

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SLBE					
	1995	1996	1997	1998	1999
Month 1	-0.30	1.85	-2.79	-2.52	-0.36
Month 2	-1.65	2.50	-0.46	-0.72	1.04
Month 3	-0.17	-1.04	0.95	-1.30	5.34

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SLBE					
	1995	1996	1997	1998	1999
April	1.89	3.10	-2.29	-1.07	-1.75
May	-0.30	-0.67	3.14	-2.25	-0.36
June	-1.65	1.85	-2.79	0.05	1.04
July	-0.17	2.50	-0.46	-2.52	5.34
August	2.10	-1.04	0.95	-0.72	-0.64
September	-1.23	0.78	-2.76	-1.30	-0.47
October	1.87	1.86	-1.51	-1.08	-0.41

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 threshold was satisfied in two years and the W126 criteria satisfied in all five of the years.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can potentially injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. The years with the two highest Sum06 indices, 1995 and 1999, experienced one month of mild

drought and normal soil moisture, respectively. In 1997, a mid-level exposure year, there was one month of mild drought, and in the two years with the same and lowest exposure, 1996 and 1998, had one month of mild drought and two months of mild and moderate drought, respectively. There is also no association between theW126 levels of exposure and the soil moisture. The W126 ozone exposure indices break down into two levels of similar exposures. The three highest ozone years, 1995, 1998, and 1999, experienced one to five months of mild and moderate stress, while the two lower ozone years, 1996 and 1997, experienced one to four months of mild to moderate stress.

The risk of foliar ozone injury at Sleeping Bear Dunes National Lakeshore is high. The threshold levels for injury are consistently satisfied for both the Sum06 and the W126 indices of exposure. The N-values indicate in some years there are frequent exposures to concentrations of ozone greater than 80 ppb, with numerous hours of exposure to 100 ppb. Mild to moderate drought conditions occur independent of the level of ozone exposure and reduce the uptake by plants. It is anticipated that the risk of injury may be greatest in years such as 1995, 1996 and 1999 when levels of exposure exceed injury thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

VOYAGEURS NATIONAL PARK (VOYA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VOYA					
	1995	1996	1997	1998	1999
Sum06	6	3	8	6	8
W126	9.7	8.7	13.2	12.2	12.3
N60	116	96	170	137	175
N80	6	0	8	0	5
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VOYA					
	1995	1996	1997	1998	1999
Month 1	0.01	-1.35	-1.13	0.44	0.14
Month 2	-0.64	0.33	-0.28	-2.07	1.16
Month 3	-5.16	-0.74	0.86	-1.01	-0.41

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VOYA					
	1995	1996	1997	1998	1999
April	0.01	0.33	-1.13	-2.07	0.14
May	-0.64	-0.74	-0.28	-1.01	1.16
June	-5.16	1.35	0.86	0.68	-0.41
July	2.98	2.98	-0.87	-1.38	7.86
August	1.51	-1.22	-2.44	-2.41	1.22
September	0.84	0.75	-2.18	-0.70	4.08
October	4.84	3.03	0.07	3.83	0.94

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. There does not appear to be any association between the Sum06 levels of exposure and drought. Three years had one month of mild or moderate drought, one year had two months of drought, and one had favorable conditions. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake

of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone, 1997, had three months of mild and moderate drought. The two next highest years, 1998 and 1999, had the same level of ozone, but experienced four months of mild and moderate drought and favorable moisture conditions, respectively. The lowest ozone year had one month of mild drought, and the second lowest year had one month of severe drought.

The low levels of ozone exposure at Voyageurs National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied, and there are only a few hours above 80 ppb and no hours above 100 ppb. Months of drought in most high ozone years constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

GREATER YELLOWSTONE NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE GREATER YELLOWSTONE NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on

the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher

concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE GREATER YELLOWSTONE NETWORK

Park	Code	State	Risk	O3 Data
Bighorn Canyon NRA	BICA	MT	low	kriged
Grand Teton NP	GRTE	WY	low	kriged
Yellowstone NP	YELL	WY	low	monitored

BIGHORN CANYON NATIONAL RECREATION AREA (BICA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BICA					
	1995	1996	1997	1998	1999
Sum06	5	11	9	12	16
W126	15.3	22.3	18.9	27.8	27.5
N60	136	311	206	396	388
N80	9	13	5	19	6
N100	1	1	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BICA					
	1995	1996	1997	1998	1999
Month 1	2.56	3.23	2.26	1.32	-2.52
Month 2	2.03	0.23	0.71	-0.55	2.25
Month 3	4.97	4.88	2.52	-2.70	-0.75

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BICA					
	1995	1996	1997	1998	1999
April	3.08	0.23	2.26	-0.55	2.25
May	2.56	4.88	0.71	-2.70	-0.75
June	2.03	-1.74	2.52	3.42	-0.90
July	4.97	-0.15	6.60	1.71	-1.50
August	2.45	-2.09	4.23	0.65	1.11
September	0.10	0.13	-0.32	-1.29	-0.66
October	1.67	0.13	1.38	0.23	-2.13

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation although the values are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and in only three years did concentrations reach 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of drought make it difficult to assess relationships between the levels of ozone and soil moisture, however no association is apparent. There were only two months of drought, one each in 1998 and 1999, the years with the highest and second highest exposure values respectively. The remaining three years had lower levels of exposure and normal soil moisture conditions. Soil moisture levels during the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two highest ozone years, 1998 and 1999, had similar levels of exposure and each experienced two months of mild and moderate drought. The mid-level ozone year 1996 also experienced two months of mild and moderate drought stress. In the two lowest ozone years, 1997 and 1995, soil moisture conditions were normal.

The low level of ozone exposure at Bighorn Canyon National Recreation Area makes the risk of foliar ozone injury to plants low. The Sum06 threshold is marginally satisfied in most years, while the W126 thresholds are not achieved. Concentrations reach 80 ppb for only a few hours each year, and exposure to 100 ppb is rare. The inverse relationship

between exposure and soil moisture constrains the uptake of ozone in higher exposure years and reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, skunkbush, cut-leaf coneflower, American elder and common snowberry.

GRAND TETON NATIONAL PARK (GRTE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GRTE					
	1995	1996	1997	1998	1999
Sum06	3	8	5	8	11
W126	15.5	22.9	19.2	28.1	31.4
N60	136	307	203	378	459
N80	12	20	5	23	10
N100	1	2	1	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRTE					
	1995	1996	1997	1998	1999
Month 1	2.17	-0.35	1.40	0.71	-1.29
Month 2	0.91	0.32	1.43	0.41	1.42
Month 3	3.38	3.86	0.67	0.40	1.77

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRTE					
	1995	1996	1997	1998	1999
April	1.19	0.32	1.40	0.41	1.42
May	2.17	3.86	1.43	0.40	1.77
June	0.91	-1.58	0.67	5.35	1.12
July	3.38	-0.63	4.53	0.63	0.11
August	1.50	-2.20	3.42	0.66	1.29
September	-0.49	-0.47	2.09	0.45	0.21
October	0.47	-0.57	1.35	-0.22	-2.01

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb. No year had more than four hours in which the concentration exceeded 100 ppb, and in most years there was only one hour. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the Sum06 accumulation periods showed normal conditions with one month of mild drought in the five-year period. Soil moisture levels associated with the W126 index also indicated generally normal conditions with only a total of three months of drought in 1996 and 1999. This incidence and pattern of drought does not permit assessment of associations.

The low level of ozone exposure at Grand Teton National Park makes the risk of foliar ozone injury to plants low. Although soil moisture conditions are generally favorable for the uptake of ozone, the levels of ozone exposure are low enough that the risk of foliar injury is low.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen and Scouler's willow.

YELLOWSTONE NATIONAL PARK (YELL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for YELL					
	1995	1996	1997	1998	1999
Sum06	-	4	3	6	19
W126	12.5	15.1	12.4	19.8	29.8
N60	46	104	52	157	426
N80	0	0	0	0	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at YELL					
	1995	1996	1997	1998	1999
Month 1	-	-2.09	0.95	-1.52	-3.43
Month 2	-	-1.49	-0.47	-3.06	-0.36
Month 3	-	-2.45	0.05	-3.09	-0.19

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at YELL					
	1995	1996	1997	1998	1999
April	1.43	-0.34	0.95	-3.06	-0.36
May	-0.79	3.26	-0.47	-3.09	-0.19
June	-0.02	-2.09	0.05	4.17	0.10
July	1.31	-1.49	3.33	-1.09	-2.72
August	0.05	-2.45	2.32	-1.94	2.02
September	-0.58	-0.47	1.42	-0.42	-2.00
October	0.52	-1.48	0.60	-2.40	-2.28

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. Both the Som06 and W126 indices are below the levels considered necessary for injury to vegetation.

- The N-values for the site show no concentrations greater than 60 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 index of ozone exposure and soil moisture status. Four years of Sum06 exposure data are available, and most years show low and similar levels of exposure making it difficult to evaluate associations. Soil moisture levels associated with the Sum06 index show there was one month of severe drought in the highest exposure year, 1999. There were three months of mild to severe drought in both the second highest year, 1998, and a mid-level year, 1996. Moisture conditions were normal in 1997, the lowest exposure year. Soil moisture levels associated with the seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The five years of data show the two highest exposure years, 1999 and 1998, experienced three and five months of mild to severe drought, respectively. The mid-level exposure year1996 had four months of mild and moderate drought. The lowest exposure years, 1995 and 1997 both had normal moisture conditions.

The low levels of ozone exposure at Yellowstone National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 exposure criteria are satisfied, and exposures never exceed 80 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone and further reduces the likelihood of injury developing in the highest ozone years.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen and Scouler's willow.

GULF COAST NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE GULF COAST NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE GULF COAST NETWORK

Park	Code	State	Risk	O3 Data
Big Thicket N PRES	BITH	TX	high	kriged
Gulf Islands NS	GUIS	FL	low	kriged
Jean Lafitte NHP & PRES	JELA	LA	moderate	kriged
Natchez Trace NST	NATR	MS	various	krig/monit
Padre Island NS	PAIS	TX	low	kriged
Palo Alto Battlefield NHS	PAAL	TX	low	kriged
San Antonio Missions NHP	SAAN	TX	moderate	kriged
Vicksburg NMP	VICK	MS	low	kriged

BIG THICKET NATIONAL PRESERVE (BITH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BITH					
	1995	1996	1997	1998	1999
Sum06	26	13	21	16	18
W126	39.6	18.5	28.2	25.0	24.3
N60	617	283	461	389	384
N80	213	74	121	114	106
N100	62	24	35	38	34

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BITH					
	1995	1996	1997	1998	1999
Month 1	-0.06	-0.60	-0.49	-0.41	0.04
Month 2	0.90	0.09	2.46	3.40	-2.57
Month 3	-0.07	4.20	-1.22	3.15	-1.16

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BITH					
	1995	1996	1997	1998	1999
April	1.79	-0.33	3.18	-1.73	-0.87
May	-0.19	-3.21	-0.69	-3.53	0.52
June	-0.06	-0.60	1.27	-3.59	1.20
July	0.90	0.09	-0.49	-4.04	0.04
August	-0.07	4.20	2.46	-0.41	-2.57
September	0.00	2.39	-1.22	3.40	-1.16
October	-1.55	-0.24	1.46	3.15	-0.76

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day Sum06 accumulation periods were generally normal and favored the uptake of ozone. One month of mild drought occurred in 1997, the second highest exposure year, and two months of mild and moderate drought occurred in 1999, a mid-level exposure year, otherwise soil moisture was normal over the five-year period. There is also no association between the seasonal W126 exposure index and soil moisture. There was one month of mild drought in the highest and second highest ozone years, 1995 and 1997 respectively. The mid-level exposure years, 1998 and 1999, had four and two months of mild to

severe drought respectively, while the lowest exposure year, 1996, had one month of severe drought.

The risk of foliar ozone injury to plants at Big Thicket National Preserve is high. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions constrain the uptake of ozone and reduce the likelihood of injury in some years. Levels of exposure capable of producing foliar injury also occur in years with minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1995 and 1997 when ozone exposures exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, American sycamore, black cherry, and American elder.

GULF ISLAND NATIONAL SEASHORE (GUIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
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	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
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Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GUIS					
	1995	1996	1997	1998	1999
Sum06	13	10	18	21	19
W126	23.6	23.5	29.0	34.6	34.3
N60	412	427	515	582	638
N80	52	34	67	127	90
N100	6	4	5	22	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GUIS					
	1995	1996	1997	1998	1999
Month 1	0.32	-0.69	0.77	-2.91	-0.55
Month 2	-0.55	1.76	-0.56	-4.34	-2.10
Month 3	0.15	0.52	-1.66	-1.34	1.67

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GUIS					
	1995	1996	1997	1998	1999
April	0.81	1.52	1.92	-1.48	-2.10
May	1.38	-1.70	1.62	-2.91	1.67
June	0.32	-0.71	1.20	-4.34	1.34
July	-0.55	-0.69	0.77	-1.34	0.75
August	0.15	1.76	-0.56	-2.40	-1.62
September	-1.50	0.52	-1.66	8.81	-1.92
October	3.49	2.85	1.53	-1.68	-0.46

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had twenty-two hours in which the concentration exceeded 100 ppb, but there were generally six or fewer hours. These levels of exposure may injure vegetation in a high exposure year.

- Relationships between both the 90-day Sum06 and seasonal W126 accumulation period ozone levels and soil moisture appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1998, had three months of mild to severe drought stress. The next two highest ozone years, 1999 and 1997, each had one month of mild or moderate stress,

while the two lowest ozone years both had favorable moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the two years with the highest and similar levels of ozone, 1998 and 1999, soil moisture conditions were at moderate to severe drought levels for six and three months, respectively. In the three years with the lowest ozone exposures there was one month of mild drought each year.

The risk of foliar ozone injury at Gulf Island National Seashore is low. The threshold level for injury is consistently satisfied only by the Sum06 index, while the W126 index satisfies the criteria on occasion. The N-values indicate that there are occasional exposures to concentrations of ozone greater than 80 ppb, with a few hours of exposure to 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: yellow-poplar, black cherry, and American elder.

JEAN LAFITTE NATIONAL HISTORIC PARK AND PRESERVE (JELA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JELA					
	1995	1996	1997	1998	1999
Sum06	21	15	17	16	21
W126	29.6	19.9	23.8	25.1	32.0
N60	510	359	421	438	573
N80	110	45	60	78	117
N100	13	4	5	13	7

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JELA					
	1995	1996	1997	1998	1999
Month 1	-0.53	-2.58	2.29	2.16	-3.20
Month 2	3.20	0.84	-1.53	0.02	-0.24
Month 3	-0.58	0.41	-3.11	-3.34	3.74

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JELA					
	1995	1996	1997	1998	1999
April	-0.53	-0.32	1.29	0.02	-3.20
May	3.20	-2.58	2.25	-3.34	-0.24
June	-0.58	0.84	0.65	-1.86	3.74
July	0.36	0.41	2.29	-2.25	-0.38
August	-1.38	0.52	-1.53	-1.35	-2.08
September	-2.89	-0.44	-3.11	7.52	-0.86
October	-0.49	-0.68	-0.71	-0.94	1.44

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeded the threshold each year and the N100 count shows that the required number of hours was met in three of the years. The criteria for injury under the W126 exposure index are generally satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. Some years had a greater number of hours above 80 and 100 ppb. Two years had thirteen hours in which the concentration exceeded 100 ppb, while the others had seven or fewer. These levels of exposure may possibly injure vegetation in high exposure years.

- Relationships between the 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposures were relatively consistent over the five years. Months of mild to severe drought were distributed over four of the years without respect to the ozone level, and one year had no drought months. There does not appear to be any association between the Sum06 level of ozone exposure and soil moisture status. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence

of drought. The highest and second highest ozone years, 1999 and 1995, had two months of mild moderate drought, and the mid-exposure year, 1998, had four months of mild to severe drought. The second lowest exposure year, 1997, had two months of mild to severe drought, and the lowest year, 1996, had one month of moderate drought.

The risk of foliar ozone injury at Jean Lafitte National Historic Park and Preserve is moderate. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb and 100 ppb in some years, with considerably less exposure in other years. The levels of ozone and soil moisture show no association, and suggest that conditions limiting the uptake of ozone occur for several months during most years. It is anticipated that the risk of injury may be greatest in years such as 1995 when ambient levels of ozone exceed injury thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: American sycamore, black cherry, Allegheny blackberry, and American elder.

NATCHEZ TRACE NATIONAL SCENIC TRAIL (NATR)

A stand-alone risk assessment was prepared for the Natchez Trace National Scenic Trail. The assessment evaluates the risk of foliar injury at nine sites along the Trail.

PADRE ISLAND NATIONAL SEASHORE (PAIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PAIS					
	1995	1996	1997	1998	1999
Sum06	11	5	6	11	14
W126	27.6	11.7	11.1	13.7	16.1
N60	465	197	182	247	283
N80	96	32	17	31	45
N100	16	4	1	3	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PAIS					
	1995	1996	1997	1998	1999
Month 1	-0.15	-1.99	3.13	1.63	-1.71
Month 2	0.20	-1.07	2.03	-1.66	-0.69
Month 3	-0.83	-1.49	2.85	-4.03	-1.87

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PAIS					
	1995	1996	1997	1998	1999
April	-1.53	-1.49	3.13	-1.66	-2.21
May	-0.67	-3.61	2.03	-4.03	-1.60
June	-0.56	-2.04	2.85	-2.84	0.69
July	-1.48	-1.23	-1.87	-2.52	-0.04
August	-0.15	2.45	-2.18	3.50	2.33
September	0.20	-0.93	-1.43	0.43	-1.71
October	-0.83	-1.68	1.65	3.29	-0.69

Risk Analysis

- There is one ozone-sensitive species listed for the site.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had sixteen hours in which the concentration exceeded 100 ppb, but the remainder had four or fewer hours. The highest level of exposure may possibly injure vegetation.

- There appears to be no relationship between either the 90-day Sum06 or seasonal W126 accumulation period ozone levels and soil moisture conditions. For the Sum06 index, months of drought were distributed over three of the years without respect to the ozone level, and two years had no drought. The year with the highest ozone, 1999, had two months of mild drought while the year with the lowest ozone, 1996, had three months of mild drought. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. Each year experienced two to five months of mild to severe drought stress. The highest ozone year, 1995, had two months of mild stress, while the

second highest year, 1999, had three months of mild and moderate drought. The intermediate ozone year, 1998, had three and four months of mild to severe drought, and the lowest ozone years, 1996 and 1997, had five and three months of mild to severe drought, respectively.

The risk of foliar ozone injury to plants at Padre Island National Seashore is low. The Sum06 and W126 exposure indices are either marginally or not satisfied, and exposure to concentrations over 100 ppb is generally rare. There are three or more months of mild and moderate drought in most years. These levels of soil moisture constrain the uptake of ozone and reduce the likelihood of foliar injury. There are no ozone bioindicator species at the site.

PALO ALTO BATTLEFIELD NATIONAL HISTORIC SITE (PAAL)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PAAL

	1995	1996	1997	1998	1999
Sum06	4	2	3	10	8
W126	13.4	5.8	6.5	9.7	7.8
N60	227	93	88	170	130
N80	33	9	6	10	8
N100	6	2	1	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PAAL					
	1995	1996	1997	1998	1999
Month 1	-1.93	-0.40	-2.29	0.79	-0.65
Month 2	-0.67	-2.70	-1.16	-0.98	-1.44
Month 3	-1.96	-1.47	5.70	-2.94	-1.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PAAL					
	1995	1996	1997	1998	1999
April	-0.81	-0.40	4.37	-0.98	-1.61
May	-1.93	-2.70	1.43	-2.94	-0.96
June	-0.67	-1.47	-0.33	-3.08	-1.01
July	-1.96	-2.48	-1.65	-2.37	1.78
August	2.79	1.71	-2.29	-1.92	1.61
September	-1.70	-0.60	-1.16	3.28	-0.65
October	2.86	2.09	5.70	3.58	-1.44

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value generally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or W126 seasonal accumulation period levels of ozone and soil moisture. For the Sum06 index this is a consequence of the consistently low levels of exposure at the site and the regular distribution of drought over the five-year period. Each year experienced one or two months of mild and moderate drought that occurred without any relationship to the level of ozone. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought; each of the five years had three or four months of drought. The highest ozone year, 1999, and the lowest ozone years, 1996 and 1997, each experienced three months of mild and moderate drought.

The risk of foliar ozone injury to plants at Palo Alto Battlefield National Historic Site is low. This is the result of the low levels of ozone, and the reduction in the uptake of ozone that occurs as a result of several months of low soil moisture each year. No ozone-sensitive species have been identified at the site.

SAN ANTONIO MISSIONS NATIONAL HISTORIC PARK (SAAN)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAAN					
	1995	1996	1997	1998	1999
Sum06	11	3	7	15	15
W126	35.6	12.9	19.2	20.2	26.0
N60	580	195	322	352	447
N80	159	43	64	56	93
N100	30	9	7	8	9

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAAN					
	1995	1996	1997	1998	1999
Month 1	-0.22	-1.62	3.27	-1.28	0.72
Month 2	0.68	-4.14	0.23	-3.12	-0.33
Month 3	-1.17	-1.28	-0.97	-3.17	-1.91

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAAN					
	1995	1996	1997	1998	1999
April	0.11	-1.62	3.31	-1.28	-1.32
May	1.14	-4.14	1.70	-3.12	-0.24
June	0.78	-1.28	3.27	-3.17	0.98
July	-0.22	-2.91	0.23	-2.70	0.72
August	0.68	2.69	-0.97	2.86	-0.33
September	-1.17	0.43	-0.59	1.64	-1.91
October	-0.38	-1.86	4.25	7.36	-1.44

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had thirty hours in which the concentration exceeded 100 ppb, but the remainder had nine or fewer hours. The higher levels of exposure may injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. The years with the highest and lowest ozone exposures, 1998 and 1996 respectively, each experienced three months of mild and severe drought. The other years had either a month of mild drought or favorable conditions. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The highest ozone year, 1995, had one month of mild drought and the lowest year, 1996, experienced five months of mild and severe drought. Years with intermediate ozone exposures had favorable moisture conditions or several months of mild to

severe drought.

The risk of foliar ozone injury at San Antonio Missions National Historic Park is moderate. The Sum06 and W126 indices both satisfy their thresholds for injury. Although there is considerable variation among years, there are frequent exposures to ozone greater than 80 ppb and occasional exposures to concentrations greater than 100 ppb. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often several consecutive months of mild and moderate drought. These levels of soil moisture constrain the uptake of ozone and reduce the likelihood of foliar injury. The co-occurrence of higher levels of ozone and of soil moisture conditions that favor uptake, such as in 1995 and 1997, increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, American sycamore, and American elder.

VICKSBURG NATIONAL MILITARY PARK (VICK)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VICK					
	1995	1996	1997	1998	1999
Sum06	18	15	17	13	16
W126	27.5	22.7	25.5	28.5	31.4
N60	521	411	490	525	600
N80	46	34	31	68	59
N100	1	1	1	4	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VICK					
	1995	1996	1997	1998	1999
Month 1	-1.48	2.05	-1.34	-0.06	-2.45
Month 2	-0.11	-0.83	0.16	-2.44	0.39
Month 3	-0.95	2.11	-1.29	0.98	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VICK					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
October	1.02	0.37	1.48	-1.40	-0.35

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Ozone exposures were similar over the five-year period, and no relationship is apparent between the 90-day Sum06 levels of ozone and soil moisture. Four of the five years experienced one or more months of drought, and only 1996 had favorable conditions. The years with the highest and lowest ozone exposures, 1995 and 1998, experienced one month of mild and moderate drought, respectively. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposure in producing

foliar injury. The highest ozone year, 1999, had three months of mild to moderate drought stress. The next two highest ozone years, 1998 and 1995, had similar levels of ozone, but experienced four months of mild to severe drought and one month of mild drought, respectively. The two years with the lowest ozone, 1996 and 1997, had one and two months of mild drought respectively.

The low levels of ozone exposure and the frequent low soil moisture conditions at Vicksburg National Monument Park make the risk of foliar ozone injury to plants low. While the Sum06 index exceeds the threshold levels for injury, the W126 does not since the N100 criterion is generally not satisfied. There are occasional exposures to concentrations of ozone above 80 ppb, and rare exposure to 100 ppb. Soil moisture conditions of moderate to severe drought reduce the effectiveness of the higher concentration exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, and American elder.

HEARTLAND NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE HEARTLAND NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE HEARTLAND NETWORK

Park	Code	State	Risk	O3 Data
Arkansas Post NM	ARPO	AR	moderate	kriged
Buffalo NR	BUFF	AR	low	kriged
Cuyahoga Valley NRA	CUVA	OH	high	kriged
Effigy Mounds NM	EFMO	IA	low	kriged
Fort Scott NHS	FOSC	KS	moderate	kriged
George Washington Carver NM	GWCA	MO	moderate	kriged
Herbert Hoover NHS	HEHO	IA	low	kriged
Homestead NM of America	HOME	NB	low	kriged
Hopewell Culture NHP	HOCU	OH	high	kriged
Hot Springs NP	HOSP	AR	low	kriged
Lincoln Boyhood NM	LIBO	IN	high	kriged
Ozark NSR	OZAR	MO	high	kriged
Pea Ridge NMP	PERI	AR	low	kriged
Pipestone NM	PIPE	MN	low	kriged
Tallgrass Prairie NP	TAPR	KS	moderate	kriged
Wilson's Creek NB	WICR	MO	low	kriged

ARKANSAS POST NATIONAL MEMORIAL (ARPO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values

include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ARPO					
	1995	1996	1997	1998	1999
Sum06	27	19	20	27	30
W126	35.4	24.8	27.7	37.6	39.6
N60	632	429	513	683	719
N80	95	52	46	107	123
N100	8	5	4	8	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ARPO					
	1995	1996	1997	1998	1999
Month 1	-0.65	1.18	-0.28	-2.58	-1.39
Month 2	0.50	2.26	-0.30	-1.14	-2.86
Month 3	-2.20	0.08	-0.04	-2.16	-1.85

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ARPO					
	1995	1996	1997	1998	1999
April	1.04	-1.16	3.95	-0.92	0.61
May	-0.90	-0.55	-0.10	-2.53	-0.77
June	-0.65	1.18	2.01	-3.08	1.47
July	0.50	2.26	-0.28	-2.58	-1.39
August	-2.20	0.08	-0.30	-1.14	-2.86
September	-2.17	2.04	-0.04	-2.16	-1.85
October	-0.87	2.00	0.91	-0.35	0.07

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a number of hours every year. The higher levels of exposure can injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the three years with the highest ozone exposure values, 1999 and 1998 each had three months of mild and moderate drought, and 1995 had one month of moderate drought. The two years with lower ozone exposures, 1996 and 1997, had normal soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, although the relationship is not consistent. In the two highest ozone years, 1999 and 1998, there were three and five months,

respectively, of mild to severe drought. The mid-level ozone year, 1995, had two months of moderate drought. The two years with the lowest exposure, 1996 and 1997, had one month of mild drought between them.

The risk of foliar ozone injury at Arkansas Post National Memorial is moderate. The threshold level for injury is consistently satisfied by the Sum06 index and generally satisfied for the W126 index. The N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb, and there are a number of hours of exposure to 100 ppb in some years. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone levels are reduced but still exceed the thresholds, and soil moisture levels are normal most of the growing season with drought occurring late in the year.

A program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator species redbud and American sycamore.

BUFFALO NATIONAL RIVER (BUFF)

Plant Species of Interest

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
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W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BUFF					
	1995	1996	1997	1998	1999
Sum06	16	12	11	17	23
W126	25.9	24.1	25.7	34.4	38.5
N60	406	388	431	598	706
N80	37	26	19	43	55
N100	4	2	1	2	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BUFF					
	1995	1996	1997	1998	1999
Month 1	0.90	-2.25	1.56	-1.33	-1.60
Month 2	0.26	0.26	0.39	-1.29	-1.33
Month 3	-2.66	100	0.12	0.62	-2.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BUFF					
	1995	1996	1997	1998	1999
April	2.27	1.00	-0.34	-1.52	0.88
May	0.70	-2.06	-1.11	-1.49	1.08
June	0.90	-0.82	0.13	-2.75	2.41
July	0.26	0.09	0.34	-2.42	-0.77
August	-2.66	-0.75	1.56	-1.33	-1.60
September	-0.21	3.92	0.39	-1.29	-1.33
October	-0.11	-0.39	0.12	0.62	-2.03

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 4 hours in which the concentration exceeded 100 ppb.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The Sum06 index was highest in 1999 when there were three months of mild and moderate drought, and second highest in 1998 when there were two months of mild drought. There was one month of moderate drought in both 1995 and 1997 the mid-level exposure years, and soil moisture was normal in 1997, the lowest exposure year. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the year with the highest W126

index, 1999, there were three months of mild and moderate drought, while the second highest exposure year, 1998, had six months of mild to moderate drought. The three remaining years had lower levels of exposure and each had one month of mild or moderate drought.

The risk of foliar ozone injury at Buffalo National River is low. The threshold level for injury is satisfied only by the Sum06 index, and the N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb while exposure to 100 ppb is rare. The inverse relationship between exposure and soil moisture further reduces the likelihood of injury developing in the high ozone years.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, American sycamore, black cherry, cut-leaf coneflower, American elder, and northern fox grape.

CUYAHOGA VALLEY NATIONAL PARK (CUVA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CUVA					
	1995	1996	1997	1998	1999
Sum06	29	27	24	29	31
W126	30.7	31.3	27.5	39.6	35.7
N60	521	523	464	669	610
N80	119	117	85	159	138
N100	15	7	5	21	13

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CUVA					
	1995	1996	1997	1998	1999
Month 1	-1.47	2.03	1.82	-1.46	-1.77
Month 2	0.57	0.54	-3.01	0.43	-2.70
Month 3	-2.30	-0.89	1.72	-2.72	0.53

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CUVA					
	1995	1996	1997	1998	1999
April	0.62	3.33	-0.62	3.88	0.80
May	0.81	0.68	2.63	-3.47	-1.77
June	-1.47	2.03	1.82	0.44	-2.70
July	0.57	0.54	-3.01	-1.46	0.53
August	-2.30	-0.89	1.72	0.43	-0.65
September	-2.57	6.70	0.05	-2.72	1.11
October	2.04	3.04	-1.13	-0.58	0.31

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value is significantly greater than the threshold and the N100 count is generally greater than the threshold value, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the

exposure in producing foliar injury. The years with the highest and similar ozone exposure values, 1999, 1995 and 1998, each show two months of mild and moderate drought. The two years with the lowest ozone exposures had one month of moderate drought, between them. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, although the pattern is not consistent. In the two highest ozone years, 1998 and 1999, there were three and two months of mild to severe drought, respectively. The mid-ozone years 1996 and 1997 experienced normal soil moisture and three months of mild and moderate drought, respectively, while there was one month of severe drought in 1997, the year with the lowest ozone.

The risk of foliar ozone injury to plants at Cuyahoga Valley National Park is high. While the levels of ozone exposure consistently create the potential for injury, months with low soil moisture may reduce the likelihood of injury developing in some years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 or 1999 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under limited drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, cut-leaf coneflower and American elder.

EFFIGY MOUNDS NATIONAL MONUMENT (EFMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for EFMO					
	1995	1996	1997	1998	1999
Sum06	13	8	10	11	15
W126	16.0	13.9	14.4	17.4	22.0
N60	265	203	224	270	365
N80	27	22	13	17	43
N100	2	1	0	0	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at EFMO					
	1995	1996	1997	1998	1999
Month 1	5.48	8.66	1.79	-0.09	0.00
Month 2	-0.25	-1.31	-0.14	3.27	0.05
Month 3	0.75	-0.70	-0.49	-1.00	-1.25

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at EFMO					
	1995	1996	1997	1998	1999
April	3.16	-0.95	0.19	1.68	2.24
May	5.48	8.66	1.79	-0.09	0.00
June	-0.25	-1.31	-0.14	3.27	0.05
July	0.75	-0.70	-0.49	-1.00	-1.25
August	-0.18	-0.88	1.33	1.09	-0.80
September	0.05	-0.83	-0.76	0.16	-0.04
October	-0.91	-0.71	1.39	4.28	-1.51

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 2 hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels were generally normal to high and favored the uptake of ozone. During the five-year W126 assessment period, two years had one month of mild drought each, and one year had two months of mild drought.

The risk of foliar ozone injury at Effigy Mounds National Monument is low. The threshold level for injury is satisfied by the Sum06 index, but the criteria for W126 index are not since the requisite number of hours of exposure to 100 ppm is not attained. The

N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, while exposure to 100 ppb is rare. While soil moisture conditions are generally favorable for the uptake of ozone during most of the growing season, the levels of exposure are low and should be below the threshold for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, tall milkweed, common milkweed, white ash, quaking aspen, black cherry and American elder.

FORT SCOTT NATIONAL HISTORIC SITE (FOSC)

Plant Species Sensitive to Ozone

No ozone-sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOSC					
	1995	1996	1997	1998	1999
Sum06	26	19	15	23	21
W126	32	24.7	23.4	31.8	33.1
N60	533	430	383	589	584
N80	101	46	46	64	53
N100	14	4	6	9	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOSC					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-2.85	-0.43
Month 2	-	-	-	-0.92	-1.01
Month 3	-	-	-	0.94	1.33

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOSC					
	1995	1996	1997	1998	1999
April	1.09	-0.70	0.37	0.61	3.43
May	4.08	-1.49	0.86	-2.85	1.65
June	3.54	-0.97	1.63	-0.92	2.89
July	0.72	0.17	0.87	0.94	-0.43
August	1.55	2.28	1.61	-1.68	-1.01
September	-1.44	1.83	0.66	1.51	1.33
October	-2.57	0.32	0.41	4.76	-1.31

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index exceeded the threshold for injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years although concentrations exceeded 100 ppb every year. Thus, both the Sum06 and W126 thresholds are satisfied intermittently at the site.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Relationships between the 90-day Sum06 index of exposure and soil moisture cannot be assessed because moisture data can only be obtained for two of the five years. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The three years with the highest and similar ozone exposures, 1999, 1995 and 1998, each had two months of mild or moderate drought. The two years with the lowest exposures, 1996 and 1997, had one month of mild drought between them.

The risk of foliar ozone injury at Fort Scott National Historic Site is moderate. The threshold for injury is satisfied for the Sum06 index, and is occasionally satisfied for the W126 index. The N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb, with several hours of exposure to 100 ppb each year. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone. While the level of risk under the conditions of exposure is moderate, there are no ozone-sensitive species listed for the site. Until sensitive species are identified either through plant surveys at the site or as a result of further ozone research, the risk of injury remains potential rather than actual.

GEORGE WASHINGTON CARVER NATIONAL MONUMENT (GWCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GWCA					
	1995	1996	1997	1998	1999
Sum06	12	10	6	24	17
W126	31.5	26.2	21.0	33.2	32.3
N60	526	454	347	601	571
N80	82	46	23	62	58
N100	11	3	2	6	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GWCA					
	1995	1996	1997	1998	1999
Month 1	2.90	-0.73	0.07	2.67	-1.16
Month 2	-0.99	0.67	1.60	-0.58	-1.28
Month 3	-1.83	-0.84	0.41	0.17	-1.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GWCA					
	1995	1996	1997	1998	1999
April	3.39	1.24	-0.87	-0.85	2.15
May	2.72	-0.87	0.46	-1.18	1.18
June	2.90	-0.73	-0.17	-0.52	1.33
July	-0.99	0.67	0.07	2.67	-1.16
August	-1.83	-0.84	1.60	-0.58	-1.28
September	-1.60	3.52	0.41	0.17	-1.36
October	-2.30	0.85	-0.09	1.52	-2.43

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is generally below the required number and thus the criteria for injury are not consistently satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally 80 ppb, and exceeded 100 ppb a few times every year. These levels of exposure can injure vegetation.

- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture status. Soil moisture conditions were favorable in the highest and lowest Sum06 ozone years. The year with the second highest Sum06 exposure, 1999, had three months of mild drought, and a mid-ozone year, 1995, had one month of mild drought. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not fully consistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The three years with the highest

ozone exposures, 1998, 1999 and 1995, each had, respectively, one, four and three months of mild or moderate drought stress. The two years with the lowest exposures, 1996 and 1997, both had normal soil moisture levels.

The risk of foliar ozone injury at George Washington Carver National Monument is moderate. The threshold for injury is occasionally satisfied for both the Sum06 and the W126 indices. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and between two and eleven hours of exposure to 100 ppb each year. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, American sycamore, black cherry, cut-leaf coneflower and American elder.

HERBERT HOOVER NATIONAL HISTORIC SITE (HEHO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values

include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HEHO					
	1995	1996	1997	1998	1999
Sum06	10	7	6	8	13
W126	11.3	10.9	10.1	11.9	20.1
N60	176	160	143	174	333
N80	15	15	4	9	35
N100	1	1	0	0	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HEHO					
	1995	1996	1997	1998	1999
Month 1	-1.31	-0.71	2.25	-0.90	3.11
Month 2	-0.65	-1.17	-0.63	3.33	-0.24
Month 3	-2.36	-0.96	-2.38	-2.03	0.37

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HEHO					
	1995	1996	1997	1998	1999
April	4.30	-0.95	-1.35	0.56	3.11
May	2.92	7.54	2.25	-0.90	-0.24
June	-1.31	-0.56	-0.63	3.33	0.37
July	-0.65	-0.71	-2.38	-2.03	1.16
August	-2.36	-1.17	0.66	2.26	-0.13
September	-1.62	-0.96	-0.64	0.08	-0.87
October	-1.05	1.24	0.24	5.04	-1.51

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only one year in which concentrations reached 100 ppb, and relatively few hours in which concentrations exceeded 80 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The Sum06 indices were low and consistent over the five years. The distribution of the five months of drought over the period is such that no relationship between ozone and soil moisture is apparent. Similarly, here does not appear to be any association between the W126 accumulative index and soil moisture. In 1999 when ozone concentrations were high, there was one month of mild drought. The four

remaining years had similar levels of ozone exposure, and each had one to four months of mild and moderate drought, including two months of drought in 1997, the lowest exposure year.

The levels of ozone exposure at Herbert Hoover National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 index intermittently exceeds the threshold while W126 index does not satisfy the thresholds for injury. The number of hours of exposure greater than 80 ppb is low, and no year had more that one hour of exposure greater than 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, American sycamore, black cherry and American elder.

HOMESTEAD NATIONAL MONUMENT OF AMERICA (HOME)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOME					
	1995	1996	1997	1998	1999
Sum06	11	6	8	8	8
W126	14.9	9.9	12.7	14.0	13.6
N60	225	138	184	220	211
N80	39	14	23	26	21
N100	5	1	3	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOME					
	1995	1996	1997	1998	1999
Month 1	-1.23	-	-	-	-
Month 2	-0.08	-	-	-	-
Month 3	-0.67	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOME					
	1995	1996	1997	1998	1999
April	1.46	-0.27	1.86	0.85	3.85
May	6.34	6.41	-0.12	-2.62	2.88
June	-1.23	-1.57	0.57	1.58	0.92
July	-0.08	1.39	0.92	3.18	-0.49
August	-0.67	1.47	-0.39	-0.72	-0.96
September	-1.25	0.31	-0.35	-1.20	-1.74
October	-1.23	-0.08	2.28	0.35	-2.45

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 5 hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- Relationships between the 90-day Sum06 index of exposure and soil moisture cannot be assessed since only one year of moisture data were obtained. The low and consistent seasonal W126 indices of exposure make it difficult to assess associations between the levels of ozone and soil moisture, however an inverse relationship appears to exist: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The three years with the highest ozone exposures, 1995, 1998 and 1999, each had two or three months of mild and

moderate drought. The two years with the lowest exposures, 1996 and 1997, had one month of mild drought between them.

The risk of foliar ozone injury at Homestead National Monument of America is low. The threshold for injury is exceeded by the Sum06 index, but is not satisfied by the W126 index of exposure. The N-value counts indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposures and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, skunkbush and American elder.

HOPEWELL CULTURE NATIONAL HISTORICAL PARK (HOCU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOCU					
	1995	1996	1997	1998	1999
Sum06	29	23	35	36	29
W126	35.1	31.7	28.2	47.0	48.1
N60	602	525	485	795	808
N80	138	128	91	203	218
N100	19	14	8	35	24

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOCU					
	1995	1996	1997	1998	1999
Month 1	-0.73	1.45	2.53	-0.66	-2.49
Month 2	-1.12	1.86	-0.17	-1.60	-3.22
Month 3	0.52	-0.85	1.27	-2.44	-2.76

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOCU					
	1995	1996	1997	1998	1999
April	-1.27	0.80	-1.80	2.88	-1.78
May	3.87	4.62	0.25	0.00	-2.49
June	-0.73	1.45	2.53	5.52	-3.22
July	-1.12	1.86	-0.17	-0.66	-2.76
August	0.52	-0.85	1.27	-1.60	0.87
September	-0.67	2.08	-0.99	-2.44	-2.38
October	2.01	0.04	-0.63	0.19	0.06

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone that can produce foliar injury.

- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture status. The two years with the highest Sum06 indices, 1998 and 1997, had two months of mild and moderate drought and favorable moisture conditions, respectively. Two mid-ozone years, 1995 and 1999, with the same exposure had three and one month of drought, respectively. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This

relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the two years with the highest ozone indices, 1999 and 1998, there were, respectively, six months of mild to severe drought and two months of mild and moderate drought. The two years with mid-level exposures, 1995 and 1996, had two months of mild drought and normal soil moisture conditions, respectively. There was one month of drought in 1997, the year with the lowest exposure.

The risk of foliar ozone injury to plants at Hopewell Culture National Historic Park is high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

HOT SPRINGS NATIONAL PARK (HOSP)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOSP					
	1995	1996	1997	1998	1999
Sum06	21	10	14	24	25
W126	26.4	15.0	22.0	30.6	30.8
N60	464	240	392	558	559
N80	56	20	31	64	82
N100	3	1	1	3	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOSP					
	1995	1996	1997	1998	1999
Month 1	-0.63	-0.26	2.27	-2.60	-2.17
Month 2	0.47	2.93	-1.15	-2.27	-1.66
Month 3	-2.09	-0.08	-0.41	-0.86	0.01

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOSP					
	1995	1996	1997	1998	1999
April	0.40	-0.21	2.85	-1.81	0.69
May	-0.28	-0.28	-0.98	-2.03	-0.75
June	-0.63	-0.26	2.27	-2.60	0.64
July	0.47	2.93	-1.15	-2.27	-1.43
August	-2.09	-0.08	-0.41	-0.86	-2.17
September	-0.90	1.89	-0.44	-0.07	-1.66
October	-0.44	1.68	1.43	1.11	0.01

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 5 hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of

ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1999 and 1998, both show two months of mild and moderate drought. Two years with lower ozone exposures had one month of moderate drought, and the lowest exposure year had favorable conditions throughout. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, there were three and four months, respectively, of mild and moderate drought. The two mid-ozone years, 1995 and 1997, each had one month of mild or moderate drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury at Hot Springs National Park is low. While the threshold for injury is satisfied by the Sum06 index, the W126 criteria are not met. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, but rare exposures to 100 ppb. The inverse relationship between the level of ozone and soil moisture constrains the uptake of ozone and further reduces the likelihood the higher exposures will produce foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower and American elder.

LINCOLN BOYHOOD NATIONAL MEMORIAL (LIBO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LIBO					
	1995	1996	1997	1998	1999
Sum06	27	21	19	27	30
W126	39.4	34.3	31.5	42.8	39.0
N60	694	586	545	750	679
N80	154	129	101	159	155
N100	17	11	11	21	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LIBO					
	1995	1996	1997	1998	1999
Month 1	0.56	1.73	2.21	1.30	1.58
Month 2	-0.56	0.75	-1.79	0.29	-0.33
Month 3	0.42	-1.23	0.98	-2.21	-1.88

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LIBO					
	1995	1996	1997	1998	1999
April	1.30	5.86	-0.22	4.15	0.85
May	5.47	2.52	2.19	1.07	-0.97
June	0.56	1.73	2.21	2.70	1.58
July	-0.56	0.75	-1.79	1.30	-0.33
August	0.42	-1.23	0.98	0.29	-1.88
September	-2.20	4.80	-1.36	-2.21	-2.64
October	-1.41	0.65	-1.07	0.82	-0.68

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture conditions during the Sum06 accumulation periods showed that one month of mild or moderate drought occurred in four of the five years, and were unrelated to the level of ozone exposure. Both the W126 exposure indices and soil moisture conditions were relatively consistent over the five-year period making it difficult to assess their relationships. The highest ozone year 1998 had one month of moderate drought. Two mid-ozone years, 1995 and 1999, had

similar levels of exposure and each had two months of mild and moderate drought stress. The second lowest year had one month of mild drought, while the lowest year, 1997, had three months of mild drought. There was no apparent relationship between the W126 index of ozone exposure and soil moisture conditions.

The risk of foliar ozone injury to plants at Lincoln Boyhood National Memorial is high. The levels of ozone exposure consistently create the potential for injury, and soil conditions generally favor uptake, although dry conditions can reduce the uptake from one to several months in any particular year. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

OZARK NATIONAL SCENIC RIVERWAYS (OZAR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for OZAR					
	1995	1996	1997	1998	1999
Sum06	17	20	14	21	24
W126	28.7	29.9	23.2	33.6	40.0
N60	472	512	396	585	693
N80	101	92	45	89	140
N100	13	8	4	11	19

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at OZAR					
	1995	1996	1997	1998	1999
Month 1	1.42	-0.47	-0.39	4.88	-1.68
Month 2	0.91	1.11	0.66	-0.79	-0.90
Month 3	-1.48	-1.12	0.29	-1.14	-2.30

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at OZAR					
	1995	1996	1997	1998	1999
April	0.30	2.75	-0.20	-0.16	1.91
May	2.96	0.51	1.30	-1.65	-1.22
June	1.42	-0.47	1.13	2.45	-0.24
July	0.91	1.11	-0.39	4.88	-1.68
August	-1.48	-1.12	0.66	-0.79	-0.90
September	-0.82	3.75	0.29	-1.14	-2.30
October	-0.94	0.79	-0.18	0.86	-1.50

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 exposure value, 1999, had two months of mild and moderate drought; the lowest ozone year, 1997, had favorable moisture conditions. The intervening years each have one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, there were

four and two months, respectively, of mild and moderate drought. The two mid-ozone years, 1996 and 1995, each had one month of mild drought. In the lowest ozone year, 1997, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Ozark National Scenic Riverways is high. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone in most years, the probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: big-leaf aster, redbud, white ash, American sycamore, black cherry, cut-leaf coneflower and American elder.

PEA RIDGE NATIONAL MILITARY PARK (PERI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PERI					
	1995	1996	1997	1998	1999
Sum06	13	10	7	23	16
W126	29.4	24.6	22.0	35.2	32.5
N60	482	414	365	633	580
N80	64	36	19	60	53
N100	8	2	1	4	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PERI					
	1995	1996	1997	1998	1999
Month 1	0.90	-0.82	1.56	-2.42	-1.60
Month 2	0.26	0.09	0.39	-1.33	-1.33
Month 3	-2.66	-0.75	0.12	-1.29	-2.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PERI					
	1995	1996	1997	1998	1999
April	2.27	1.00	-0.34	-1.52	0.88
May	0.70	-2.06	-1.11	-1.49	1.08
June	0.90	-0.82	0.13	-2.75	2.41
July	0.26	0.09	0.34	-2.42	-0.77
August	-2.66	-0.75	1.56	-1.33	-1.60
September	-0.21	3.92	0.39	-1.29	-1.33
October	-0.11	-0.39	0.12	0.62	-2.03

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows the required number of hours was met in only one year although concentrations exceeded 100 ppb every year. The Sum06 index generally satisfies while the W126 index does not satisfy the criteria necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. Years generally had 4 or fewer hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1998 and 1999, each had three months of mild and moderate drought. The remaining three years with lower

levels of ozone exposure had one month of moderate drought among them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the two highest ozone years, 1998 and 1999, there were six and three months, respectively, of mild and moderate drought. The three years with lower levels of ozone each had one month of mild or moderate drought.

The risk of foliar ozone injury at Pea Ridge National Military Park is low. The threshold level for injury is satisfied mainly by the Sum06 index, while the criteria for the W126 index are satisfied in only one year. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, with rare exposure to 100 ppb. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone exposure exceeds the thresholds, and soil moisture levels moderately constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, white ash, American sycamore and American elder.

PIPESTONE NATIONAL MONUMENT (PIPE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PIPE					
	1995	1996	1997	1998	1999
Sum06	2	1	2	3	4
W126	11.0	7.0	10.7	12.5	10.2
N60	154	74	151	180	130
N80	22	4	8	11	5
N100	3	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PIPE					
	1995	1996	1997	1998	1999
Month 1	-1.47	1.61	0.14	-0.43	3.06
Month 2	3.09	0.73	-0.27	-2.71	0.32
Month 3	0.31	-0.15	0.76	0.26	0.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PIPE					
	1995	1996	1997	1998	1999
April	4.05	-1.74	0.44	-0.43	3.06
May	2.04	1.61	0.14	-2.71	0.32
June	-1.47	0.73	-0.27	0.26	0.36
July	3.09	-0.15	0.76	0.63	-0.36
August	0.31	2.16	-0.46	1.45	-1.04
September	1.36	0.17	-1.55	-3.00	-1.92
October	2.10	1.74	-0.60	3.55	-1.20

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and only one year in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Low levels of Sum06 exposures and only two months of drought over five years make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. The W126 index also shows no relationship with soil moisture. The highest exposure year, 1998, had two months of moderate and severe drought. The three mid-ozone years, 1995, 1997 and 1999, had similar indices of exposure and experienced one, one and three months of mild drought, respectively. The lowest exposure year, 1996, had one month of mild drought.

No association between the W126 levels of ozone and soil moisture is apparent in these observations.

The levels of ozone exposure at Pipestone National Monument make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there were some hours with concentrations of ozone above 80 ppb, the numbers were not high and concentrations of 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed and American elder.

TALLGRASS PRAIRIE NATIONAL PRESERVE (TAPR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for TAPR					
	1995	1996	1997	1998	1999
Sum06	14	12	14	16	17
W126	25.1	20.3	28.8	35.4	28.2
N60	452	393	492	664	498
N80	85	36	52	68	46
N100	11	3	5	8	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TAPR					
	1995	1996	1997	1998	1999
Month 1	0.92	1.87	2.27	-0.02	5.29
Month 2	-0.22	0.96	-1.15	-4.08	1.92
Month 3	0.30	1.07	0.15	0.76	0.88

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at TAPR					
	1995	1996	1997	1998	1999
April	0.55	-1.34	1.60	-0.02	5.29
May	7.92	1.87	2.27	-4.08	1.92
June	0.92	0.96	-1.15	0.76	0.88
July	-0.22	1.07	0.15	2.83	-1.72
August	0.30	3.38	0.79	-1.17	-0.94
September	-0.69	0.94	-0.44	2.63	2.84
October	-2.48	0.62	0.52	3.50	-1.63

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years although concentrations exceeded 100 ppb every year. Thus, the criteria for the W126 index are not consistently satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. Concentrations exceeded 100 ppb generally less than 10 times each year. These levels of exposure may possibly injure vegetation.

- Low levels of ozone during the 90-day Sum06 accumulation periods and only two months of drought over five years make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the year with the highest ozone index, 1998, there were two months of mild and severe drought. The two years with the second highest and

similar exposures, 1997 and 1999, had one and two months, respectively, of mild drought. There was one month of drought each year in 1995 and 1996, the years with the lowest exposure indices.

The risk of foliar ozone injury at Tallgrass Prairie National Preserve is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index are satisfied on occasion. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and a few hours of exposure to 100 ppb. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under short-term drought that does not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, redbud, American sycamore and American elder.

WILSON'S CREEK NATIONAL BATTLEFIELD (WICR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WICR					
	1995	1996	1997	1998	1999
Sum06	18	15	6	18	20
W126	29.3	25.0	15.7	24.7	28.9
N60	501	439	228	427	510
N80	50	38	10	25	41
N100	5	1	1	2	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WICR					
	1995	1996	1997	1998	1999
Month 1	2.90	-0.73	-0.17	2.67	-1.16
Month 2	-0.99	0.67	0.07	-0.58	-1.28
Month 3	-1.83	-0.84	1.60	0.17	-1.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WICR					
	1995	1996	1997	1998	1999
April	3.39	1.24	-0.87	-0.85	2.15
May	2.72	-0.87	0.46	-1.18	1.18
June	2.90	-0.73	-0.17	-0.52	1.33
July	-0.99	0.67	0.07	2.67	-1.16
August	-1.83	-0.84	1.60	-0.58	-1.28
September	-1.60	3.52	0.41	0.17	-1.36
October	-2.30	0.85	-0.09	1.52	-2.43

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 5 hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure, 1999, has three months of mild drought. The remaining years experienced only one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. Soil moisture levels in the two highest ozone years, 1995 and 1999, show three and four months, respectively, of mild to

moderate drought. When the ozone index was slightly lower in 1998 and 1996, there was one month of mild drought and normal soil moisture, respectively. Soil moisture was normal in 1997 when the index was the lowest.

The risk of foliar ozone injury at Wilson's Creek National Battlefield is low. The threshold level for injury is satisfied only by the Sum06 index, the N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone during high exposure years and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, redbud, white ash, American sycamore, black cherry, American elder and northern fox grape.

KLAMATH NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE KLAMATH NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE KLAMATH NETWORK

Park	Code	State	Risk	O3 Data
Crater Lake NP	CRLA	OR	moderate	kriged
Lassen Volcanic NP	LAVO	CA	low	monitored
Lava Beds NM	LABE	CA	moderate	kriged
Oregon Caves NM	ORCA	OR	moderate	kriged
Redwood NP	REDW	CA	moderate	kriged
Whiskeytown-Shasta-Trinity NRA	WHIS	CA	high	kriged

CRATER LAKE NATIONAL PARK (CRLA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CRLA					
	1995	1996	1997	1998	1999
Sum06	6	13	7	13	11
W126	8.2	16.8	8.4	15.6	14.9
N60	122	276	132	245	272
N80	14	76	7	65	35
N100	1	13	0	12	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CRLA					
	1995	1996	1997	1998	1999
Month 1	3.21	-0.60	4.23	1.40	-1.74
Month 2	-0.20	0.37	-0.46	-0.46	-0.73
Month 3	-1.17	-0.17	-1.80	-1.19	-0.64

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CRLA					
	1995	1996	1997	1998	1999
April	1.64	0.99	-0.46	-0.92	-0.73
May	-0.04	1.72	-1.80	5.93	-0.64
June	1.26	-0.60	0.04	0.04	-1.55
July	3.21	0.37	0.29	1.40	-1.51
August	-0.20	-0.17	-0.50	-0.46	3.24
September	-1.17	-0.44	0.64	-1.19	-1.93
October	-1.62	-0.12	0.71	-1.69	-1.48

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb most years. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. The concentration of ozone exceeded 100 ppb for a significant number of hours in two years, but there were three or fewer hours in the remaining years. The higher levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the Sum06 accumulation periods were generally normal and favored the uptake of ozone. There was one month of mild drought in each of four years, but there was no association with the level of ozone. Similarly, the seasonal W126 accumulative index and soil moisture conditions were not associated. In 1996 when the W126 ozone exposure was highest, soil moisture

conditions were normal. The mid-level ozone years had two and four months of mild drought. The years with the two lowest exposures, 1995 and 1997, experienced two and one month of mild drought, respectively. Collectively, there is no relationship between the W126 index of exposure and soil moisture.

The risk of foliar ozone injury at Crater Lake National Park is moderate. The threshold level for injury is satisfied intermittently by the Sum06 index, and on occasion by the W126 index. The N-values indicate that exposures to concentrations of ozone greater than 100 ppb are highly variable, and in some years reach a significant number of hours. Since there is no association between the level of ozone and soil moisture, conditions favorable for the uptake of ozone occur at all levels of exposure. Annual variations in ozone exposure and soil moisture interact to create highly variable levels of risk among years. It is anticipated the risk of injury is greatest in years such as 1996 and 1998 when ambient levels of ozone are high, and soil moisture conditions favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, Scouler's willow, and common snowberry.

LASSEN VOLCANIC NATIONAL PARK (LAVO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LAVO

	1995	1996	1997	1998	1999
Sum06	12	20	9	20	25
W126	21.9	28.0	15.3	29.6	42.7
N60	316	473	188	485	699
N80	17	17	3	26	56
N100	0	0	0	0	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LAVO					
	1995	1996	1997	1998	1999
Month 1	3.33	4.80	-1.38	2.23	-0.25
Month 2	1.19	0.44	0.54	2.89	0.33
Month 3	-0.99	1.21	-0.21	0.57	-1.30

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LAVO					
	1995	1996	1997	1998	1999
April	1.90	1.14	-1.18	1.08	-0.37
May	2.77	4.80	-1.38	6.91	-1.02
June	3.57	0.44	0.54	2.23	-0.26
July	3.33	1.21	-0.21	2.89	-0.25
August	1.19	-0.42	0.99	0.57	0.33
September	-0.99	-0.28	0.03	0.76	-1.30
October	-2.39	-0.15	0.06	-0.79	-0.88

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb in only one year with a count below the required number. Thus, the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb, and in most years that concentration was not reached. These levels of exposure are not likely to injure vegetation.

- Soil moisture conditions during the 90-day Sum06 accumulation period were generally favorable. Since only two months of mild drought occurred over the five-year assessment period, it is not possible to determine whether there is a relationship between the Sum06 ozone exposure and soil moisture. There appears to be no association between the seasonal W126 index of exposure and soil moisture conditions. There were two months of mild drought in both the highest and lowest ozone exposure years, 1999 and 1997 respectively, and only one month of moderate drought among the remaining three years. Overall, soil moisture levels were generally normal and favored the uptake of ozone.

The low levels of ozone exposure at Lassen Volcano National Park make the risk of foliar ozone injury to plants low. While the Sum06 indices exceed the threshold level for injury, the W126 do not since the N100 criterion is not satisfied. There are only a few hours with concentrations of ozone above 80 ppb, and exposures above 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator

species: spreading dogbane, mugwort, ponderosa pine, quaking aspen, skunkbush, Scouler's willow, and blue elderberry.

LAVA BEDS NATIONAL MONUMENT (LABE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LABE					
	1995	1996	1997	1998	1999
Sum06	11	15	11	22	20
W126	15.1	31.5	16.5	28.5	34.3
N60	251	603	286	498	638
N80	33	99	27	123	94
N100	2	11	1	23	8

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LABE					
	1995	1996	1997	1998	1999
Month 1	1.18	-0.57	-0.04	0.75	-0.57
Month 2	2.33	-0.13	1.36	1.36	-0.11
Month 3	2.35	-0.28	0.74	-0.28	-1.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LABE					
	1995	1996	1997	1998	1999
April	2.37	1.78	-0.30	0.26	-0.16
May	1.18	2.83	-0.94	4.49	-0.88
June	2.33	0.21	0.68	0.75	-0.82
July	2.35	1.15	-0.04	1.36	-0.57
August	0.22	-0.57	1.36	-0.28	-0.11
September	-0.91	-0.13	0.74	-1.04	-1.35
October	-2.66	-0.28	0.31	-0.78	-1.07

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations of 80 and 100 ppb were highly variable. While one year had 23 hours over 100 ppb, another year had only one. The higher levels of exposure may injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture conditions were generally favorable. Over the five years, there was one month of mild drought during the Sum06 accumulation period, and four months of mild and moderate drought during the seasonal W126 period.

The risk of foliar ozone injury at Lava Beds National Monument is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, and generally by the W126 index. The N-values indicate that exposure to concentrations of ozone greater than 100 ppb is highly variable. Since there is no association between the level of ozone

and soil moisture, conditions favorable for the uptake of ozone occur at all levels of exposure. It is anticipated that the risk of injury is greatest in years such as 1996 and 1998 when ambient levels of ozone are high, and soil moisture conditions favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: Jeffrey pine, ponderosa pine, quaking aspen, and Scouler's willow.

OREGON CAVES NATIONAL MONUMENT (ORCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ORCA					
	1995	1996	1997	1998	1999
Sum06	4	8	5	9	8
W126	6.5	23.5	11.0	19.8	22.3
N60	92	443	187	319	430
N80	11	93	11	80	59
N100	1	13	1	15	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ORCA					
	1995	1996	1997	1998	1999
Month 1	2.66	-0.45	-0.22	0.42	0.07
Month 2	3.45	0.78	2.31	-1.15	-0.76
Month 3	0.49	-0.86	-0.77	-1.71	0.20

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ORCA					
	1995	1996	1997	1998	1999
April	4.01	3.39	2.31	0.56	-0.76
May	0.06	3.89	-0.77	5.06	0.20
June	2.66	-0.45	1.10	-0.04	-1.11
July	3.45	0.78	0.50	0.42	-0.31
August	0.49	-0.86	1.76	-1.15	2.48
September	-0.26	0.78	1.69	-1.71	-1.94
October	-1.34	2.27	2.11	-0.46	0.32

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury to vegetation, although the levels are marginal in value. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at these concentrations was significantly lower. The higher levels of exposure could injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the Sum06 accumulation periods were generally normal and favored the uptake of ozone. There were two months of mild drought in the year with the highest level of ozone, but no association with exposure can be

assumed. Similarly, the seasonal W126 accumulative index and soil moisture conditions are not associated. In 1996 when ozone exposure was highest, soil moisture conditions were normal. The next two lower exposure years, 1999 and 1998, both had two months of mild drought. The second lowest exposure year had normal soil moisture, and the year with the lowest exposure, 1995, experienced one month of mild drought. Collectively, there is no relationship between the W126 index of exposure and soil moisture.

The risk of foliar ozone injury at Oregon Caves National Monument is moderate. The threshold level for injury is intermittently satisfied by the Sum06 index, and the criteria for the W126 index are satisfied in two years. The N-values indicate that annual exposures to concentrations of ozone greater than 100 ppb are variable. Since there is no association between the level of ozone and soil moisture, conditions favorable for the uptake of ozone occur at all levels of exposure. Annual variations in ozone exposure create highly variable levels of risk among years. It is anticipated that the risk of injury is greatest in years such as 1996 and 1998 when ambient levels of ozone are high, and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, spreading dogbane, mugwort, ponderosa pine, Scouler's willow, blue elderberry, and common snowberry.

REDWOOD NATIONAL PARK (REDW)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Oenothera elata	Evening primrose	Onagraceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus radiata	Monterey pine	Pinaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for REDW					
	1995	1996	1997	1998	1999
Sum06	4	18	13	26	22
W126	7.8	26.6	14.7	27	32
N60	121	522	259	481	601
N80	18	99	27	134	97
N100	1	12	1	26	8

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at REDW					
	1995	1996	1997	1998	1999
Month 1	1.18	-0.57	-0.04	0.75	-0.57
Month 2	2.33	-0.13	1.36	1.36	-0.11
Month 3	2.35	-0.28	0.74	-0.28	-1.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at REDW					
	1995	1996	1997	1998	1999
April	2.37	1.78	-0.30	0.26	-0.16
May	1.18	2.83	-0.94	4.49	-0.88
June	2.33	0.21	0.68	0.75	-0.82
July	2.35	1.15	-0.04	1.36	-0.57
August	0.22	-0.57	1.36	-0.28	-0.11
September	-0.91	-0.13	0.74	-1.04	-1.35
October	-2.66	-0.28	0.31	-0.78	-1.07

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at these concentrations was significantly lower. The higher levels of exposure could injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the Sum06 accumulation periods were generally normal and favored the uptake of ozone; there was one month of mild drought in five-year period. Similarly, the seasonal W126 accumulative index and soil moisture conditions were not associated. In 1999 when ozone exposure was highest, there

were two months of mild drought. There were only two additional months of drought in the remaining four years of the W126 assessments.

The risk of foliar ozone injury at Redwood National Park is moderate. The threshold level for injury is satisfied by the Sum06 index, and generally satisfied by the W126 index. The N-values indicate that annual exposures to concentrations of ozone greater than 100 ppb are variable. Since there is no association between the level of ozone and soil moisture, conditions favorable for the uptake of ozone occur at all levels of exposure. Annual variations in ozone exposure create highly variable levels of risk among years. It is anticipated that the risk of injury is greatest in years such as 1996 and 1998 when ambient levels of ozone are high, and soil moisture conditions favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, spreading dogbane, mugwort, yellow-poplar, evening primrose, ninebark, Jeffrey pine, Scouler's willow, and blue elderberry.

WHISKEYTOWN-SHASTA-TRINITY NATIONAL RECREATION AREA (WHIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WHIS					
	1995	1996	1997	1998	1999
Sum06	15	22	17	36	29
W126	19.4	33.1	23.6	47.8	48.6
N60	345	685	438	901	906
N80	63	154	65	308	167
N100	5	20	4	62	15

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WHIS					
	1995	1996	1997	1998	1999
Month 1	3.33	1.21	-0.21	2.89	-0.25
Month 2	1.19	-0.42	0.99	0.57	0.33
Month 3	-0.99	-0.28	0.03	0.76	-1.30

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WHIS					
	1995	1996	1997	1998	1999
April	1.90	1.14	-1.18	1.08	-0.37
May	2.77	4.80	-1.38	6.91	-1.02
June	3.57	0.44	0.54	2.23	-0.26
July	3.33	1.21	-0.21	2.89	-0.25
August	1.19	-0.42	0.99	0.57	0.33
September	-0.99	-0.28	0.03	0.76	-1.30
October	-2.39	-0.15	0.06	-0.79	-0.88

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.

- In three years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at these concentrations was significantly lower. The higher levels of exposure could injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the Sum06 accumulation periods were generally normal and favored the uptake of ozone; there was one month of mild drought in five-year period. The seasonal W126 accumulative index and soil moisture conditions were also not associated. There were two months of mild drought in 1999 when

ozone exposure was highest. Soil moisture was favorable in both the second highest year 1998 and the mid-level ozone year 1996. The second lowest exposure year had two months of mild drought and the lowest year, 1995, had one month of moderate drought.

The risk of foliar ozone injury at Whiskeytown-Shasta-Trinity National Recreation Area is high. The threshold level for injury is consistently satisfied by the Sum06 index, and intermittently by the W126 index. The N-values indicate that annual exposures to concentrations of ozone greater than 80 and 100 ppb are variable. Since there is no association between the level of ozone and soil moisture, conditions favorable for the uptake of ozone occur at all levels of exposure. Annual variations in ozone exposure create highly variable levels of risk among years. It is anticipated that the risk of injury is greatest in years such as 1996 and 1998 when ambient levels of ozone are high, and soil moisture conditions favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, mugwort, ninebark, Jeffrey pine, ponderosa pine, skunkbush, Scouler's willow, blue elderberry, and common snowberry.

MEDITERRANEAN COAST NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE MEDITERRANEAN COAST NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on

the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher

concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE MEDITERRANEAN COAST NETWORK

Park	Code	State	Risk	O3 Data
Cabrillo NM	CABR	CA	low	kriged
Channel Islands NP	CHIS	CA	low	monitored
Santa Monica Mountains NRA	SAMO	CA	high	kriged

CABRILLO NATIONAL MONUMENT (CABR)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CABR					
	1995	1996	1997	1998	1999
Sum06	14	11	11	8	6
W126	21.6	19.0	15.9	17.9	15.5
N60	321	272	226	257	178
N80	33	34	26	25	12
N100	3	1	6	1	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CABR					
	1995	1996	1997	1998	1999
Month 1	0.45	-1.47	-2.18	1.89	-2.18
Month 2	-0.76	-1.51	-2.09	-0.02	-1.98
Month 3	-1.51	-1.43	-1.74	-1.06	-1.63

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CABR					
	1995	1996	1997	1998	1999
April	0.02	-1.47	-2.18	1.66	0.78
May	1.71	-1.51	-2.09	6.41	-2.08
June	2.93	-1.43	-1.74	3.35	-2.18
July	1.93	-1.31	-1.38	4.09	-1.98
August	0.45	-1.33	-1.36	1.89	-1.63
September	-0.76	-1.14	1.40	-0.02	-0.95
October	-1.51	1.90	-1.34	-1.06	-1.84

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than six hours in which the concentration exceeded 100 ppb and most years have only one hour. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The year with the highest exposure, 1995, had one month of mild drought, while the two years with the second highest level of exposure, 1996 and 1997, both had three months of mild and moderate drought. The lowest exposure year, 1999, also had three months of mild and moderate drought, and the second lowest year had one month of mild drought. There is no apparent relationship between the W126 indices of ozone exposure and soil moisture conditions, and entire growing seasons are either favorable or unfavorable with respect to soil moisture. The

years with the highest and a mid-level exposure, 1995 and 1998 respectively, each had one month of mild drought. The remaining three years with the second highest and the two lowest exposures, 1996, 1999 and 1997 respectively, each had five or six months of mild and moderate drought.

The low level of ozone exposure and the extended periods of low soil moisture in some years at Cabrillo National Monument make the risk of foliar ozone injury to plants low. While the Sum06 threshold is satisfied, the W126 is not because the N100 criterion is not attained. Atmospheric concentrations of ozone exceed 80 ppb on occasion, but exposure to 100 ppb is rare. Whole growing seasons either have either normal soil moisture or extended periods of low soil moisture. The extended periods of mild to moderate drought constrain the uptake of ozone and further reduce the likelihood of producing foliar injury. No ozone-sensitive species have been identified at the site.

CHANNEL ISLANDS NATIONAL PARK (CHIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Artemisia douglasiana	Mugwort	Asteraceae
Pinus radiata	Monterey pine	Pinaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHIS					
	1995	1996	1997	1998	1999
Sum06	-	5	4	6	3
W126	-	17.9	11.4	15.8	13.9
N60	-	216	95	145	123
N80	-	18	2	4	4
N100	-	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHIS					
	1995	1996	1997	1998	1999
Month 1	-	-1.47	-3.06	4.09	-1.63
Month 2	-	-1.51	-2.18	1.89	-0.95
Month 3	-	-1.43	-2.09	-0.02	-1.98

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHIS					
	1995	1996	1997	1998	1999
April	0.02	-1.47	-2.18	1.66	0.78
May	1.71	-1.51	-2.09	6.41	-2.08
June	2.93	-1.43	-1.74	3.35	-2.18
July	1.93	-1.31	-1.38	4.09	-1.98
August	0.45	-1.33	-1.36	1.89	-1.63
September	-0.76	-1.14	1.40	-0.02	-0.95
October	-1.51	1.90	-1.34	-1.06	-1.84

Risk Analysis

- There are a few ozone-sensitive species at the site.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show no concentrations of 100 ppb and relatively few greater than 80 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The Sum06 exposure levels were low and similar over the four years of data available. Three of the years had two or three months of mild to severe drought, and one year, 1998, had normal soil moisture. Similarly, there does not appear to be any association between the W126 index and soil moisture. Three of the four years of soil moisture data had five or six months of mild and moderate drought, and there was one month of mild drought in the fourth year.

The low levels of ozone exposure and frequent periods of dry soil moisture at Channel Islands National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 exposure indices satisfy their thresholds, and there are only a few hours of exposure over 80 ppb and no hours over 100 ppb. Although ozone exposure and soil moisture conditions are not associated, most years experience five or more months of drought that significantly constrain the uptake of ozone and reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the presence of ozone injury could employ mugwort and blue elderberry.

SANTA MONICA MOUNTAINS NATIONAL RECREATION AREA (SAMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Artemisia douglasiana	Mugwort	Asteraceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAMO					
	1995	1996	1997	1998	1999
Sum06	35	33	24	24	18
W126	49.0	48.0	36.7	32.7	28.0
N60	739	743	607	506	470
N80	272	251	154	146	97
N100	93	74	30	45	14

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAMO					
	1995	1996	1997	1998	1999
Month 1	1.93	-1.43	-2.09	4.09	-2.18
Month 2	0.45	-1.31	-1.74	1.89	-1.98
Month 3	-0.76	-1.33	-1.38	-0.02	-1.63

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAMO					
	1995	1996	1997	1998	1999
April	0.02	-1.47	-2.18	1.66	0.78
May	1.71	-1.51	-2.09	6.41	-2.08
June	2.93	-1.43	-1.74	3.35	-2.18
July	1.93	-1.31	-1.38	4.09	-1.98
August	0.45	-1.33	-1.36	1.89	-1.63
September	-0.76	-1.14	1.40	-0.02	-0.95
October	-1.51	1.90	-1.34	-1.06	-1.84

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during the 90-day Sum06 accumulation periods show no association with the levels of ozone. The two highest ozone years, 1995 and 1996, experienced normal soil moisture and three months of mild drought, respectively, while a mid-ozone year, 1997, and the lowest year, 1999, experienced three months of mild and moderate drought. There is no apparent relationship between the W126 index of exposure and soil moisture conditions, and the entire growing season is either favorable or unfavorable with respect to soil moisture. In three of the five years, mild to moderate drought conditions

occurred for five or six months; the other two years each had one month of mild drought. The drought periods occurred independently of the levels of ozone exposure. This pattern indicates that for major portions of the growing season, soil moisture conditions are either favorable or unfavorable for the uptake of ozone and that these conditions are not related to levels of ozone exposure.

The risk of foliar ozone injury to plants at Santa Monica Mountains National Recreation Area is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may significantly reduce the likelihood of injury developing in any particular year. Since there is no apparent relationship between the level of ozone exposure and soil moisture conditions, and since entire seasons appear to be characterized by either favorable or unfavorable soil moisture conditions, the levels of risk vary considerably among years. The site is subject to potentially harmful levels of ozone annually, and the probability of foliar injury developing will be greatest during years such as 1995 and 1998 when soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven and mugwort.

MID-ATLANTIC NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE MID-ATLANTIC NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE MID-ATLANTIC NETWORK

Park	Code	State	Risk	O3 Data
Appomattox Court House NHP	APCO	VA	moderate	kriged
Booker T. Washington NM	BOWA	VA	moderate	kriged
Eisenhower NHS	EISE	PA	high	kriged
Fredericksburg & Spotsylvania NMP	FRSP	VA	high	kriged
Gettysburg NMP	GETT	PA	high	kriged
Hopewell Furnace NHS	HOFU	PA	high	kriged
Petersburg NB	PETE	VA	moderate	kriged
Richmond NBP	RICH	VA	moderate	kriged
Shenandoah NP	SHEN	VA	moderate	monitored
Valley Forge NHP	VAFO	PA	high	kriged

A portion of the Appalachian National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Appalachian Trail.

APPOMATTOX COURT HOUSE NATIONAL HISTORIC PARK (APCO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for APCO					
	1995	1996	1997	1998	1999
Sum06	17	16	21	26	30
W126	34.6	27.9	42.1	57.2	41.5
N60	643	523	758	1040	750
N80	77	50	114	212	131
N100	5	4	9	27	9

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was

estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at APCO					
	1995	1996	1997	1998	1999
Month 1	6.78	0.26	-2.18	-0.88	-2.56
Month 2	-0.32	-0.32	0.60	-2.82	-1.22
Month 3	-2.45	1.89	-0.09	-0.71	-1.80

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at APCO					
	1995	1996	1997	1998	1999
April	-2.57	-1.21	1.43	1.98	-0.55
May	1.17	1.53	-2.18	2.25	-1.93
June	6.78	0.26	0.60	-0.88	-2.56
July	-0.32	-0.32	-0.09	-2.82	-1.22
August	-2.45	1.89	-1.19	-0.71	-1.80
September	-0.68	7.05	0.42	-2.84	5.84
October	2.76	0.16	-0.62	-2.38	-0.64

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation in the higher ozone years.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year

with the highest Sum06 ozone exposure value, 1999, experienced three months of mild and moderate drought. The three intermediate ozone years had one month of moderate drought each, and the year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of moderate drought. The next two lower exposure years, 1997 and 1999, had two and four months of mild and moderate drought, respectively. The second lowest exposure year had two months of moderate drought, and the lowest year had one month of mild drought.

The risk of foliar ozone injury at Appomattox Court House National Historic Park is moderate. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in some years, and considerably reduced exposure in other years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, American elder, crownbeard, and northern fox grape.

BOOKER T. WASHINGTON NATIONAL MONUMENT (BOWA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BOWA					
	1995	1996	1997	1998	1999
Sum06	19	17	23	24	26
W126	35.4	29.1	42.5	60.8	43.5
N60	677	527	769	1089	812
N80	66	51	108	232	137
N100	3	5	6	29	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BOWA					
	1995	1996	1997	1998	1999
Month 1	-0.32	1.53	0.60	-2.82	-2.56
Month 2	-2.45	0.26	-0.09	-0.71	-1.22
Month 3	-0.68	-0.32	-1.19	-2.84	-1.80

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BOWA					
	1995	1996	1997	1998	1999
April	-2.57	-1.21	1.43	1.98	-0.55
May	1.17	1.53	-2.18	2.25	-1.93
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August	-2.45	1.89	-1.19	-0.71	-1.80
September	-0.68	7.05	0.42	-2.84	5.84
October	2.76	0.16	-0.62	-2.38	-0.64

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation in the higher ozone years.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, experienced three months of mild and moderate drought. The year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. The three intermediate ozone years had one or

two months of mild and moderate drought each. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of moderate drought. The three intermediate ozone years, 1997, 1999 and 1995, had two to four months of mild and moderate drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury at Booker T. Washington National Monument is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, and intermittently by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in some years, and considerably reduced levels of exposure in other years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, white ash, yellow-poplar, American sycamore, black cherry, and American elder.

EISENHOWER NATIONAL HISTORIC SITE (EISE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

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	W126	N100
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Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for EISE					
	1995	1996	1997	1998	1999
Sum06	20	20	25	32	33
W126	39.5	32.1	44.2	59.4	48.5
N60	651	573	749	1007	812
N80	168	87	160	270	199
N100	23	6	21	32	23

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at EISE					
	1995	1996	1997	1998	1999
Month 1	2.52	4.42	-1.49	0.10	-2.02
Month 2	2.25	4.57	-0.64	-0.64	-2.40
Month 3	-2.09	0.38	-0.21	-2.42	-2.98

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at EISE					
	1995	1996	1997	1998	1999
April	-1.43	0.35	-2.05	1.39	0.68
May	0.05	1.37	-0.52	1.00	-2.02
June	2.52	4.42	-1.49	1.01	-2.40
July	2.25	4.57	-0.64	0.10	-2.98
August	-2.09	0.38	-0.21	-0.64	-0.41
September	-0.55	5.89	1.42	-2.42	4.11
October	2.22	2.17	-1.37	-0.89	0.19

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, had three months of moderate drought. The three intermediate years covered a wide range of exposure values, but each had only one month of drought. The lowest exposure year, 1996, had favorable conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, and the pattern is again not consistent.

The highest ozone year, 1998, experienced one month of moderate drought. The next two highest ozone years, 1999 and 1997, had similar levels of exposure and three months of mild and moderate drought each. There were two months of drought in the second lowest year, and the lowest ozone year, 1996, had favorable soil moisture conditions.

The risk of foliar ozone injury to plants at Eisenhower National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the largely inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing is greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under limited drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, and black cherry.

FREDERICKSBURG & SPOTSYLVANIA NATIONAL MILITARY PARK (FRSP)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FRSP					
	1995	1996	1997	1998	1999
Sum06	24	26	30	37	38
W126	34.7	31.0	38.6	49.1	46.6
N60	613	567	660	831	777
N80	121	79	141	212	215
N100	16	3	17	36	26

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FRSP					
	1995	1996	1997	1998	1999
Month 1	0.11	-0.73	-0.02	-2.74	-1.80
Month 2	-2.62	1.51	0.79	-2.87	-0.95
Month 3	-0.54	0.72	-1.63	-2.28	-1.34

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FRSP					
	1995	1996	1997	1998	1999
April	-1.62	-0.63	1.01	1.37	-0.75
May	1.57	0.66	-2.03	0.29	-1.51
June	3.93	-0.73	-0.02	0.24	-1.80
July	0.11	1.51	0.79	-2.74	-0.95
August	-2.62	0.72	-1.63	-2.87	-1.34
September	-0.54	3.99	-0.88	-2.28	7.71
October	3.44	2.23	-0.19	-2.46	-0.22

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations of 60 and 80 ppb are generally elevated, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of

ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1999 and 1998, experienced two and three months, respectively, of moderate or mild drought. The two mid-level ozone years each had one month of drought, and the year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone year, 1998, there were four months of moderate drought. The three intermediate ozone years each had two months of mild and moderate drought. In the lowest ozone year, 1996, soil moisture was favorable throughout.

The risk of foliar ozone injury at Fredericksburg and Spotsylvania National Military Park is high. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in most years, and considerably reduced exposure in others. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood the exposures will produce foliar injury. Annual variations in ozone exposure and soil moisture interact to create highly variable levels of risk. The probability of foliar injury developing is greatest during years such as 1995 and 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, and Allegheny blackberry.

GETTYSBURG NATIONAL MILITARY PARK (GETT)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GETT					
	1995	1996	1997	1998	1999
Sum06	21	21	26	32	33
W126	39.5	32.1	43.7	57.9	47.5
N60	648	571	734	977	791
N80	172	90	165	266	199
N100	26	7	24	32	25

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GETT					
	1995	1996	1997	1998	1999
Month 1	2.52	4.42	-1.49	0.10	-2.02
Month 2	2.25	4.57	-0.64	-0.64	-2.40
Month 3	-2.09	0.38	-0.21	-2.42	-2.98

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GETT					
	1995	1996	1997	1998	1999
April	-1.43	0.35	-2.05	1.39	0.68
May	0.05	1.37	-0.52	1.00	-2.02
June	2.52	4.42	-1.49	1.01	-2.40
July	2.25	4.57	-0.64	0.10	-2.98
August	-2.09	0.38	-0.21	-0.64	-0.41
September	-0.55	5.89	1.42	-2.42	4.11
October	2.22	2.17	-1.37	-0.89	0.19

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone

concentrations: when ozone is high, soil moisture is low, but the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two highest Sum06 ozone years had similar levels of exposure, but different soil moisture regimes. The year with the highest exposure, 1999, had three months of moderate drought, while the second highest year, 1998, had one month of moderate drought. The three years with lower ozone exposure had two months of drought among them. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, and the pattern is again not consistent. The highest ozone year, 1998, experienced one month of moderate drought. The next two highest ozone years, 1999 and 1997, had three months of mild and moderate drought each. There were two months of drought in the second lowest year, and the lowest ozone year, 1996, had favorable soil moisture conditions.

The risk of foliar ozone injury to plants at Gettysburg National Military Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are generally high. While the levels of ozone exposure consistently create the potential for injury, the largely inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under limited drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

HOPEWELL FURNACE NATIONAL HISTORIC SITE (HOFU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOFU					
	1995	1996	1997	1998	1999
Sum06	29	25	28	29	32
W126	34.6	28.1	34.5	42.5	41.1
N60	556	485	524	686	647
N80	173	106	170	215	206
N100	36	13	38	28	45

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOFU					
	1995	1996	1997	1998	1999
Month 1	-1.51	1.51	-1.33	-1.18	-2.41
Month 2	0.10	3.68	-0.12	-1.24	-4.16
Month 3	-3.35	0.21	-0.50	-2.27	-0.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOFU					
	1995	1996	1997	1998	1999
April	-1.83	1.58	-1.67	1.26	-0.39
May	0.13	0.02	-0.25	0.98	-1.74
June	-1.51	1.51	-1.33	1.69	-2.41
July	0.10	3.68	-0.12	-1.18	-4.16
August	-3.35	0.21	-0.50	-1.24	-0.58
September	-0.49	1.93	-0.77	-2.27	7.56
October	4.01	4.32	-1.32	0.10	1.08

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day

accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, but the pattern in not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value experienced two months of mild and severe drought. The two years with the same, second highest exposure, 1995 and 1998, had two months of mild and severe and three months of mild and moderate drought, respectively. The year with the second lowest exposure, 1997, had one month of mild drought, and the lowest exposure year, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone exposure. The two years with the highest exposure levels, 1998 and 1999, experienced three sequential months of mild and moderate drought. The two intermediate ozone years, 1995 and 1997, had three months of intermittent mild or severe drought, while the lowest ozone year, 1996, had favorable soil moisture conditions throughout.

The risk of foliar ozone injury to plants at Hopewell Furnace National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

PETERSBURG NATIONAL BATTLEFIELD (PETE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PETE					
	1995	1996	1997	1998	1999
Sum06	25	24	35	38	35
W126	32.6	28.5	44.0	48.7	42.6
N60	570	514	745	843	711
N80	97	65	174	187	180
N100	11	3	24	27	26

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PETE					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PETE					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours almost every year. These levels of exposure can injure vegetation.
- Ozone exposure levels for the 90-day Sum06 accumulation periods were high and relatively uniform over the five years, and soil moisture conditions showed scattered months of mild to severe drought stress. There was no apparent

association between the Sum06 index of ozone exposure and soil moisture. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone year, 1998, there were four months of mild and moderate drought. The two next highest ozone years, 1997 and 1999, had four and two months of mild and moderate drought, respectively. The lowest ozone year had favorable conditions, but the second lowest year, 1995, had three months of mild and severe drought.

The risk of foliar ozone injury to plants at Petersburg National Battlefield is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The generally inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. However, years such as 1999, in which high levels of exposure occur under conditions of less severe drought, may have the potential to produce foliar injury. The probability of foliar injury developing may greatest during years such as this when ozone levels are elevated, and soil moisture levels are under mild drought and do not create a long-term constraint on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, crownbeard, and northern fox grape.

RICHMOND NATIONAL BATTLEFIELD PARK (RICH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for RICH					
	1995	1996	1997	1998	1999
Sum06	26	27	36	40	37
W126	33.9	29.9	44.3	50.6	44.8
N60	588	540	739	860	743
N80	111	74	183	209	201
N100	13	3	26	34	31

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at RICH					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at RICH					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours almost every year. These levels of exposure can injure vegetation.
- There was no apparent association between the 90-day Sum06 index of ozone exposure and soil moisture. Ozone exposure levels for the Sum06 accumulation periods varied moderately among the five years, and soil moisture conditions

showed scattered months of mild to severe drought stress. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone year, 1998, there were four months of mild and moderate drought. The two next highest ozone years, 1997 and 1999, had four and two months of mild and moderate drought, respectively. The lowest ozone year had favorable conditions, but the second lowest year, 1995, had three months of mild and severe drought.

The risk of foliar ozone injury to plants at Richmond National Battlefield Park is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The generally inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. However, years such as 1999, in which high levels of exposure occur under conditions of less extensive drought, have the greatest potential to produce foliar injury. The probability of injury developing may greatest during years when ozone levels are elevated, and soil moisture levels are under limited drought and do not produce long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, American elder, crownbeard, and northern fox grape.

SHENANDOAH NATIONAL PARK (SHEN)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SHEN					
	1995	1996	1997	1998	1999
Sum06	33	31	29	57	43
W126	73.1	63.7	65.5	118.3	69.4
N60	1454	1268	1239	2321	1307
N80	134	55	123	387	231
N100	1	0	4	67	11

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SHEN					
	1995	1996	1997	1998	1999
Month 1	-0.52	2.64	0.60	-2.56	-2.03
Month 2	-1.56	1.73	0.15	-2.57	-1.60
Month 3	-0.68	3.13	-1.30	-2.87	6.55

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SHEN					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only two years, and thus the criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a few hours most years and for a significant number of hours in one year. The higher levels of exposure can injure vegetation.

- Soil moisture levels during both the 90-day Sum06and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest Sum06 exposure year, 1998, there were three months of moderate drought stress, and two months of drought in the second highest ozone year, 1999. The three lowest ozone years had similar levels of exposure, with two of the years each having one month of mild drought. Soil moisture levels associated with the

W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. There were four months of moderate drought in the highest ozone year, 1998, and two months of mild drought in the second highest year, 1995. The median exposure year, 1999, had five months of mild and moderate drought. The lowest ozone year, 1996, had favorable soil moisture conditions, while the second lowest year, 1997, had four months of mild drought.

The risk of foliar ozone injury at Shenandoah National Park is moderate. The threshold for injury is consistently satisfied for the Sum06 and occasionally the W126 indices. The N-values indicate that there are frequent exposures to concentrations of ozone greater than 80 ppb. There are several hours of exposure to 100 ppb in most years, and a significant number of hours of exposure in some years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the higher exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

VALLEY FORGE NATIONAL HISTORIC PARK (VAFO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VAFO					
	1995	1996	1997	1998	1999
Sum06	31	26	27	29	32
W126	35.8	28.8	34.0	41.5	40.7
N60	574	498	512	670	633
N80	187	122	170	211	209
N100	44	17	39	30	52

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VAFO					
	1995	1996	1997	1998	1999
Month 1	-1.51	1.51	-1.33	-1.18	-2.41
Month 2	0.10	3.68	-0.12	-1.24	-4.16
Month 3	-3.35	0.21	-0.50	-2.27	-0.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VAFO					
	1995	1996	1997	1998	1999
April	-1.83	1.58	-1.67	1.26	-0.39
May	0.13	0.02	-0.25	0.98	-1.74
June	-1.51	1.51	-1.33	1.69	-2.41
July	0.10	3.68	-0.12	-1.18	-4.16
August	-3.35	0.21	-0.50	-1.24	-0.58
September	-0.49	1.93	-0.77	-2.27	7.56
October	4.01	4.32	-1.32	0.10	1.08

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day periods appear to be inversely related to ozone concentrations: when ozone is high, soil

moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the three highest ozone exposure values, 1999, 1995 and 1998, experienced two, two and three months of mild to severe drought, respectively. The two years with the lowest ozone exposure, 1996 and 1997, had one month of mild drought between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In each of the two highest ozone years, 1998 and 1999, there were three consecutive months of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had three interspersed months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Valley Forge National Historic Park is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in higher ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

MOJAVE DESERT NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE MOJAVE DESERT NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The consistent evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, medium or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE MOJAVE DESERT NETWORK

Park	Code	State	Risk	O3 Data
Death Valley NP	DEVA	CA	low	monitored
Great Basin NP	GRBA	NV	low	monitored
Joshua Tree NP	JOTR	CA	high	monitored
Lake Mead NRA	LAME	NV	low	kriged
Manzanar NHS	MANZ	CA	high	kriged
Mojave N PRES	MOJA	CA	high	kriged

DEATH VALLEY NATIONAL PARK (DEVA)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DEVA

	1995	1996	1997	1998	1999
Sum06	7	29	26	42	44
W126	-	46.2	44.9	69.7	72.5
N60	-	819	748	1386	1501
N80	-	24	17	80	48
N100	-	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DEVA					
	1995	1996	1997	1998	1999
Month 1	2.00	-2.36	-3.41	4.53	-1.02
Month 2	2.90	-1.20	-1.64	5.24	-0.18
Month 3	0.81	-1.52	-0.20	5.11	-1.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DEVA					
	1995	1996	1997	1998	1999
April	1.00	-2.62	-2.58	1.51	0.51
May	2.00	-2.50	-3.41	4.53	-2.18
June	2.90	-2.36	-1.64	5.24	-1.62
July	0.81	-1.20	-0.20	5.11	1.24
August	-1.06	-1.52	-1.45	-0.52	-1.02
September	-1.33	-0.87	5.14	1.26	-0.18
October	-1.46	0.41	-0.89	-0.85	-1.48

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year concentrations that exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There are no associations between either the 90-day Sum06 or the seasonal W126 accumulation period levels of ozone and soil moisture conditions. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought. The second highest year, 1998, had favorable conditions, as did 1995, the lowest ozone year. The two mid-ozone years, 1996 and 1997, had three and two months of mild to severe drought, respectively. Although only four years of data are available for analysis, there is also no apparent pattern of association between the W126 index of exposure and soil moisture conditions. The highest ozone year, 1999, had four months of mild and moderate drought, while the lowest ozone year, 1997, had four months of mild to severe drought. Mid-level ozone years had five months of mild and moderate drought in 1996 and favorable conditions in 1998.

The low levels of ozone exposure at Death Valley National Park make the risk of foliar ozone injury to plants low. The W126 criteria are not satisfied, and there are occasional hours above 80 ppb and none above 100 ppb. Months of drought constrain the uptake of ozone in most years and further reduce the likelihood of foliar injury. No ozone-sensitive species are found at the site.

GREAT BASIN NATIONAL PARK (GRBA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Oenothera elata	Evening primrose	Onagraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GRBA					
	1995	1996	1997	1998	1999
Sum06	6	19	14	16	21
W126	22.9	38.3	128.8	36.8	40.4
N60	202	571	456	538	632
N80	0	5	4	3	2
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRBA					
	1995	1996	1997	1998	1999
Month 1	0.94	3.83	2.10	5.02	0.80
Month 2	2.87	3.32	3.15	6.07	1.21
Month 3	4.08	3.07	3.57	5.64	-0.17

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRBA					
	1995	1996	1997	1998	1999
April	0.94	3.41	2.75	2.82	0.80
May	2.87	3.83	2.10	4.16	0.80
June	4.08	3.32	3.15	5.02	1.21
July	5.05	3.07	3.57	6.07	-0.17
August	5.15	2.26	3.40	5.64	-0.16
September	4.68	1.79	3.80	6.24	-0.63
October	3.58	1.67	3.47	6.17	-1.27

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- There are no associations between the levels of ozone and soil moisture conditions for either the Sum06 or W126 indices of exposure. Soil moisture levels were normal throughout the five-year assessment period, with only one month of mild drought.

The low levels of ozone exposure at Great Basin National Park make the risk of foliar ozone injury to plants low. The W126 criteria are not satisfied, and there are only a few hours above 80 ppb and none above 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: evening primrose, ponderosa pine, quaking aspen, and skunkbush.

JOSHUA TREE NATIONAL PARK (JOTR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix gooddingii	Gooding's willow	Salicaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JOTR					
	1995	1996	1997	1998	1999
Sum06	45	69	65	48	64
W126	97.7	138.3	128.8	92.7	118.4
N60	1670	2277	2171	1637	2141
N80	397	700	616	363	497
N100	81	159	146	66	69

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JOTR					
	1995	1996	1997	1998	1999
Month 1	2.74	-4.27	-5.38	4.29	-2.99
Month 2	3.43	-4.33	-5.38	5.60	-2.27
Month 3	3.35	-4.18	-4.89	6.72	-2.38

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JOTR					
	1995	1996	1997	1998	1999
April	2.32	-3.45	-4.73	3.10	-2.24
May	2.74	-3.93	-5.38	4.29	-2.73
June	3.43	-4.31	-5.38	5.60	-2.99
July	3.35	-4.27	-4.89	6.72	-2.27
August	-0.35	-4.33	-4.87	5.86	-2.38
September	-0.76	-4.18	1.71	5.67	-2.19
October	-1.17	-3.61	1.24	-0.28	-2.46

Risk Analysis

- There are a few ozone-sensitive species at the site, two of which are bioindicators for ozone

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The three years with the highest and similar levels of Sum06 ozone, 1996, 1997 and 1999, each had three months of moderate or severe drought. The two years with significantly lower levels of ozone, 1995 and 1998, had favorable conditions. Soil moisture levels associated with the W126 index also appear to be inversely related to ozone concentration. The three highest ozone years, 1996, 1999 and 1997, each had from five to seven months of moderate to severe drought, while the two lowest ozone years, 1998 and 1995, had only one month of mild drought between them. In addition to the inverse relationship, entire seasons were either highly drought stressed or had normal moisture conditions.

The risk of foliar ozone injury to plants at Joshua Tree National Park is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury, particularly in higher ozone years. Since entire growing seasons are characterized by either high drought stress or normal soil moisture

conditions, levels of risk vary considerably among years. The site is subject to potentially harmful levels of ozone annually, and the probability of foliar injury developing is greatest during years such as 1995 and 1998 when soil moisture levels do not create long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush and blue elderberry as bioindicator species.

LAKE MEAD NATIONAL RECREATION AREA (LAME)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LAME					
	1995	1996	1997	1998	1999
Sum06	17	36	24	25	33
W126	29.5	43.7	32.2	39.1	44.6
N60	516	815	608	738	867
N80	36	97	37	52	51
N100	3	3	2	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LAME					
	1995	1996	1997	1998	1999
Month 1	3.86	-4.15	-4.57	4.32	-2.23
Month 2	4.56	-4.29	-4.33	5.83	-1.98
Month 3	-0.29	-3.74	-4.24	5.08	-0.59

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LAME					
	1995	1996	1997	1998	1999
April	3.05	-4.05	-4.06	3.11	-1.82
May	3.86	-4.15	-4.57	3.46	-2.23
June	4.56	-4.29	-4.33	4.32	-1.98
July	-0.29	-3.74	-4.24	5.83	-0.59
August	-0.77	-4.16	-4.01	5.08	-1.14
September	-1.29	-4.25	1.91	5.53	-1.03
October	-1.69	-3.70	1.27	5.05	-1.51

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. The two highest ozone years, 1996 and 1999, experienced three months of moderate and severe drought and two months of mild and moderate drought, respectively. The two mid-level exposure years, 1998 and 1997, had normal soil moisture and three months of severe drought, respectively. There was normal soil moisture in 1995, the lowest exposure year. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the

effectiveness of the higher exposures in producing foliar injury. In the highest ozone years, 1996 and 1999, there were seven months of severe drought and six months of mild and moderate drought, respectively. The intermediate exposure year 1998 had normal moisture conditions while there were five months of severe drought in the second lowest exposure year and two months of mild drought in the lowest year.

The low levels of ozone exposure at Lake Meade National Recreation Area make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures to concentrations greater than 100 ppb are rare. Soil moisture conditions vary considerably among years, but extended periods of drought in some years constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine and skunkbush as bioindicators.

MANZANAR NATIONAL HISTORIC SITE (MANZ)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MANZ

	1995	1996	1997	1998	1999
Sum06	28	32	28	28	38
W126	72.8	91.4	74.3	71.8	95.9
N60	1214	1512	1254	1163	1626
N80	367	508	349	356	495
N100	61	91	49	77	84

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MANZ					
	1995	1996	1997	1998	1999
Month 1	3.35	-4.31	-5.38	5.60	-2.27
Month 2	-0.35	-4.27	-4.89	6.72	-2.38
Month 3	-0.76	-4.33	-4.87	5.86	-2.19

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MANZ					
	1995	1996	1997	1998	1999
April	2.32	-3.45	-4.73	3.10	-2.24
May	2.74	-3.93	-5.38	4.29	-2.73
June	3.43	-4.31	-5.38	5.60	-2.99
July	3.35	-4.27	-4.89	6.72	-2.27
August	-0.35	-4.33	-4.87	5.86	-2.38
September	-0.76	-4.18	1.71	5.67	-2.19
October	-1.17	-3.61	1.24	-0.28	-2.46

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two highest Sum06 ozone years, 1999 and 1996, each experienced three months of moderate or severe drought. The three years with lower and similar levels of ozone had among them one year with three months of severe drought and two years of normal moisture. A similar inverse relationship appears to exist between the W126 index and soil moisture, although the pattern is again not consistent. In the highest ozone years, 1999 and 1996, there were seven months of moderate drought and seven months of severe drought, respectively. The three years with lower and similar levels of ozone had five months of severe drought in 1997, one month of mild drought in 1995, and normal moisture in 1998, the lowest exposure year.

The risk of foliar ozone injury at Manzanar National Historic Site is high. The threshold for injury is satisfied for both the Sum06 and the W126 indices, and there are a significant number of hours of exposure to concentrations of ozone greater than 80 and

100 ppb each year. Entire years experience soil moisture conditions that either favor or constrain the uptake of ozone. In some years there are extended periods of moderate and severe drought that significantly restrict the uptake of ozone by plants. However, in years such as 1995 and 1998, ozone levels significantly exceed thresholds for injury and soil moisture levels are normal. Under these conditions, the likelihood of foliar injury is high. While the level of risk for the site is high, there are no ozone-sensitive species listed. Until sensitive species are identified either through plant surveys at the site or as a result of further ozone research, the risk of injury remains potential rather than actual.

MOJAVE NATIONAL PRESERVE (MOJA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Artemisia douglasiana	Mugwort	Asteraceae
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix gooddingii	Gooding's willow	Salicaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
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Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MOJA					
	1995	1996	1997	1998	1999
Sum06	12	13	10	23	30
W126	40.1	71.2	60.6	53.4	61.2
N60	704	1213	1065	946	1167
N80	103	305	235	161	142
N100	19	61	57	35	12

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MOJA					
	1995	1996	1997	1998	1999
Month 1	3.43	-4.31	-5.38	5.60	-2.73
Month 2	3.35	-4.27	-5.38	6.72	-2.99
Month 3	-0.35	-4.33	-4.89	5.86	-2.27

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MOJA					
	1995	1996	1997	1998	1999
April	2.32	-3.45	-4.73	3.10	-2.24
May	2.74	-3.93	-5.38	4.29	-2.73
June	3.43	-4.31	-5.38	5.60	-2.99
July	3.35	-4.27	-4.89	6.72	-2.27
August	-0.35	-4.33	-4.87	5.86	-2.38
September	-0.76	-4.18	1.71	5.67	-2.19
October	-1.17	-3.61	1.24	-0.28	-2.46

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. The highest ozone year, 1999, experienced three months of moderate drought and the second highest, 1998, had three months of normal moisture. The three lower ozone years had similar levels of exposure: two years, 1996 and 1997, each had three months of severe drought, and one year, 1995, had normal soil moisture. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations. This relationship reduces the uptake of ozone and the effectiveness of the higher

exposures in producing foliar injury. In the highest ozone year, 1996, there were seven months of severe drought. The next two highest ozone years, 1997 and 1999, had similar levels of exposure and five months of severe drought and seven months of moderate drought, respectively. The two years with the lowest ozone had only one month of mild drought among them.

The risk of foliar ozone injury at Mojave National Preserve is high. The threshold for injury is satisfied for both the Sum06 and the W126 indices, and the N-values indicate that there are a significant number of hours of exposure to concentrations of ozone greater than 80 and 100 ppb each year. Entire years experience soil moisture conditions that either favor or constrain the uptake of ozone. In some years there are extended periods of moderate and severe drought that significantly restrict the uptake of ozone by plants. However, in years such as 1995 and 1998, ozone levels significantly exceed thresholds for injury and soil moisture levels are normal. Under these conditions, the likelihood of foliar injury is high.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: mugwort, skunkbush, and blue elderberry.

NATCHEZ TRACE NATIONAL SCENIC TRAIL (NATR)

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION AT SITES ALONG THE NATCHEZ TRACE NATIONAL SCENIC TRAIL

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers to better understand the risk of ozone injury to vegetation and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used, and how they were applied and modified to meet the requirements of producing an assessment for the 444-mile long Natchez Trace Trail. It also provides a summary of the results of risk assessments for sites along the Trail.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Due to its linear configuration and length, the Natchez Trace Trail is represented by nine sub-sites with a risk assessment for each. The sub-sites consist of US National Park sites on and near the Natchez Trace Trail and EPA AIRS ozone monitoring sites located near

the Trail. Plant species and ozone exposure data are not complete for each site, and therefore the quality of the risk assessment varies among sites.

Natchez Trace National Scenic Trail Assessment Sites and Data Availability

State	Location	County	AIRS ID #	Sum06 yrs	W126 yrs	N-value yrs
MS	Natchez	Adams	280010004	95-99	95-99	95-99
	Vicksburg NMP		NPS	95-99	95-99	95-99
	Jackson	Hinds	280890002	95-99	95-99	95-99
	Ackerman	Choctaw	280190001	97	97	97
	Tupelo	Lee	280810005	98-99	99	99
TN	Shiloh NMP		NPS	95-99	95-99	94-99
	Busby	Lawrence	470990002	97-99	97-99	97-99
	Fairview	Williamson	471870103	95-96	95-96	95-96
	Stones River NB		NPS	95-99	95-99	95-99

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone.

Ozone-sensitive and bioindicator plant species at each National Park Service site along the Natchez Trace Trail were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop. Since there are no floral lists for the EPA AIRS monitoring sites used in the assessment, another approach had to be adopted for them. The database maintained by the US Forest Service for the Forest Inventory/Forest Health Monitoring program (FIA/FHM) was consulted. Data on all FIA/FHM assessment plots within 25 miles of the AIRS monitoring site were evaluated to identify ozone-sensitive tree species occurring there. Since the FIA/FHM assessments currently examine only trees, it was not possible to identify ozone-sensitive herbaceous or understory species associated with the AIRS sites.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 were obtained either from on-site monitoring or by kriging, a statistical interpolation process. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the

assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Ozone exposure values for the sites along the Natchez Trace Trail were provided by the Air Resources Division of the National Park Service using hourly data either from their own or from the EPA AIRS database. Exposure values for the National Park Service sites were produced using hourly data either from on-site monitoring or estimated by kriging. Hourly monitoring data from EPA AIRS were used to generate exposure values for the non-Park Service sites in the assessment.

Although the assessment period is five years, 1995 through 1999, not all sites have the complete suite of data for the exposure indices. This limits the understanding of the exposure regimes at some sites and constrains their risk assessments. Sites with limited ozone data were included in the Natchez Trace Trail assessment to both identify them for use future evaluation and to provide an initial look at their ozone environments.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not

available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

The collection of nine National Park Service and AIRS sites provides a reasonable spatial distribution of assessment points from Mississippi to Tennessee along the Natchez Trace Trail. However, there are several factors that need to be considered when relating the risk assessments for the sites to that of the Trail. Except where the Trail passes through a national park, the species lists represent those found in the vicinity of the assessment site and not those actually on the Trail. A second consideration is that since the Park Service and AIRS monitoring sites are generally at elevations different from those of the Trail in that area, the ozone regimes at the monitoring sites may not be representative of those on the Trail. The magnitudes of the differences between the sites cannot be accurately assessed except to note that ozone exposures generally increase with increasing elevation. Lastly, the Palmer Z data used for the monitoring sites may not accurately represent soil

moisture conditions on the Trail due to differences in soil type, physiography, and precipitation that occur with elevation. As a consequence of these factors, the assessments should be viewed as providing insight to the levels of risk that exist at selected points along the Natchez Trace Trail, and used as guidance in determining either whether a field injury survey is appropriate, or whether additional ozone exposure and species information should be collected and evaluated before a decision about risk can be made.

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SUMMARY OF RISK ASSESSMENTS FOR SITES ALONG THE NATCHEZ TRACE NATIONAL SCENIC TRAIL

Site / Park		State	Risk
Natchez		MS	low
Vicksburg NMP	VICK	MS	low
Jackson		MS	low
Ackerman		MS	low
Tupelo		MS	high
Shiloh NMP	SHIL	TN	high
Busby		TN	moderate
Fairview		TN	low
Stones River NB	STRI	TN	high

MISSISSIPPI

Natchez, Adams County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Natchez, Adams County					
	1995	1996	1997	1998	1999
Sum06	12	21	20	22	28
W126	19.2	26.1	30.8	35.5	37.3
N60	356	499	609	631	688
N80	24	45	34	107	105
N100	2	0	3	2	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Natchez					
	1995	1996	1997	1998	1999
Month 1	-0.12	-1.63	-1.34	-0.06	-2.45
Month 2	-1.48	2.05	0.16	-2.44	0.39
Month 3	-0.11	-0.83	-1.29	0.98	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Natchez					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
October	1.02	0.37	1.48	-1.40	-0.35

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a significant number of hours in some years. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Soil moisture levels show one or two months of mild to moderate drought stress each year, and no relationship between levels of ozone exposure and soil moisture conditions can be established. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The years with the highest and second highest exposure levels, 1999 and 1998, experienced three and four months,

respectively, of mild to severe drought stress. The two mid-level ozone years, 1997 and 1996, experienced two and one month of mild drought, while the lowest exposure year had normal soil moisture throughout.

The low levels of ozone exposure at Natchez, Adams County make the risk of foliar ozone injury to plants low. While the Sum06 index exceeds the threshold for injury, the W126 does not since the N100 criterion is not satisfied. Hourly concentrations of ozone exceed 80 ppb for a significant number of hours in some years, but the number of hours above 100 ppb in these years is low. Soil moisture conditions of several months of drought constrain the uptake of ozone in the years with higher exposures and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Vicksburg National Military Park (VICK)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VICK					
	1995	1996	1997	1998	1999
Sum06	18	15	17	13	16
W126	27.5	22.7	25.5	28.5	31.4
N60	521	411	490	525	600
N80	46	34	31	68	59
N100	1	1	1	4	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to

foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VICK					
	1995	1996	1997	1998	1999
Month 1	-1.48	2.05	-1.34	-0.06	-2.45
Month 2	-0.11	-0.83	0.16	-2.44	0.39
Month 3	-0.95	2.11	-1.29	0.98	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VICK					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
October	1.02	0.37	1.48	-1.40	-0.35

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Ozone exposures were similar over the five-year period, and no relationship is apparent between the 90-day Sum06 levels of ozone and soil moisture. Four of the five years experienced one or more months of drought, and only 1996 had favorable conditions. The years with the highest and lowest ozone exposures, 1995 and 1998, experienced one month of mild and moderate drought, respectively. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposure in producing foliar injury. The highest ozone year, 1999, had three months of mild to moderate drought stress. The next two highest ozone years, 1998 and 1995, had similar levels of ozone, but experienced four months of mild to severe drought and one month of mild drought, respectively. The two years with the lowest ozone, 1996 and 1997, had one and two months of mild drought respectively.

The low levels of ozone exposure and the frequent low soil moisture conditions at Vicksburg National Monument Park make the risk of foliar ozone injury to plants low. While the Sum06 index exceeds the threshold levels for injury, the W126 does not since the N100 criterion is generally not satisfied. There are occasional exposures to concentrations of ozone above 80 ppb, and rare exposure to 100 ppb. Soil moisture conditions of moderate to severe drought reduce the effectiveness of the higher concentration exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, and American elder.

Jackson, Hinds County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Jackson, Hinds County					
	1995	1996	1997	1998	1999
Sum06	18	21	19	20	26
W126	25.7	26.7	25.6	34.2	35.6
N60	512	495	495	617	671
N80	22	33	18	83	56
N100	0	0	1	7	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Jackson					
	1995	1996	1997	1998	1999
Month 1	-1.48	-1.63	-1.34	-2.44	-2.45
Month 2	-0.11	2.05	0.16	0.98	0.39
Month 3	-0.95	-0.83	-1.29	-1.40	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Jackson					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
October	1.02	0.37	1.48	-1.40	-0.35

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone satisfies the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had seven hours in which the concentration exceeded 100 ppb, but two years had no hours at this level. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Soil moisture levels show one or two months of mild to moderate drought stress each year, and no relationship between levels of ozone exposure and soil moisture conditions can be established. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The years with the highest and second

highest exposure levels, 1999 and 1998, experienced three and four months, respectively, of mild to severe drought stress. The remaining three years had lower and similar levels of ozone and each had one or two months of mild drought.

The low ozone exposure at Jackson. Hinds County makes the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Since soil moisture conditions of mild to severe drought reduce the effectiveness of the exposures in the higher ozone years, and hourly concentrations of ozone seldom exceeded 80 ppb, foliar injury on plants is unlikely.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Ackerman, Choctaw County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Ackerman, Choctaw County					
	1995	1996	1997	1998	1999
Sum06	-	-	13	-	-
W126	-	-	24.3	-	-
N60	-	-	440	-	-
N80	-	-	6	-	-
N100	-	-	0	-	-

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Ackerman					
	1995	1996	1997	1998	1999
Month 1	-	-	-1.89	-	-
Month 2	-	-	1.82	-	-
Month 3	-	-	1.69	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Ackerman					
	1995	1996	1997	1998	1999
April	2.19	0.97	1.82	-0.05	-1.69
May	-0.15	-2.20	1.69	-1.79	-0.07
June	0.61	-0.49	3.50	-1.37	1.07
July	-0.21	-0.09	-0.79	0.36	-0.54
August	1.22	1.54	1.58	-0.68	-1.36
September	-0.34	0.73	0.10	-1.64	0.72
October	1.08	-0.60	2.04	-1.61	-0.58

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- Since only one year of ozone monitoring data is available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. In the single year of data, the Sum06 threshold is satisfied while the W126 is not.
- The N-values show only six hours in which concentrations exceeded 80 ppb and no hours at 100 ppb. These levels of exposure are not likely to injure vegetation.

- No assessment of the relationship between the levels of ozone exposure and soil moisture can be conducted since only one year of ozone data is available.

From the single year of ozone data, the risk of foliar ozone injury to plants at Ackerman, Choctaw County appears to be low. Hourly concentrations of ozone rarely exceed 80 ppb and do not reach 100 ppb. Additional ozone data should be examined to assess whether the single year of data is representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Tupelo, Lee County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less

weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Tupelo, Lee County					
	1995	1996	1997	1998	1999
Sum06	-	-	-	28	38
W126	-	-	-	-	52.7
N60	-	-	-	-	928
N80	-	-	-	-	198
N100	-	-	-	-	12

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Tupelo					
	1995	1996	1997	1998	1999
Month 1	-	-	-	1.81	-2.72
Month 2	-	-	-	1.93	-2.73
Month 3	-	-	-	-2.15	-1.31

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Tupelo					
	1995	1996	1997	1998	1999
April	0.68	0.78	-0.42	1.56	0.07
May	-1.16	-1.73	3.32	-0.82	-0.38
June	0.65	1.29	6.49	-2.13	2.68
July	0.86	1.57	0.13	1.81	-0.83
August	2.67	1.26	1.25	1.93	-2.72
September	-0.86	2.28	0.17	-2.15	-2.73
October	0.46	0.96	1.18	-0.67	-1.31

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- Since limited ozone monitoring data are available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. Two years of data are available for the Sum06 index, and the threshold is exceeded in both years. One year of data is available for the Sum06 index, and both the cumulative and N100 criteria are exceeded.

- The N-values for the year show concentrations of 60, 80, and 100 ppb are all elevated and there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- No assessment of the relationship between the levels of ozone exposure and soil moisture can be conducted since only one year of ozone data is available. In that year, there were two months of mild drought.

From the single year of ozone data, the risk of foliar injury to plants at Tupelo, Lee County appears to be high. Hourly concentrations of ozone frequently exceed 80 ppb, and there are a significant number of hours above 100 ppb. Additional ozone data should be examined to assess whether the data are representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, and black cherry.

TENNESSEE

SHILOH NATIONAL MILITARY PARK (SHIL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SHIL					
	1995	1996	1997	1998	1999
Sum06	6	6	7	8	14
W126	34.7	36.1	32.7	48.8	62.2
N60	619	648	604	887	1103
N80	94	81	69	158	262
N100	9	6	4	19	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SHIL					
	1995	1996	1997	1998	1999
Month 1	-2.06	0.49	-1.50	-0.93	-1.23
Month 2	-0.95	3.03	0.61	-2.50	-2.01
Month 3	-0.25	-0.02	1.74	-0.88	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SHIL					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation; in one year it just met the threshold and in another it was slightly above. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and the W126 criteria were satisfied in two the five years of data presented.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours at all three levels were significantly lower. In high exposure years, the levels of ozone could injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because ozone exposure was relatively similar in all five years. Soil moisture levels during the year with the highest exposure, 1999, show three months of mild to moderate drought. There were only three months of drought in the remaining four years and no associations between the Sum06 index of exposure and soil moisture were apparent. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five and one month, respectively. In the remaining three years, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997, the lowest exposure year.

The risk of foliar ozone injury at Shiloh National Military Park is high. The Sum06 and

W126 thresholds for injury are satisfied intermittently. The N-values indicate that exposures to 80 to 100 ppb vary considerably among years, and in some years exposure to 100 ppb is significant. In the highest exposure years, low soil moisture levels reduce the uptake of ozone, however exposure thresholds are also satisfied in years with more normal soil moisture conditions. It is anticipated that the risk of foliar injury developing may be greatest during years such as 1995, 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry and American elder.

Busby, Lawrence County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Busby, Lawrence County					
	1995	1996	1997	1998	1999
Sum06	-	-	22	30	52
W126	-	-	28.5	41.6	77.8
N60	-	-	526	769	1350
N80	-	-	35	118	404
N100	-	-	0	9	36

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Busby					
	1995	1996	1997	1998	1999
Month 1	-	-	-1.50	-0.93	-1.23
Month 2	-	-	0.61	-2.50	-2.01
Month 3	-	-	1.74	-0.88	-1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Busby					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- Since only three years of ozone monitoring data are available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. The Sum06 index significantly exceeds the threshold for foliar injury. While the W126 accumulative values exceed the threshold each year, the N100 count shows that the required number of hours is met in two of the three years. The criteria for injury under the W126 exposure index are generally satisfied.

- The N-values for the three years show concentrations of 60, 80, and 100 ppb are elevated in two years, and significantly lower in the remaining year. The high levels of exposure may injure vegetation.

- Although data are limited, soil moisture levels during the 90-day Sum06 accumulation periods and the seasonal W126 accumulation period appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest ozone exposure value, 1999, had the four months of mild and moderate drought, while the remaining two years had lower levels of exposure and one month of drought each.

From the ozone data available, the risk of foliar injury to plants at Busby, Lawrence County appears to be moderate. In two years, hourly concentrations of ozone frequently exceed 80 ppb, and there are a significant number of hours above 100 ppb. Low levels of soil moisture constrain the uptake of ozone in the highest exposure year, 1999, and reduce the likelihood of foliar injury occurring, but the level of exposure and soil moisture conditions are favorable for injury in 1998, the second highest year. Exposures in the remaining year are significantly lower. Additional ozone data should be examined to assess whether these data are representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Fairview, Williamson County

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for Fairview, Williamson County					
	1995	1996	1997	1998	1999
Sum06	18	7	-	-	-
W126	31.3	26.5	-	-	-
N60	568	480	-	-	-
N80	60	33	-	-	-
N100	3	2	-	-	-

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at Fairview					
	1995	1996	1997	1998	1999
Month 1	0.98	1.09	-	-	-
Month 2	0.14	2.72	-	-	-
Month 3	0.59	1.59	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at Fairview					
	1995	1996	1997	1998	1999
April	-0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- Since only two years of ozone monitoring data are available, it is difficult to draw conclusions regarding the ozone exposure regime at the site. The Sum06 index exceeds the threshold for injury to vegetation in one of the two years. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- No assessment of the relationship between the levels of ozone exposure and soil moisture can be conducted since only two years of ozone data are available. However, there were no months of drought stress in the two years examined.

From the ozone data available, the risk of foliar injury to plants at Fairview, Williamson County appears to be low. Hourly concentrations of ozone frequently exceed 60 ppb, but exceed 80 ppb only occasionally. Exposures exceed 100 ppb no more than three hours in any year. Additional ozone data should be examined to assess whether these data are representative of the exposure regime at the site and to determine whether the preliminary risk assessment is accurate.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, and black cherry.

Stones River National Battlefield (STRI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for STRI					
	1995	1996	1997	1998	1999
Sum06	24	25	21	25	27
W126	31.9	34.8	36.7	41.0	54.2
N60	590	650	680	744	969
N80	92	101	118	128	211
N100	12	11	14	17	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at STRI					
	1995	1996	1997	1998	1999
Month 1	0.98	0.49	-1.50	3.31	1.61
Month 2	0.14	3.03	0.61	-0.93	-1.23
Month 3	0.59	-0.02	1.74	-2.50	-2.01

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at STRI					
	1995	1996	1997	1998	1999
April	0.25	0.80	-0.80	3.42	-1.35
May	2.39	0.31	1.51	0.15	-0.35
June	0.98	0.49	4.61	5.86	1.61
July	0.14	3.03	-1.50	3.31	-1.23
August	0.59	-0.02	0.61	-0.93	-2.01
September	0.96	4.20	1.74	-2.50	-1.97
October	2.81	1.09	0.43	-0.88	-0.87

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods and soil moisture are difficult to assess because ozone exposure was relatively similar in all five years. However, soil moisture levels associated with the Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Soil moisture levels during the year with the highest Sum06 value, 1999, show three months of mild to moderate levels of drought. There were only two months of drought in the remaining four years. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1998 and 1999, soil moisture conditions were at mild and moderate drought levels for five months and one month, respectively. In the three years when ozone exposures were lower, soil moisture conditions were favorable for the uptake of ozone with only one month of mild drought in 1997.

The risk of foliar ozone injury to plants at Stones River National Battlefield is high. While the levels of ozone exposure consistently create the potential for injury, dry soil

conditions may reduce the likelihood of injury developing in the highest exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995, 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, American sycamore, black cherry and American elder.

NORTHEAST COASTAL AND BARRIER ISLAND NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHEAST COASTAL AND BARRIER ISLAND NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHEAST COAST AND BARRIER ISLAND NETWORK

Park	Code	State	Risk	O3 Data
Assateague Island NS	ASIS	MD	high	kriged
Cape Cod NS	CACO	MA	high	monitored
Colonial NHP	COLO	VA	high	kriged
Fire Island NS	FIIS	NY	high	kriged
Gateway NRA	GATE	NY	high	kriged
Geo Washington Birthplace NM	GEWA	VA	high	kriged
Sagamore Hill NHS	SAHI	NY	high	kriged
Thomas Stone NHS	THST	MD	high	kriged

ASSATEAGUE ISLAND NATIONAL SEASHORE (ASIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ASIS					
	1995	1996	1997	1998	1999
Sum06	31	31	38	36	38
W126	37.5	33.8	48.9	52.9	50.1
N60	632	595	790	868	802
N80	149	109	222	241	236
N100	28	9	38	45	42

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ASIS					
	1995	1996	1997	1998	1999
Month 1	0.38	1.63	-0.88	0.91	-2.09
Month 2	-2.75	4.18	0.35	2.10	-1.61
Month 3	-3.87	0.37	-1.77	-2.07	-1.00

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ASIS					
	1995	1996	1997	1998	1999
April	-0.11	1.17	0.21	-0.52	-0.23
May	0.78	1.46	-0.78	0.91	-2.20
June	0.38	1.63	-0.88	2.10	-2.09
July	-2.75	4.18	0.35	-2.07	-1.61
August	-3.87	0.37	-1.77	-2.03	-1.00
September	-1.21	3.26	-2.74	-3.06	4.64
October	0.69	1.59	0.38	-2.86	1.90

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. In the two years with the highest exposures, there were three months of mild and moderate drought in 1999

and one month of mild drought in 1997. In the mid-level exposure year 1998 there was one month of moderate drought. In the two years with the same, lowest exposure, there were two months of moderate and severe drought in 1995 and normal soil moisture conditions in 1996. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two highest ozone years, 1998 and 1999, each had four months of drought ranging from mild to severe. The mid-level exposure year 1997 had two months of mild and moderate drought. In the second lowest ozone year, 1996, there were three months of mild to severe drought, and soil moisture conditions were favorable during 1996, the lowest exposure year.

The risk of foliar ozone injury at Assateague Island National Seashore is high. The Sum06 and W126 threshold criteria are both satisfied, and the hours of exposure to 80 and 100 ppb ozone are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are reduced but still exceed the thresholds and soil moisture levels are normal, or in years such as 1997 when exposures are high and periods of drought occur late in the growing season.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, yellow-poplar, American sycamore, black cherry, skunkbush, American elder and crownbeard.

CAPE COD NATIONAL SEASHORE (CACO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CACO					
	1995	1996	1997	1998	1999
Sum06	20	17	25	17	23
W126	34.8	33.6	40.4	34.8	34.5
N60	518	510	638	586	480
N80	142	105	193	77	168
N100	52	30	47	6	42

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CACO					
	1995	1996	1997	1998	1999
Month 1	-0.41	-0.43	-1.75	6.79	0.13
Month 2	-0.70	-1.56	-1.04	-0.18	-3.30
Month 3	-2.61	2.18	0.19	0.48	-0.73

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CACO					
	1995	1996	1997	1998	1999
April	-1.80	1.88	2.21	0.31	-3.25
May	-0.46	-0.43	-0.23	0.90	0.13
June	-0.41	-1.56	-1.75	6.79	-3.30
July	-0.70	2.18	-1.04	-0.18	-0.73
August	-2.61	-0.20	0.19	0.48	-1.85
September	-0.80	5.52	-2.36	-1.29	2.54
October	1.54	8.00	-2.07	1.39	2.55

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. Both the Sum06 and W126 indices exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and demonstrate that there are a significant numbers of hours during which plants are exposed to potentially harmful levels of ozone.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 exposure, 1997, had two months of mild drought. The two mid-level exposure years 1999 and 1995 had one month of severe and one month of moderate drought, respectively. The two lowest exposure years had one month of mild drought

between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but the pattern is again inconsistent. In the highest ozone year, 1997, there were four months of mild and moderate drought. The three mid-ozone years, 1995, 1998 and 1999, had two, one and three months, respectively, of mild to severe drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Cape Cod National Seashore is high. Exposure criteria for both the Sum06 and W126 are satisfied, and there are a significant number of hours of exposure to 80 and 100 ppb. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions may reduce the likelihood of injury developing in the highest exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as1996 and 1998 in which ozone levels exceed the thresholds, and soil moisture levels are normal or under mild or short-term drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, quaking aspen, black cherry, and northern fox grape.

COLONIAL NATIONAL HISTORICAL PARK (COLO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

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W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for COLO					
	1995	1996	1997	1998	1999
Sum06	25	23	36	36	34
W126	32.8	28.2	45.4	48.1	42.8
N60	573	498	763	830	699
N80	91	60	184	180	183
N100	8	2	24	23	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at COLO					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at COLO					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant numbers of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations:

when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. When the Sum06 exposure index was the highest in 1997 and 1998, there were two months and one month of mild and moderate drought, respectively. Mid-ozone years had one and two months of drought stress. Soil moisture was normal in 1996, the year with the lowest index of exposure. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. When the W126 exposure was the highest in 1998, 1997 and 1999, there were, respectively, four, four and two months of mild and moderate drought. In 1996 when exposure was the lowest, soil moisture was normal, and in the second lowest exposure year, 1995, there were three months of mild and severe drought.

The risk of foliar ozone injury to plants at Colonial National Historic Park is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high in most years. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1999 when ozone levels are high, and months of drought do not impose extended constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, American elder, crownbeard and northern fox grape.

FIRE ISLAND NATIONAL SEASHORE (FIIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FIIS					
	1995	1996	1997	1998	1999
Sum06	17	14	21	19	22
W126	24.2	20.7	26.5	29.7	28.4
N60	355	312	379	460	410
N80	108	76	132	127	135
N100	37	15	42	21	39

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FIIS					
	1995	1996	1997	1998	1999
Month 1	-0.96	0.69	-0.94	2.97	-3.06
Month 2	-0.06	3.25	1.24	-2.18	-3.96
Month 3	-3.62	-0.39	0.68	-1.97	-0.94

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FIIS					
	1995	1996	1997	1998	1999
April	-1.74	2.18	0.21	1.84	-2.31
May	-0.61	-0.62	-0.40	1.69	-0.26
June	-0.96	0.69	-0.94	2.97	-3.06
July	-0.06	3.25	1.24	-2.18	-3.96
August	-3.62	-0.39	0.68	-1.97	-0.94
September	-0.12	1.71	-1.66	-1.45	2.84
October	1.76	4.81	-1.20	-1.57	0.46

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant numbers of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations:

when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 exposure index, 1999, had two months of severe drought, however the year with the second highest exposure, 1997, had normal conditions. As exposure decreased in the remaining years, so did the incidence of drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and three months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, each had two months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Fire Island National Seashore is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are high, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, American sycamore, quaking aspen, black cherry, American elder and northern fox grape.

GATEWAY NATIONAL RECREATION AREA (GATE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GATE					
	1995	1996	1997	1998	1999
Sum06	15	12	17	15	18
W126	26.2	22.1	26.4	28.4	29.8
N60	386	344	390	451	450
N80	136	92	131	135	143
N100	40	15	33	19	46

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GATE					
	1995	1996	1997	1998	1999
Month 1	-0.61	0.69	-0.94	2.97	-3.06
Month 2	-0.96	3.25	1.24	-2.18	-3.96
Month 3	-0.06	-0.39	0.68	-1.97	-0.94

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GATE					
	1995	1996	1997	1998	1999
April	-1.74	2.18	0.21	1.84	-2.31
May	-0.61	-0.62	-0.40	1.69	-0.26
June	-0.96	0.69	-0.94	2.97	-3.06
July	-0.06	3.25	1.24	-2.18	-3.96
August	-3.62	-0.39	0.68	-1.97	-0.94
September	-0.12	1.71	-1.66	-1.45	2.84
October	1.76	4.81	-1.20	-1.57	0.46

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- There does not appear to be any association between the 90-day Sum06 index of

ozone exposure and soil moisture status. The uniform Sum06 indices of exposure and limited distribution of drought over the five-year period make it difficult to assess relationships. A year with the highest Sum06 index, 1999, and a year with a mid-level exposure, 1998, each had two months of mild to severe drought stress. The remaining three years had normal levels of soil moisture. Although the high and uniform levels of ozone also make it difficult to assess relationships for W126 ozone exposures, soil moisture levels appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. In the highest ozone years, 1999 and 1998, there were three and four months, respectively, of mild to severe drought. The two mid-ozone years, 1995 and 1997, had the same level of exposure and each had two months of mild and severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Gateway National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, American elder, common snowberry and northern fox grape.

GEORGE WASHINGTON BIRTHPLACE NATIONAL MONUMENT (GEWA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GEWA					
	1995	1996	1997	1998	1999
Sum06	24	27	31	38	39
W126	35.9	31.3	41.5	49.6	48.1
N60	622	566	693	821	786
N80	138	92	172	225	237
N100	21	4	24	40	38

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GEWA					
	1995	1996	1997	1998	1999
Month 1	0.63	1.68	-1.25	-2.05	-1.18
Month 2	0.65	4.40	0.98	-2.06	-0.87
Month 3	-1.60	1.67	-2.69	-1.42	-0.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GEWA					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year while the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in four years. The criteria for injury under the W126 exposure index are generally satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is

high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest ozone exposure values, 1999 and 1998, had, respectively, one and three months of mild and moderate drought. There were two months of mild and moderate drought in 1997, the year with mid-level ozone exposure. The two lowest ozone years had one month of mild drought between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The three years with the highest ozone exposures, 1998, 1999 and 1997, experienced four, two, and four months of mild and moderate drought, respectively. The year with the second lowest index, 1995, had three months of mild and severe drought, while the year with the lowest exposure had normal soil moisture conditions.

The risk of foliar ozone injury to plants at George Washington Birthplace National Monument is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high in most years. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1999 when ozone levels are high, and months of drought do not impose extended constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, yellow-poplar, American sycamore, black cherry, American elder, crownbeard and northern fox grape.

SAGAMORE HILL NATIONAL HISTORIC SITE (SAHI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAHI					
	1995	1996	1997	1998	1999
Sum06	16	13	19	16	20
W126	23.2	19.3	24.3	25.8	26.2
N60	340	296	352	406	386
N80	115	75	120	111	123
N100	33	15	34	17	39

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAHI					
	1995	1996	1997	1998	1999
Month 1	-0.96	0.69	-0.94	2.97	-3.06
Month 2	-0.06	3.25	1.24	-2.18	-3.96
Month 3	-3.62	-0.39	0.68	-1.97	-0.94

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAHI					
	1995	1996	1997	1998	1999
April	-1.74	2.18	0.21	1.84	-2.31
May	-0.61	-0.62	-0.40	1.69	-0.26
June	-0.96	0.69	-0.94	2.97	-3.06
July	-0.06	3.25	1.24	-2.18	-3.96
August	-3.62	-0.39	0.68	-1.97	-0.94
September	-0.12	1.71	-1.66	-1.45	2.84
October	1.76	4.81	-1.20	-1.57	0.46

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two years with the highest ozone were marked by two months of severe drought in 1999 and normal soil moisture conditions in 1997. The mid-ozone years had one and two months of drought, and soil moisture conditions were favorable in 1996 the year with the lowest ozone

exposure. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations. In the highest ozone years, 1999 and 1998, there were three and four months, respectively, of mild to severe drought. The two mid-ozone years, 1997 and 1995, each had two months of mild and severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Sagamore Hill National Historic Site is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, yellow-poplar, black cherry and American elder.

THOMAS STONE NATIONAL HISTORIC SITE (THST)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for THST					
	1995	1996	1997	1998	1999
Sum06	25	26	28	37	38
W126	36.0	30.5	37.6	47.2	46.2
N60	610	549	627	769	751
N80	153	96	154	225	230
N100	29	5	23	44	37

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at THST					
	1995	1996	1997	1998	1999
Month 1	-0.49	0.42	0.39	-2.53	-1.66
Month 2	-3.22	2.85	-0.80	-2.62	-2.86
Month 3	-1.37	0.14	0.14	-3.36	1.11

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at THST					
	1995	1996	1997	1998	1999
April	-0.63	-1.06	0.02	-0.21	-0.24
May	-0.01	1.35	-1.97	0.06	-3.07
June	0.96	0.42	0.39	3.74	-1.66
July	-0.49	2.85	-0.80	-2.53	-2.86
August	-3.22	0.14	0.14	-2.62	1.11
September	-1.37	0.95	-1.38	-3.36	6.57
October	4.49	2.32	-0.57	-2.56	1.17

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two years with the highest ozone, 1999 and 1998, experienced two and three months of mild and severe, respectively. Soil moisture conditions for the two intermediate ozone years were favorable. The lowest ozone year, 1995, had two months of mild and severe drought. Soil moisture

levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1998 and 1999, there were four and three months, respectively, of mild to severe drought. The two mid-ozone years, 1997 and 1995, each had two months of mild and severe drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Thomas Stone National Historic Site is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, American elder, crownbeard and northern fox grape.

NORTH COAST AND CASCADES NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTH COAST AND CASCADES NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTH COAST AND CASCADES NETWORK

Park	Code	State	Risk	O3 Data
Ebey's Landing NH Reserve	EBLA	WA	low	kriged
Fort Clatsop NM	FOCL	OR	low	kriged
Fort Vancouver NHS	FOVA	WA	low	kriged
Mount Rainier NP	MORA	WA	low	monitored
North Cascades NP	NOCA	WA	low	monitored
Olympic NP	OLYM	WA	low	monitored
San Juan Island NHP	SAJH	WA	low	kriged

EBEY'S LANDING NATIONAL HISTORICAL RESERVE (EBLA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for EBLA					
	1995	1996	1997	1998	1999
Sum06	2	3	1	2	1
W126	3.8	4.3	2.7	3.1	2.5
N60	44	53	21	36	24
N80	3	8	1	8	2
N100	0	1	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at EBLA					
	1995	1996	1997	1998	1999
Month 1	-1.35	-0.87	1.25	-1.10	-0.27
Month 2	-1.81	0.33	2.30	2.19	2.88
Month 3	0.34	-0.69	2.05	0.40	1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at EBLA					
	1995	1996	1997	1998	1999
April	0.02	2.60	0.87	-1.10	-0.27
May	-1.35	2.70	1.25	2.19	2.88
June	-1.81	-0.87	2.30	0.40	1.97
July	0.34	0.33	2.05	1.63	2.44
August	3.74	-0.69	0.24	-1.85	1.73
September	-1.62	2.57	1.55	-2.60	-2.20
October	2.02	2.94	4.43	-0.80	0.73

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. Since the W126 accumulative value is below the threshold and the N100 count is below the required number, the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show occasional concentrations above 60 ppb and only a few hours each year in which concentrations exceeded 80 ppb. Concentrations rarely exceeded 100 ppb. These levels of exposure are unlikely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The low levels of ozone at the site make it difficult to assess relationships between ozone exposure and soil moisture, however no patterns are evident. Years with the highest and lowest W126 exposures, 1996 and 1997 respectively, both had normal soil moisture conditions throughout. The three remaining years had two or three months of mild or moderate drought.

The low levels of ozone exposure at Ebey's Landing National Historic Site make the risk of foliar ozone injury to plants low. While there are no relationships between exposure and drought, scattered months of drought reduce the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, Scouler's willow and common snowberry.

FORT CLATSOP NATIONAL MEMORIAL (FOCL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Physocarpus capitatus	Ninebark	Rosaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

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Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOCL					
	1995	1996	1997	1998	1999
Sum06	2	4	2	5	2
W126	5.4	8.9	3.9	5.5	4.0
N60	73	124	35	70	45
N80	10	34	2	15	3
N100	2	7	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

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Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOCL					
	1995	1996	1997	1998	1999
Month 1	-0.90	-0.07	0.63	-0.41	-1.34
Month 2	1.39	-1.23	-0.84	-0.95	2.18
Month 3	-0.29	0.27	0.64	-1.76	-0.21

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOCL					
	1995	1996	1997	1998	1999
April	1.68	4.33	0.63	-1.22	-1.34
May	-0.90	2.39	-0.84	2.37	2.18
June	1.39	-1.21	0.64	-0.41	-0.21
July	-0.29	-0.07	0.71	-0.95	-0.10
August	0.22	-1.23	1.31	-1.76	0.13
September	0.15	0.27	4.22	-1.96	-2.35
October	-0.68	1.24	2.76	-0.57	-1.22

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. The W126 accumulative value is generally below the threshold and the N100 count generally is below the required number. Thus the criteria for injury under the W126 exposure index are not satisfied. Collectively, the Sum06 and W126 indices are below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceed 60 ppb and rarely are greater than 80 ppb. In one year the concentration exceeded 100 ppb for seven hours while in two years it did not reach 100 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The low and similar levels of ozone at the site make it difficult to assess relationships. In the Sum06 assessments there was one month of mild drought in three of the five years, however no associations with exposure are evident. The year with the highest W126 exposure, 1996, had two months of mild drought. Two years with same second highest exposure, 1995 and 1998, had normal soil moisture and three

months of mild drought, respectively. The two years with the lowest exposures had normal soil moisture and three years of mild and moderate drought. There is no apparent relationship between the W126 index of ozone exposure and soil moisture.

The low levels of ozone exposure at Fort Clatsop National Memorial make the risk of foliar ozone injury to plants low. While there are no relationships between exposure and soil moisture, months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, ninebark and common snowberry.

FORT VANCOUVER NATIONAL HISTORIC SITE (FOVA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOVA					
	1995	1996	1997	1998	1999
Sum06	3	7	3	6	3
W126	5.4	9.7	3.8	6.0	3.6
N60	71	134	38	84	40
N80	12	43	2	19	3
N100	3	11	0	4	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOVA					
	1995	1996	1997	1998	1999
Month 1	-1.91	-1.36	0.65	-1.10	1.37
Month 2	-0.73	-0.46	2.15	-2.32	0.98
Month 3	0.08	-1.13	2.71	-2.67	1.28

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOVA					
	1995	1996	1997	1998	1999
April	-0.41	3.99	2.19	-2.53	-2.18
May	-1.91	3.07	0.65	1.36	1.37
June	-0.73	-1.36	2.15	-0.56	0.98
July	0.08	-0.46	2.71	-1.10	1.28
August	1.32	-1.13	0.90	-2.32	0.72
September	-0.80	0.44	2.80	-2.67	-2.12
October	1.97	2.80	4.77	-1.28	-0.27

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. The W126 accumulative value is generally below the threshold as is the N100 count, thus the W126 criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. One year had 11 hours in which the concentration exceeded 100 ppb, but there were two years in which there were no concentrations above 100 ppb. These levels of exposure are unlikely to injure vegetation.

- The low levels of ozone at the site make it difficult to assess relationships between ozone exposure and soil moisture. It does appear, however, that soil moisture levels during the 90-day Sum06 accumulation periods are inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest ozone exposure values, 1996 and 1998, had two and three months, respectively, of mild and moderate drought. There was only one month of mild drought among the three years with lower

levels of ozone. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, although the relationship is not consistent. In the highest ozone year, 1996, there were two months of mild and moderate drought. The two mid-ozone years, 1998 and 1995, had five and one month of mild drought, respectively. The two lowest ozone years, 1999 and 1997, experienced two months of moderate drought and normal soil moisture conditions.

The low levels of ozone exposure at Fort Vancouver National Historic Site make the risk of foliar ozone injury to plants low. Some years have several months of drought that constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, ponderosa pine, Scouler's willow and common snowberry.

MOUNT RAINIER NATIONAL PARK (MORA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix couleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MORA					
	1995	1996	1997	1998	1999
Sum06	4	6	0	1	3
W126	5.4	5.2	0.5	0.9	5.1
N60	76	82	0	10	69
N80	6	6	0	0	4
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MORA					
	1995	1996	1997	1998	1999
Month 1	-2.02	-1.75	-	-1.39	1.49
Month 2	-0.62	-0.06	-	-2.42	-0.51
Month 3	0.40	-1.16	-	-2.97	0.49

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MORA					
	1995	1996	1997	1998	1999
April	-0.43	4.88	1.92	-2.76	-2.79
May	-2.02	2.47	-0.50	0.38	1.49
June	-0.62	-1.75	1.27	-1.23	-0.51
July	0.40	-0.06	2.03	-1.39	0.49
August	0.71	-1.16	0.08	-2.42	-0.28
September	-0.72	0.27	3.14	-2.97	-2.47
October	1.68	2.08	3.28	-0.44	-0.02

Risk Analysis

- There are several ozone-sensitive species at the site some of which are bioindicators.

- The Sum06 index is below the threshold for injury. Since the W126 accumulative value did not exceed the threshold level and there were no hourly concentrations above 100 ppb, the W126 threshold criteria are not satisfied. Both the Sum06 and W126 indices are below the levels considered necessary for injury to vegetation.

- The N-values for the site show no years in which concentrations reached 100 ppb, and only a few hours in which concentrations exceeded 80 ppb. These levels of exposure are unlikely to injure vegetation.

- The low levels of ozone at the site make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident.

The low levels of ozone exposure at Mount Rainier National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 exposure indices satisfy their thresholds, and there are only a few hours of exposure over 80 ppb and no hours over 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, spreading dogbane, ninebark, ponderosa pine, quaking aspen, Scouler's willow, and common snowberry.

NORTH CASCADES NATIONAL PARK (NOCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NOCA					
	1995	1996	1997	1998	1999
Sum06	-	1	0	0	0
W126	-	2.1	0.4	0.8	1.9
N60	-	16	0	0	5
N80	-	0	0	0	0
N100	-	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NOCA					
	1995	1996	1997	1998	1999
Month 1	-	2.47	-	-	-
Month 2	-	-1.75	-	-	-
Month 3	-	-0.06	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NOCA					
	1995	1996	1997	1998	1999
April	-0.43	4.88	1.92	-2.76	-2.79
May	-2.02	2.47	-0.50	0.38	1.49
June	-0.62	-1.75	1.27	-1.23	-0.51
July	0.40	-0.06	2.03	-1.39	0.49
August	0.71	-1.16	0.08	-2.42	-0.28
September	-0.72	0.27	3.14	-2.97	-2.47
October	1.68	2.08	3.28	-0.44	-0.02

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. Since the W126 accumulative value did not exceed the threshold level and there were no hourly concentrations above 100 ppb, the W126 threshold criteria are not satisfied. Both the Sum06 and W126 indices are below the levels considered necessary for injury to vegetation.
- The N-values for the site show no years in which concentrations reached either 80 or 100 ppb, and only two years in which concentrations exceeded 60 ppb. These levels of exposure are unlikely to injure vegetation.
- The low levels of ozone at the site make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident.

The low levels of ozone exposure at North Cascades National Park make the risk of ozone injury to plants low. Neither the Sum06 nor the W126 exposure indices satisfy their thresholds, and there are no hours of exposure over 80 ppb and 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator

species: red alder, spreading dogbane, mugwort, ninebark, ponderosa pine, quaking aspen, cut-leaf coneflower, Scouler's willow, common snowberry, and huckleberry.

OLYMPIC NATIONAL PARK (OLYM)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Physocarpus capitatus	Ninebark	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for OLYM					
	1995	1996	1997	1998	1999
Sum06	1	0	0	0	0
W126	1.9	1.1	1.1	1.1	1.1
N60	12	0	0	5	0
N80	0	0	0	0	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at OLYM					
	1995	1996	1997	1998	1999
Month 1	0.16	-	-	-	-
Month 2	-2.10	-	-	-	-
Month 3	-0.63	-	-	-	-

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at OLYM					
	1995	1996	1997	1998	1999
April	0.16	4.92	1.81	-2.51	-1.85
May	-2.10	0.83	1.24	-0.62	0.78
June	-0.63	-0.95	3.01	-1.14	0.61
July	-0.50	-0.87	1.34	-0.27	-0.21
August	1.65	-1.04	1.51	-2.27	0.12
September	-0.54	-0.40	4.97	-3.08	-2.48
October	1.38	2.59	2.91	-0.71	0.40

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. Since the W126 accumulative value did not exceed the threshold level and there were no hourly concentrations above 100 ppb, the W126 threshold criteria are not satisfied. Both the Sum06 and W126 indices are below the levels considered necessary for injury to vegetation.
- The N-values for the site show no years in which concentrations reached either 80 or 100 ppb, and only two years in which concentrations exceeded 60 ppb. These levels of exposure are unlikely to injure vegetation.
- The low levels of ozone at the site make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident.

The low levels of ozone exposure at Olympic National Park make the risk of ozone injury to plants low. Neither the Sum06 nor the W126 exposure indices satisfy their thresholds, and there are no hours of exposure over 80 ppb and100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, ninebark, quaking aspen, and Scouler's willow.

SAN JUAN ISLAND NATIONAL HISTORICAL PARK (SAJH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAJH					
	1995	1996	1997	1998	1999
Sum06	2	2	1	2	1
W126	3.5	3.6	2.5	2.7	2.1
N60	36	40	17	28	16
N80	2	5	1	5	1
N100	0	1	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAJH					
	1995	1996	1997	1998	1999
Month 1	0.02	-0.87	0.87	-1.10	-0.27
Month 2	-1.35	0.33	1.25	2.19	2.88
Month 3	-1.81	-0.69	2.30	0.40	1.97

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAJH					
	1995	1996	1997	1998	1999
April	0.02	2.60	0.87	-1.10	-0.27
May	-1.35	2.70	1.25	2.19	2.88
June	-1.81	-0.87	2.30	0.40	1.97
July	0.34	0.33	2.05	1.63	2.44
August	3.74	-0.69	0.24	-1.85	1.73
September	-1.62	2.57	1.55	-2.60	-2.20
October	2.02	2.94	4.43	-0.80	0.73

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. Since the W126 accumulative value did not exceed the threshold level and the number of hourly concentrations above 100 ppb did not meet the requirement, the W126 threshold criteria are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations rarely exceed 80 ppb. Ozone exceeded 100 ppb for one hour in each of two years. These levels of exposure are unlikely to injure vegetation.

- The low and consistent exposure indices and the limited occurrence of drought make it difficult to assess relationships between ozone exposure and soil moisture. However, there appear to be no associations between either the Sum06 or the W126 index of exposure and soil moisture conditions. There were only three months of drought over the five-year Sum06 assessment period, and their occurrence was unrelated to the level of exposure. The year with the highest W126 exposure, 1996, had normal soil moisture, while the second highest year, 1995, had three months of mild drought. There was one month of moderate

drought in 1999, the lowest ozone exposure year. The two mid-ozone years had normal soil moisture and three months of mild and moderate drought. Overall, there is no association between exposure and soil moisture.

The low levels of ozone exposure at San Juan Island National Historic Park make the risk of foliar ozone injury to plants low. While there is no association between exposure and soil moisture, months of mild and moderate drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, quaking aspen, Scouler's willow and common snowberry.

NORTHERN COLORADO PLATEAU NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHERN COLORADO PLATEAU NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on

the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher

concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHERN COLORADO PLATEAU NETWORK

Park	Code	State	Risk	O3 Data
Arches NP	ARCH	UT	low	kriged
Black Canyon of the Gunnison NM	BLCA	CO	low	kriged
Bryce Canyon NP	BRCA	UT	low	kriged
Canyonlands NP	CANY	UT	low	monitored
Capitol Reef NP	CARE	UT	low	kriged
Cedar Breaks NM	CEBR	UT	low	kriged
Colorado NM	COLM	CO	low	kriged
Curecanti NRA	CURE	CO	low	kriged
Dinosaur NM	DINO	CO	low	kriged
Fossil Butte NM	FOBU	WY	moderate	kriged
Golden Spike NHS	GOSP	UT	moderate	kriged
Hovenweep NM	HOVE	CO	low	kriged
Natural Bridges NM	NABR	UT	low	kriged
Pipe Spring NM	PISP	AZ	low	kriged
Timpanogos Cave NM	TICA	UT	moderate	kriged
Zion NP	ZION	UT	low	kriged

ARCHES NATIONAL PARK (ARCH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ARCH					
	1995	1996	1997	1998	1999
Sum06	6	16	14	27	26
W126	24.6	44.3	27.9	47.9	38.0
N60	230	846	353	919	665
N80	10	17	4	19	15
N100	1	2	0	3	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ARCH					
	1995	1996	1997	1998	1999
Month 1	0.85	1.73	2.06	0.39	-0.01
Month 2	0.62	1.97	1.06	-1.53	0.39
Month 3	-0.69	5.04	0.76	-1.32	-1.53

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ARCH					
	1995	1996	1997	1998	1999
April	1.97	1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There is one ozone-sensitive species listed for the site.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. Conditions during the years with the highest Sum06 indices, 1998 and 1999, showed two and one months of mild drought, respectively, while soil moisture was normal in the three years with lower exposures. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998, and 1996, there were three months of mild and moderate drought and five months of mild to severe drought, respectively. The mid-exposure year 1999 had one month of severe drought. In the two years with the lowest ozone exposures, 1995 and 1997, soil moisture conditions were normal.

The low levels of ozone exposure at Arches National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Since soil moisture conditions of mild to severe drought reduce the effectiveness of the higher exposures, and hourly concentrations of ozone seldom exceeded 80 ppb, it is unlikely that foliar injury will be produced on plants. Only one ozone-sensitive species has been identified at the site, and that species is not sensitive enough to be used as a bioindicator.

BLACK CANYON OF THE GUNNISON NATIONAL PARK (BLCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BLCA					
	1995	1996	1997	1998	1999
Sum06	10	22	14	23	25
W126	22.4	33.3	23.8	38.8	33.7
N60	236	538	340	732	571
N80	8	20	5	23	17
N100	1	0	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BLCA					
	1995	1996	1997	1998	1999
Month 1	1.39	-0.58	-1.98	-1.94	-3.76
Month 2	1.56	-0.39	2.93	0.30	3.13
Month 3	5.61	-1.24	1.98	1.69	1.46

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BLCA					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb, and most had no hours at that concentration. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture. During the annual Sum06 accumulation periods, soil moisture conditions were generally normal with one month of drought during four of the five years of assessment. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, when ozone is high, soil moisture is low, although the pattern is not fully consistent. This relationship reduces the uptake of ozone and the effectiveness of the high exposures in producing foliar injury. The highest exposure year, 1998, had three months of mild drought. The two years with the same mid-level exposure, 1996 and 1999, experienced three months of mild and moderate drought and one month of moderate drought, respectively. The second lowest exposure year, 1997, had normal soil moisture, and the lowest exposure year, 1995, had one month of mild drought.

The risk of foliar ozone injury to plants at Black Canyon of the Gunnison is low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceeded 80 ppb, and rarely reach 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in higher exposure years and further reduces the likelihood

of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine and quaking aspen.

BRYCE CANYON NATIONAL PARK (BRCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BRCA					
	1995	1996	1997	1998	1999
Sum06	10	30	18	25	28
W126	28.4	38.0	26.0	41.5	39.7
N60	406	696	429	759	717
N80	14	41	10	34	28
N100	1	1	0	3	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BRCA					
	1995	1996	1997	1998	1999
Month 1	0.85	-1.75	0.76	0.39	2.28
Month 2	0.62	-2.18	1.31	-1.53	-0.77
Month 3	-0.69	-1.90	1.75	-1.32	-0.64

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BRCA					
	1995	1996	1997	1998	1999
April	1.97	-1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There are a few ozone-sensitive species at the site, all of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. In the highest Sum06 exposure year, 1999, there were three months of mild and moderate drought, and the mid-level exposure year, 1998, had two months of mild drought. The remaining three years had normal soil moisture conditions. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, when ozone is high, soil moisture is low, although the pattern is not fully consistent. The highest ozone year, 1998, had three months of mild and moderate drought, while the second highest year, 1999, had one month of severe drought. There were five months of mild to severe drought in the mid-level exposure year 1996, one month of moderate drought in the second lowest exposure year, and normal soil moisture in the lowest exposure year 1997.

The risk of foliar ozone injury at Bryce Canyon National Park is low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Exposures exceed 80 ppb only occasionally, and rarely reach 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in higher exposure years and further reduces the likelihood of foliar

injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen and skunkbush.

CANYONLANDS NATIONAL PARK (CANY)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CANY					
	1995	1996	1997	1998	1999
Sum06	6	16	16	31	29
W126	25.9	49.7	31.9	54.2	42.2
N60	215	985	384	1065	745
N80	6	2	0	0	9
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CANY					
	1995	1996	1997	1998	1999
Month 1	0.85	-1.09	1.06	-1.53	-0.77
Month 2	0.62	-1.75	0.76	-1.32	-0.64
Month 3	-0.69	-2.18	1.31	-0.42	1.39

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CANY					
	1995	1996	1997	1998	1999
April	1.97	-1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show no years in which concentrations reach 100 ppb, and only three years in which concentrations exceed 80 ppb. These levels of exposure are not highly likely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The highest exposure year, 1998, had two months of mild drought and a mid-level exposure year, 1996, had three months of drought; soil moisture was normal in the remaining three years. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two years with the highest ozone exposures, 1998 and 1996, experienced three and five months, respectively, of mild to severe drought stress. The mid-exposure year, 1999, had one month of severe drought, while the two years with the lowest exposures, 1995 and 1997, had one month of moderate drought between them.

The levels of ozone exposure at Canyonlands National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criteria are not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb and do not reach 100 ppb. The inverse relationship between

exposure and soil moisture constrains the uptake of ozone and further reduces the likelihood of injury developing in the higher ozone years.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine and quaking aspen.

CAPITOL REEF NATIONAL PARK (CARE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix gooddingii	Gooding's willow	Salicaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CARE					
	1995	1996	1997	1998	1999
Sum06	10	26	16	26	25
W126	24.4	38.4	24.2	40.8	33.2
N60	292	698	346	736	576
N80	17	38	9	46	24
N100	2	4	1	8	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CARE					
	1995	1996	1997	1998	1999
Month 1	0.85	-1.09	0.76	0.39	2.28
Month 2	0.62	-1.75	1.31	-1.53	-0.77
Month 3	-0.69	-2.18	1.75	-1.32	-0.64

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CARE					
	1995	1996	1997	1998	1999
April	1.97	1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than eight hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two highest Sum06 years, 1996 and 1998, had the same exposure index and experienced three and two months of mild and moderate drought, respectively. The remaining three years with lower exposures had normal soil moisture throughout. The highest W126 exposure occurred in 1998 and was accompanied by three months of mild and moderate drought. There were four months of mild to severe drought in 1996, the year with the second highest exposure. There was one month of severe drought in 1999 the mid-level exposure year, one month of moderate drought in 1995 the second lowest year, and normal soil moisture in 1997 the lowest exposure year.

The low levels of ozone exposure at Capitol Reef National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criteria are not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposure to 100 ppb is rare. The inverse

relationship between exposure and soil moisture constrains the uptake of ozone in higher exposure years and further reduces the likelihood of injury developing.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, white ash, ponderosa pine, quaking aspen, and northern fox grape.

CEDAR BREAKS NATIONAL MONUMENT (CRBR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CEBR					
	1995	1996	1997	1998	1999
Sum06	7	23	13	12	13
W126	26.8	35.5	24.0	39.8	40.0
N60	394	671	410	724	734
N80	14	41	11	36	31
N100	0	1	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CEBR					
	1995	1996	1997	1998	1999
Month 1	2.71	-0.82	2.45	0.49	3.66
Month 2	0.49	-1.97	0.91	3.76	1.28
Month 3	-0.49	-1.26	3.73	4.59	1.67

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CEBR					
	1995	1996	1997	1998	1999
April	2.71	-1.12	1.96	1.52	3.66
May	4.74	-0.82	0.76	0.49	1.28
June	3.82	-1.97	2.45	3.76	1.67
July	2.71	-1.26	0.91	4.59	3.55
August	0.49	-2.86	3.73	0.38	2.24
September	-0.49	0.38	7.21	4.60	0.44
October	-2.23	0.79	0.32	2.94	-2.19

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- During the five-year assessment period for the 90-day cumulative Sum06 index of exposure, there were only two months of mild drought. Although these months occurred the highest ozone year, 1996, it is not possible to find any relationship between ozone exposure and soil moisture since there was no drought in any of the other four years. Overall, soil moisture levels favored the uptake of ozone. There appears to be no relationship between the seasonal W126 index of exposure and the level of soil moisture. In the two years with the highest exposure indices, 1998 and 1999, there was one month of moderate drought between them; there was also one month of drought in the two years, 1995 and 1997, with the lowest

indices. The median exposure year, 1996, experienced four months of mild and moderate drought. Soil moisture levels are unrelated to exposure and are generally favorable, but in some years drought stress can significantly constrain uptake.

The low levels of ozone exposure at Cedar Breaks National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are no apparent relationships between the levels of ozone exposure and soil moisture conditions, and entire growing seasons appear to be characterized by either favorable or unfavorable soil moisture conditions. Single or consecutive months of drought constrain the uptake of ozone and further reduce the probability of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine, quaking aspen, and Scouler's willow.

COLORADO NATIONAL MONUMENT (COLM)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for COLM					
	1995	1996	1997	1998	1999
Sum06	7	17	13	23	21
W126	23.7	38.0	25.0	42.3	34.5
N60	247	667	338	792	591
N80	12	23	6	28	17
N100	1	1	0	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at COLM					
	1995	1996	1997	1998	1999
Month 1	2.25	-0.58	1.98	0.32	3.13
Month 2	0.30	-0.39	1.09	-1.94	1.46
Month 3	1.30	-1.24	0.70	0.30	1.00

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at COLM					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb, and most had only one. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods were generally normal. Months with mild drought were rare and occurred in only two years, 1996 and 1998. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The year with the highest exposure index, 1998, had three months of mild drought. The mid-exposure years, 1996 and 1999, experienced three and one month of mild and moderate drought, respectively. There was one month of mild drought between the two years with the lowest exposure levels.

The low levels of ozone exposure at Colorado National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 criteria are not satisfied. Higher ozone exposures often occur during periods of mild to moderate drought that reduce their effectiveness. Hourly concentrations of ozone seldom exceeded 80 ppb and thus are unlikely to produce foliar injury to plants under the conditions of exposure.

If the level of risk increases in the future, a program to assess the incidence of foliar

ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine and quaking aspen.

CURECANTI NATIONAL RECREATION AREA (CURE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CURE					
	1995	1996	1997	1998	1999
Sum06	7	20	13	22	21
W126	22.3	33.3	24.4	38.2	34.1
N60	237	534	358	736	586
N80	7	21	5	21	17
N100	1	0	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CURE					
	1995	1996	1997	1998	1999
Month 1	0.07	-0.58	-1.98	0.32	-3.76
Month 2	-1.87	-0.39	2.93	-1.94	3.13
Month 3	-2.48	-1.24	1.98	0.30	1.46

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CURE					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods showed six months of drought distributed evenly over the five years. With this distribution, there are no apparent relationships between Sum06 level of exposure and soil moisture. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone year, 1998, there were three months of minor drought while the two next highest years, 1999 and 1996, had one month of moderate and three months of mild and moderate drought, respectively. In the two years with the lowest ozone exposures, 1995 and 1997, there was one month of mild drought between them.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Curecanti National Recreation Area make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 criteria are not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb and thus are unlikely to produce foliar injury to plants under the conditions of exposure. High ozone exposures often occur during periods of mild to moderate drought that reduce

their effectiveness.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine and quaking aspen.

DINOSAUR NATIONAL MONUMENT (DINO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Oenothera elata	Evening primrose	Onagraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DINO					
	1995	1996	1997	1998	1999
Sum06	11	23	15	26	24
W126	23.2	35.2	23.6	36.8	29.9
N60	310	632	360	654	515
N80	25	52	16	68	32
N100	3	5	1	11	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DINO					
	1995	1996	1997	1998	1999
Month 1	1.39	0.26	2.93	-1.94	1.46
Month 2	1.56	-1.07	1.98	0.30	1.00
Month 3	5.61	-2.78	1.09	1.69	3.20

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DINO					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is generally below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. There were generally five or fewer hours each year in which the concentration exceeded 100 ppb; there were eleven hours above 100 ppb in one year. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods showed three months of drought over the five years. With this distribution, there are no apparent relationships between Sum06 level of exposure and soil moisture. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. In both of the two highest ozone years, 1998 and 1996, there were three months of mild and moderate drought. There was one month of moderate drought in 1999, a mid-exposure year. In the years when ozone exposures were lowest, 1995 and 1997, there was one month of mild drought between them.

The low levels of ozone exposure at Dinosaur National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 criteria are not generally satisfied. Hourly concentrations of ozone occasionally exceed 80 ppb, but exposures above 100 ppb are uncommon. High ozone exposures often occur during periods of mild to moderate drought that reduce their effectiveness.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: evening primrose, ponderosa pine, quaking aspen, skunkbush and Scouler's willow.

FOSSIL BUTTE NATIONAL MONUMENT (FOBU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOBU					
	1995	1996	1997	1998	1999
Sum06	11	24	14	22	20
W126	20.3	28.5	19.2	29.9	25.6
N60	299	495	292	490	424
N80	34	56	16	73	30
N100	4	6	2	11	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOBU					
	1995	1996	1997	1998	1999
Month 1	2.62	-1.81	-1.02	-0.09	0.52
Month 2	0.95	-1.23	1.35	5.54	0.79
Month 3	0.71	-2.63	-0.57	1.64	0.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOBU					
	1995	1996	1997	1998	1999
April	0.53	-1.56	1.35	-0.70	4.34
May	6.01	0.95	-0.57	-0.09	1.40
June	3.04	-1.81	0.92	5.54	0.52
July	2.62	-1.23	-0.33	1.64	0.79
August	0.95	-2.63	4.05	0.15	0.03
September	0.71	-0.53	3.10	-0.66	1.17
October	-0.43	0.61	0.05	1.53	-2.51

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally 80 ppb. While there was one year where there were eleven hours in which the concentration exceeded 100 ppb, in most years there were four or fewer hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture showed no relationship with either the Sum06 or W126 levels of exposure. Entire years were generally either favorable or unfavorable with respect to soil moisture conditions. Soil moisture levels associated with the 90-day Sum06 index showed that in 1997 high exposure was associated with three months of mild to severe drought, while the remaining four years experienced only one month of mild drought among them. The highest, 1998, and lowest, 1997, W126 exposure years both had normal soil moisture throughout. The second highest ozone year, 1996, had four months of mild to moderate drought while the two mid-exposure years had one month of moderate drought between them. There do not appear to be any relationships between ozone exposure and soil moisture, and entire growing seasons at the site have either favorable or unfavorable soil moisture conditions.

The risk of foliar ozone injury at Fossil Butte National Monument is moderate. The threshold level for injury is satisfied by the Sum06 index, while criteria for the W126 index are satisfied in two years. The N-values indicate that exposures to concentrations of ozone greater than 80 and 100 ppb are variable among years. Soil moisture conditions

appear to be either favorable or unfavorable for most of a growing season and can either significantly constrain or favor the uptake of ozone. The probability of foliar injury may be greatest during years such as 1998 when ozone exposure exceeds the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen and Scouler's willow.

GOLDEN SPIKE NATIONAL HISTORIC SITE (GOSP)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GOSP					
	1995	1996	1997	1998	1999
Sum06	12	25	14	22	19
W126	20.4	28.3	16.9	27.9	23.2
N60	304	497	265	454	394
N80	35	58	16	79	29
N100	5	7	2	11	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GOSP					
	1995	1996	1997	1998	1999
Month 1	0.77	-3.34	-3.15	0.90	-0.77
Month 2	-0.56	-1.04	0.37	3.22	-2.23
Month 3	-1.22	-3.01	-0.77	2.55	-0.63

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GOSP					
	1995	1996	1997	1998	1999
April	1.32	-1.31	0.37	0.67	2.01
May	5.71	-0.54	-0.77	0.90	-0.53
June	6.07	-3.34	2.39	3.22	-0.77
July	0.77	-1.04	0.49	2.55	-2.23
August	-0.56	-3.01	0.90	-0.86	-0.63
September	-1.22	-0.05	4.92	2.54	-1.40
October	-2.16	-0.51	-0.94	1.92	-2.53

Risk Analysis

- There is one ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. While there was one year where there were eleven hours in which the concentration exceeded 100 ppb, in most years there were five or fewer hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and the W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 exposure, 1996, experienced three months of mild and severe drought stress, while the second highest year, 1998, experienced normal soil moisture conditions. The remaining three years each had one month of drought. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to exposure, although the pattern is again not consistent. The year with the highest exposure, 1996, experienced four months of mild and severe drought stress, but the second highest year, 1998, experienced normal soil moisture conditions. The two mid-exposure years, 1999 and 1995, had three and two months of mild and moderate drought, respectively. The year with the lowest exposure, 1997, had normal moisture conditions.

The risk of foliar ozone injury to plants at Golden Spike National Historic Site is moderate. The threshold level for injury is satisfied by the Sum06 index, while criteria

for the W126 index are satisfied in two years. The N-values indicate that exposures to concentrations of ozone greater than 80 and 100 ppb are variable among years. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and reduces the likelihood of foliar injury. The probability of foliar injury may be greatest during years such as 1998 when ozone exposure exceeds the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

There are no ozone bioindicator species identified for the site.

HOVENWEEP NATIONAL MONUMENT (HOVE)

Plant Species Sensitive to Ozone

No species listed.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOVE

	1995	1996	1997	1998	1999
Sum06	4	8	7	13	13
W126	24.2	32.3	18.1	35.5	33.7
N60	209	481	204	611	520
N80	4	4	1	3	5
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOVE					
	1995	1996	1997	1998	1999
Month 1	1.39	-1.24	1.09	0.32	-3.76
Month 2	1.56	0.26	0.70	-1.94	3.13
Month 3	5.61	-1.07	2.39	0.30	1.46

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOVE					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index marginally exceeds the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-

hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. The two years with the highest exposure, 1998 and 1999, each had one month of mild or severe drought. The mid-exposure years, 1997 and 1996, had normal soil moisture and two months of mild drought, respectively. Soil moisture was normal in 1995 the lowest exposure year. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. In the three highest ozone years, 1998, 1999 and 1996, there were three months of mild to moderate drought, one month of moderate drought, and three months of mild and moderate drought, respectively. In the 1997 and 1995 when ozone exposures were lowest, there was one month of mild drought between the two years.

The risk of foliar ozone injury to plants at Hovenweep National Monument is low. This is the result of the low levels of ozone and the reduction in the uptake of ozone that occurs as a result of low soil moisture.

There are no ozone bioindicator species listed for the site.

NATURAL BRIDGES NATIONAL MONUMENT (NABR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NABR					
	1995	1996	1997	1998	1999
Sum06	5	11	10	18	17
W126	25.3	39.5	24.1	43.3	36.9
N60	252	703	310	804	625
N80	8	13	3	14	13
N100	0	1	0	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NABR					
	1995	1996	1997	1998	1999
Month 1	1.73	-1.09	2.06	0.39	-3.12
Month 2	1.97	-1.75	1.06	-1.53	2.28
Month 3	5.04	-2.18	0.76	-1.32	-0.77

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NABR					
	1995	1996	1997	1998	1999
April	1.97	-1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There is one ozone-sensitive species identified for the site, and it is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two years with the highest Sum06 exposure values, 1998 and 1999, had, respectively, two months of mild drought and one month of severe drought. The intermediate ozone years had three months of mild and moderate drought in 1996 and normal soil moisture in 1997. Soil moisture was also normal in 1995, the year with the lowest ozone exposure. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The two highest ozone years, 1998 and 1996, experienced three months of mild to moderate and five months of mild to severe drought, while a third high year, 1999, had one month of severe drought. In the two years with the lowest ozone, soil moisture was normal except for one month of moderate drought between them.

The low levels of ozone exposure at Natural Bridges National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures generally exceed the threshold level for injury, the W126 do not since the N100 criteria are not satisfied.

Higher ozone exposures occur during years with several months of mild to severe drought that significantly reduces their effectiveness. Hourly concentrations of ozone seldom exceed 80 ppb and thus are unlikely to produce foliar injury to plants under the conditions of exposure.

Only one ozone bioindicator species is identified for the site. If at some point in the future a program to assess the presence of ozone injury becomes desirable, it could employ ponderosa pine.

PIPE SPRING NATIONAL MONUMENT (PISP)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PISP					
	1995	1996	1997	1998	1999
Sum06	7	20	12	13	14
W126	34.8	39.2	28.7	46.2	44.1
N60	545	730	502	873	824
N80	17	40	11	32	33
N100	1	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PISP					
	1995	1996	1997	1998	1999
Month 1	-2.64	-3.16	-2.16	0.27	0.03
Month 2	-2.96	-2.66	-2.09	-0.36	-2.47
Month 3	-1.92	-2.71	-1.71	-0.59	-1.34

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PISP					
	1995	1996	1997	1998	1999
April	0.49	-3.16	-2.06	0.27	0.03
May	0.50	-2.66	-3.45	-0.36	-2.47
June	-0.08	-2.71	-2.16	-0.59	-1.34
July	-2.64	-2.90	-2.09	0.86	3.58
August	-2.96	-3.52	-1.71	-2.13	-1.86
September	-1.92	-1.85	2.39	2.32	0.08
October	-2.12	-0.86	-1.45	-0.52	-2.16

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than one hour in which the concentration exceeded 100 ppb, and most years had no hours above 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the 90-day Sum06 accumulation periods showed two and three months of moderate to severe drought in four of the five years. Both the highest, 1996, and lowest, 1995, exposure years had three months of drought, while 1998, a mid-exposure year, had three months of normal soil moisture. Soil moisture levels associated with the seasonal W126 index showed from three to five months of moderate to severe drought in 1995, 1996, and 1997, four months of mild to moderate drought in 1999, and one month or moderate drought in 1998. These levels of drought occurred without any apparent association to the W126 level of exposure.

The low level of ozone exposure and relatively dry soil moisture conditions at Pipe Spring National Monument make the risk of foliar ozone injury to plants low. While the levels of ozone exposure are generally below the thresholds for injury, low levels of soil moisture constrain the uptake of ozone make it unlikely that foliar injury will be produced.

If the level of risk increases in the future, a program to assess the presence of ozone

injury could employ tree-of-heaven and skunkbush.

TIMPANOGOS CAVE NATIONAL MONUMENT (TICA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for TICA					
	1995	1996	1997	1998	1999
Sum06	11	24	14	26	24
W126	19.7	31.3	18.4	31.4	25.1
N60	307	557	315	528	446
N80	34	82	22	99	41
N100	4	10	2	16	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TICA					
	1995	1996	1997	1998	1999
Month 1	2.79	-1.17	1.49	4.37	1.85
Month 2	3.09	-0.45	1.77	2.01	0.34
Month 3	0.37	-2.30	1.74	0.21	-1.15

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at TICA					
	1995	1996	1997	1998	1999
April	0.63	0.14	0.84	1.08	3.23
May	5.93	1.54	0.36	1.87	2.29
June	2.79	-1.17	1.49	5.69	1.57
July	3.09	-0.45	1.77	4.37	1.85
August	0.37	-2.30	1.74	2.01	0.34
September	-0.40	0.14	1.64	0.21	-1.15
October	-1.58	0.89	0.58	0.77	-2.69

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. The number of hours in which the concentration exceeded 100 ppb varied from two to sixteen. These levels of exposure may possibly injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the year with the highest and lowest Sum06 exposures, 1998 and 1995 respectively, showed normal moisture conditions. The two years with the second highest ozone exposures, 1996 and 1999, showed two months of mild and moderate drought and one month of mild drought, respectively. Relationships between soil moisture and the seasonal W126 index were also inconsistent. The two years with the highest ozone, 1996 and 1998, experienced two months of mild and moderate drought and normal soil moisture, respectively. The mid-exposure year 1999 had two months of mild and moderate drought, while the two lowest exposure years, 1995 and 1997, had one month of mild drought and normal soil moisture conditions, respectively.

The risk of foliar ozone injury at Timpanogos Cave National Monument is moderate. While the Sum06 exposures exceed the threshold level for injury, the W126 exposures satisfy the criteria intermittently. Hourly concentrations of ozone vary significantly among years, but in some years the hours of exposure to 80 and 100 ppb are high. Since

exposure and soil moisture levels are not associated, conditions favoring the uptake of ozone can occur under any level of exposure. The probability of foliar injury developing may be greatest during years such as 1998 when ozone exposure exceeds the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the presence of ozone injury could employ spreading dogbane.

ZION NATIONAL PARK (ZION)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Salix gooddingii	Gooding's willow	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ZION					
	1995	1996	1997	1998	1999
Sum06	7	24	14	9	10
W126	29.2	35.0	23.4	41.7	41.6
N60	449	681	414	777	781
N80	16	40	11	35	35
N100	1	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ZION					
	1995	1996	1997	1998	1999
Month 1	1.83	2.48	-0.40	2.35	-2.46
Month 2	-0.32	-2.59	-0.91	1.98	-0.48
Month 3	-0.55	-3.28	1.67	3.63	1.00

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ZION					
	1995	1996	1997	1998	1999
April	1.95	2.48	-0.30	2.35	0.53
May	3.74	-2.59	0.28	1.98	-2.46
June	5.49	-3.28	-0.40	3.63	-0.48
July	1.83	-1.47	-0.91	3.95	1.00
August	-0.32	-2.83	1.67	-0.58	0.21
September	-0.55	0.07	6.00	5.27	-1.57
October	-1.90	0.58	-0.78	2.16	-2.14

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. Concentrations of ozone reached 100 ppb for only one hour in two years.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and two years in which concentrations reached 100 ppb for one hour. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the year with the highest Sum06 exposure, 1996, showed two months of moderate and severe drought, while there was only one month of drought in the other four years. Soil moisture levels associated with the seasonal W126 index are also unrelated to ozone exposure. The two years with the same highest ozone levels, 1998 and 1999, showed normal soil moisture and three months of mild and moderate drought, respectively. The mid-exposure year of 1996 had four months of mild to severe drought, while the two lowest ozone exposure years had one month of mild drought between them.

The low levels of ozone exposure at Zion National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures generally exceed the threshold level for injury, the W126 does not since the N100 criteria are not satisfied. Hourly concentrations of ozone seldom exceed 60 ppb and thus are unlikely to produce foliar injury to plants under the conditions of exposure. The periods of mild to moderate drought that occur in some years reduce the effectiveness of ozone exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, ponderosa pine, American sycamore, quaking aspen and Scouler's willow.

NATIONAL CAPITAL REGION NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NATIONAL CAPITAL REGION NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NATIONAL CAPITAL NETWORK

Park	Code	State	Risk	O3 Data
Antietam NB	ANTI	MD	high	kriged
Appalachian NST	APPA	WV	various	krig/monit
Catoctin Mountain Park	CATO	MD	high	kriged
Chesapeake & Ohio Canal NHP	CHOH	MD	high	kriged
George Washington Memorial PKY	GWMP	VA	high	kriged
Harpers Ferry NHP	HAFE	WV	high	kriged
Manassas NBP	MANA	VA	high	kriged
Monocacy NB	MONO	MD	high	kriged
National Capital Parks-East	NACE	DC	high	kriged
Prince William Forest Park	PRWI	VA	high	kriged
Rock Creek Park	ROCR	DC	high	kriged
Wolf Trap Farm Park	WOTR	VA	high	kriged

ANTIETAM NATIONAL BATTLEFIELD (ANTI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ANTI					
	1995	1996	1997	1998	1999
Sum06	16	16	19	31	36
W126	36.5	29.7	39.1	55.2	46.0
N60	613	543	679	945	786
N80	147	74	129	247	186
N100	19	4	15	34	15

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. It was possible to do this only for 1999 for this site. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ANTI					
	1995	1996	1997	1998	1999
Month 1	2.96	1.29	-0.09	-0.53	-1.91
Month 2	0.00	3.82	-0.04	-1.43	-3.20
Month 3	-1.60	0.99	-0.20	-2.27	-2.21

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ANTI					
	1995	1996	1997	1998	1999
April	-1.51	-1.41	-1.95	1.31	0.85
May	0.51	3.75	-0.77	-0.42	-1.33
June	2.96	1.29	-0.09	1.29	-1.91
July	0.00	3.82	-0.04	-0.53	-3.20
August	-1.60	0.99	-0.20	-1.43	-2.21
September	-1.43	7.19	0.52	-2.27	2.25
October	2.45	0.41	-1.25	-2.22	-0.69

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for foliar injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1999 and 1998, experienced three and two months of mild to severe drought, respectively. The two years with the lowest ozone exposure, 1995 and 1996, had one year of mild drought between them, and 1997, a mid-ozone year, had favorable soil

moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were three and four months, respectively, of mild to severe drought. The two mid-ozone years, 1997 and 1995 respectively, experienced two and three months of mild drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Antietam National Battlefield is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high in most years. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry and cut-leaf coneflower.

APPALACHIAN NATIONAL SCENIC TRAIL (APPL)

A stand-alone risk assessment was prepared for the Appalachian National Scenic Trail. The assessment evaluates the risk of foliar injury at 30 sites along the Trail.

CATOCTIN MOUNTAIN PARK (CATO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CATO					
	1995	1996	1997	1998	1999
Sum06	32	27	33	38	36
W126	39.4	32.1	43.8	59.3	48.9
N60	652	576	749	1009	825
N80	168	87	156	269	200
N100	23	6	20	33	21

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CATO					
	1995	1996	1997	1998	1999
Month 1	-0.53	5.30	-1.78	-0.67	-1.97
Month 2	-0.74	0.32	-2.91	-1.64	-3.63
Month 3	-2.32	3.39	-1.29	-2.31	-0.40

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CATO					
	1995	1996	1997	1998	1999
April	-1.72	0.10	-1.68	-0.04	-0.91
May	0.22	1.67	-1.83	0.71	-2.45
June	-0.53	3.05	-1.78	0.86	-1.97
July	-0.74	5.30	-2.91	-0.67	-3.63
August	-2.32	0.32	-1.29	-1.64	-0.40
September	-0.58	3.39	-0.90	-2.31	5.70
October	2.48	2.34	-1.84	-1.12	0.33

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of

ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest Sum06 exposures, 1998 and 1999, had two months of mild and moderate drought and two months of mild and severe drought, respectively. In the mid-level exposure years, there were three months of mild and moderate drought in 1997, and one month of moderate drought in 1995. Soil moisture was normal in 1996, the lowest exposure year. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. The year with the highest exposure index, 1998, had three months of mild and moderate drought. The two years with next highest levels of exposure, 1999 and 1997, had three and six months of mild to severe drought, respectively. There were two months of mild and moderate drought in 1995, the second lowest exposure year, and normal soil moisture conditions in 1996, the lowest year.

The risk of foliar ozone injury at Catoctin Mountain Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 or 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or not under periods of prolonged drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and northern fox grape.

CHESAPEAKE AND OHIO CANAL NATIONAL HISTORICAL PARK (CHOH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHOH					
	1995	1996	1997	1998	1999
Sum06	26	23	26	35	37
W126	37.2	30.7	37.0	47.2	45.0
N60	609	542	604	761	724
N80	175	105	163	235	227
N100	39	8	30	46	39

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However,

in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHOH					
	1995	1996	1997	1998	1999
Month 1	-0.53	3.05	-1.78	-0.67	-1.97
Month 2	-0.74	5.30	-2.91	-1.64	-3.63
Month 3	-2.32	0.32	-1.29	-2.31	-0.40

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHOH					
	1995	1996	1997	1998	1999
April	-1.72	0.10	-1.68	-0.04	-0.91
May	0.22	1.67	-1.83	0.71	-2.45
June	-0.53	3.05	-1.78	0.86	-1.97
July	-0.74	5.30	-2.91	-0.67	-3.63
August	-2.32	0.32	-1.29	-1.64	-0.40
September	-0.58	3.39	-0.90	-2.31	5.70
October	2.48	2.34	-1.84	-1.12	0.33

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. However, the association is inconsistent for both indices. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, each had two months of mild to severe drought. The two mid-ozone years, 1995 and 1997, had the same level of exposure and experienced one and three months of mild to moderate drought. The year with the lowest exposure index, 1996, had favorable soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, although the pattern is not consistent. In both of the highest ozone years, 1998 and 1999, there were three months of mild to severe drought. The two mid-ozone years, 1995 and 1997, had the same level of exposure, but experienced two and six months of mild and moderate drought, respectively. In the lowest ozone year, 1996, soil moisture conditions were normal throughout.

The risk of foliar ozone injury to plants at Chesapeake and Ohio Canal National Historic Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the higher ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1995 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or do not put long-term constraints on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, cut-leaf coneflower, American elder, common snowberry, crownbeard and northern fox grape.

GEORGE WASHINGTON MEMORIAL PARKWAY (GWMP)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is

also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GWMP					
	1995	1996	1997	1998	1999
Sum06	26	23	26	35	37
W126	37.2	30.7	37.0	47.2	45.0
N60	609	542	604	761	724
N80	175	105	163	235	227
N100	39	8	30	46	39

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GWMP					
	1995	1996	1997	1998	1999
Month 1	3.57	1.73	0.15	-2.56	-2.42
Month 2	-0.52	3.13	-1.30	-2.57	-2.03
Month 3	-1.56	1.41	1.02	-2.87	-1.60

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GWMP					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, each had three months of mild to moderate drought. The two mid-ozone years, 1995 and 1997, had the same level of exposure and each experienced a month of mild drought. The year with the lowest exposure index had favorable soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and five months, respectively, of mild and moderate drought. The two mid-ozone years, 1995 and 1997, had similar levels of exposure and experienced two and four months of mild drought, respectively. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at George Washington Memorial Parkway is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1995 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, cut-leaf coneflower, American elder and crownbeard.

HARPER'S FERRY NATIONAL HISTORICAL PARK (HAFE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is

also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HAFE					
	1995	1996	1997	1998	1999
Sum06	17	17	19	31	36
W126	35.4	29.2	37.4	51.2	44.8
N60	596	532	647	869	760
N80	144	74	128	232	187
N100	22	5	15	35	17

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HAFE					
	1995	1996	1997	1998	1999
Month 1	2.31	0.42	0.35	-2.15	-3.10
Month 2	-0.03	5.12	-0.60	-1.60	-2.86
Month 3	-0.30	3.15	-1.05	-2.04	-1.57

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HAFE					
	1995	1996	1997	1998	1999
April	-1.18	-1.33	-1.57	1.67	-0.41
May	0.41	4.74	-1.10	-0.45	-2.03
June	2.31	0.42	0.35	1.63	-3.10
July	-0.03	5.12	-0.60	-2.15	-2.86
August	-0.30	3.15	-1.05	-1.60	-1.57
September	-1.22	7.78	0.87	-2.04	2.85
October	1.33	0.72	-1.80	-2.56	-0.75

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two years with the highest Sum06 index of exposure, 1999 and 1998, each had three years of mild to severe drought. The mid-level exposure year 1997 had one year of mild drought, while the two years with the lowest exposure had normal soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In both of the highest ozone years, 1998 and 1999, there were four months of mild to severe drought. The two mid-ozone years, 1997 and 1995, had four and two months of mild drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury to plants at Harper's Ferry National Historic Park is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone in most years, the probability of foliar injury developing may be greatest during years such as 1995 when ozone levels exceed the thresholds, and soil moisture levels are under mild drought.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

MANASSAS NATIONAL BATTLEFIELD PARK (MANA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MANA					
	1995	1996	1997	1998	1999
Sum06	23	22	23	35	36
W126	34.6	29.5	34.2	47.3	43.6
N60	591	536	584	795	727
N80	139	80	124	216	199
N100	25	5	17	38	23

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MANA					
	1995	1996	1997	1998	1999
Month 1	3.57	1.73	0.60	-2.56	-2.42
Month 2	-0.52	3.13	0.15	-2.57	-2.03
Month 3	-1.56	1.41	-1.30	-2.87	-1.60

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MANA					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, each had three months of mild and moderate drought. The two mid-ozone years, 1997 and 1995, had the same level of exposure and each experienced a month of mild drought. The year with the lowest exposure index, 1996, had favorable soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and five months, respectively, of mild and moderate drought. The two mid-ozone years, 1995 and 1997, had similar ozone exposures and two and four months of mild drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Manassas National Battlefield Park is high. The Sum06 and W126 threshold criteria are both generally satisfied, and the N80 and N100 counts are high While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone in most years, the probability of foliar injury developing may be greatest during years such as 1995 when ozone levels exceed the thresholds, and soil moisture levels under mild drought that does not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, cut-leaf coneflower, American elder, crownbeard and northern fox grape.

MONOCACY NATIONAL BATTLEFIELD (MONO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MONO					
	1995	1996	1997	1998	1999
Sum06	21	19	22	31	35
W126	37.8	30.8	39.0	52.3	45.2
N60	617	548	653	872	748
N80	172	93	154	246	202
N100	32	8	24	36	26

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MONO					
	1995	1996	1997	1998	1999
Month 1	-0.53	3.05	-1.78	-0.67	-2.45
Month 2	-0.74	5.30	-2.91	-1.64	-1.97
Month 3	-2.32	0.32	-1.29	-2.31	-3.63

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MONO					
	1995	1996	1997	1998	1999
April	-1.72	0.10	-1.68	-0.04	-0.91
May	0.22	1.67	-1.83	0.71	-2.45
June	-0.53	3.05	-1.78	0.86	-1.97
July	-0.74	5.30	-2.91	-0.67	-3.63
August	-2.32	0.32	-1.29	-1.64	-0.40
September	-0.58	3.39	-0.90	-2.31	5.70
October	2.48	2.34	-1.84	-1.12	0.33

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, had three and two months of mild to severe drought, respectively. The two mid-ozone years, 1997 and 1995, experienced three and one month of mild and moderate drought, while the year with the lowest

exposure index had favorable soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, although again the pattern is not consistent. The two highest ozone years, 1998 and 1999, each had three months of mild to severe drought. The two mid-ozone years, 1997 and 1995, had six and two months of mild and moderate drought, respectively. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Monocacy National Battlefield is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, , redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower and American elder.

NATIONAL CAPITAL PARKS – EAST (NACE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster umbellatus	Flat-toppped aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NACE					
	1995	1996	1997	1998	1999
Sum06	26	23	26	36	37
W126	36.5	30.3	36.4	47.3	45.2
N60	603	538	599	766	731
N80	166	99	155	233	226
N100	35	7	27	46	37

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NACE					
	1995	1996	1997	1998	1999
Month 1	-0.58	1.98	0.24	-2.33	-1.73
Month 2	-1.54	2.06	-2.23	-3.16	-3.83
Month 3	-2.72	-0.41	-0.65	-2.74	0.05

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NACE					
	1995	1996	1997	1998	1999
April	-1.63	-0.05	-0.57	-0.02	-1.14
May	1.25	1.94	0.50	0.15	-2.87
June	-0.58	1.98	0.24	0.39	-1.73
July	-1.54	2.06	-2.23	-2.33	-3.83
August	-2.72	-0.41	-0.65	-3.16	0.05
September	-0.78	3.19	-1.80	-2.74	6.78
October	3.44	1.94	0.11	-2.89	0.04

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations:

when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, had two and three months of mild to severe drought respectively. The two mid-ozone years, 1997 and 1995, had the same level of exposure and experienced one and two months of mild and moderate drought. The year with the lowest exposure index, 1996, had favorable soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In both of the highest ozone years, 1998 and 1999, there were four months of mild to severe drought. The two mid-ozone years, 1995 and 1997, had similar levels of exposure and three and two months of mild and moderate drought, respectively. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at National Capital Parks – East is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or do not place significant constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and northern fox grape.

PRINCE WILLIAM FOREST PARK (PRWI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PRWI					
	1995	1996	1997	1998	1999
Sum06	24	24	26	36	37
W126	34.6	29.8	35.3	46.8	44.9
N60	593	541	598	775	740
N80	137	85	133	216	214
N100	24	4	18	41	28

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PRWI					
	1995	1996	1997	1998	1999
Month 1	3.57	1.73	0.60	-2.56	-2.42
Month 2	-0.52	3.13	0.15	-2.57	-2.03
Month 3	-1.56	1.41	-1.30	-2.87	-1.60

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PRWI					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in four of the years although concentrations exceeded 100 ppb every year. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, each had three months of mild and moderate drought. The mid-ozone year, 1997, experienced a month of mild drought, and the two years with the same and lowest exposure index, 1995 and 1996, had one month of mild drought between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and five months, respectively, of mild and moderate drought. The two mid-ozone years, 1997 and 1995, had similar levels of exposure and both had two months of mild drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Prince William Forest Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 and 1999 when ozone levels are high, and months of drought do not impose extended constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, cut-leaf coneflower, American elder and northern fox grape.

ROCK CREEK PARK (ROCR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ROCR					
	1995	1996	1997	1998	1999
Sum06	26	23	26	35	37
W126	37.2	30.7	37.0	47.2	45.0
N60	609	542	604	761	724
N80	175	105	163	235	227
N100	39	8	30	46	39

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995

through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ROCR					
	1995	1996	1997	1998	1999
Month 1	-0.58	1.98	0.24	-2.33	-1.73
Month 2	-1.54	2.06	-2.23	-3.16	-3.83
Month 3	-2.72	-0.41	-0.65	-2.74	0.05

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ROCR					
	1995	1996	1997	1998	1999
April	-1.63	-0.05	-0.57	-0.02	-1.14
May	1.25	1.94	0.50	0.15	-2.87
June	-0.58	1.98	0.24	0.39	-1.73
July	-1.54	2.06	-2.23	-2.33	-3.83
August	-2.72	-0.41	-0.65	-3.16	0.05
September	-0.78	3.19	-1.80	-2.74	6.78
October	3.44	1.94	0.11	-2.89	0.04

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, had two and three months of mild and moderate drought respectively. The two mid-ozone years, 1997 and 1995, had the same level of exposure and experienced one and two months of mild and moderate drought. The year with the lowest exposure index, 1996, had favorable soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In both of the highest ozone years, 1998 and 1999, there were four months of mild to severe drought. The two mid-ozone years, 1995 and 1997, had similar levels of ozone exposure and experienced three and two months of mild and moderate drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Rock Creek Park is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or do not place significant constrains the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder and northern fox grape.

WOLF TRAP NATIONAL PARK FOR THE PERFORMING ARTS (WOTR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WOTR					
	1995	1996	1997	1998	1999
Sum06	25	22	24	34	37
W126	36.2	30.1	35.8	47.0	44.3
N60	595	534	590	765	720
N80	165	98	152	230	218
N100	35	8	26	44	34

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WOTR					
	1995	1996	1997	1998	1999
Month 1	3.57	1.73	0.60	-2.56	-2.42
Month 2	-0.52	3.13	0.15	-2.57	-2.03
Month 3	-1.56	1.41	-1.30	-2.87	-1.60

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WOTR					
	1995	1996	1997	1998	1999
April	-1.59	-0.67	-1.04	0.61	-1.17
May	0.83	2.64	-1.55	1.10	-1.96
June	3.57	1.73	0.60	2.27	-2.42
July	-0.52	3.13	0.15	-2.56	-2.03
August	-1.56	1.41	-1.30	-2.57	-1.60
September	-0.68	7.58	1.02	-2.87	6.55
October	2.43	1.00	-1.00	-2.22	-0.47

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure indices, 1999 and 1998, each had three months of mild and moderate drought. The two mid-ozone years, 1997 and 1995, each experienced a month of mild drought, and the year with the lowest exposure index, 1996, had favorable soil moisture. Soil moisture levels associated with the

seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1998 and 1999, there were four and five months, respectively, of mild and moderate drought. The two mid-ozone years, 1997 and 1995, had similar levels of exposure and experienced four and two months of mild drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Wolf Trap National Park for the Performing Arts is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, yellow-poplar and black cherry.

NORTHEAST TEMPERATE NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHEAST TEMPERATE NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHEAST TEMPERATE NETWORK

Park	Code	State	Risk	O3 Data
Acadia NP	ACAD	ME	moderate	monitored
Boston Harbor Islands NRA	BOHA	MA	moderate	kriged
Marsh-Billings NHP	MABI	VT	low	kriged
Minute Man NHP	MIMA	MA	moderate	kriged
Morristown NHP	MORR	NJ	high	kriged
Roosevelt-Vanderbilt Headquarters	ROVA	NY	high	kriged
Saint-Gaudens NHS	SAGA	NH	low	kriged
Saratoga NHP	SARA	NY	low	kriged
Saugus Iron Works NHS	SAIR	MA	moderate	kriged
Weir Farm NHS	WEFA	CT	high	kriged

A portion of the Appalachian National Scenic Trail passes through the network. A stand-alone assessment of risk has been produced for sites along the Appalachian Trail.

ACADIA NATIONAL PARK (ACAD)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus rigida	Pitch pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ACAD					
	1995	1996	1997	1998	1999
Sum06	11	4	7	15	12
W126	19.2	10.1	11.2	33.4	28.8
N60	275	123	147	520	378
N80	79	18	24	77	70
N100	13	4	3	21	13

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ACAD					
	1995	1996	1997	1998	1999
Month 1	0.35	-0.18	-1.64	-0.35	-2.83
Month 2	-0.55	5.12	-0.78	5.98	-2.43
Month 3	0.51	-2.49	0.10	-0.83	-1.31

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ACAD					
	1995	1996	1997	1998	1999
April	-1.19	2.69	2.03	-0.92	-4.67
May	0.35	1.09	-0.12	-0.35	-0.38
June	-0.55	-0.18	-1.64	5.98	-2.83
July	0.51	5.12	-0.78	-0.83	-2.43
August	-2.29	-2.49	0.10	0.35	-1.31
September	-1.35	3.00	-0.86	-1.70	4.72
October	0.91	3.61	-2.87	4.36	1.88

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are intermittently satisfied.

- In three years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the other years, the number of hours was significantly lower. In the high ozone years, the levels of exposure could injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. In 1998 when ozone concentrations were highest, soil moisture was normal. In the two mid-level exposure years there were three months of mild and moderate drought in 1999 and normal soil moisture in 1995. The two lowest exposure years each had one month of mild or moderate drought. Soil moisture levels associated with the

seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. There was one month of mild drought in 1998, the highest exposure year, and four months of mild to severe drought in 1999, the second highest year. There were three months of mild and moderate drought in 1995, the mid-level exposure year. The lowest and second lowest years, 1996 and 1997 respectively, had one and two months of mild and moderate drought.

The risk of foliar ozone injury to plants at Acadia National Park is moderate. The levels of ozone exposure intermittently create the potential for injury, and exposures to 80 and 100 ppb varies widely among the years. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, quaking aspen, black cherry, Allegheny blackberry, and American elder.

BOSTON HARBOR ISLANDS NATIONAL RECREATION AREA (BOHA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BOHA					
	1995	1996	1997	1998	1999
Sum06	16	13	14	16	16
W126	21.7	16.8	19.9	21.9	19.9
N60	333	255	296	337	296
N80	90	38	72	68	74
N100	18	3	12	12	12

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BOHA					
	1995	1996	1997	1998	1999
Month 1	-0.41	-1.56	-1.75	6.79	-3.30
Month 2	-0.70	2.18	-1.04	-0.18	-0.73
Month 3	-2.61	-0.20	0.19	0.48	-1.85

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BOHA					
	1995	1996	1997	1998	1999
April	-1.80	1.88	2.21	0.31	-3.25
May	-0.46	-0.43	-0.23	0.90	0.13
June	-0.41	-1.56	-1.75	6.79	-3.30
July	-0.70	2.18	-1.04	-0.18	-0.73
August	-2.61	-0.20	0.19	0.48	-1.85
September	-0.80	5.52	-2.36	-1.29	2.54
October	1.54	8.00	-2.07	1.39	2.55

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. Most years had 12 or more hours of exposure greater than 100 ppb. These levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Three years, 1995, 1998 and 1999, had the same highest Sum06 exposure index and experienced one month of moderate drought, normal moisture conditions, and two months of mild and severe drought, respectively. The second lowest and lowest exposure years, 1997 and 1996, had two and one month of mild drought, respectively. There does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. The two years with the highest indices, 1995 and 1998, experienced two months of mild and moderate drought and two months of mild drought, respectively. In two years with slightly lower exposures, there were

four months of mild and moderate drought in 1997, and three months of mild and severe drought in 1999. There was one month of mild drought in 1996, the year with the lowest exposure.

The risk of foliar ozone injury at Boston Harbor Islands National Recreation Area is moderate. The thresholds for injury are satisfied for both the Sum06 and W126 exposure indices. The N-values indicate that exposures exceed 80 ppb and 100 ppb, but the numbers of hours at these levels vary among years. Mild to severe drought conditions occur during most years and can significantly reduce the uptake of ozone. It is anticipated that the risk of injury may be greatest in years such as 1998 when ambient levels of ozone are moderately high and soil moisture conditions constrain uptake late in the year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.

MARSH-BILLINGS NATIONAL HISTORIC PARK (MABI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MABI					
	1995	1996	1997	1998	1999
Sum06	8	5	7	8	9
W126	14.2	11.5	11.7	13.5	16.4
N60	216	145	158	203	245
N80	22	21	20	12	33
N100	1	1	2	0	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MABI					
	1995	1996	1997	1998	1999
Month 1	-3.75	1.22	-0.57	-1.63	-1.63
Month 2	1.84	6.51	3.81	6.56	6.56
Month 3	2.48	-0.80	5.10	4.22	4.22

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MABI					
	1995	1996	1997	1998	1999
April	-0.49	6.44	0.18	-1.30	-1.30
May	-0.28	3.19	2.28	-1.63	-1.63
June	-3.75	1.22	-0.57	6.56	6.56
July	1.84	6.51	3.81	4.22	4.22
August	2.48	-0.80	5.10	2.57	2.57
September	1.53	-0.28	0.61	2.55	2.55
October	5.79	2.29	-0.07	0.26	0.26

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury at a marginal level. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposures were low and relatively similar over the five-year period. No relationships were apparent between the Sum06 levels of ozone and soil moisture conditions. In general, soil moisture conditions were favorable for the uptake of ozone with only two months of mild and one of severe drought stress over the five-year period. With the seasonal W126 index there were few months of drought during the five-year period, however there is some indication of an inverse relationship: when ozone is high, soil moisture is low, but the relationship is not consistent. This relationship

reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the three years with the highest ozone, there were two months of mild drought in both 1999 and 1998, and one month of severe drought in 1995. Soil moisture conditions were favorable in the remaining two years with lower levels of ozone.

The risk of foliar ozone injury to plants at Marsh-Billings Historic Park is low. The Sum06 and W126 exposure indices are either marginally attained or not satisfied. The N-values indicate that exposure to ozone greater than 80 ppb is uncommon and exposure to 100 ppb is rare. While soil moisture conditions generally favor the uptake of ozone, periods of drought constrain uptake in higher exposure years and reduce the potential for foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, big-leaf aster, white ash, American sycamore, quaking aspen, black cherry, Allegheny blackberry, and American elder.

MINUTE-MAN NATIONAL HISTORIC PARK (MIMA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MIMA					
	1995	1996	1997	1998	1999
Sum06	13	10	10	12	12
W126	21.7	16.9	20.2	20.5	20.2
N60	335	255	298	314	305
N80	86	37	67	61	72
N100	15	2	11	12	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MIMA					
	1995	1996	1997	1998	1999
Month 1	-1.60	-0.77	-2.49	6.98	-2.92
Month 2	-0.94	3.80	-1.19	-0.15	-0.88
Month 3	-2.24	-1.28	0.06	-1.17	-1.81

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MIMA					
	1995	1996	1997	1998	1999
April	-1.67	3.85	2.01	-0.74	-3.53
May	-0.72	0.43	-0.18	1.10	-0.12
June	-1.60	-0.77	-2.49	6.98	-2.92
July	-0.94	3.80	-1.19	-0.15	-0.88
August	-2.24	-1.28	0.06	-1.17	-1.81
September	-0.60	2.82	-2.11	-1.50	4.74
October	4.43	5.66	-1.62	1.78	1.44

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index marginally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 threshold was satisfied each year and the W126 criteria in four of the five years.

- The N-values for the site show concentrations frequently exceeded 60 ppb, occasionally exceeded 80 ppb, and exceeded 100 ppb for a significant number of hours in most years. These levels of exposure can injure vegetation.

- Relationships between 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposures were relatively similar over the five-year period. Months of mild and moderate drought stress were

distributed over the five years, with three years each having two months of drought and two years each having one month. No relationship was apparent between the Sum06 level of exposure and drought. The relatively uniform levels of ozone also make it difficult to assess relationships between the W126 exposure index and soil moisture, however there appears to be an inverse association: when ozone is high, soil moisture is low, but the relationship is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. Exposure indices in 1995, 1997, 1998 and 1999 were high and similar, and each year experienced two to four months of mild to severe drought. The lowest exposure year, 1996, had one month of mild drought.

The risk of foliar ozone injury at Minute-Man National Historic Park is moderate. The thresholds for injury are consistently satisfied for the Sum06 and the W126 indices, and the N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb, with a significant number of hours of exposure to 100 ppb in most years. Mild to severe drought conditions reduce the uptake by plants in most years. It is anticipated that the risk of injury may be greatest in years such as 1998 when ambient levels of ozone are high and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.

MORRISTOWN NATIONAL HISTORIC PARK (MORR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Aesculus octandra	Yellow buckeye	Hippocastanaceae
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MORR					
	1995	1996	1997	1998	1999
Sum06	21	16	20	21	26
W126	33.4	25.9	30.9	36.6	39.2
N60	503	409	465	595	604
N80	179	111	150	178	194
N100	43	15	33	21	57

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MORR					
	1995	1996	1997	1998	1999
Month 1	-1.73	1.31	-1.34	-2.28	-3.26
Month 2	0.13	3.38	1.30	-1.71	-4.17
Month 3	-3.29	-1.64	0.10	-1.98	-0.54

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MORR					
	1995	1996	1997	1998	1999
April	-1.97	1.45	0.00	1.42	-1.63
May	-0.54	-0.53	-0.41	1.87	-0.83
June	-1.73	1.31	-1.34	2.36	-3.26
July	0.13	3.38	1.30	-2.28	-4.17
August	-3.29	-1.64	0.10	-1.71	-0.54
September	-0.07	1.82	-0.71	-1.98	6.12
October	4.17	5.16	-1.16	-1.28	0.56

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. Ozone levels during the Sum06 accumulation periods were relatively similar over the five-years. The year with the highest Sum06 ozone exposure value, 1999, had two months of severe drought. The three years with a slightly lower ozone exposure, 1995, 1997, and 1998, each had one to three months of mild to severe drought, with 1998 being most significantly affected. In the lowest ozone year, 1996, there was one month of mild drought. The W126 index of exposure and soil moisture levels also appear to have an inverse relationship. The two years with the highest exposures, 1999 and 1998, experienced three and four months of mild to severe drought, respectively. In the two intermediate exposure years there were three months of mild and severe drought in 1995 and two months of mild drought in 1997. There was one month of mild drought in 1996, the lowest exposure year.

The risk of foliar ozone injury to plants at Morristown National Historic Park is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in the higher exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.

ROOSEVELT-VANDERBILT HEADQUARTERS (ROVA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ROVA					
	1995	1996	1997	1998	1999
Sum06	20	15	19	18	21
W126	25.9	21.8	24.7	28.4	29.7
N60	408	340	373	469	452
N80	97	66	89	92	114
N100	18	12	13	11	25

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ROVA					
	1995	1996	1997	1998	1999
Month 1	-3.26	1.08	-2.31	-1.72	-2.93
Month 2	-0.79	6.42	-0.42	-1.75	-2.40
Month 3	-2.62	-1.18	0.84	-2.05	-0.75

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ROVA					
	1995	1996	1997	1998	1999
April	-1.05	3.59	0.89	0.02	-3.01
May	-1.59	0.56	-0.23	1.03	-0.22
June	-3.26	1.08	-2.31	5.16	-2.93
July	-0.79	6.42	-0.42	-1.72	-2.40
August	-2.62	-1.18	0.84	-1.75	-0.75
September	-1.04	2.19	-0.39	-2.05	5.84
October	5.01	1.56	-1.26	0.04	0.73

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations:

when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The Sum06 indices of exposure were relatively similar over the five-year period, and the inverse relationship with soil moisture is not consistent. The two years with the highest ozone exposures, 1999 and 1995, both had two months of moderate and severe drought. The two next highest years, 1997 and 1998, respectively experienced one and three months of mild to moderate drought, while the year with the lowest ozone, 1996, has one month of mild drought. Annual ozone levels associated with the seasonal W126 index were similar in value, and also appear to be inversely related to soil moisture. The two highest ozone years, 1999 and 1998, each had three months of mild to severe drought. Two years with mid-level exposures, 1995 and 1997, had five and two months of mild to severe drought, respectively, and the year with lowest ozone, 1996, has one month of mild drought.

The risk of foliar ozone injury to plants at Roosevelt-Vanderbilt Headquarters is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in higher exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest in years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under drought conditions that do not extensively constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, redbud, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, and northern fox grape.

SAINT-GAUDENS NATIONAL HISTORIC SITE (SAGA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Aster macrophyllus	Big-leaf aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAGA					
	1995	1996	1997	1998	1999
Sum06	7	5	7	7	9
W126	13.0	10.9	11.2	12.4	15.0
N60	198	134	149	183	221
N80	21	22	23	12	32
N100	1	1	3	1	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAGA					
	1995	1996	1997	1998	1999
Month 1	-2.43	-1.03	-2.37	-0.70	-0.28
Month 2	0.51	4.24	0.24	8.48	-2.02
Month 3	-1.60	-3.39	1.24	-1.14	-1.13

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAGA					
	1995	1996	1997	1998	1999
April	-1.75	4.73	2.08	-1.97	-4.13
May	-0.59	1.79	-0.30	-0.70	-0.28
June	-2.43	-1.03	-2.37	8.48	-2.02
July	0.51	4.24	0.24	-1.14	-1.13
August	-1.60	-3.39	1.24	-1.21	-1.16
September	-1.27	0.48	-1.38	-1.76	5.80
October	4.81	7.22	-2.06	0.91	1.32

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between both the 90-day Sum06 and the seasonal W126 indices of ozone exposure and soil moisture are difficult to assess because the levels of exposure for both were low and similar over the five-year period. There does not appear to be any association between the Sum06 levels of ozone exposure and the incidence of drought. Soil moisture levels show that each year had one or two months of mild to severe drought. The relatively uniform levels of ozone exposure for the W126 index also make it difficult to assess relationships between exposure and soil moisture. Months of mild, moderate, and severe drought stress were distributed throughout the five-year period with each year having two to four months of drought. No associations between the W126 levels of ozone and soil moisture are apparent in the distribution.

The low levels of ozone exposure at Saint-Gaudens National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 and W126 exposures indices do not exceed the threshold levels for injury, the number of hours of exposure greater than 80 ppb is low, and exposure to concentrations greater than 100 ppb are rare. Months of mild to severe drought throughout the assessment period limit the uptake of ozone and serve to reduce the effectiveness of the ozone exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, tall milkweed, common milkweed, big-leaf aster, white ash, yellow-poplar, American sycamore, quaking aspen, black cherry, Allegheny blackberry, and American elder.

SARATOGA NATIONAL HISTORIC PARK (SARA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus rigida	Pitch pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SARA					
	1995	1996	1997	1998	1999
Sum06	13	8	12	12	16
W126	18.1	14.5	17.4	18.0	23.5
N60	290	212	260	300	380
N80	44	31	39	24	62
N100	2	2	4	2	7

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SARA					
	1995	1996	1997	1998	1999
Month 1	-3.26	1.08	-2.31	1.03	-0.22
Month 2	-0.79	6.42	-0.42	5.16	-2.93
Month 3	-2.62	-1.18	0.84	-1.72	-2.40

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SARA					
	1995	1996	1997	1998	1999
April	-1.05	3.59	0.89	0.02	-3.01
May	-1.59	0.56	-0.23	1.03	-0.22
June	-3.26	1.08	-2.31	5.16	-2.93
July	-0.79	6.42	-0.42	-1.72	-2.40
August	-2.62	-1.18	0.84	-1.75	-0.75
September	-1.04	2.19	-0.39	-2.05	5.84
October	5.01	1.56	-1.26	0.04	0.73

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation, but often on a marginal basis. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 threshold was marginally satisfied while the W126 was not.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had seven hours in which the concentration exceeded 100 ppb, but most years had only two hours. These levels of exposure are not likely to injure vegetation.

- Although ozone exposure indices during the 90-day Sum06 accumulation periods were relatively similar, they appear to be inversely related to soil moisture levels: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest Sum06 ozone exposure values, 1999 and 1995, each had two months of

moderate to severe drought. Two years with slightly lower ozone exposure, 1997 and 1998, each had one month of mild or moderate drought. In the lowest ozone year, 1996, there was one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but the pattern is not consistent. The year with the highest exposure, 1999, had three months of moderate and severe drought. In the three mid-level exposure years, there were five months of mild to severe drought in 1995, three months of mild and moderate drought in 1998, and two months of mild and moderate drought in 1997. The lowest exposure year, 1996, experienced one month of mild drought.

The low levels of ozone exposure at Saratoga National Historic Park make the risk of foliar ozone injury to plants low. The Sum06 and W126 exposure indices marginally exceed and do not exceed, respectively, the threshold levels for injury. The number of hours of exposure greater than 80 ppb is low, and exposure to concentrations greater than 100 ppb are rare. Months of mild to severe drought throughout the assessment period serve to constrain the uptake of ozone and reduce the effectiveness of the exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, white ash, American sycamore, quaking aspen, black cherry, Allegheny blackberry, cut-leaf coneflower, and American elder.

SAUGUS IRON WORKS NATIONAL HISTORIC SITE (SAIR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Prunus serotina	Black cherry	Rosaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAIR					
	1995	1996	1997	1998	1999
Sum06	12	10	10	11	12
W126	20.6	16.6	19.3	19.8	19.0
N60	316	250	283	302	285
N80	83	38	65	60	69
N100	14	2	11	11	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAIR					
	1995	1996	1997	1998	1999
Month 1	-0.41	-1.56	-1.75	6.79	-3.30
Month 2	-0.70	2.18	-1.04	-0.18	-0.73
Month 3	-2.61	-0.20	0.19	0.48	-1.85

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAIR					
	1995	1996	1997	1998	1999
April	-1.80	1.88	2.21	0.31	-3.25
May	-0.46	-0.43	-0.23	0.90	0.13
June	-0.41	-1.56	-1.75	6.79	-3.30
July	-0.70	2.18	-1.04	-0.18	-0.73
August	-2.61	-0.20	0.19	0.48	-1.85
September	-0.80	5.52	-2.36	-1.29	2.54
October	1.54	8.00	-2.07	1.39	2.55

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index marginally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. Ambient concentrations exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Ozone exposure values during the 90-day Sum06 and seasonal W126 accumulation periods were similar for each index over the five-year period of evaluation, and provide little opportunity to assess relationships between levels of exposure and soil moisture. For the Sum06 index, one and two months of mild, moderate, and severe drought were distributed over four of the five years without any apparent relationship to the level of ozone. The W126 index of exposure saw two to four months of mild to severe drought distributed in four of the five years, with one month of mild drought in 1996, the lowest ozone exposure year. No

relationship appears to exist between the W126 level of exposure and soil moisture conditions.

The risk of foliar ozone injury to plants at Saugus Iron Works National Historic Site is moderate. While the levels of ozone exposure create the potential for injury, dry soil conditions significantly reduce the likelihood of injury in some years. However, levels of exposure capable of producing foliar injury also occur under conditions of minor drought. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels exceed the thresholds, and soil moisture levels do not serve as a long-term constraint to the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, common milkweed, black cherry, and northern fox grape.

WEIR FARM NATIONAL HISTORIC SITE (WEFA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Aster acuminatus	Whorled aster	Asteraceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Populus tremuloides	Quaking aspen	Salicaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WEFA					
	1995	1996	1997	1998	1999
Sum06	18	13	19	17	23
W126	23.6	19.2	24.3	27.3	28.4
N60	351	295	347	432	418
N80	110	70	114	109	128
N100	29	14	31	17	38

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WEFA					
	1995	1996	1997	1998	1999
Month 1	-2.05	-0.91	-1.80	3.97	-3.65
Month 2	-1.45	3.27	-0.82	0.19	-1.80
Month 3	-1.82	-1.27	2.01	-1.52	-1.74

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WEFA					
	1995	1996	1997	1998	1999
April	-1.37	3.37	0.37	0.04	-3.16
May	-0.75	-0.44	-0.44	1.42	-0.36
June	-2.05	-0.91	-1.80	3.97	-3.65
July	-1.45	3.27	-0.82	0.19	-1.80
August	-1.82	-1.27	2.01	-1.52	-1.74
September	-0.53	1.98	-2.07	-1.55	4.99
October	4.44	3.89	-1.68	1.47	1.71

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period indices of ozone exposure appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, had three months of mild and severe drought while the year with the second highest exposure, 1997, had one month of mild drought. The two years with mid-level exposures, 1995 and 1998,

experienced three months of mild and moderate drought and one month of mild drought, respectively. There was one month of mild drought in 1996, the lowest exposure year. The W126 level of ozone exposure also appears to be an inversely related to soil moisture, although the pattern is not consistent. In 1999 when the exposure was the greatest, there were four months of mild and severe drought. There were two months of mild drought in 1998, the year with the second highest exposure. The two years with mid-level exposures, 1997 and 1995, experienced three and four months of mild and moderate drought, respectively. There was one month of mild drought in 1996, the lowest exposure year.

The risk of foliar ozone injury to plants at Weir Farm National Historic Site is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury in high exposure years. Levels of exposure capable of producing foliar injury also occur under conditions of minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, white ash, yellow-poplar, quaking aspen, black cherry, Allegheny blackberry, American elder, and northern fox grape.

NORTHERN GREAT PLAINS NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHERN GREAT PLAINS NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHERN GREAT PLAINS NETWORK

Park	Code	State	Risk		O3 Data
Agate Fossil Beds NM	AGFO	NB	low		kriged
Badlands NP	BADL	SD	low		kriged
Devils Tower NM	DETO	WY	low		kriged
Fort Laramie NHS	FOLA	WY	low		kriged
Fort Union Trading Post NHS	FOUS	ND	low		kriged
Jewel Cave NM	JECA	SD	low		kriged
Knife River Indian Village NHS	KNRI	ND	low		kriged
Missouri NNR	MNRR	SD	low		kriged
Mount Rushmore N MEM	MORUSD	low		kriged	
Niobrara NSR	NIOB	NB	low		kriged
Scotts Bluff NM	SCBL	NB	low		kriged
Theodore Roosevelt NP	THRO	ND	low		monitored
Wind Cave NP	WICA	SD	low		kriged

AGATE FOSSIL BEDS NATIONAL MONUMENT (AGFO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for AGFO					
	1995	1996	1997	1998	1999
Sum06	13	19	14	21	14
W126	18.9	25.8	20.9	34.2	24.4
N60	266	454	309	605	391
N80	19	21	13	53	20
N100	1	1	0	7	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at AGFO					
	1995	1996	1997	1998	1999
Month 1	4.89	1.94	-1.08	5.59	-1.85
Month 2	5.49	1.58	2.62	5.27	-1.01
Month 3	1.74	0.04	0.59	4.13	-1.68

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at AGFO					
	1995	1996	1997	1998	1999
April	1.59	0.38	-0.30	1.45	0.21
May	6.18	2.34	-1.08	5.59	-1.85
June	4.89	1.94	2.62	5.27	-1.01
July	5.49	1.58	0.59	4.13	-1.68
August	1.74	0.04	-0.60	0.14	0.24
September	-0.72	-0.64	-0.07	6.51	-1.44
October	-1.74	-0.29	-1.10	0.66	-1.32

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is generally below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- The similar levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of low soil moisture make it difficult to assess relationships between the levels of ozone and soil moisture. Three months of mild drought occurred in one year, and three years had favorable soil moisture. With this incidence and pattern of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and the Sum06 index of exposure. There appears to be no relationship between the seasonal W126 index of exposure and soil moisture conditions. The highest ozone year, 1998, had favorable soil moisture, while the lowest exposure year, 1995, had one month of

mild drought. A middle ozone year, 1999, had five months of mild drought. There is no relationship between ozone and soil moisture in this pattern of drought.

The risk of foliar ozone injury at Agate Fossil Beds National Monument is low. The Sum06 threshold for injury is satisfied, but the Sum06 criteria are not. The N-value counts indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are unrelated to the level of exposure and conditions in most years favor the uptake of ozone.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

BADLANDS NATIONAL PARK (BADL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BADL					
	1995	1996	1997	1998	1999
Sum06	10	14	12	15	9
W126	16.0	21.4	18.8	28.5	18.0
N60	203	345	266	484	254
N80	14	15	10	39	10
N100	0	0	0	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BADL					
	1995	1996	1997	1998	1999
Month 1	3.16	-0.59	-2.19	-1.32	0.95
Month 2	-1.68	3.49	-1.92	-0.85	6.46
Month 3	7.19	-1.42	2.27	-1.33	0.67

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BADL					
	1995	1996	1997	1998	1999
April	0.87	-0.09	2.62	-1.48	0.95
May	3.16	0.09	-2.19	-1.32	6.46
June	-1.68	-0.59	-1.92	-0.85	0.67
July	7.19	3.49	2.27	-1.33	1.54
August	0.31	-1.42	-0.69	1.38	6.87
September	-0.85	0.67	0.61	-2.52	2.21
October	2.04	0.22	1.10	4.86	-0.86

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index marginally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show a few hours in which concentrations exceeded 80 ppb, and two years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations, when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The low and similar levels of exposure over the five-year period make it difficult to assess the relationship. There were two months of mild drought in 1998 the highest exposure year, and one month of mild drought in 1996 the second highest exposure year. In the years with mid-level exposures, there were two months of mild and moderate drought in1997, and one month of mild drought in 1995. Soil moisture was normal in 1999, the lowest exposure

year. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is again not consistent. There were four months of mild and moderate drought in 1998 the year with the highest exposure, and one month of mild drought in 1996 the year with the second highest exposure. The two years with mid-level exposure had two months of mild and moderate drought in 1997, and normal conditions in 1999. There was one month of mild drought in 1995, the year with the lowest exposure.

The risk of foliar ozone injury at Badlands National Park is low. The thresholds for injury are marginally satisfied for the Sum06 index, but not satisfied for the W126 index of exposure. The N-value counts indicate there are limited exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposures and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or common snowberry.

DEVILS TOWER NATIONAL MONUMENT (DETO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DETO					
	1995	1996	1997	1998	1999
Sum06	8	11	11	11	9
W126	15.4	21.1	20.0	29.9	20.1
N60	169	314	260	488	270
N80	10	10	7	27	6
N100	0	0	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DETO					
	1995	1996	1997	1998	1999
Month 1	1.50	-2.47	3.57	-1.49	0.88
Month 2	6.04	-0.37	0.09	-2.74	4.13
Month 3	1.59	1.48	-1.40	2.33	-0.21

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DETO					
	1995	1996	1997	1998	1999
April	1.50	1.06	3.57	-1.49	4.13
May	6.04	3.38	0.09	-2.74	-0.21
June	1.59	-2.47	-1.40	2.33	3.31
July	3.60	-0.37	4.26	1.15	2.60
August	2.36	1.48	0.17	2.14	2.74
September	0.07	-0.46	-0.60	0.85	0.69
October	5.40	2.52	0.05	9.06	-1.72

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is marginally satisfied. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low and consistent levels of exposure in the five-year period make it difficult to assess relationships between the 90-day Sum06 accumulation period indices of ozone and soil moisture. However, soil moisture levels associated with the Sum06 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The three years with the same, highest exposure index, 1996, 1997 and 1998, each had one or two months of mild or moderate drought. The two years with lower levels of

exposure, 1999 and 1995, had normal levels of soil moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. Only five months of drought occurred over the five-year period. There were two months of mild and moderate drought in the highest ozone year 1998. The three intermediate years had similar levels of exposure and one month of mild or moderate drought occurred in each. There were normal soil moisture conditions in the lowest exposure year, 1995.

The risk of foliar ozone injury at Devils Tower National Monument is low. The threshold levels for injury are marginally satisfied by the Sum06 index, but not by the W126 index. The N-value counts indicate there are few exposures to concentrations of ozone greater than 80 ppb, and exposure to 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and skunkbush.

FORT LARAMIE NATIONAL HISTORIC SITE (FOLA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOLA					
	1995	1996	1997	1998	1999
Sum06	12	19	14	21	15
W126	20.0	27.8	22.2	35.4	25.8
N60	276	496	323	632	414
N80	18	19	12	49	18
N100	1	1	0	6	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOLA					
	1995	1996	1997	1998	1999
Month 1	0.21	-1.35	0.96	-0.94	-1.95
Month 2	7.25	0.03	1.17	0.46	4.11
Month 3	6.41	0.68	0.48	1.51	0.31

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOLA					
	1995	1996	1997	1998	1999
April	0.21	-0.21	0.96	-0.70	4.11
May	7.25	2.05	1.17	-0.94	0.31
June	6.41	-1.35	0.48	0.46	1.58
July	2.39	0.03	2.42	1.51	0.81
August	0.86	0.68	5.46	1.41	0.63
September	4.16	0.44	1.20	-1.30	3.32
October	1.65	0.72	2.30	6.70	-1.53

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than six hours in which the concentration exceeded 100 ppb, and most had only one hour. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The risk of foliar ozone injury at Fort Laramie National Historic Site is low. The threshold levels for injury are satisfied by the Sum06, but not by the W126 index of

exposure. The N-value counts indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are generally favorable for the uptake of ozone, although isolated months of mild drought occur.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or skunkbush.

FORT UNION TRADING POST NATIONAL HISTORIC SITE (FOUS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOUS					
	1995	1996	1997	1998	1999
Sum06	1	1	5	1	1
W126	7.7	9.2	12.3	13.3	8.8
N60	32	61	139	147	54
N80	1	0	4	1	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOUS					
	1995	1996	1997	1998	1999
Month 1	0.92	-0.19	1.98	-2.54	-0.08
Month 2	3.21	0.98	-1.78	-1.85	6.77
Month 3	-2.09	-0.73	-2.39	1.16	0.47

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOUS					
	1995	1996	1997	1998	1999
April	0.92	0.04	1.98	-2.54	-0.08
May	3.21	1.12	-1.78	-1.85	6.77
June	-2.09	-0.19	-2.39	1.16	0.47
July	5.28	0.98	3.99	-1.20	0.62
August	2.25	-0.73	-1.37	-0.15	4.58
September	-0.52	1.46	-2.35	-2.18	1.87
October	0.06	0.04	-0.35	5.76	-0.90

Risk Analysis

- There are a few ozone-sensitive species at the site, however none of them are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations rarely exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years, and no relationships are apparent. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In each of the two highest ozone years, 1998 and 1997, there were four months of mild and moderate drought. In the three remaining years with

lower levels of ozone, there was one month of moderate drought.

The risk of foliar ozone injury at Fort Union Trading Post National Historic Site is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there are rare exposures to concentrations of ozone greater than 80 ppb, and no exposure to 100 ppb.

There are no bioindicators for ozone at the site.

JEWEL CAVE NATIONAL MONUMENT (JECA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias exaltata	Tall milkweed	Asclepiadaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JECA					
	1995	1996	1997	1998	1999
Sum06	8	13	10	14	10
W126	17.8	24.2	20.8	32.2	21.5
N60	226	404	295	560	318
N80	15	17	11	43	13
N100	0	1	0	5	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JECA					
	1995	1996	1997	1998	1999
Month 1	6.17	-1.99	1.66	-0.81	2.81
Month 2	2.72	0.07	-0.92	4.14	-0.54
Month 3	2.63	3.99	5.81	2.45	3.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JECA					
	1995	1996	1997	1998	1999
April	1.63	0.76	2.70	-1.45	2.81
May	6.17	3.79	1.66	-0.81	-0.54
June	2.72	-1.99	-0.92	4.14	3.50
July	2.63	0.07	5.81	2.45	0.32
August	0.03	3.99	2.58	4.47	3.67
September	0.67	1.88	1.03	2.09	0.46
October	4.16	6.49	0.69	8.42	-1.44

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure at Jewel Cave National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels

for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposures above 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, tall milkweed, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

KNIFE RIVER INDIAN VILLAGE NATIONAL HISTORIC SITE (KNRI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for KNRI					
	1995	1996	1997	1998	1999
Sum06	1	1	3	2	2
W126	6.3	7.1	9.0	10.4	6.5
N60	15	22	86	82	41
N80	0	0	0	0	1
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at KNRI					
	1995	1996	1997	1998	1999
Month 1	0.92	-0.19	1.98	-0.95	-0.16
Month 2	3.21	0.98	-1.78	-2.54	-0.08
Month 3	-2.09	-0.73	-2.39	-1.85	6.77

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at KNRI					
	1995	1996	1997	1998	1999
April	0.92	0.04	1.98	-2.54	-0.08
May	3.21	1.12	-1.78	-1.85	6.77
June	-2.09	-0.19	-2.39	1.16	0.47
July	5.28	0.98	3.99	-1.20	0.62
August	2.25	-0.73	-1.37	-0.15	4.58
September	-0.52	1.46	-2.35	-2.18	1.87
October	0.06	0.04	-0.35	5.76	-0.90

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only one hour in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low levels of ozone during the 90-day Sum06 accumulation periods preclude assessing relationships between the levels of ozone and soil moisture. Relationships between the seasonal W126 index of exposure and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The highest ozone years, 1998 and 1997, each experienced four

months of mild and moderate drought. The three years with lower levels of ozone exposure experienced favorable soil moisture conditions with only one month of drought among them.

The risk of foliar ozone injury at Knife River Indian Village National Historic Site is low. The threshold levels for injury are not satisfied by either the Sum06 or W126 indices of exposure. The N-value counts indicate there was only one hour of exposure to concentrations of ozone greater than 80 ppb, and no exposure to 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, and quaking aspen.

MISSOURI NATIONAL RECREATION RIVER (MNRR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Sambucus canadensis	American elder	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MNRR					
	1995	1996	1997	1998	1999
Sum06	2	1	4	3	5
W126	10.4	6.5	9.7	9.7	10.3
N60	149	69	136	133	137
N80	19	6	6	10	8
N100	2	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MNRR					
	1995	1996	1997	1998	1999
Month 1	4.84	-0.28	1.22	3.14	4.46
Month 2	-1.96	-1.13	-0.94	-1.50	0.29
Month 3	-1.14	3.33	-0.69	3.45	4.93

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MNRR					
	1995	1996	1997	1998	1999
April	3.32	-1.13	1.75	3.14	4.46
May	4.84	3.33	1.22	-1.50	0.29
June	-1.96	-0.75	-0.94	3.45	4.93
July	-1.14	1.47	-0.69	1.81	2.36
August	2.70	2.57	-0.85	3.32	0.15
September	2.45	2.17	0.87	-2.45	-1.87
October	2.92	-0.47	1.41	3.82	-1.78

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. Exposure indices were similar over the five-year period. The two highest exposure years, 1999 and 1997, had favorable soil moisture throughout, while the remaining three years each experienced one or two months of drought. Collectively, there is no relationship between the levels of ozone and soil moisture conditions. The seasonal W126 exposure indices were similar over the five-year period making it difficult to assess relationships between ozone exposure and soil moisture. However, soil moisture levels appear to be inversely related to ozone concentrations: when

ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. Years with the highest and second highest exposure indices, 1995 and 1999, each experienced two months of mild drought. Years with two slightly lower levels of exposure had either favorable conditions or two months of drought, while the lowest exposure year, 1996, had one month of mild drought.

The low levels of ozone exposure at Missouri National Recreation River make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there are some hours with concentrations of ozone above 80 ppb, the numbers are not high and concentrations of 100 ppb are rare. The apparent inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone and further reduces the likelihood that the exposures will produce foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, American elder, and common snowberry.

MOUNT RUSHMORE NATIONAL MEMORIAL (MORU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MORU					
	1995	1996	1997	1998	1999
Sum06	7	11	8	11	8
W126	17.0	22.9	20.1	30.6	19.8
N60	210	374	282	526	285
N80	14	16	11	40	11
N100	0	1	0	4	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MORU					
	1995	1996	1997	1998	1999
Month 1	6.17	-1.99	1.66	-0.81	2.81
Month 2	2.72	0.07	-0.92	4.14	-0.54
Month 3	2.63	3.99	5.81	2.45	3.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MORU					
	1995	1996	1997	1998	1999
April	1.63	0.76	2.70	-1.45	2.81
May	6.17	3.79	1.66	-0.81	-0.54
June	2.72	-1.99	-0.92	4.14	3.50
July	2.63	0.07	5.81	2.45	0.32
August	0.03	3.99	2.58	4.47	3.67
September	0.67	1.88	1.03	2.09	0.46
October	4.16	6.49	0.69	8.42	-1.44

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation, but some levels are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had four hours in which the concentration exceeded 100 ppb while the others had one or none. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Mount Rushmore National Memorial make the risk of foliar ozone injury to plants low. While

the Sum06 exposures marginally exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are only a few hours with concentrations of ozone above 80 ppb, and no year has more than four hours greater than 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and common snowberry.

NIOBRARA NATIONAL SCENIC RIVER (NIOB)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Sambucus canadensis	American elder	Caprifoliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NIOB					
	1995	1996	1997	1998	1999
Sum06	2	1	4	3	5
W126	10.4	6.5	9.7	9.7	10.3
N60	149	69	136	133	137
N80	19	6	6	10	8
N100	2	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NIOB					
	1995	1996	1997	1998	1999
Month 1	7.22	-0.37	0.22	0.65	4.09
Month 2	0.20	-0.45	-0.77	0.26	0.51
Month 3	0.31	4.42	2.54	4.63	3.22

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NIOB					
	1995	1996	1997	1998	1999
April	5.00	-0.45	2.53	0.65	4.09
May	7.22	4.42	0.22	0.26	0.51
June	0.20	-1.28	-0.77	4.63	3.22
July	0.31	0.17	2.54	2.50	1.45
August	-0.23	1.58	1.13	1.75	-0.86
September	3.17	5.40	1.46	-1.16	1.50
October	4.41	0.72	3.84	5.12	-1.79

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods were normal and favored the uptake of ozone. There were no months of drought stress in the five-year assessment period. Relationships between the seasonal W126 index of exposure and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years and there were only three months of drought stress. There does not appear to be any association between the W126 levels of ozone and drought.

The low levels of ozone exposure at Niobrara National Scenic River make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there are some hours with concentrations of ozone above 80 ppb, the numbers are not high and concentrations of 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, American elder, and common snowberry.

SCOTTS BLUFF NATIONAL MONUMENT (SCBL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SCBL					
	1995	1996	1997	1998	1999
Sum06	13	18	13	20	14
W126	18.2	24.7	20.1	33.2	23.7
N60	259	431	300	585	380
N80	19	21	13	54	20
N100	1	1	0	7	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SCBL					
	1995	1996	1997	1998	1999
Month 1	2.56	-1.69	0.85	-1.67	-1.79
Month 2	5.38	0.56	1.61	0.47	4.74
Month 3	4.76	4.46	0.78	2.20	-0.17

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SCBL					
	1995	1996	1997	1998	1999
April	2.56	-0.83	0.85	-1.62	4.74
May	5.38	2.94	1.61	-1.67	-0.17
June	4.76	-1.69	0.78	0.47	2.73
July	2.56	0.56	1.75	2.20	2.03
August	1.61	4.46	1.67	0.58	2.16
September	1.03	3.76	-0.40	-1.58	4.01
October	2.89	0.81	2.96	6.50	-1.56

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had seven hours in which the concentration exceeded 100 ppb, but in most years there was one hour. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only three months of mild drought over the five-year period, and no association is apparent. Although there were only five months of mild drought during the W126 assessment period, soil moisture levels appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the highest ozone year, 1998, there were three months of mild drought, and one month in each of the

two next highest ozone years, 1996 and 1999. Soil moisture was favorable throughout the two lowest ozone years.

The low levels of ozone exposure at Scotts Bluff National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours of exposure with concentrations above 80 ppb, but exposure above 100 ppb is rare. In addition, drought in the higher exposure years constrains the uptake of ozone and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, ponderosa pine, skunkbush, and common snowberry.

THEODORE ROOSEVELT NATIONAL PARK (THRO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for THRO					
	1995	1996	1997	1998	1999
Sum06	1	2	10	1	-
W126	7.7	8.5	14.6	-	9.7
N60	19	30	178	-	25
N80	0	0	8	-	0
N100	0	0	0	-	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at THRO					
	1995	1996	1997	1998	1999
Month 1	0.77	-1.69	4.10	-2.19	-0.98
Month 2	5.04	0.37	-1.36	-2.11	0.08
Month 3	-1.74	-0.99	-1.85	2.59	3.36

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at THRO					
	1995	1996	1997	1998	1999
April	0.77	-0.57	4.10	-2.19	0.45
May	5.04	2.69	-1.36	-2.11	3.27
June	-1.74	-1.69	-1.85	2.59	-0.98
July	4.47	0.37	4.94	-1.29	0.08
August	4.32	-0.99	0.17	2.01	3.36
September	-1.19	2.89	-2.10	-0.86	1.97
October	0.40	-0.28	-0.36	7.46	-0.88

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low levels of ozone and one year of missing data make it difficult to assess relationships between the 90-day Sum06 accumulation period levels of ozone and soil moisture. Each year had one or two months of mild to moderate drought, and no relationships between ozone and soil moisture are evident. Although he seasonal W126 index of exposure shows greater range of values, one year of missing data makes it difficult to accurately assess relationships. The exposure index in 1997 was considerably greater than the other indices, and the year experienced three months of mild and moderate drought. The year with the lowest index, 1995, had two months of mild drought. The two intermediate years had favorable conditions and one month of mild drought. Overall, there is no clear relationship between ozone exposure and soil moisture conditions.

The low levels of ozone exposure at Theodore Roosevelt National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied, and in only one year did concentrations of ozone exceed 80 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and common snowberry.

WIND CAVE NATIONAL PARK (WICA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WICA					
	1995	1996	1997	1998	1999
Sum06	9	14	10	15	10
W126	17.8	24.2	20.6	32.1	21.6
N60	231	408	295	560	324
N80	16	17	11	45	14
N100	0	1	0	5	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WICA					
	1995	1996	1997	1998	1999
Month 1	6.17	-1.99	1.66	-0.81	2.81
Month 2	2.72	0.07	-0.92	4.14	-0.54
Month 3	2.63	3.99	5.81	2.45	3.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WICA					
	1995	1996	1997	1998	1999
April	1.63	0.76	2.70	-1.45	2.81
May	6.17	3.79	1.66	-0.81	-0.54
June	2.72	-1.99	-0.92	4.14	3.50
July	2.63	0.07	5.81	2.45	0.32
August	0.03	3.99	2.58	4.47	3.67
September	0.67	1.88	1.03	2.09	0.46
October	4.16	6.49	0.69	8.42	-1.44

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb, and two years had no hours. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day and seasonal accumulation periods were generally normal and favored the uptake of ozone. In the five-year W126 assessment period, soil moisture was at mild drought for a total of three months.

The low levels of ozone exposure at Wind Cave National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of

hours of exposure with concentrations above 80 ppb, but exposure above 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, ponderosa pine, quaking aspen, skunkbush, and common snowberry.

NORTHERN SEMI-ARID NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE NORTHERN SEMI-ARID NETWORK

October 2001

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE NORTHERN-SEMI ARID NETWORK

Park	Code	State	Risk	O3 Data
Big Hole NB	BIHO	MT	low	kriged
City of Rocks N RES	CIRO	ID	moderate	kriged
Craters of the Moon NHP	CRMO	ID	low	monitored
Hagerman Fossil Beds NM	HAFO	ID	low	kriged
John Day Fossil Beds NM	JODA	OR	low	kriged
Nez Perce NHP	NEPE	ID	low	kriged
Whitman Mission NHS	WHMI	WA	low	kriged

BIG HOLE NATIONAL BATTLEFIELD (BIHO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicacea

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BIHO					
	1995	1996	1997	1998	1999
Sum06	5	13	7	13	13
W126	13.6	19.5	13.2	22.1	20.8
N60	130	267	137	296	274
N80	13	22	6	26	8
N100	2	3	1	4	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BIHO					
	1995	1996	1997	1998	1999
Month 1	-1.20	-0.18	1.57	-0.86	-1.61
Month 2	3.04	2.69	0.34	-0.51	-1.81
Month 3	2.82	3.10	0.76	4.18	-1.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BIHO					
	1995	1996	1997	1998	1999
April	3.76	0.19	1.27	0.43	-0.25
May	1.84	3.87	0.15	0.07	1.20
June	2.83	-2.69	1.89	4.35	-0.26
July	4.77	-1.51	3.81	1.95	-2.53
August	2.44	-2.21	2.95	-0.40	1.55
September	0.59	-1.27	0.20	-1.48	-2.24
October	1.76	-0.44	2.10	-0.81	-2.63

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Three years, 1996, 1998 and 1999, had the same highest Sum06 index of exposure. Soil moisture was normal in 1996 and 1998, and there were three months of mild drought in 1999. The remaining two years had one month of mild drought between them. No relationship is apparent between the W126 index of exposure and soil moisture. The year with the highest exposure, 1998, experienced one month of mild drought, while the second highest year, 1999, had three months of moderate drought. The mid-level exposure year 1996 had four months of mild

and moderate drought, and the two lowest exposure years had normal soil moisture conditions.

The risk of foliar ozone injury at Big Hole National Battlefield is low. The threshold levels for injury are not consistently satisfied by the Sum06 and not satisfied by the W126 index of exposure. The N-value counts indicate there are a few hours of exposure to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are not associated with ozone exposure, however some years have periods of drought that significantly constrain uptake and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: ponderosa pine and quaking aspen.

CITY OF ROCKS NATIONAL RESERVE (CIRO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CIRO					
	1995	1996	1997	1998	1999
Sum06	9	19	10	17	16
W126	18.8	28.1	16.4	28.5	24.4
N60	247	470	246	449	388
N80	28	57	16	76	31
N100	4	7	2	12	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CIRO					
	1995	1996	1997	1998	1999
Month 1	0.19	-2.20	0.21	3.20	0.83
Month 2	2.43	-0.51	0.47	2.83	0.88
Month 3	2.00	-2.41	3.63	2.05	1.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CIRO					
	1995	1996	1997	1998	1999
April	0.19	-0.22	0.90	-0.14	1.85
May	2.43	4.64	0.21	3.20	2.45
June	2.00	-2.20	0.47	2.83	0.83
July	2.37	-0.51	3.63	2.05	0.88
August	0.46	-2.41	2.75	0.21	1.35
September	-0.93	-0.24	2.12	1.60	-1.12
October	-0.68	-0.25	0.47	-0.14	-1.84

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had twelve hours in which the concentration exceeded 100 ppb. The highest levels of exposure may injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the Sum06 assessment, there were two months of moderate drought stress in the year with the highest exposure, 1996, while the remaining four years had normal soil moisture. No associations between ozone and soil moisture can be discerned from these observations. Soil moisture levels associated with the seasonal W126 index of exposure were generally normal and favored the uptake of ozone. In

1996 and 1998, years with similar high exposures, there were two months of moderate drought and normal soil moisture conditions, respectively. The mid-level exposure year 1999 had two months of mild drought, and the lowest exposure years 1995 and 1997 had normal soil moisture. No clear relationship between ozone exposure and soil moisture can be derived from this pattern.

The risk of foliar ozone injury at City of Rocks National Reserve is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, and there are a few years in which the W126 criteria are fulfilled. Since there is no association between levels of ozone and soil moisture, conditions favorable for the uptake of ozone can occur at all levels of exposure. This creates the opportunity for reaching the threshold for injury at both high and more moderate levels of ambient ozone. The risk of injury is greatest in years such as 1998 when the ambient level of ozone is high, and soil moisture conditions favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: quaking aspen and Scouler's willow.

CRATERS OF THE MOON NATIONAL HISTORIC PARK (CRMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CRMO					
	1995	1996	1997	1998	1999
Sum06	1	12	2	10	11
W126	12.2	19.9	9.8	22.7	5.4
N60	20	223	40	267	234
N80	0	5	0	0	2
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CRMO					
	1995	1996	1997	1998	1999
Month 1	1.12	-1.49	-0.05	3.52	1.91
Month 2	4.49	-0.21	1.05	3.11	1.12
Month 3	7.03	-1.66	3.38	2.15	1.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CRMO					
	1995	1996	1997	1998	1999
April	1.12	0.30	1.04	-0.26	2.33
May	4.49	2.95	-0.05	3.52	3.61
June	7.03	-1.49	1.05	3.11	1.91
July	5.41	-0.21	3.38	2.15	1.12
August	3.05	-1.66	3.01	-0.99	1.52
September	-0.15	0.41	1.59	1.92	-1.66
October	-0.71	-0.55	0.60	-0.70	-1.57

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value generally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only two years in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels were generally normal and favored the uptake of ozone. Four months of mild drought were distributed among two of the years. With this incidence of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and either the 90-day cumulative Sum06 or the seasonal W126 index of exposure.

The low levels of ozone exposure at Craters of the Moon National Historic Park make the risk of foliar ozone injury to plants low. The Sum06 exposures intermittently exceed the threshold for injury, but the W126 exposures do not since the N100 criterion is not satisfied. While soil moisture levels are generally favorable for the uptake of ozone, ambient levels of exposure are such that the threshold for foliar injury is not likely to be reached.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen, and Scouler's willow.

HAGERMAN FOSSIL BEDS NATIONAL MONUMENT (HAFO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HAFO					
	1995	1996	1997	1998	1999
Sum06	7	17	8	15	14
W126	16.8	25.8	14.8	27.1	24.7
N60	177	398	192	402	350
N80	19	43	12	56	24
N100	2	5	1	9	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HAFO					
	1995	1996	1997	1998	1999
Month 1	0.40	1.24	0.01	6.72	1.70
Month 2	4.41	1.59	2.75	3.71	1.48
Month 3	5.76	-0.74	2.18	3.27	1.01

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HAFO					
	1995	1996	1997	1998	1999
April	0.40	0.19	1.56	-0.28	2.30
May	4.41	3.91	0.01	6.72	2.04
June	5.76	1.24	2.75	3.71	1.70
July	4.57	1.59	2.18	3.27	1.48
August	1.04	-0.74	1.02	0.10	1.01
September	-0.10	-0.94	1.43	2.39	-1.39
October	-0.63	0.16	0.31	-1.40	-1.47

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb; the second highest year had five hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the five-year Sum06 assessment, there were no months of drought. Soil moisture levels during the W126 accumulation periods were also generally normal. In the five-year period, soil moisture was at mild drought for one month in the highest ozone year 1998, and for two months in a mid-level ozone year 1999.

The risk of foliar ozone injury at Hagerman Fossil Beds National Monument is low. The threshold level for injury is satisfied by the Sum06 index, and there is one year in which

the W126 criteria are fulfilled. Since there is no association between levels of ozone and soil, conditions favorable for the uptake of ozone can occur at all levels of exposure. The risk of injury is greater in years such as 1998 when ambient levels of ozone are high, and soil moisture conditions favor uptake by the plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator species skunkbush.

JOHN DAY FOSSIL BEDS NATIONAL MONUMENT (JODA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JODA					
	1995	1996	1997	1998	1999
Sum06	3	9	3	6	4
W126	6.7	11.2	4.9	6.6	5.9
N60	85	152	47	87	69
N80	10	37	1	16	3
N100	2	9	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JODA					
	1995	1996	1997	1998	1999
Month 1	0.60	1.10	-1.42	1.66	-0.70
Month 2	2.16	1.15	1.82	4.03	-0.56
Month 3	3.04	-0.32	-0.47	0.10	-0.12

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JODA					
	1995	1996	1997	1998	1999
April	2.61	0.87	1.82	0.43	0.51
May	0.60	2.62	-0.47	7.10	-0.70
June	2.16	1.10	0.70	1.66	-0.56
July	3.04	1.15	1.94	4.03	-0.12
August	0.26	-0.32	0.28	0.10	2.16
September	-0.75	-0.19	0.41	0.52	-1.69
October	-1.33	-0.17	-0.15	-1.11	-0.17

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value marginally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb; the second highest year had three hours. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods were normal and favored the uptake of ozone. In the five-year assessment period, soil moisture was at mild drought for one month. Soil moisture levels during the seasonal W126 accumulation periods were also generally normal. One month of mild drought occurred in each of three years without any association with the level of ozone exposure.

The low levels of ozone exposure at John Day Fossil Beds National Monument make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. Concentrations over 100 ppb are rare, but one year has a higher number of hours. Since there is no association between levels of ozone and soil, conditions favorable for the uptake of ozone can occur at all levels of exposure. The risk of injury is greatest in years such as 1998 when ambient levels of ozone are higher, and soil moisture conditions favor uptake by plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator ponderosa pine.

NEZ PERCE NATIONAL HISTORIC PARK (NEPE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Artemisia douglasiana	Mugwort	Asteraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NEPE					
	1995	1996	1997	1998	1999
Sum06	2	5	1	5	5
W126	8.9	11.7	7.3	11.4	10.1
N60	82	141	57	142	113
N80	6	13	3	9	3
N100	1	2	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NEPE					
	1995	1996	1997	1998	1999
Month 1	1.96	-1.51	-0.97	2.75	-0.32
Month 2	-0.40	-1.07	-0.83	-0.18	0.47
Month 3	1.86	-1.60	3.60	1.47	-2.07

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NEPE					
	1995	1996	1997	1998	1999
April	1.96	3.41	3.34	0.51	-0.85
May	-0.40	4.08	-0.97	3.85	-0.52
June	1.86	-1.51	-0.83	1.09	0.61
July	4.77	-1.07	3.60	2.75	-0.32
August	3.90	-1.60	1.24	-0.18	0.47
September	-0.07	0.09	1.03	1.47	-2.07
October	3.42	0.99	0.85	-0.37	0.01

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low and similar levels of ozone during the 90-day Sum06 and the seasonal W126 accumulation periods and the infrequent occurrence of low soil moisture make it impossible to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. During the five-year W126 assessment period, there were four months of drought; three in one year and one in another. The periods of drought were not associated with the levels of ozone exposure in these years.

The low levels of ozone exposure at Nez Perce National Park make the risk of foliar

ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. There are some hours of exposure to concentrations of ozone above 80 ppb, however the numbers are not high. Exposure to concentrations over 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, mugwort, ponderosa pine, and common snowberry.

WHITMAN MISSION NATIONAL HISTORIC SITE (WHMI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WHMI					
	1995	1996	1997	1998	1999
Sum06	2	5	1	5	4
W126	7.8	10.3	6.4	8.2	7.7
N60	93	137	59	110	91
N80	9	21	4	13	3
N100	1	4	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WHMI					
	1995	1996	1997	1998	1999
Month 1	1.92	2.09	0.82	-1.50	-0.84
Month 2	3.02	2.94	1.15	0.59	-1.87
Month 3	3.86	-0.63	2.52	-1.35	-0.72

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WHMI					
	1995	1996	1997	1998	1999
April	3.17	1.32	1.15	-1.24	-1.92
May	1.92	2.75	2.52	0.86	-0.84
June	3.02	2.09	2.23	-1.50	-1.87
July	3.86	2.94	3.14	0.59	-0.72
August	0.76	-0.63	0.45	-1.35	0.12
September	1.54	-0.18	0.50	-1.40	-1.76
October	0.42	1.88	2.40	-1.58	-0.51

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is marginally above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Low and similar levels of ozone during the Sum06 accumulation periods and only three months of mild drought over five years make it difficult to assess relationships between the levels of ozone and soil moisture, and no pattern is evident. In the W126 assessment period, drought was concentrated in two years: five months in 1998, the second highest year, and three months in 1999, the second lowest year. Ozone exposures over the five-year period were relatively similar, and no association between ozone and drought can be discerned.

The low levels of ozone exposure at Whitman Mission National Historic Site make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. There are some hours of exposure to concentrations of ozone above 80 ppb, however the numbers are not high. Exposure to concentrations over 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: American sycamore, quaking aspen, and common snowberry.

PACIFIC ISLAND NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE PACIFIC ISLAND NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

It was not possible to assess risk for sites in the Pacific Island Network since ozone was neither monitored nor kriged for them, and Palmer Z values are not calculated for the region.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE PACIFIC ISLAND NETWORK

Park	Code	State	Risk	O3 Data
American Memorial Park	AMME	MP	cannot eval	no data
Haleakala NP	HALE	HI	cannot eval	no data
Hawaii Volcanoes NP	HAVO	HI	cannot eval	no data
Kalaupapa NHP	KALA	HI	cannot eval	no data
Kaloko-Honokohau NHP	KAHO	HI	cannot eval	no data
National Park of American Samoa	NPSA	AS	cannot eval	no data
Pu'uhonua o Honaunau NHP	PUHO	HI	cannot eval	no data
Puukohola Heiau NHS	PUHE	HI	cannot eval	no data
War in the Pacific NHP	WAPA	GU	cannot eval	no data

AMERICAN MEMORIAL PARK (AMME)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at American Memorial Park cannot be assessed due to the lack of information on ozone exposure at the site.

HALEAKALA NATIONAL PARK (HALE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus banksiana	Jack pine	Pinaceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Pinus radiata	Monterey pine	Pinaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Haleakala National Park cannot be assessed due to the lack of information on ozone exposure at the site.

HAWAII VOLCANOES NATIONAL PARK (HAVO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Pinus radiata	Monterey pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Hawaii Volcanoes National Park cannot be assessed due to the lack of information on ozone exposure at the site.

KALAUPAPA NATIONAL HISTORIC PARK (KALA)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Kalaupapa National Historic Park cannot be assessed due to the lack of information on ozone exposure at the site.

KALOKO-HONOKOHUA NATIONAL HISTORIC PARK (KAHO)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Kaloko-Honokohua National Historic Park cannot be assessed due to the lack of information on ozone exposure at the site.

NATIONAL PARK OF AMERICAN SAMOA (NPSA)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at National Park of American Samoa cannot be assessed due to the lack of information on ozone exposure at the site.

PU'UHONUA O HONAUNAU NATIONAL HISTORIC PARK (PUHO)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Pu'uhonua O Honaunau National Historic Park cannot be assessed due to the lack of information on ozone exposure at the site.

PUUKOHOLA HEIAU NATIONAL HISTORIC PARK (PUHE)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Puukohola Heiau National Historic Park cannot be assessed due to the lack of information on ozone exposure at the site.

WAR IN THE PACIFIC NATIONAL HISTORIC PARK (WAPA)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Pacific islands.

Risk Analysis

The risk of ozone injury on foliage of vegetation at War in the Pacific National Historic Park cannot be assessed due to the lack of information on ozone exposure at the site.

ROCKY MOUNTAIN NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE ROCKY MOUNTAIN NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE ROCKY MOUNTAIN NETWORK

Park	Code	State	Risk	O3 Data
Florissant Fossil Beds NM	FLFO	CO	low	kriged
Glacier NP	GLAC	MT	low	monitored
Grant-Kohrs Ranch NHS	GRKO	MT	low	kriged
Great Sand Dunes NM	GRSA	CO	low	kriged
Little Bighorn Battlefield NM	LIBI	MT	low	kriged
Rocky Mountain NP	ROMO	CO	low	monitored

FLORISSANT FOSSIL BEDS NATIONAL MONUMENT (FLFO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FLFO					
	1995	1996	1997	1998	1999
Sum06	8	11	7	11	8
W126	13.5	16.1	15.6	25.5	19.2
N60	191	250	229	403	287
N80	14	24	13	51	21
N100	1	1	0	7	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FLFO					
	1995	1996	1997	1998	1999
Month 1	5.31	0.86	-0.65	0.67	1.58
Month 2	1.79	1.08	3.47	5.84	1.70
Month 3	0.89	0.32	3.35	1.81	3.00

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FLFO					
	1995	1996	1997	1998	1999
April	3.79	-0.69	3.50	2.92	7.48
May	7.46	1.38	-0.65	-0.85	1.58
June	5.31	0.86	3.47	0.67	1.70
July	1.79	1.08	3.35	5.84	3.00
August	0.89	0.32	6.34	1.81	5.30
September	3.10	3.91	2.47	-0.80	2.21
October	-0.26	-0.55	3.49	2.04	-0.11

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation although the values are marginal. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 and the seasonal W126 accumulation periods were normal and favored the uptake of ozone. In the five-year assessment period, there were no months of drought.

The risk of foliar ozone injury to plants at Florissant Fossil Beds National Monument is low. While the Sum06 threshold is marginally satisfied, W126 exposure criteria are not. Soil moisture conditions are consistently normal. Even when moisture conditions do not

constrain the uptake of ozone, the levels of exposure are below those likely to produce foliar injury. The occurrence of somewhat higher levels of ozone exposure, such as in 1998, could increase the possibility of injury in a given year.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use spreading dogbane and quaking aspen.

GLACIER NATIONAL PARK (GLAC)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GLAC					
	1995	1996	1997	1998	1999
Sum06	0	2	0	1	1
W126	2.7	5.4	2.3	5.6	9.7
N60	4	30	0	23	20
N80	0	0	0	0	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GLAC					
	1995	1996	1997	1998	1999
Month 1	-	2.69	-	-0.86	-1.61
Month 2	-	3.10	-	-0.51	-1.81
Month 3	-	-1.06	-	4.18	-1.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GLAC					
	1995	1996	1997	1998	1999
April	0.09	2.69	1.57	-0.51	-1.81
May	-1.20	3.10	0.34	4.18	-1.48
June	3.04	-1.06	0.76	3.18	-0.07
July	2.82	-0.70	1.82	3.01	-0.68
August	1.28	-0.88	0.68	0.04	-0.20
September	1.13	0.03	0.18	-1.15	-2.05
October	2.86	0.08	0.97	-1.30	0.46

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold in one year, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show no concentrations greater than 60 ppb. These levels of exposure are unlikely to injure vegetation.

- The low levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of low soil moisture make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. Although the W126 indices of exposure are low, soil moisture levels appear inversely related to the ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The highest ozone year, 1999, had three months of mild and moderate drought, and the second highest year, 1998, had two months of mild drought. Two intermediate years, 1996 and 1995, each had one month of mild drought, and the lowest ozone year, 1997, had favorable conditions. While an inverse relationship appears to exist, the limited range of the W126 ozone indices and the relatively few months of drought make the analysis uncertain.

The low levels of ozone exposure at Glacier National Park make the risk of foliar ozone injury to plants low. The Sum06 and W126 exposures indices do not exceed the threshold levels for injury, and there are no hours of exposure greater than 60 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, Scouler's willow, and common snowberry.

GRANT-KOHRS RANCH NATIONAL HISTORIC SITE (GRKO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GRKO					
	1995	1996	1997	1998	1999
Sum06	2	8	3	7	9
W126	11.9	17.2	12.2	19.8	19.1
N60	109	225	120	255	250
N80	11	16	5	19	6
N100	1	2	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRKO					
	1995	1996	1997	1998	1999
Month 1	-1.20	-0.18	1.57	-0.86	-1.61
Month 2	3.04	2.69	0.34	-0.51	-1.81
Month 3	2.82	3.10	0.76	4.18	-1.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRKO					
	1995	1996	1997	1998	1999
April	0.09	2.69	1.57	-0.51	-1.81
May	-1.20	3.10	0.34	4.18	-1.48
June	3.04	-1.06	0.76	3.18	-0.07
July	2.82	-0.70	1.82	3.01	-0.68
August	1.28	-0.88	0.68	0.04	-0.20
September	1.13	0.03	0.18	-1.15	-2.05
October	2.86	0.08	0.97	-1.30	0.46

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of low soil moisture make it difficult to assess relationships between ozone and soil moisture. Although there were three months of mild drought in the highest ozone year 1999, there was only one month of drought among the other four years. No association between ozone and drought is apparent from this pattern of distribution. Relationships between the seasonal W126 index of exposure and soil moisture are also difficult to assess because the levels of ozone were relatively similar over the five-year period. There is, however, some indication of an inverse relationship: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the

effectiveness of the higher exposures in producing foliar injury. In the three highest ozone years, 1998, 1999 and 1996, there were two, three and one month, respectively, of mild and moderate drought. The two lowest ozone years had one month of mild drought between them.

The risk of foliar ozone injury to plants at Grant-Kohrs Ranch National Historic Site is low. The Sum06 and W126 exposure criteria are not satisfied, and there are only a few hours of exposure each year to ozone concentrations greater than 80 ppb. Soil moisture conditions generally favor the uptake of ozone and months of drought are rare and mild. Even with these favorable soil conditions, the levels of exposure are unlikely to produce foliar ozone injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use quaking aspen.

GREAT SAND DUNES NATIONAL MONUMENT (GRSA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Oenothera elata	Evening primrose	Onagraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GRSA					
	1995	1996	1997	1998	1999
Sum06	7	11	8	11	9
W126	14.9	19.4	17.3	29.2	23.3
N60	194	301	254	499	372
N80	12	21	11	48	23
N100	1	1	0	6	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRSA					
	1995	1996	1997	1998	1999
Month 1	4.95	-1.34	1.38	-1.00	4.22
Month 2	2.83	-1.12	2.40	-0.19	3.32
Month 3	1.48	-0.05	1.46	3.61	2.88

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRSA					
	1995	1996	1997	1998	1999
April	1.32	-0.80	1.07	0.68	4.22
May	2.98	-3.06	1.38	-1.00	3.32
June	4.95	1.23	2.40	-0.19	2.88
July	2.83	-1.34	1.46	3.61	5.04
August	1.48	-1.12	1.90	0.38	5.61
September	1.94	-0.05	4.45	-0.59	2.33
October	-2.17	1.83	1.00	5.09	-1.71

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation, although the levels are marginal. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between both the 90-day Sum06 and seasonal W126 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years and the occurrence of drought limited. The two years with the highest ozone levels, 1998 and 1996, had one and two months of mild drought. Soil moisture was normal in the other years. There does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. This is a consequence of the scattered

distribution of months of drought over the five-year period. In 1998 when ozone exposure was highest and in 1995 when ozone was the lowest, there was one month of mild or moderate drought each year. The second highest ozone year, 1999, also had one month of drought. The mid-level ozone years, 1996 and 1997, had, respectively, three months of mild and severe drought and normal soil moisture. Overall, there is no association between the W126 index of exposure and soil moisture.

The risk of foliar ozone injury to plants at Great Sand Dunes National Monument is low. While the Sum06 threshold is marginally satisfied, the W126 exposure criteria are not. There are only a few hours of exposure each year to ozone concentrations greater than 80 ppb, and exposure to 100 ppb is generally rare. There is no apparent relationship between ozone exposure and soil moisture, and most years have generally favorable soil moisture conditions. When soil moisture is favorable and ozone exposures levels are slightly elevated, such as in 1998, the possibility of foliar ozone injury, while still low, is greatest.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, evening primrose, ponderosa pine, quaking aspen, skunkbush, cut-leaf coneflower, and Scouler's willow.

LITTLE BIGHORN BATTLEFIELD NATIONAL MONUMENT (LIBI)

Plant Species Sensitive to Ozone

Very Sensitive Species

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Rhus trilobata	Skunkbush	Anacardiaceae.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LIBI					
	1995	1996	1997	1998	1999
Sum06	4	10	8	10	12
W126	14.2	20.3	18.0	26.8	23.1
N60	123	279	199	390	309
N80	7	7	4	13	3
N100	1	0	0	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LIBI					
	1995	1996	1997	1998	1999
Month 1	2.56	-1.74	-0.29	1.32	-2.52
Month 2	2.03	-0.15	2.26	-0.55	2.25
Month 3	4.97	-2.09	0.71	-2.70	-0.75

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LIBI					
	1995	1996	1997	1998	1999
April	3.08	0.23	2.26	-0.55	2.25
May	2.56	4.88	0.71	-2.70	-0.75
June	2.03	-1.74	2.52	3.42	-0.90
July	4.97	-0.15	6.60	1.71	-1.50
August	2.45	-2.09	4.23	0.65	1.11
September	0.10	0.13	-0.32	-1.29	-0.66
October	1.67	0.13	1.38	0.23	-2.13

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and two years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the three highest ozone exposure values, 1999, 1996 and 1998, experienced one, two and one month of mild to severe drought, respectively. The two years with the lowest ozone exposure, 1996 and 1997, had favorable soil moisture conditions. Soil

moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The three highest ozone years, 1998, 1999 and 1996, each had two months of mild and moderate drought. The two lowest ozone years had normal soil moisture throughout.

The low levels of ozone exposure at Little Bighorn Battlefield National Monument make the risk of foliar ozone injury to plants low. The Sum06 exposure index exceeds the threshold for injury, but the W126 index does not. The number of hours of exposure greater than 80 ppb is very low, and only two hours of exposure greater than 100 ppb occur during the five-year period. Soil moisture conditions in the higher exposure years constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, common milkweed, and skunkbush.

ROCKY MOUNTAIN NATIONAL PARK (ROMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ROMO					
	1995	1996	1997	1998	1999
Sum06	15	24	10	28	13
W126	29.1	37.0	28.7	47.0	6.9
N60	331	566	388	843	431
N80	21	21	8	36	15
N100	0	0	0	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ROMO					
	1995	1996	1997	1998	1999
Month 1	5.31	0.86	3.50	-0.85	1.58
Month 2	1.79	1.08	-0.65	0.67	1.70
Month 3	0.89	0.32	3.47	5.84	3.00

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ROMO					
	1995	1996	1997	1998	1999
April	3.79	-0.69	3.50	2.92	7.48
May	7.46	1.38	-0.65	-0.85	1.58
June	5.31	0.86	3.47	0.67	1.70
July	1.79	1.08	3.35	5.84	3.00
August	0.89	0.32	6.34	1.81	5.30
September	3.10	3.91	2.47	-0.80	2.21
October	-0.26	-0.55	3.49	2.04	-0.11

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb, and three years had no hours at this level. These levels of exposure are not likely to injure vegetation.

- During the five-year assessment period, soil moisture levels were normal to high and favored the uptake of ozone. Since there were no months of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and either the 90-day cumulative Sum06 or the seasonal W126 index of exposure.

The risk of foliar ozone injury at Rocky Mountain National Park is low. The threshold for injury is satisfied by the Sum06 index, but not by the W126 index. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and exposures to 100 ppb are rare. While soil moisture levels are favorable for the uptake of ozone, ambient levels of exposure are low and the threshold for foliar injury is not likely to be reached.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen, cut-leaf coneflower, and Scouler's willow.

SOUTHERN COLORADO PLATEAU NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHERN COLORADO PLATEAU NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on

the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher

concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHERN COLORADO PLATEAU NETWORK

Park	Code	State	Risk	O3 Data
Aztec Ruins NM	AZRU	NM	low	kriged
Bandelier NM	BAND	NM	low	kriged
Canyon de Chelly NM	CACH	AZ	low	kriged
Chaco Culture NHP	CHCU	NM	low	kriged
El Malpais NM	ELMA	NM	low	kriged
El Morro NM	ELMO	NM	low	kriged
Glen Canyon NRA	GLCA	UT	low	kriged
Grand Canyon NP	GRCA	AZ	low	monitored
Hubbell Trading Post NHS	HUTR	AZ	low	kriged
Mesa Verde NP	MEVE	CO	low	monitored
Navajo NM	NAVA	AZ	low	kriged
Petrified Forest NP	PEFO	AZ	moderate	kriged
Petroglyph NM	PETR	NM	low	kriged
Rainbow Bridge NM	RABR	UT	low	kriged
Salinas Pueblo Missions NM	SAPU	NM	low	kriged
Sunset Crater Volcano NM	SUCR	AZ	moderate	kriged
Walnut Canyon NM	WACA	AZ	moderate	kriged
Wupatki NM	WUPA	AZ	moderate	kriged
Yucca House NM	YUHO	CO	low	kriged

AZTEC RUINS NATIONAL MONUMENT (AZRU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for AZRU					
	1995	1996	1997	1998	1999
Sum06	6	15	8	10	16
W126	18.5	25.0	15.2	30.5	28.4
N60	171	345	184	518	423
N80	3	5	1	4	5
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at AZRU					
	1995	1996	1997	1998	1999
Month 1	0.44	-4.19	2.31	-0.26	1.18
Month 2	-1.72	-0.70	1.86	-0.25	-0.21
Month 3	0.12	-1.79	1.42	3.53	3.55

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at AZRU					
	1995	1996	1997	1998	1999
April	1.87	-1.81	3.08	1.25	1.63
May	2.07	-4.19	1.19	-0.26	1.18
June	0.44	-0.70	2.31	-0.25	-0.21
July	-1.72	-1.79	1.86	3.53	3.55
August	0.12	-1.34	1.42	-0.52	5.05
September	0.47	1.98	2.06	-1.65	0.39
October	-2.43	1.40	-0.30	5.08	-2.51

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had concentration greater than 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. Soil moisture conditions in the two years with the highest exposures, 1999 and 1996, were favorable and two months of mild and severe drought, respectively. The three years with lower levels of exposure had one month of mild drought among them. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The highest and second highest ozone years, 1998 and 1999, each had one month of mild or moderate drought. The mid-level ozone year 1996 had four months of mild and severe drought. There were two months of mild and moderate drought

in 1995, the year with the second lowest exposure, and soil moisture conditions were normal in 1997, the year with the lowest exposure.

The risk of foliar ozone injury to plants at Aztec Ruins National Monument is low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and do not exceed 100 ppb. It is unlikely that these levels of exposure will produce foliar injury on plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush as a bioindicator.

BANDELIER NATIONAL MONUMENT (BAND)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BAND					
	1995	1996	1997	1998	1999
Sum06	10	19	12	18	17
W126	17.8	23.8	18.9	25.4	26.6
N60	240	391	285	443	436
N80	17	12	9	14	21
N100	1	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BAND					
	1995	1996	1997	1998	1999
Month 1	0.30	-4.72	0.50	2.93	2.21
Month 2	2.14	0.53	1.76	-0.04	2.20
Month 3	4.26	0.20	0.40	-1.77	3.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BAND					
	1995	1996	1997	1998	1999
April	2.14	-2.33	2.69	0.46	4.42
May	4.26	-4.72	0.50	-2.65	2.21
June	3.60	0.53	1.76	-2.14	2.20
July	0.31	0.20	0.40	2.93	3.52
August	-0.31	0.58	0.93	-0.04	3.56
September	1.51	0.13	2.02	-1.77	0.24
October	-2.28	1.55	-0.22	5.19	-1.25

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had one hour in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and similar levels of ozone exposure and the scarcity of drought. One month of severe and mild drought occurred in each of the two highest ozone years, 1996 and 1998, and soil moisture was normal in the other three years. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone year, 1999, there was

one month of mild drought, while the second highest ozone year, 1998, had three months of mild and moderate and drought. The mid-level exposure year 1996 had two months of moderate and severe drought. The lowest ozone year, 1995, had one month of moderate drought while the second lowest year, 1997, had normal soil moisture.

The risk of foliar injury to plants at Bandelier National Monument is low. While the Sum06 exposure index is satisfied, the W126 index is not because the N100 criterion is not fulfilled. The number of hours of exposure greater than 80 ppb is low, and only one hour of exposure greater than 100 ppb occurred during the five-year period. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposures and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, quaking aspen, skunkbush, and cut-leaf coneflower.

CANYON DE CHELLEY NATIONAL MONUMENT (CACH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CACH					
	1995	1996	1997	1998	1999
Sum06	8	17	11	17	20
W126	22.1	27.9	19.4	34.5	32.8
N60	253	428	269	616	540
N80	9	9	8	16	19
N100	1	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CACH					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	-3.23	1.25	-1.25
Month 2	-0.85	-3.23	-1.22	0.96	-1.53
Month 3	0.27	-1.22	-2.54	2.34	4.49

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CACH					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and one year in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or the seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 exposure year, 1999, had two months of mild drought. The two years with the same second-highest exposure index, 1996 and 1998, had three months of mild and severe drought and normal moisture conditions, respectively. In 1997, the mid-level exposure year, there were three months of mild to severe drought. Soil moisture was normal in 1995, the year with the lowest exposure. Soil moisture levels associated with the W126 index also appear to be unrelated to ozone exposure levels. In the highest ozone year, 1998, there was one month of moderate drought, while the second highest ozone year, 1999, had three months

of mild and moderate drought. The mid-level exposure year, 1996, had five months of mild to severe drought. The two lowest ozone years, 1995 and 1997, each had one month of mild or moderate drought.

The risk of foliar ozone injury to plants at Canyon de Chelley National Monument is low. While the Sum06 exposures exceeded the threshold level for injury, the W126 did not since the N100 criteria were not satisfied. There are only a few hours of exposure to 80 ppb each year, and exposure to 100 ppb is rare. Although levels of exposure and drought are not associated , months of mild to severe drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine, quaking aspen, skunkbush, and cut-leaf coneflower.

CHACO CULTURE NATIONAL HISTORIC PARK (CHCU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHCU					
	1995	1996	1997	1998	1999
Sum06	5	10	9	12	10
W126	17.8	23.8	17.6	27.5	26.3
N60	209	365	249	477	410
N80	10	9	6	9	13
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHCU					
	1995	1996	1997	1998	1999
Month 1	0.44	-4.19	2.31	-0.26	1.18
Month 2	-1.72	-0.70	1.86	-0.25	-0.21
Month 3	0.12	-1.79	1.42	3.53	3.55

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHCU					
	1995	1996	1997	1998	1999
April	1.87	-1.81	3.08	1.25	1.63
May	2.07	-4.19	1.19	-0.26	1.18
June	0.44	-0.70	2.31	-0.25	-0.21
July	-1.72	-1.79	1.86	3.53	3.55
August	0.12	-1.34	1.42	-0.52	5.05
September	0.47	1.98	2.06	-1.65	0.39
October	-2.43	1.40	-0.30	5.08	-2.51

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and uniform level of ozone exposure and the scarcity of drought. The highest ozone year, 1998, had normal soil moisture, while the lowest ozone year, 1995, had one month of mild drought. The other three years had two months of drought stress among them. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, had one month of mild and one month of moderate drought, while the two lowest ozone years, 1995 and 1997, experienced two months of mild and moderate drought and

normal moisture conditions, respectively. The intermediate ozone year 1996 had four months of mild to severe drought.

The low levels of ozone exposure at Chaco Culture Historic Park make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for foliar injury, but the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and no exposures greater than 100 ppb occur during the five-year period. Low soil moisture levels occur independently of the level of ozone exposure, and scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush as a bioindicator.

EL MALPAIS NATIONAL MONUMENT (ELMA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ELMA					
	1995	1996	1997	1998	1999
Sum06	9	16	11	17	14
W126	17.0	23.1	19.0	26.1	25.5
N60	228	373	285	462	414
N80	12	11	9	12	18
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ELMA					
	1995	1996	1997	1998	1999
Month 1	0.57	-3.37	0.29	-0.20	-1.31
Month 2	-1.25	0.61	1.98	-0.62	-0.38
Month 3	0.30	1.10	0.35	4.66	3.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ELMA					
	1995	1996	1997	1998	1999
April	0.16	-2.92	0.29	1.15	-0.73
May	0.87	-3.37	1.98	-0.20	-1.31
June	0.57	0.61	0.35	-0.62	-0.38
July	-1.25	1.10	1.78	4.66	3.48
August	0.30	0.76	-0.77	-0.99	3.67
September	0.30	1.78	2.99	-2.52	1.95
October	-2.63	3.22	0.09	3.15	-2.62

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and uniform level of ozone exposure and the scarcity of drought. Three months of mild or severe drought occurred over the five-year period independent of the level of ozone, and soil moisture was generally normal. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. Four years each had one or two months of mild to moderate drought that occurred without any relationship to the level of ozone. One year had normal levels of soil moisture throughout.

The low levels of ozone exposure at El Malpais National Monument make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for foliar injury, but the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there are no hours of exposure greater than 100 ppb. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: ponderosa pine and quaking aspen.

EL MORRO NATIONAL MONUMENT (ELMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ELMO					
	1995	1996	1997	1998	1999
Sum06	8	15	11	16	14
W126	17.7	23.4	19.0	26.8	26.0
N60	232	374	285	473	420
N80	12	11	9	12	18
N100	1	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ELMO					
	1995	1996	1997	1998	1999
Month 1	0.57	-3.37	0.29	-0.20	-1.31
Month 2	-1.25	0.61	1.98	-0.62	-0.38
Month 3	0.30	1.10	0.35	4.66	3.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ELMO					
	1995	1996	1997	1998	1999
April	0.16	-2.92	0.29	1.15	-0.73
May	0.87	-3.37	1.98	-0.20	-1.31
June	0.57	0.61	0.35	-0.62	-0.38
July	-1.25	1.10	1.78	4.66	3.48
August	0.30	0.76	-0.77	-0.99	3.67
September	0.30	1.78	2.99	-2.52	1.95
October	-2.63	3.22	0.09	3.15	-2.62

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and only one year in which concentration reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and uniform level of ozone exposure and the scarcity of drought. Three months of mild or severe drought occurred over the five-year period independent of the level of ozone, and soil moisture was generally normal. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. Four years had one or two months of mild to moderate drought that occurred without any relationship to the level of ozone. One year had normal levels of soil moisture throughout.

The low levels of ozone exposure at El Morro National Monument make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for foliar injury, but the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there is only one hour of exposure greater than 100 ppb. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: ponderosa pine and skunkbush

GLEN CANYON NATIONAL RECREATION AREA (GLCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Oenothera elata	Evening primrose	Onagraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GLCA					
	1995	1996	1997	1998	1999
Sum06	5	13	10	16	16
W126	28.0	40.1	26.4	46.5	41.3
N60	340	711	388	868	732
N80	11	25	7	29	23
N100	1	1	0	3	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GLCA					
	1995	1996	1997	1998	1999
Month 1	2.67	-2.18	0.76	0.39	2.28
Month 2	0.85	-1.90	1.31	-1.53	-0.77
Month 3	0.62	-2.50	1.75	-1.32	-0.64

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GLCA					
	1995	1996	1997	1998	1999
April	1.97	-1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to soil moisture, when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two highest Sum06 ozone years, 1998 and 1999, experienced two months of mild drought and normal soil moisture, respectively. The mid-level exposure year 1996 had three months of mild and moderate drought, and the two lowest exposure years both had normal soil moisture. Soil moisture levels associated with the W126 index also appear

inversely related to ozone concentrations, but the pattern is again not consistent. In the three years with the highest levels of ozone, 1998, 1999, and 1996, there were three months of mild to moderate drought, one month of mild drought, and five months of mild to severe drought, respectively. The two lowest ozone years, 1997 and 1995, had normal moisture conditions and one month of mild drought, respectively.

The low levels of ozone exposure at Glen Canyon National Recreation Area make the risk of foliar ozone injury to plants low. While the Sum06 index generally meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: evening primrose, ponderosa pine, and skunkbush.

GRAND CANYON NATIONAL PARK (GRCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GRCA

	1995	1996	1997	1998	1999
Sum06	19	27	21	28	31
W126	47.2	47.5	38.8	52.5	51.2
N60	733	772	623	980	902
N80	0	8	0	0	18
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GRCA					
	1995	1996	1997	1998	1999
Month 1	1.86	-3.96	0.06	1.25	-1.25
Month 2	1.32	-3.23	0.28	0.96	-1.53
Month 3	2.00	-1.22	-1.17	2.34	4.49

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GRCA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index significantly exceeds the threshold for foliar injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- There are no associations between either the 90-day Sum06 or the seasonal W126 accumulation period levels of ozone and soil moisture conditions. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought. The second highest year, 1998, and the lowest ozone year, 1995, both had favorable conditions. The two intermediate years, 1996 and 1997, had three months of moderate and severe drought and one month of mild drought, respectively. Similarly, there is no pattern of association between the seasonal W126 index of exposure and soil moisture conditions. The highest, 1998, and the second highest, 1998, ozone years had one month of mild drought and three months of mild and moderate drought. Two years with the same mid-level of ozone, 1995 and 1996, experienced one month of mild drought and five months of mild to severe drought, respectively. The lowest ozone year 1997 had one month of mild drought.

The low levels of ozone exposure at Grand Canyon National Park make the risk of foliar ozone injury to plants low. The W126 criteria are not satisfied, and there are only a few hours above 80 ppb and none above 100 ppb. Months of moderate and severe drought constrain the uptake of ozone in some years and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, ponderosa pine, quaking aspen, skunkbush, and Scouler's willow.

HUBBELL TRADING POST NATIONAL HISTORIC SITE (HUTR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HUTR					
	1995	1996	1997	1998	1999
Sum06	12	21	13	20	26
W126	25.8	30.1	23.7	42	40.9
N60	352	483	362	780	736
N80	32	30	21	51	46
N100	5	3	1	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HUTR					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	0.28	1.25	-1.25
Month 2	-0.85	-3.23	-1.17	0.96	-1.53
Month 3	0.27	-1.22	1.38	2.34	4.49

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HUTR					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- No clear relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. The highest ozone year, 1999, experienced two months of mild drought. The two mid-level years, 1996 and 1998, had similar levels of exposure and experienced three months of mild and severe drought and normal soil moisture, respectively. The second lowest exposure year, 1997, had one month of mild drought, and the lowest year, 1995, had normal soil moisture. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced one month and two months of mild and one or moderate drought, while the three lowest ozone years, 1997 and 1995, had one month of

mild or moderate drought each. The year with mid-level ozone had five months of mild to severe drought.

The low levels of ozone exposure at Hubbell Trading Post National Historic Site make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. Soil moisture levels are variable, and months of drought constrain the uptake of ozone by plants and further reduce the likelihood of foliar injury. There are no bioindicator species at the site.

MESA VERDE NATIONAL PARK (MEVE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MEVE					
	1995	1996	1997	1998	1999
Sum06	6	13	2	15	19
W126	26.1	29.7	13.9	33.5	37.5
N60	182	349	92	507	543
N80	0	0	0	0	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MEVE					
	1995	1996	1997	1998	1999
Month 1	1.56	-0.39	1.98	-1.94	3.13
Month 2	5.61	-1.24	1.09	0.30	1.46
Month 3	2.71	0.26	0.70	1.69	1.00

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MEVE					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show no years in which concentrations reached either 80 or 100 ppb. These levels of exposure are not likely to injure vegetation.

- There are no associations between the 90-day Sum06 accumulation period levels of ozone and soil moisture conditions. There were only two months of mild drought stress over the five-year period, and soil moisture was generally normal. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The highest ozone year, 1999, had one month of moderate drought, and the next two years, 1998 and 1996, each had three months of mild and mild to moderate drought, respectively. The two lowest ozone years had favorable conditions and one month of mild drought.

The low levels of ozone exposure at Mesa Verde National Park make the risk of foliar ozone injury to plants low. The W126 criteria are not satisfied, and there are no hours above 80 ppb and 100 ppb. Months of drought constrain the uptake of ozone in higher exposure years and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and skunkbush.

NAVAJO NATIONAL MONUMENT (NAVA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Oenothera elata	Evening primrose	Onagraceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NAVA					
	1995	1996	1997	1998	1999
Sum06	5	10	10	15	17
W126	33.2	41.0	29.9	53.7	51.2
N60	457	709	473	1023	952
N80	33	39	18	53	46
N100	5	3	1	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NAVA					
	1995	1996	1997	1998	1999
Month 1	2.00	-3.96	0.06	1.25	1.47
Month 2	2.08	-3.23	0.28	0.96	-1.25
Month 3	-0.85	-1.22	-1.17	2.34	-1.53

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NAVA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The two highest ozone years, 1999 and 1998, experienced, respectively, two months of mild drought and normal soil moisture. One year with mid-level ozone had three months of mild and severe drought, while the other year had one month of mild drought. The lowest ozone year, 1995, had normal soil moisture. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced one month of mild drought and three months of mild and moderate drought, respectively, while

the two lowest ozone years, 1997 and 1995, had one month of mild or moderate drought each. The year with mid-level ozone, 1996, had five months of mild to severe drought.

The low levels of ozone exposure at Navajo National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index generally exceeds the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. Soil moisture is variable among years, and months of drought constrain the uptake of ozone by plants and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: evening primrose, quaking aspen, and skunkbush.

PETRIFIED FOREST NATIONAL PARK (PEFO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PEFO					
	1995	1996	1997	1998	1999
Sum06	22	27	19	32	39
W126	34.6	36.5	34.2	56.2	55.9
N60	565	633	593	1080	1091
N80	87	84	68	123	100
N100	14	9	5	5	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PEFO					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	0.06	0.96	-2.92
Month 2	-0.85	-3.23	0.28	2.34	1.47
Month 3	0.27	-1.22	-1.17	-1.82	-1.25

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PEFO					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for concentrations of 80 and 100 ppb are variable with counts high in some years and significantly lower in others. In some years, the levels of exposure could injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought, while the two mid-level years, 1998 and 1996, had one month of mild drought and three months of mild and severe drought, respectively. The lowest ozone years, 1995 and 1997, had normal soil moisture and one month of mild drought. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced one month of

mild and three months of mild and moderate drought. The three lowest ozone years had similar levels of ozone and experienced one month of mild, one month of moderate, and five months of mild to severe drought.

The risk of foliar ozone injury to plants at Petrified Forest National Park is moderate. The Sum06 exposure index meets the criteria for injury, while the W126 index does in two years. The numbers of hours of exposure greater than 80 and 100 ppb are variable, with two years having a higher number of hours above 100 ppb. The incidence of drought varies considerably among years and can significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. The year 1995 is an exception to this pattern and is characterized by higher levels of ozone exposure under generally normal soil moisture conditions. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: tree-of-heaven and skunkbush.

PETROGLYPH NATIONAL MONUMENT (PETR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PETR					
	1995	1996	1997	1998	1999
Sum06	9	17	11	17	14
W126	17.2	23.0	19.0	25.9	25.8
N60	236	375	287	460	423
N80	13	11	9	12	20
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PETR					
	1995	1996	1997	1998	1999
Month 1	-2.13	4.94	1.48	6.08	-0.16
Month 2	-1.16	0.20	3.46	-2.03	-0.02
Month 3	1.08	0.20	-0.19	-3.45	3.60

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PETR					
	1995	1996	1997	1998	1999
April	0.52	-1.99	2.85	2.65	-0.26
May	-0.67	-3.01	-0.27	-0.51	-0.16
June	-0.62	4.94	1.48	-0.78	-0.02
July	-2.13	0.20	3.46	6.08	3.60
August	-1.16	0.20	-0.19	-2.03	4.47
September	1.08	2.33	3.14	-3.45	-0.84
October	-2.50	2.01	-1.15	3.01	-1.49

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. In the Sum06 assessment, soil moisture was generally normal with only four months of drought over the five-year period. The two highest ozone years, 1998 and 1996, experienced, respectively, two months of mild drought and normal soil moisture, while the lowest ozone year, 1995, had two months of mild and moderate drought. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. Eight months of drought were distributed over the five years. The two highest ozone years, 1998 and 1999, experienced two months of moderate and severe drought and one month of mild drought, respectively. The

year with mid-level ozone had two months of mild and severe drought, and the two lowest ozone years, 1995 and 1997, had three months of mild and moderate drought and normal moisture conditions, respectively.

The low levels of ozone exposure at Petroglyph National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there are no exposures greater than 100 ppb. Soil moisture levels are variable, and scattered months of drought constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

If the level of risk increases in the future, skunkbush can be used as a bioindicator.

RAINBOW BRIDGE NATIONAL MONUMENT (RABR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for RABR					
	1995	1996	1997	1998	1999
Sum06	6	13	10	15	16
W126	31.7	41.6	29.2	50.7	47.1
N60	427	734	457	959	860
N80	18	32	11	37	33
N100	2	2	1	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at RABR					
	1995	1996	1997	1998	1999
Month 1	2.67	-2.18	0.76	0.39	2.28
Month 2	0.85	-1.90	1.31	-1.53	-0.77
Month 3	0.62	-2.50	1.75	-1.32	-0.64

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at RABR					
	1995	1996	1997	1998	1999
April	1.97	-1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. In the Sum06 assessment, the two highest ozone years, 1998 and 1999, experienced, respectively, two months of mild drought and normal soil moisture. One of the intermediate ozone years had three months of mild and moderate drought, while the other had normal conditions. The lowest ozone year, 1995, had normal soil moisture. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced three months of mild and moderate drought and one month of severe drought,

respectively. The two years with mid-level ozone had five months of mild to severe drought and normal soil moisture conditions, and the lowest ozone year, 1995, had one month of moderate drought.

The low levels of ozone exposure at Rainbow Bridge National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. Soil moisture levels are variable, and months of drought constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

If the level of risk increases in the future, skunkbush can be used as a bioindicator.

SALINAS PUEBLO MISSIONS NATIONAL MONUMENT (SAPU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAPU					
	1995	1996	1997	1998	1999
Sum06	9	17	11	17	15
W126	17.4	22.8	18.5	26.0	25.3
N60	242	370	273	463	414
N80	13	11	8	12	18
N100	1	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAPU					
	1995	1996	1997	1998	1999
Month 1	0.54	-4.43	2.44	-0.81	0.23
Month 2	-1.34	2.98	1.43	-1.06	0.00
Month 3	-0.78	1.88	2.04	2.82	0.33

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAPU					
	1995	1996	1997	1998	1999
April	-0.23	-2.76	2.44	0.24	0.23
May	-0.90	-4.43	1.43	-0.81	0.00
June	0.54	2.98	2.04	-1.06	0.33
July	-1.34	1.88	-0.37	2.82	-0.13
August	-0.78	-0.33	-0.14	-1.03	2.28
September	1.51	1.45	2.91	-1.57	-0.69
October	-2.47	1.77	-0.34	3.77	-1.33

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and only one hour in the five-year period during which the concentration of ozone reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. In the Sum06 assessment, soil moisture was generally normal with only three months of drought over the five-year period. The two highest ozone years, 1996 and 1998, experienced, respectively, one month of severe drought and one month of mild drought, while the lowest ozone year, 1995, had one month of mild drought. The remaining two years had normal moisture conditions. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. Months of

drought were distributed over four of the five years. The two highest ozone years, 1998 and 1999, experienced three months of mild and one month of mild drought, respectively. The two years with mid-level ozone had two months of mild and severe drought and normal conditions, and the lowest ozone year, 1995, had two months of mild and moderate drought.

The low levels of ozone exposure at Salinas Pueblo Missions National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there is only one hour or exposure to levels greater than 100 ppb. Soil moisture is variable, and months of drought constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

If the risk increases in the future, ponderosa pine and skunkbush can be used as bioindicators.

SUNSET CRATER VOLCANO NATIONAL MONUMENT (SUCR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SUCR					
	1995	1996	1997	1998	1999
Sum06	6	11	17	25	33
W126	43.6	46.3	43.0	65.8	66.8
N60	737	835	781	1284	1329
N80	94	96	65	123	102
N100	16	9	5	6	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SUCR					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	1.13	1.53	-2.92
Month 2	-0.85	-3.23	0.06	1.25	1.47
Month 3	0.27	-1.22	0.28	0.96	-1.25

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SUCR					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a number of hours every year. These levels of exposure may possibly injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought while second highest exposure year, 1998, had normal soil moisture. The mid-level year 1997 had normal soil moisture. The second lowest ozone year, 1996, had three months of mild to severe drought, and the lowest year, 1995, had normal soil moisture conditions. There is also no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1999 and

1998, experienced three months of mild and moderate drought and one month of mild drought, respectively. The mid-level exposure year 1996 had five months of mild to severe drought. The two years with the lowest and similar levels of ozone had one month of mild drought and one month of moderate drought.

The risk of foliar ozone injury to plants at Sunset Crater Volcano National Monument is moderate. The Sum06 and W126 exposure indices generally meet the criteria for injury. The number of hours of exposure greater than 80 and 100 ppb varies among years, and reaches levels that can injure vegetation. The relationships between levels of ozone and soil moisture show no association, and conditions constraining the uptake of ozone occur for one or more months during most years. It is anticipated that the risk of injury may be greatest in years such as 1995 and 1998 when ambient levels of ozone exceed thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine, quaking aspen, and skunkbush.

WALNUT CANYON NATIONAL MONUMENT (WACA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WACA					
	1995	1996	1997	1998	1999
Sum06	5	10	18	27	37
W126	43.2	46.0	43.5	67.7	68.3
N60	740	840	799	1327	1371
N80	107	110	76	141	113
N100	18	10	6	7	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WACA					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	1.13	1.53	-2.92
Month 2	-0.85	-3.23	0.06	1.25	1.47
Month 3	0.27	-1.22	0.28	0.96	-1.25

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WACA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The distribution of hourly concentrations of ozone varies considerably among years. In some years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the other years, the number of hours was significantly lower. In the higher ozone years, the levels of exposure could injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought, and the second lowest ozone year, 1996, had three months of mild and severe drought. The three remaining years had normal moisture conditions. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1999 and 1998, experienced three months

of mild and moderate drought and one month of mild drought, respectively. The mid-level ozone year 1996 had five months of mild to severe drought, and the two years with the lowest and similar levels of ozone each experienced a month of mild or moderate drought.

The risk of foliar ozone injury to plants at Walnut Canyon National Monument is moderate. The Sum06 and W126 exposure indices generally meet the criteria for injury. The number of hours of exposure greater than 80 and 100 ppb varies among years, and reaches levels that can injure vegetation. The relationships between levels of ozone and soil moisture show no association, and conditions limiting the uptake of ozone occur for one or more months during most years. It is anticipated that the risk of injury may be greatest in years such as 1995, 1997 and 1998 when ambient levels of ozone exceed thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine, quaking aspen, and skunkbush.

WUPATKI NATIONAL MONUMENT (WUPA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WUPA					
	1995	1996	1997	1998	1999
Sum06	6	11	16	23	30
W126	43.9	46.2	42.1	64.0	65.0
N60	731	822	752	1242	1277
N80	81	84	56	108	92
N100	14	8	4	5	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WUPA					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	0.06	1.25	-2.92
Month 2	-0.85	-3.23	0.28	0.96	1.47
Month 3	0.27	-1.22	-1.17	2.34	-1.25

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WUPA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are two ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had fourteen hours in which the concentration exceeded 100 ppb, but there were eight or fewer hours in the other years. These levels of exposure may possibly injure vegetation.

- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought, while the second highest year, 1998, had normal moisture conditions. The two mid-level exposure years, 1997 and 1996, experienced one month of mild and three months of mild and severe drought, respectively. The lowest exposure year, 1995, had normal soil moisture. There is also no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1999

and 1998, experienced three months of mild and moderate drought and one month of mild drought, respectively. The mid-level ozone year 1996 had five months of mild to severe drought, and the two years with the lowest and similar levels of ozone each experienced a month of mild or moderate drought.

The risk of foliar ozone injury to plants at Wupatki National Monument is moderate. The Sum06 index meets the criteria for injury, and the W126 exposure index meets the criteria in two years. The number of hours of exposure greater than 100 ppb is variable. The incidence of drought varies considerably among years, and can constrain the uptake of ozone by plants and reduce the likelihood of foliar injury. The year 1995 is an exception and is characterized by higher levels of ozone exposure under more normal soil moisture conditions. The co-occurrence of levels of ozone exposure above thresholds and soil moisture conditions that generally favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush as a bioindicator.

YUCCA HOUSE NATIONAL MONUMENT (YUHO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for YUHO					
	1995	1996	1997	1998	1999
Sum06	3	7	5	12	12
W126	23.7	29.9	16.0	33.5	32.9
N60	189	404	166	555	491
N80	2	2	1	2	3
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at YUHO					
	1995	1996	1997	1998	1999
Month 1	1.56	-1.24	1.98	0.32	3.13
Month 2	5.61	0.26	1.09	-1.94	1.46
Month 3	2.71	-1.07	0.70	0.30	1.00

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at YUHO					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There is one ozone-sensitive species listed for the site.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations rarely exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. Soil moisture was generally normal with only three months of drought over the five-year period. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone years, 1998 and 1999, there were three months of mild and one month of moderate drought, respectively.

The next highest ozone year, 1996, had three months of mild and moderate drought, and the two lowest ozone years had one month of mild drought between them.

The low levels of ozone exposure at Yucca House National Monument make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 exposure indices meet the criteria for injury, the number of hours of exposure greater than 80 ppb is very low, and there are no exposures greater than 100 ppb. Soil moisture levels are variable, and years with higher ozone years are accompanied by months of drought that constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush as a bioindicator.

SOUTHEAST ALASKA NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHEAST ALASKA NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

It was not possible to assess risk for sites in the Southeast Alaska Network since ozone was neither monitored nor kriged for them, and Palmer Z values are not calculated for the state.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHEAST ALASKA NETWORK

Park	Code	State	Risk	O3 Data
Glacier Bay NP & PRES	GLBA	AK	cannot eval	no data
Klondike Gold Rush NHP	KLGO	AK	cannot eval	no data
Sitka NHP	SITK	AK	cannot eval	no data

GLACIER BAY NATIONAL PARK AND PRESERVE (GLBA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Glacier Bay National Park and Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

KLONDIKE GOLD RUSH NATIONAL HISTORIC PARK (KLGO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Klondike Gold Rush National Historic Park cannot be assessed due to the lack of information on ozone exposure at the site.

SITKA NATIONAL HISTORIC PARK (SITK)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Sitka National Historic Park cannot be assessed due to the lack of information on ozone exposure at the site.

SOUTHEAST COAST NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHEAST COAST NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHEAST COAST NETWORK

Park	Code	State	Risk	O3 Data
Canaveral NS	CANA	FL	low	kriged
Cape Hatteras NS	CAHA	NC	moderate	kriged
Cape Lookout NS	CALO	NC	moderate	kriged
Castillo de San Marcos NM	CASA	FL	low	kriged
Chattahoochee River NRA	CHAT	GA	high	kriged
Congaree Swamp NM	COSW	SC	low	monitored
Cumberland Island NS	CUIS	GA	low	kriged
Fort Caroline NM	FOCA	FL	low	kriged
Fort Frederica NM	FOFR	GA	low	kriged
Fort Matanzas NM	FOMA	FL	low	kriged
Fort Pulaski NM	FOPU	GA	low	kriged
Fort Sumter NM	FOSU	SC	low	kriged
Horseshoe Bend NMP	HOBE	AL	moderate	kriged
Kennesaw Mountain NBP	KEMO	GA	high	kriged
Moores Creek NB	MOCR	NC	moderate	kriged
Ocmulgee NM	OCMU	GA	high	kriged
Timucuan Ecol & Hist Preserve	TIMU	FL	low	kriged

CANAVERAL NATIONAL SEASHORE (CANA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CANA					
	1995	1996	1997	1998	1999
Sum06	10	6	10	24	16
W126	14.5	13.1	19.0	27.6	19.0
N60	232	189	321	466	319
N80	12	11	24	75	32
N100	0	0	1	7	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CANA					
	1995	1996	1997	1998	1999
Month 1	0.16	5.61	1.63	-2.38	-1.79
Month 2	-0.87	0.02	-0.89	-2.88	-2.08
Month 3	1.59	-0.75	0.05	-5.73	-1.09

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CANA					
	1995	1996	1997	1998	1999
April	0.16	0.02	1.63	-2.38	-2.08
May	-0.87	-0.75	-0.89	-2.88	-1.09
June	1.59	0.82	0.05	-5.73	0.73
July	-0.71	-2.95	-0.26	-1.67	-2.60
August	2.08	-0.13	-0.34	-2.41	-2.10
September	-0.65	-1.65	-0.15	0.50	0.34
October	2.53	0.65	1.49	-2.50	1.60

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest exposures, 1998 and 1999, each had three months of mild to severe drought. The three remaining years with lower levels of exposure had normal soil moisture conditions. Soil moisture levels associated

with the seasonal W126 index also appear inversely related to ozone concentrations, but the association is not consistent. The year with the highest ozone exposure value, 1998, had six months of mild to severe drought. The two years with mid-level exposures, 1997 and 1999, had normal moisture conditions and four months of mild and moderate drought, respectively. There were normal moisture conditions in 1995, the second lowest exposure year, and two months of mild and moderate drought in 1996, the lowest exposure year.

The low levels of ozone exposure and accompanying soil moisture conditions at Canaveral National Seashore make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone occasionally exceeded 80 ppb and rarely exceed 100 ppb. Low soil moisture conditions constrain the uptake of ozone during higher ozone exposures, and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: black cherry, and American elder.

CAPE HATTERAS NATIONAL SEASHORE (CAHA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CAHA					
	1995	1996	1997	1998	1999
Sum06	21	22	29	30	26
W126	26.8	27.2	39.4	38.8	36.4
N60	494	484	698	705	615
N80	41	49	102	103	112
N100	2	1	7	6	10

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CAHA					
	1995	1996	1997	1998	1999
Month 1	-2.27	-0.20	1.14	-0.27	-0.78
Month 2	-1.01	-0.35	-1.29	0.29	-1.07
Month 3	4.32	1.00	-0.90	-0.42	-0.50

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CAHA					
	1995	1996	1997	1998	1999
April	-2.27	-0.20	1.14	-0.27	-0.78
May	-1.01	-0.35	-1.29	0.29	-1.07
June	4.32	1.00	-0.90	-0.42	-0.50
July	-1.78	3.72	-0.93	0.01	-1.35
August	-1.03	0.74	-2.47	-0.64	-0.60
September	-0.57	3.54	0.17	-1.17	4.09
October	1.62	2.42	-1.07	-1.72	4.04

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years. The criteria for injury under the W126 exposure index are generally satisfied.

- In three years, the N-values for concentrations of 80 and 100 ppb are significantly higher than in the other two years. In the highest years, the levels of exposure could injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposures were relatively similar over the five years. Soil moisture levels show that three years had one or two months of mild or moderate drought, but there was no association between the levels of ozone and drought. The relatively uniform levels of ozone exposure also make it difficult to assess relationships between the W126 ozone index and soil moisture, and no association between ozone and drought is apparent in the distributions.

The highest ozone year, 1997, and the second highest year, 1998, had three and two months of mild and moderate drought, respectively. The mid-level exposure year 1999 had two months of mild drought. In 1996, the second lowest year, soil moisture was normal while in 1995, the lowest year, there were four months of mild and moderate drought.

The risk of foliar ozone injury at Cape Hatteras National Seashore is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index satisfies the criteria on occasion. The N-values indicate that in a few years there are frequent exposures to concentrations of ozone greater than 80 ppb, and additional hours of exposure at 100 ppb. The lack of a relationship between level of ozone and soil moisture suggests that conditions favorable for the uptake of ozone occur independently of the levels of exposure. This creates the opportunity for injury when high levels of exposure coincide with favorable soil moisture conditions, such as in 1998 when mild drought occurred late in the year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: yellow-poplar, American sycamore, black cherry, American elder, crownbeard, and northern fox grape.

CAPE LOOKOUT NATIONAL SEASHORE (CALO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CALO					
	1995	1996	1997	1998	1999
Sum06	16	15	18	22	23
W126	37.1	36.1	31.0	36.7	38.6
N60	652	650	551	663	716
N80	112	104	62	88	78
N100	18	12	4	4	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CALO					
	1995	1996	1997	1998	1999
Month 1	-0.61	-0.91	-1.19	1.56	-0.47
Month 2	-2.80	-0.10	-1.71	-0.42	-0.85
Month 3	-0.28	-0.42	-0.81	-0.61	-0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CALO					
	1995	1996	1997	1998	1999
April	-2.80	-0.91	0.74	1.73	-0.85
May	-0.28	-0.10	-1.19	1.56	-0.86
June	6.48	-0.42	-1.71	-0.42	-0.75
July	-1.56	2.26	-0.81	-0.61	-2.05
August	-0.70	0.03	-2.09	1.97	0.16
September	-0.65	4.58	0.81	-1.00	1.70
October	1.70	1.93	-0.86	-1.70	2.44

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours was significantly lower. In some years, these levels of exposure could injure vegetation.

- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because only three months of drought occurred during the five-year period. The two highest, 1999 and 1998, and the one lowest ozone year, 1996, had favorable conditions throughout. Two months of mild and the one of moderate drought occurred in the mid-level exposure months. Soil moisture levels associated with the seasonal W126 index also appear to be

unrelated to ozone concentration. The highest ozone year, 1999, had one month of moderate drought, and the second highest year, 1995, had two months of mild and moderate drought. Two years with the same mid-level of ozone, 1996 and 1998, had normal conditions and two months of mild drought, respectively. The lowest exposure year, 1997, had three months of mild and moderate drought. No pattern of association between ozone and drought is evident from these observations.

The risk of foliar ozone injury at Cape Lookout National Seashore is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index satisfies the criteria on occasion. The N-values indicate that in some years there are frequent exposures to concentrations of ozone greater than 80 ppb, and significant hours of exposure at 100 ppb. The lack of a relationship between ozone exposure and soil moisture suggests that conditions favorable for the uptake of ozone occur independently of the levels of exposure. The likelihood of foliar injury being produced is greatest when high levels of exposure coincide with favorable soil moisture conditions as in 1996.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: yellow-poplar, black cherry, and northern fox grape.

CASTILLO DE SAN MARCOS NATIONAL MONUMENT (CASA)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CASA

	1995	1996	1997	1998	1999
Sum06	10	10	11	25	17
W126	14.4	16.0	21.6	28.1	20.0
N60	224	262	377	472	338
N80	15	15	27	86	35
N100	3	1	3	13	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CASA					
	1995	1996	1997	1998	1999
Month 1	1.56	0.10	-0.06	-1.63	-1.68
Month 2	-0.77	-1.59	0.81	-2.80	-1.93
Month 3	2.44	0.72	0.34	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CASA					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the criterion in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had a greater number of hours over 80 ppb and 13 hours above 100 ppb. Overall, the levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest ozone exposure values, 1998 and 1999, each had three months of mild to severe drought. In the three years with lower levels of ozone there was only one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. In the highest ozone years, 1998, there were three months of mild to severe drought. In the two years with intermediate ozone, 1997 and 1999, there was one and five months of mild and moderate stress. The second lowest exposure year, 1996, had two months of mild drought and the lowest year, 1995, had normal soil moisture conditions.

The risk of foliar ozone injury at Castillo De San Marcos National Monument is low. The Sum06 threshold is attained each year, while the W126 threshold is satisfied only in one year. The N-values indicate that exposures to 80 to 100 ppb are generally low. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and further reduces the likelihood of foliar injury. At present, no

ozone-sensitive species have been identified at the site.

CHATTAHOOCHEE RIVER NATIONAL RECREATION AREA (CHAT)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Krigia montana	Mountain dandelion	Asteraceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHAT					
	1995	1996	1997	1998	1999
Sum06	19	16	16	27	37
W126	42.0	37.3	36.1	58.2	60.5
N60	689	631	603	933	944
N80	190	149	143	308	340
N100	55	34	28	91	92

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHAT					
	1995	1996	1997	1998	1999
Month 1	-1.49	-0.95	0.75	-0.96	-2.08
Month 2	-1.24	0.22	1.93	-0.84	-1.77
Month 3	2.87	-1.17	0.62	-2.60	0.17

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHAT					
	1995	1996	1997	1998	1999
April	-1.49	0.22	0.76	4.22	-1.77
May	-1.24	-0.95	0.75	-0.96	0.17
June	2.87	0.22	1.93	-0.84	1.82
July	-2.11	-1.17	0.62	-2.60	-0.23
August	2.84	0.23	-1.40	0.21	-1.21
September	0.01	1.70	2.65	-1.53	-0.59
October	4.86	-1.23	3.20	-2.04	0.96

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is

low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure values, 1999, had two months of mild and moderate drought, and the second highest year, 1998, had one month of moderate drought. The intermediate exposure year 1995 had two months of mild drought. The two years with the lowest levels of ozone, 1996 and 1997, had one month of mild drought between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is again not consistent. In the highest ozone years, 1999 and 1998, there were two and three months of mild and severe drought, respectively. A year with significantly lower intermediate ozone, 1995, had three months of mild and moderate stress. The lowest ozone years, 1997 and 1996, experienced one and two months, respectively, of mild stress.

The risk of foliar ozone injury to plants at Chattahoochee River National Recreation Area is high. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions may reduce the likelihood of injury in high exposure years. However, levels of exposure capable of producing foliar injury also occur under conditions of minor drought. The likelihood of foliar injury developing may be greatest during years such as 1996, 1997 and 1999 when ozone levels exceed the thresholds, and soil moisture levels are under mild drought for periods that do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, redbud, white ash, yellow-poplar, American sycamore, black cherry, Allegheny blackberry, cut-leaf coneflower, American elder, crownbeard, and northern fox grape.

CONGAREE SWAMP NATIONAL MONUMENT (COSW)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for COSW					
	1995	1996	1997	1998	1999
Sum06	12	12	6	19	18
W126	15.8	12.8	13.9	20.7	25.9
N60	283	225	147	360	444
N80	42	29	10	72	107
N100	2	2	0	8	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at COSW					
	1995	1996	1997	1998	1999
Month 1	-2.49	-0.78	-0.31	0.11	-1.08
Month 2	-1.64	-1.72	2.51	-1.43	0.02
Month 3	4.16	-1.95	1.75	-2.48	-0.78

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at COSW					
	1995	1996	1997	1998	1999
April	-2.49	0.11	1.94	2.18	0.02
May	-1.64	-0.78	-0.31	0.11	-0.78
June	4.16	-1.72	2.51	-1.43	0.51
July	0.08	-1.95	1.75	-2.48	-2.12
August	3.13	-0.17	-1.53	-2.35	-2.84
September	0.71	0.02	1.49	1.34	1.09
October	2.15	0.75	2.33	-1.78	0.23

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the association is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The Sum06 indices in the highest and second highest years, 1999 and 1998, were similar, and the years experienced two months of mild and moderate drought and one month of mild drought,

respectively. The two mid-ozone years each had two months of mild and moderate drought, while the year with the lowest ozone, 1997, had favorable conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The two highest ozone years, 1999 and 1998, had two months of moderate drought and four months of mild and moderate drought, respectively. The mid-level exposure year 1995 had two months of mild and moderate drought and the two lowest years, 1996 and 1997, had two and one month, respectively, of mild drought.

The risk of foliar ozone injury at the Congaree Swamp National Monument is low. While the threshold level for injury is satisfied by the Sum06 index, there are only occasional exposures to concentrations of ozone greater than 80 ppb and exposures above 100 ppb are rare. The inverse relationship between ozone and soil moisture limits the uptake of ozone during high exposure years and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry, American elder, and crownbeard.

CUMBERLAND ISLAND NATIONAL SEASHORE (CUIS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CUIS					
	1995	1996	1997	1998	1999
Sum06	7	11	11	21	15
W126	14.1	15.9	20.3	25.1	22.5
N60	227	257	352	422	384
N80	16	12	29	71	39
N100	3	1	2	9	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CUIS					
	1995	1996	1997	1998	1999
Month 1	4.10	-0.35	-0.14	0.06	0.00
Month 2	0.11	-2.27	0.26	-2.29	-1.82
Month 3	-0.54	-0.97	-1.32	-4.20	0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CUIS					
	1995	1996	1997	1998	1999
April	-1.77	-0.35	0.93	0.06	-1.98
May	-1.50	-2.27	-0.14	-2.29	-2.13
June	2.66	-0.97	0.26	-4.20	2.95
July	-1.95	-2.74	-1.32	-1.17	0.00
August	4.10	-0.25	-0.52	-1.12	-1.82
September	0.11	-0.86	-1.73	0.67	0.86
October	-0.54	2.83	4.20	-0.97	-0.59

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb, but the remaining years had three or fewer hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure values, 1998, had two months of moderate and severe drought. In the year with lowest levels of ozone, 1995, soil moisture was favorable. The intermediate ozone years each had

one month of mild or moderate drought. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, although the relationship is not consistent. In the highest ozone year, 1998, there were four months of mild to severe drought. The two years with slightly lower ozone, 1999 and 1997, had three and two months, respectively, of mild and moderate drought. The two years with the lowest ozone, 1995 and 1996, had three and two months of drought, respectively. Overall, this pattern of distribution is highly indicative of an inverse relationship, although every year had two or more months of drought.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Cumberland Island National Seashore make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone occasionally exceed 80 ppb, and rarely exceed 100 ppb. Several months of mild to moderate drought occur annually and reduce the effectiveness of the exposures.

If the level of risk should increase in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, American sycamore, black cherry, American elder, and crownbeard.

FORT CAROLINE NATIONAL MONUMENT (FOCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Pinus taeda	Loblolly pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOCA					
	1995	1996	1997	1998	1999
Sum06	9	12	12	21	14
W126	14.6	17.3	22.1	29.5	20.8
N60	230	291	389	498	352
N80	19	17	31	92	36
N100	4	2	5	17	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOCA					
	1995	1996	1997	1998	1999
Month 1	-0.37	0.10	4.65	-1.63	-1.68
Month 2	1.56	-1.59	-0.06	-2.80	-1.93
Month 3	-0.77	0.72	0.81	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOCA					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had seventeen hours in which the concentration exceeded 100 ppb, however the other years had five or fewer hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest ozone exposure values, 1998 and 1999, each had three months of mild to severe drought. In the two years with mid-level ozone, 1997 and 1996, there were normal soil moisture conditions and one month of mild drought, respectively. The year with the lowest ozone level, 1995, had favorable soil

moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of mild to severe drought. In the two years with next highest ozone, 1997 and 1999, there was one month of moderate drought and five months of mild and moderate drought, respectively. There were two months of mild drought in 1996, the second lowest exposure year, and in 1995 when ozone was the lowest, soil moisture was favorable.

The low levels of ozone exposure at Fort Caroline National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Soil moisture conditions of mild to severe drought reduce the effectiveness of the higher exposures. Hourly concentrations of ozone occasionally exceed 80 ppb, and the number of hours of exposure to concentrations greater than 100 ppb is generally low.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use black cherry.

FORT FREDERICA NATIONAL MONUMENT (FOFR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOFR					
	1995	1996	1997	1998	1999
Sum06	7	11	12	21	15
W126	14.7	16.5	20.6	25.4	24.4
N60	238	269	356	431	419
N80	18	13	32	69	47
N100	2	1	1	9	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOFR					
	1995	1996	1997	1998	1999
Month 1	4.10	-0.35	-0.14	0.06	0.00
Month 2	0.11	-2.27	0.26	-2.29	-1.82
Month 3	-0.54	-0.97	-1.32	-4.20	0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOFR					
	1995	1996	1997	1998	1999
April	-1.77	-0.35	0.93	0.06	-1.98
May	-1.50	-2.27	-0.14	-2.29	-2.13
June	2.66	-0.97	0.26	-4.20	2.95
July	-1.95	-2.74	-1.32	-1.17	0.00
August	4.10	-0.25	-0.52	-1.12	-1.82
September	0.11	-0.86	-1.73	0.67	0.86
October	-0.54	2.83	4.20	-0.97	-0.59

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb, however the other years had two or fewer hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure value, 1998, had two months of moderate and severe drought. In the three years with mid-level ozone, there was one month of mild or moderate drought in each. The year with the lowest ozone level, 1995, had favorable soil

moisture. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations, although the pattern is not consistent. In the highest ozone years, 1998 and 1999, there were four and three months, respectively, of mild to severe drought. The remaining three years each had two or three months of mild or moderate drought; there were three months of moderate drought in 1995 when ozone was lowest.

The low levels of ozone exposure and soil moisture conditions at Fort Frederica National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Soil moisture conditions of mild to severe drought reduce the effectiveness of the higher exposures, and hourly concentrations of ozone seldom exceed 80 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, American sycamore, black cherry, and, crownbeard.

FORT MATANZAS NATIONAL MONUMENT (FOMA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Sambucus canadensis	American elder	Caprifoliaceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOMA					
	1995	1996	1997	1998	1999
Sum06	9	8	10	19	13
W126	14.6	15.8	21.4	28.0	20.0
N60	230	259	372	470	338
N80	15	15	27	87	35
N100	2	1	3	13	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOMA					
	1995	1996	1997	1998	1999
Month 1	1.56	0.10	-0.06	-1.63	-1.68
Month 2	-0.77	-1.59	0.81	-2.80	-1.93
Month 3	2.44	0.72	0.34	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOMA					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had thirteen hours in which the concentration exceeded 100 ppb, however the other years had three or fewer hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure value, 1998, had three months of mild and severe drought while the next highest year, 1999, had three months of mild drought. The remaining three years had one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure levels,

although the pattern is not consistent. In the highest ozone year, 1998, there were three months of mild to severe drought. The next two highest years, 1997 and 1999, had one and five months of mild and moderate drought, respectively. The next to lowest year, 1996, had two months of mild drought and the lowest year, 1995, had normal soil moisture conditions.

The low levels of ozone exposure and the soil moisture conditions at Fort Matanzas National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Soil moisture conditions of mild to severe drought reduce the effectiveness of the higher exposures. Hourly concentrations of ozone occasionally exceed 80 ppb, and rarely exceed 100 ppb.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: black cherry and American elder.

FORT PULASKI NATIONAL MONUMENT (FOPU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOPU					
	1995	1996	1997	1998	1999
Sum06	10	12	10	21	18
W126	14.9	17.8	17.7	28.6	27.3
N60	246	299	296	517	475
N80	17	21	20	62	66
N100	1	1	1	6	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOPU					
	1995	1996	1997	1998	1999
Month 1	-1.50	-2.27	-2.71	-2.29	0.00
Month 2	2.66	-0.97	0.93	-4.20	-1.82
Month 3	-1.95	-2.74	-0.14	-1.17	0.86

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOPU					
	1995	1996	1997	1998	1999
April	-1.77	-0.35	0.93	0.06	-1.98
May	-1.50	-2.27	-0.14	-2.29	-2.13
June	2.66	-0.97	0.26	-4.20	2.95
July	-1.95	-2.74	-1.32	-1.17	0.00
August	4.10	-0.25	-0.52	-1.12	-1.82
September	0.11	-0.86	-1.73	0.67	0.86
October	-0.54	2.83	4.20	-0.97	-0.59

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had six hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or seasonal W126 index of ozone exposure and soil moisture status. In the year with the highest Sum06 exposure index, 1998, there were three months of mild to severe drought while the second highest year, 1999, had one month of mild drought. The year with mid-level exposure, 1996, had two months of moderate drought, and 1995 and 1997 had the same exposure index and two months of mild drought and one month of moderate drought, respectively. The highest and second highest W126 exposure years, 1998 and 1999, had four and three months

of mild to severe drought. There were two months of moderate drought and two of mild drought in the mid-level exposure years 1996 and 1997. The lowest exposure year, 1995, had three months of mild drought. Overall the patterns of distribution of drought among the years show no association with either index of exposure.

The low levels of ozone exposure and the soil moisture conditions at Fort Pulaski National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposures over 100 ppb are rare. The occurrence of two to four months of mild to severe drought annually constrains the uptake of ozone by plants and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, and crownbeard.

FORT SUMTER NATIONAL MONUMENT (FOSU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOSU					
	1995	1996	1997	1998	1999
Sum06	8	10	12	23	17
W126	12.1	14.4	16.7	28.0	24.7
N60	181	216	294	503	424
N80	15	21	21	73	67
N100	0	2	1	4	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOSU					
	1995	1996	1997	1998	1999
Month 1	1.41	-0.25	-2.16	-2.25	-0.69
Month 2	-0.09	-1.09	2.88	-0.78	-2.03
Month 3	3.42	0.38	-0.74	-2.54	1.46

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOSU					
	1995	1996	1997	1998	1999
April	-1.85	-0.05	2.88	2.49	-0.03
May	-2.26	-2.43	-0.74	-0.27	-0.49
June	1.41	-2.20	3.28	-2.25	0.67
July	-0.09	-0.25	0.95	-0.78	-0.69
August	3.42	-1.09	-1.12	-2.54	-2.03
September	0.80	0.38	1.87	0.09	1.46
October	1.44	1.67	1.80	-1.49	1.45

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure value, 1998, had two months of moderate drought, while the next highest year had one month of moderate drought. The two intermediate years each had one month of mild and moderate drought, and the lowest ozone year, 1995, had favorable soil moisture. There does not appear to be any association between the W126 level of ozone exposure and soil moisture. In the highest

ozone year, 1998, there were three months of mild to moderate drought, while the second highest year, 1999, had one month each of moderate drought. The remaining three years, 1997, 1996 and 1995, experienced, in decreasing order of exposure, one, three and two months of mild and moderate drought. The incidence of drought appears unrelated to the W126 levels of ozone over the five-year period.

The low levels of ozone exposure and the soil moisture conditions at Fort Sumter National Monument make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for injury, but the W126 does not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and rarely exceed 100 ppb. Soil moisture conditions of mild to moderate drought constrain the uptake of ozone by plants in most years and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, American sycamore, black cherry, crownbeard, and northern fox grape.

HORSESHOE BEND NATIONAL MILITARY PARK (HOBE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HOBE					
	1995	1996	1997	1998	1999
Sum06	25	18	19	25	32
W126	33.3	26.0	26.2	41.3	44.8
N60	573	444	475	727	768
N80	119	68	55	158	185
N100	21	10	4	28	30

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOBE					
	1995	1996	1997	1998	1999
Month 1	-0.82	-0.53	-0.78	-0.63	-0.53
Month 2	-3.22	-0.96	-0.61	-0.87	-1.30
Month 3	-0.48	-0.59	1.01	-1.61	-1.06

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HOBE					
	1995	1996	1997	1998	1999
April	-1.35	-1.01	1.37	0.97	-2.30
May	-2.13	-0.53	0.05	-1.60	-0.11
June	-0.82	-0.96	4.42	-0.63	6.59
July	-3.22	-0.59	-0.78	-0.87	-0.53
August	-0.48	0.09	-0.61	-1.61	-1.30
September	-0.76	2.39	1.01	0.78	-1.06
October	6.37	-0.47	1.28	-1.77	0.17

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- In three years, the N-values for concentrations of 80 and 100 ppb are high and show there are a significant number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours was significantly lower. In some years, these levels of exposure could injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest ozone exposure values, 1999, experienced two months of mild drought. The years with intermediate ozone exposure, 1995 and 1998, each had one month of mild or severe drought, while the two years with the lowest exposures experienced favorable soil moisture throughout. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. The highest ozone years, 1999 and 1998, each had three months of mild to moderate drought. There were three months of mild to severe drought in 1995, a mid-level exposure year, and the two years with the lowest levels of ozone experienced one month of mild drought between them.

The risk of foliar ozone injury to plants at Horseshoe Bend National Military Park is moderate. While the levels of ozone exposure generally create the potential for injury, low soil moisture reduces the likelihood of injury developing in the higher ozone years. Since the site is subject to potentially harmful levels of ozone most years, the probability of foliar injury developing may be greatest during years such as 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, and crownbeard.

KENNESAW MOUNTAIN NATIONAL BATTLEFIELD PARK (KEMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus rigida	Pitch pine	Pinaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for KEMO					
	1995	1996	1997	1998	1999
Sum06	15	15	16	26	36
W126	42.0	38.0	36.9	59.4	62.2
N60	689	647	626	954	979
N80	190	145	139	308	346
N100	54	32	23	88	87

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at KEMO					
	1995	1996	1997	1998	1999
Month 1	2.87	0.22	0.62	-2.60	-1.21
Month 2	-2.11	-1.17	-1.40	0.21	-0.59
Month 3	2.84	0.23	2.65	-1.53	0.96

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at KEMO					
	1995	1996	1997	1998	1999
April	-1.49	0.22	0.76	4.22	-1.77
May	-1.24	-0.95	0.75	-0.96	0.17
June	2.87	0.22	1.93	-0.84	1.82
July	-2.11	-1.17	0.62	-2.60	-0.23
August	2.84	0.23	-1.40	0.21	-1.21
September	0.01	1.70	2.65	-1.53	-0.59
October	4.86	-1.23	3.20	-2.04	0.96

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- There is no association between the 90-day Sum06 accumulation period levels of ozone and soil moisture conditions. Months of mild and moderate drought were

distributed over the five-year period without any relationship to the level of ozone. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not fully consistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. In the highest ozone years, 1999 and 1998, there were two and three months, respectively, of mild and moderate drought. In the mid-level exposure year, 1995, there were three months of mild and moderate drought. The second lowest exposure year, 1996, had two months of mild drought, and the lowest year, 1997, had one month of mild drought.

The risk of foliar ozone injury to plants at Kennesaw Mountain National Battlefield Park is high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in higher exposure years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest in years such as 1996, 1997 and 1999 when ozone exposures exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the long-term uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, common milkweed, redbud, white ash, yellow-poplar, American sycamore, black cherry, cut-leaf coneflower, American elder, and northern fox grape.

MOORE'S CREEK NATIONAL BATTLEFIELD (MOCR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours

above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MOCR					
	1995	1996	1997	1998	1999
Sum06	10	19	21	35	20
W126	23.5	26.9	34.3	46.4	29.9
N60	440	490	607	842	503
N80	42	51	86	166	101
N100	2	2	4	14	13

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MOCR					
	1995	1996	1997	1998	1999
Month 1	-2.98	-0.47	-1.45	1.02	0.97
Month 2	-0.71	-0.38	-0.56	-1.31	-0.35
Month 3	7.20	2.48	-0.58	-2.71	-2.15

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MOCR					
	1995	1996	1997	1998	1999
April	-2.98	0.23	0.91	2.20	0.32
May	-0.71	-0.47	-1.45	1.02	0.97
June	7.20	-0.38	-0.56	-1.31	-0.35
July	-1.15	2.48	-0.58	-2.71	-2.15
August	-1.64	-0.19	-3.34	2.43	-0.86
September	-0.87	7.28	0.83	-0.48	1.80
October	3.11	3.72	-0.13	-1.38	3.90

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- In two years, the N-values for concentrations of 80 and 100 ppb are high and show there are a number of hours during which plants are exposed to potentially harmful levels of ozone. In the remaining years, the number of hours was significantly lower. In some years, these levels of exposure could injure vegetation.

- There are no associations between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture conditions. In the Sum06 assessment, months of mild and moderate drought were distributed over the five-year period without any relationship to the level of ozone. The highest ozone year, 1998, had one month of mild and one of moderate drought, while the lowest ozone year, 1995, had a month of moderate drought. There is no association

between the W126 index of exposure and soil moisture with one to three months of moderate to severe drought occurring in four of the five years. The years with both the highest and lowest exposure levels, 1998 and 1995, each had three months of mild and moderate drought.

The risk of foliar ozone injury at Moore's Creek National Battlefield is moderate. The Sum06 threshold is satisfied annually while the W126 threshold is satisfied only in the highest exposure years. The N-values indicate that exposures to 80 to 100 ppb vary considerably among years. Months of low soil moisture occur independent of the level of ozone and can significantly constrain the uptake of ozone. The risk of injury may be greatest in years such as 1999 when high levels of ozone coincide with soil moisture conditions that generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, yellow-poplar, American sycamore, black cherry, and American elder.

OCMULGEE NATIONAL MONUMENT (OCMU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for OCMU					
	1995	1996	1997	1998	1999
Sum06	13	10	25	32	42
W126	41.9	34.1	33.9	50.9	53.1
N60	703	573	568	842	836
N80	184	132	130	257	280
N100	46	28	32	61	81

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at OCMU					
	1995	1996	1997	1998	1999
Month 1	2.15	-1.18	-0.09	-2.76	-0.51
Month 2	-2.19	-0.77	-2.00	-3.25	-2.59
Month 3	0.60	0.46	2.14	-1.39	1.20

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at OCMU					
	1995	1996	1997	1998	1999
April	-2.21	-0.58	0.18	2.83	-2.37
May	-2.22	-0.82	-0.11	-1.60	-1.65
June	2.15	-1.18	0.47	-2.76	1.84
July	-2.19	-0.77	-0.09	-3.25	-0.51
August	0.60	0.46	-2.00	-1.39	-2.59
September	-0.32	0.80	2.14	3.77	1.20
October	2.04	0.74	2.62	-1.33	0.20

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Soil moisture levels associated with the 90-day Sum06 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest ozone exposure values, 1999 and 1998, had one month of moderate drought and three months of mild to severe drought, respectively. The remaining years each had one month of mild or moderate drought; the year with the lowest ozone had one month of mild drought.

Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the highest ozone years, 1999 and 1998, there were three and five months, respectively, of mild to severe drought. The mid-level ozone year 1995 had three months of moderate drought, and the two years with the lowest levels of ozone each had one month of drought.

The risk of foliar ozone injury to plants at Ocmulgee National Monument is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury in a high exposure year. Levels of exposure capable of producing foliar injury also occur under conditions of minor drought. The probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, yellow-poplar, American sycamore, black cherry, American elder, crownbeard, and northern fox grape.

TIMUCUAN ECOLOGICAL AND HISTORIC PRESERVE (TIMU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for TIMU					
	1995	1996	1997	1998	1999
Sum06	9	12	12	22	14
W126	14.6	17.3	21.7	29.2	21.2
N60	230	289	379	492	360
N80	19	17	31	90	37
N100	4	2	4	16	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TIMU					
	1995	1996	1997	1998	1999
Month 1	0.63	0.10	-0.06	-1.63	-1.68
Month 2	-0.37	-1.59	0.81	-2.80	-1.93
Month 3	1.56	0.72	0.34	-4.66	-1.03

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at TIMU					
	1995	1996	1997	1998	1999
April	0.63	0.10	4.65	-1.63	-1.93
May	-0.37	-1.59	-0.06	-2.80	-1.03
June	1.56	0.72	0.81	-4.66	1.07
July	-0.77	-0.96	0.34	-0.35	-2.71
August	2.44	0.84	-0.47	-0.46	-1.16
September	-0.77	-1.04	-2.15	2.84	1.15
October	0.61	4.94	2.13	-0.95	-1.13

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had sixteen hours in which the concentration exceeded 100 ppb, but there were generally four or fewer hours over 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The years with the highest and second highest ozone exposure levels, 1998 and 1999, each had three months of mild to severe drought. The remaining three years had lower levels of ozone and experienced one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to

ozone concentrations, although the pattern is not consistent. The year with the highest ozone exposure value, 1998, had three months of mild to severe drought. In 1997 and 1999, two years both with the second highest level of exposure, there was one month of moderate and five months of mild and moderate drought, respectively. The second lowest exposure year, 1996, had two months of mild drought, and the lowest year had normal soil moisture conditions.

The low levels of ozone exposure and soil moisture conditions at Timucuan Ecological and Historic Preserve make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 criteria are not satisfied. Hourly concentrations of ozone exceed 80 ppb for a few hours each year and hours of exposure to concentrations greater than 100 ppb are generally low. High ozone exposures occur during periods of low soil moisture that constrain uptake by plants and reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, yellow-poplar, black cherry, and American elder.

SAN FRANCISCO BAY AREA NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SAN FRANCISCO BAY AREA NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SAN FRANCISCO BAY NETWORK

Park	Code	State	Risk	O3 Data
Golden Gate NRA	GOGA	CA	low	kriged
John Muir NHS	JOMU	CA	high	kriged
Muir Woods NM	MUWO	CA	moderate	kriged
Pinnacles NM	PINN	CA	high	monitored
Point Reyes NS	PORE	CA	low	kriged

GOLDEN GATE NATIONAL RECREATION AREA (GOGA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Oenothera elata	Evening primrose	Onagraceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus radiata	Monterey pine	Pinaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GOGA					
	1995	1996	1997	1998	1999
Sum06	4	4	2	4	4
W126	6	6.2	3.4	5	6.4
N60	78	84	36	60	82
N80	24	19	7	14	22
N100	7	3	1	4	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GOGA					
	1995	1996	1997	1998	1999
Month 1	1.18	1.78	-0.04	-	-0.11
Month 2	2.33	2.83	1.36	-	-1.35
Month 3	2.35	0.21	0.74	-	-1.07

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GOGA					
	1995	1996	1997	1998	1999
April	2.37	1.78	-0.30	0.26	-0.16
May	1.18	2.83	-0.94	4.49	-0.88
June	2.33	0.21	0.68	0.75	-0.82
July	2.35	1.15	-0.04	1.36	-0.57
August	0.22	-0.57	1.36	-0.28	-0.11
September	-0.91	-0.13	0.74	-1.04	-1.35
October	-2.66	-0.28	0.31	-0.78	-1.07

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. The W126 accumulative value exceeds the threshold in some years, and the N100 count meets the threshold requirement in two years. In general, the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. One year had seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the 90-day Sum06 accumulation periods show only two months of drought stress over the five-year period, and the uptake of ozone is generally fostered. Similarly, soil moisture levels during the W126 periods were generally normal and favored the uptake of ozone. There were four months of drought over the five-year period, with only one month of moderate drought.

The risk of foliar ozone injury to plants at Golden Gate National Recreation Area is low.

Neither the Sum06 nor the W126 injury criteria are satisfied. Although soil moisture conditions favor the uptake of ozone and levels of drought stress are rare and mild, exposures to 80 and 100 ppb levels of ozone are low.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder, spreading dogbane, mugwort, evening primrose, ninebark and Scouler's willow.

JOHN MUIR NATIONAL HISTORIC SITE (JOMU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Artemisia douglasiana	Mugwort	Asteraceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae
Vitis vinifera	European wine grape	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JOMU					
	1995	1996	1997	1998	1999
Sum06	9	12	4	11	9
W126	13.0	17.6	7.5	13.3	15.0
N60	194	276	103	193	221
N80	54	71	17	58	64
N100	12	10	2	12	11

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JOMU					
	1995	1996	1997	1998	1999
Month 1	2.33	0.21	-0.04	1.36	-0.11
Month 2	2.35	1.15	1.36	-0.28	-1.35
Month 3	0.22	-0.57	0.74	-1.04	-1.07

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JOMU					
	1995	1996	1997	1998	1999
April	2.37	1.78	-0.30	0.26	-0.16
May	1.18	2.83	-0.94	4.49	-0.88
June	2.33	0.21	0.68	0.75	-0.82
July	2.35	1.15	-0.04	1.36	-0.57
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September	-0.91	-0.13	0.74	-1.04	-1.35
October	-2.66	-0.28	0.31	-0.78	-1.07

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury. While the W126 accumulative value exceeds the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. There were usually ten to twelve hours each year in which the concentration exceeded 100 ppb, but one year had only two hours above 100 ppb. The higher levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The Sum06 indices of exposure were low and no relationship between ozone exposure and soil moisture levels was evident. Soil moisture levels during the five-year W126 assessment period show three months of mild stress and thus ozone uptake would be fostered. Soil moisture levels were generally normal and favored the uptake of ozone. Months with drought were rare and occurred in three of the five years;

there was only one month of moderate drought in the five-year assessment period.

The risk of foliar ozone injury to plants at John Muir National Historic Site is high. The Sum06 and W126 exposure indices are generally satisfied. Months of drought stress are rare and mild. Soil moisture conditions consistently favor the uptake of ozone and sustain the ability of the exposures to produce foliar injury.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, mugwort and common snowberry.

MUIR WOODS NATIONAL MONUMENT (MUWO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Artemisia douglasiana	Mugwort	Asteraceae
Pinus radiata	Monterey pine	Pinaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
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W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
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Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MUWO					
	1995	1996	1997	1998	1999
Sum06	6	6	2	6	5
W126	7.9	9.4	4.5	7.6	9.1
N60	107	137	53	101	125
N80	33	33	9	28	36
N100	8	5	1	7	7

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MUWO					
	1995	1996	1997	1998	1999
Month 1	2.33	1.78	-0.04	0.75	-0.11
Month 2	2.35	2.83	1.36	1.36	-1.35
Month 3	0.22	0.21	0.74	-0.28	-1.07

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MUWO					
	1995	1996	1997	1998	1999
April	2.37	1.78	-0.30	0.26	-0.16
May	1.18	2.83	-0.94	4.49	-0.88
June	2.33	0.21	0.68	0.75	-0.82
July	2.35	1.15	-0.04	1.36	-0.57
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September	-0.91	-0.13	0.74	-1.04	-1.35
October	-2.66	-0.28	0.31	-0.78	-1.07

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count marginally satisfies the threshold during three years. The Sum06 index is not satisfied and theW126 criteria are not consistently satisfied.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The Sum06 indices of exposure were low and no relationship between ozone exposure and soil moisture levels was evident. Soil moisture levels during the five-year assessment period show two months of mild drought stress and thus ozone uptake would be fostered. Soil moisture levels during the seasonal W126 periods were generally normal and favored the uptake of ozone. Months with drought were rare and occurred in three of the five years; there was only one month of moderate

drought in the five-year assessment period.

The risk of foliar ozone injury to plants at Muir Woods National Monument is moderate. Although the Sum06 threshold is not satisfied, the W126 criteria are often fulfilled. Months of drought stress are rare and mild. Soil moisture conditions consistently favor the uptake of ozone and sustain the ability of the exposures to produce foliar injury.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder and mugwort.

PINNACLES NATIONAL MONUMENT (PINN)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Artemisia douglasiana	Mugwort	Asteraceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PINN					
	1995	1996	1997	1998	1999
Sum06	30	41	21	35	29
W126	37.9	50.9	28.9	35.5	38.2
N60	693	889	524	609	733
N80	113	197	39	93	60
N100	5	22	2	11	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PINN					
	1995	1996	1997	1998	1999
Month 1	2.32	0.70	-1.63	3.23	0.76
Month 2	0.83	-0.06	0.52	1.87	0.17
Month 3	-0.47	-0.70	-1.27	0.18	-1.57

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PINN					
	1995	1996	1997	1998	1999
April	0.59	-0.22	-2.08	1.43	0.90
May	2.48	3.59	-2.50	7.25	0.07
June	3.59	1.06	-1.72	2.72	1.30
July	2.32	0.70	-1.63	3.23	1.09
August	0.83	-0.06	0.52	1.87	0.76
September	-0.47	-0.70	-1.27	0.18	0.17
October	-2.08	1.09	-0.82	-0.42	-1.57

Risk Analysis

- There are a few ozone-sensitive species at the site, all of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years although concentrations exceeded 100 ppb every year. Thus the Sum06 threshold was satisfied each year and the W126 criteria in two of the five years.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and that concentrations exceeded 100 ppb every year. The higher levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. For the Sum06 index, here were two months of drought in 1997, the year with the lowest level of exposure, and one month of drought among the remaining four years. In the year with the lowest W126 exposure index, 1997, there were five months of mild and moderate drought, and only two months of mild and moderate drought occurred among the remaining four years.

The risk of foliar ozone injury to plants at Pinnacles National Monument is high. The threshold for injury is consistently satisfied by the Sum06 index and occasionally by the W126 index. Exposures frequently exceed 80 ppb and in some years there are a significant number of hours of exposure greater than 100 ppb. There is no association between ozone exposure and soil moisture, and during entire years soil moisture appears to either favor or constrain the uptake of ozone. Consequently, the likelihood for the production of foliar injury is greatest in years such as 1996 and 1998 when exposure levels and soil moisture conditions are both favorable.

A program to assess the incidence of foliar ozone injury on plants at the site could use

one or more of the following bioindicator species: tree-of-heaven, mugwort and blue elderberry.

POINT REYES NATIONAL SEASHORE (PORE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Alnus rubra	Red alder	Betulaceae
Artemisia douglasiana	Mugwort	Asteraceae
Pinus radiata	Monterey pine	Pinaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PORE					
	1995	1996	1997	1998	1999
Sum06	3	3	2	3	4
W126	4.7	6.1	3.6	5.3	7.2
N60	66	88	46	72	98
N80	13	13	8	16	24
N100	2	1	1	4	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PORE					
	1995	1996	1997	1998	1999
Month 1	2.33	1.78	1.36	0.75	-0.11
Month 2	2.35	2.83	0.74	1.36	-1.35
Month 3	0.22	0.21	0.31	-0.28	-1.07

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PORE					
	1995	1996	1997	1998	1999
April	2.37	1.78	-0.30	0.26	-0.16
May	1.18	2.83	-0.94	4.49	-0.88
June	2.33	0.21	0.68	0.75	-0.82
July	2.35	1.15	-0.04	1.36	-0.57
August	0.22	-0.57	1.36	-0.28	-0.11
September	-0.91	-0.13	0.74	-1.04	-1.35
October	-2.66	-0.28	0.31	-0.78	-1.07

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. Since the W126 accumulative value is generally below the threshold and the N100 count is below the required number, the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 4 hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The Sum06 indices of exposure were low and no relationship between ozone exposure and soil moisture levels was evident. Soil moisture levels during the five-year assessment period show two months of mild drought stress and thus ozone uptake would be fostered. Soil moisture levels during the seasonal W126 periods were generally normal and favored the uptake of ozone. Months with drought were rare and occurred in three of the five years; there was only one month of moderate

drought in the five-year assessment period.

The risk of foliar ozone injury to plants at Point Reyes National Seashore is low. The Sum06 and W126 exposure indices are not satisfied. Soil moisture conditions generally favor the uptake of ozone and levels of drought stress are rare and mild. If the ambient concentration of ozone increases over time, or the level of exposure increases in a year in which soil moisture conditions favor uptake, the probability of foliar injury to vegetation could increase.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: red alder and mugwort.

SOUTH FLORIDA / CARIBBEAN NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTH FLORIDA / CARIBBEAN NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on

the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher

concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTH FLORIDA / CARIBBEAN NETWORK

Park	Code	State	Risk	O3 Data
Big Cypress N PRES	BICY	FL	low	kriged
Biscayne NP	BISC	FL	low	kriged
Buck Island Reef NM	BUIS	VI	low	kriged
Dry Tortugas NP	DRTO	FL	cannot eval	no data
Everglades NP	EVER	FL	low	monitored
Virgin Islands NP	VIIS	VI	low	monitored

BIG CYPRESS NATIONAL PRESERVE (BICY)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BICY					
	1995	1996	1997	1998	1999
Sum06	4	4	5	15	10
W126	7.1	6.9	9.4	17.6	10.3
N60	100	87	129	301	158
N80	10	7	14	47	22
N100	1	1	1	5	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BICY					
	1995	1996	1997	1998	1999
Month 1	-0.34	-1.12	-0.60	2.28	-1.24
Month 2	1.29	1.31	2.96	-1.33	-1.48
Month 3	-0.61	-0.07	0.08	-1.84	-1.02

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BICY					
	1995	1996	1997	1998	1999
April	1.29	-0.07	2.96	-1.33	-1.02
May	-0.61	3.12	0.08	-1.84	-0.63
June	2.32	0.30	0.17	-3.10	3.51
July	3.23	-3.04	0.86	-1.21	-0.10
August	4.63	-1.25	-1.37	-0.05	-0.23
September	0.26	-2.71	-0.75	0.10	2.18
October	6.92	1.31	-2.34	-1.85	2.91

Risk Analysis

- There are two ozone-sensitive species at the site, but neither of them is a bioindicator for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations often exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- The low levels of ozone during the 90-day Sum06 accumulation periods make it difficult to assess relationships between the levels of ozone and soil moisture, however they appear to be inversely related: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest and second highest ozone exposures, 1998 and 1999 respectively, experienced two and three months of mild drought, while the remaining three years, with lower ozone exposures, had one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to

ozone concentrations, although the pattern is not consistent. In the highest ozone year, 1998, there were five months of mild and severe drought. The two mid-level exposure years, 1999 and 1997, had one and two months of mild and moderate drought respectively, while the second lowest year, 1995, had normal soil moisture and the lowest year, 1996, had three months of mild to severe drought.

The low levels of ozone exposure and the relatively dry soil moisture conditions at Big Cypress National Preserve make the risk of foliar ozone injury to plants low. The Sum06 criteria are generally not satisfied, while the W126 are not fulfilled. Hourly concentrations of ozone seldom exceed 80 ppb, and exposure to 100 ppb is rare. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and further reduces the likelihood of foliar injury.

While ozone-sensitive species occur at the site, they are not bioindicator species.

BISCAYNE NATIONAL PARK (BISC)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BISC					
	1995	1996	1997	1998	1999
Sum06	4	4	4	14	9
W126	7.7	7.5	9.2	16.3	10.8
N60	111	93	118	270	168
N80	17	11	19	44	25
N100	2	2	1	4	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BISC					
	1995	1996	1997	1998	1999
Month 1	0.23	1.32	0.12	3.09	-1.66
Month 2	0.46	-0.05	-0.46	-1.55	-1.88
Month 3	0.33	1.54	0.72	-1.58	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BISC					
	1995	1996	1997	1998	1999
April	0.33	-0.05	0.72	-1.55	-1.88
May	-1.91	1.54	-0.79	-1.58	-1.56
June	3.30	1.74	3.27	-2.45	4.22
July	1.11	-2.27	-0.02	-1.07	-1.79
August	6.71	-0.51	1.71	-0.38	3.63
September	-0.84	-1.10	1.60	2.51	0.25
October	2.22	1.30	-2.80	-2.27	4.13

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low levels of ozone during the 90-day Sum06 accumulation periods make it difficult to assess relationships between the levels of ozone and soil moisture, however they appear to be inversely related, when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The two highest ozone years, 1998 and 1999, had two and three months of mild drought, respectively. The remaining three years had lower levels of exposure and favorable soil moisture throughout. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, but again the pattern is not consistent. There were five months of mild and moderate

drought in 1998, the year with the highest exposure. In 1999 and 1997, years with mid-level exposures, there were four months of mild and severe drought and one month of moderate drought, respectively. The second lowest year, 1995, had one month of mild drought, and the lowest year, 1996, had two months of mild and moderate drought.

The low levels of ozone exposure and soil moisture conditions at Biscayne National Park make the risk of foliar ozone injury to plants low. The Sum06 exposures generally do not exceed the threshold for injury, and the W126 exposures do not since the N100 requirement is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and exposure to 100 ppb is rare. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in higher exposure years and further reduces the likelihood of foliar injury.

While one ozone-sensitive species occurs at the site, it is not a bioindicator species.

BUCK ISLAND REEF NATIONAL MONUMENT (BUIS)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BUIS

	1995	1996	1997	1998	1999
Sum06	14	10	10	16	22
W126	25.7	23.8	26.1	34.6	38.8
N60	399	379	438	601	714
N80	36	23	19	42	54
N100	4	2	1	2	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data are not available for the area. Therefore, it is not possible to assess the relationship between ozone exposure and drought and to evaluate the possible effects of drought stress on the uptake of ozone at the site.

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year has more than four hours in which the concentration exceed 100 ppb. These levels of exposure are not likely to injure vegetation.
- Palmer Z index data are not available for the region in which the site is located. Consequently, relationships between ozone exposure and soil moisture cannot be assessed.

The low levels of ozone exposure at Buck Island Reef National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 requirement is not satisfied. Hourly concentrations of ozone occasionally exceed 80 ppb while exposure to 100 ppb is rare. The possible role of soil moisture in constraining the uptake of ozone is unknown, but any drought would further reduce the likelihood of foliar injury.

No ozone- sensitive species are listed for the site.

DRY TORTUGAS NATIONAL PARK (DRTO)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status does not include this site that is over 60 miles offshore.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Dry Tortugas National Park cannot be assessed due to the lack of information on ozone exposure at the site.

EVERGLADES NATIONAL PARK (EVER)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Spartina alterniflora	Smooth cordgrass	Poaceae
Sambucus canadensis	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for EVER					
	1995	1996	1997	1998	1999
Sum06	2	2	2	13	4
W126	2.8	2.8	4.2	11.5	25.1
N60	33	27	43	208	97
N80	3	6	9	17	15
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at EVER					
	1995	1996	1997	1998	1999
Month 1	0.04	-1.12	-0.60	2.28	-1.24
Month 2	-0.34	1.31	2.96	-1.33	-1.48
Month 3	1.29	-0.07	0.08	-1.84	-1.02

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at EVER					
	1995	1996	1997	1998	1999
April	1.29	-0.07	2.96	-1.33	-1.02
May	-0.61	3.12	0.08	-1.84	-0.63
June	2.32	0.30	0.17	-3.10	3.51
July	3.23	-3.04	0.86	-1.21	-0.10
August	4.63	-1.25	-1.37	-0.05	-0.23
September	0.26	-2.71	-0.75	0.10	2.18
October	6.92	1.31	-2.34	-1.85	2.91

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold in two years, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over most of the five years. Although the two years with the highest levels of ozone exposure also had the most months of drought, the bi-modal distribution of the levels of exposure make any conclusions about their association suspect. No relationships are apparent between the W126 index and soil moisture. In the highest ozone year, 1999, there was one month of mild drought, while the second highest year, 1998, had half the level of exposure and experienced five months of mild to severe drought. The lowest ozone years, 1995 and 1996, had the same level of exposure, but one had favorable conditions and the other had three months of mild to severe drought.

The low levels of ozone exposure at Everglades National Park make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied, exposures above 80 ppb were uncommon, and concentrations never reached 100 ppb.

If the level of risk increases in the future, American elder can be used as a bioindicator species.

VIRGIN ISLANDS NATIONAL PARK (VIIS)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VIIS					
	1995	1996	1997	1998	1999
Sum06	-	-	-	0	0
W126	-	-	-	-	1
N60	-	-	-	-	0
N80	-	-	-	-	0
N100	-	-	-	-	0

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Virgin Islands.

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- Ozone monitoring data indicate that exposure levels at the site are extremely low and the thresholds for the Sum06 and the W126 indices are not satisfied.
- The N-values for the site show that exposures are extremely low and that ambient concentrations do not reach 60 ppb. These levels of exposure will not injure vegetation.
- Associations between the levels of ozone exposure and soil moisture cannot be assessed since data are not available.

The low level of ozone exposure at Virgin Islands National Park makes the risk of foliar ozone injury to plants low. However, ozone data are extremely limited and additional data should be evaluated to confirm the risk assessment.

SIERRA NEVADA NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SIERRA NEVADA NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SIERRA NEVADA NETWORK

Park	Code	State	Risk	O3 Data
Devils Postpile NM	DEPO	CA	high	kriged
Sequoia & Kings Canyon NP	SEKI	CA	high	monitored
Yosemite NP	YOSE	CA	high	monitored

DEVILS POSTPILE NATIONAL MONUMENT (DEPO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for DEPO					
	1995	1996	1997	1998	1999
Sum06	27	38	20	24	21
W126	48.8	66.3	50.5	69.2	82.5
N60	909	1277	896	1189	1491
N80	189	266	138	285	339
N100	32	34	23	63	44

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at DEPO					
	1995	1996	1997	1998	1999
Month 1	3.44	1.54	-2.98	1.62	0.84
Month 2	1.55	0.65	-2.14	6.71	0.32
Month 3	-0.88	-0.54	-1.72	4.64	-0.66

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at DEPO					
	1995	1996	1997	1998	1999
April	1.09	-0.07	-2.47	1.62	0.17
May	3.82	2.50	-2.98	6.71	-0.31
June	3.64	1.54	-2.14	4.64	0.97
July	3.44	0.65	-1.72	5.60	0.84
August	1.55	-0.54	-0.84	1.98	0.32
September	-0.88	-1.07	-0.73	1.03	-0.66
October	-2.12	1.68	-0.70	-0.55	-1.96

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- There are no apparent relationships between the 90-day Sum06 and seasonal W126 accumulative indices of ozone and soil moisture conditions, and the entire growing season appears to be either largely favorable or unfavorable with respect to soil moisture. Soil moisture levels associated with the Sum06 index show that 1997, a low exposure year, experienced three months of mild and moderate drought. Soil moisture conditions were favorable the remaining four years. Soil moisture levels associated with the seasonal W126 index of exposure show that in 1997, the second lowest exposure year, there were four months of mild to moderate drought. In each of three remaining years there was one month of drought, and normal soil moisture in the last year.

The risk of foliar ozone injury to plants at Devils Postpile National Monument is high. The levels of ozone exposure consistently create the potential for injury, however dry soil conditions may reduce the likelihood of injury developing in a particular year. Since there are no apparent relationships between the levels of ozone exposure and soil moisture conditions, and since entire growing seasons appear to be characterized by either favorable or unfavorable soil moisture conditions, the levels of risk vary considerably among years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing is greatest during years in which soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, Jeffrey pine, and quaking aspen.

SEQUOIA & KINGS CANYON NATIONAL PARK (SEKI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SEKI					
	1995	1996	1997	1998	1999
Sum06	-	-	74	66	77
W126	-	-	107.8	75.2	29.8
N60	-	-	1792	1221	2187
N80	-	-	589	400	851
N100	-	-	72	62	164

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SEKI					
	1995	1996	1997	1998	1999
Month 1	3.44	1.54	-2.14	5.60	0.84
Month 2	1.55	0.65	-1.72	1.98	0.32
Month 3	-0.88	-0.54	-0.84	1.03	-0.66

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SEKI					
	1995	1996	1997	1998	1999
April	1.09	-0.07	-2.47	1.62	0.17
May	3.82	2.50	-2.98	6.71	-0.31
June	3.64	1.54	-2.14	4.64	0.97
July	3.44	0.65	-1.72	5.60	0.84
August	1.55	-0.54	-0.84	1.98	0.32
September	-0.88	-1.07	-0.73	1.03	-0.66
October	-2.12	1.68	-0.70	-0.55	-1.96

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- Only three years of ozone monitoring data are available for assessing the Sum06 and W126 indices of exposure. The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- In the three years of monitoring data, the N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.

- Since only three years of ozone monitoring data are available, statements regarding the relationship between ozone exposure and soil moisture are speculative and subject to assessment of additional data. The 90-day Sum06 accumulative indices of exposure were relatively similar across the three years, and no association is apparent between exposure level and soil moisture. Two months of mild and moderate drought occurred in the second highest ozone year, 1997, and soil moisture was favorable in the other two years. The seasonal W126 exposure indices varied greatly among the three years, and it appears there may be an inverse relationship between ozone exposure and soil moisture: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. In the highest ozone year, 1997, there were four months of mild and moderate drought. Ozone exposure was considerably lower in the other two years and there was only one month of mild drought between them. Conclusions for both the Sum06 and W126 exposures are subject to further confirmation.

The risk of foliar ozone injury to plants at Sequoia and Kings Canyon National Park is high. The levels of ozone exposure consistently create the potential for injury in both the Sum06 and W126 indices during the three years of data available. The suspected inverse

relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years such as 1998 and 1999 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, mugwort, ninebark, ponderosa pine, quaking aspen, skunkbush, Scouler's willow, and blue elderberry.

YOSEMITE NATIONAL PARK (YOSE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Artemisia douglasiana	Mugwort	Asteraceae
Physocarpus capitatus	Ninebark	Rosaceae
Pinus jeffreyi	Jeffrey pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for YOSE					
	1995	1996	1997	1998	1999
Sum06	35	57	18	51	50
W126	65.3	86.1	43.8	71.0	80.3
N60	1151	1617	743	1336	1650
N80	215	246	59	154	145
N100	10	6	6	13	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at YOSE					
	1995	1996	1997	1998	1999
Month 1	3.44	2.50	-0.84	5.60	0.84
Month 2	1.55	1.54	-0.73	1.98	0.32
Month 3	-0.88	0.65	-0.70	1.03	-0.66

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at YOSE					
	1995	1996	1997	1998	1999
April	1.09	-0.07	-2.47	1.62	0.17
May	3.82	2.50	-2.98	6.71	-0.31
June	3.64	1.54	-2.14	4.64	0.97
July	3.44	0.65	-1.72	5.60	0.84
August	1.55	-0.54	-0.84	1.98	0.32
September	-0.88	-1.07	-0.73	1.03	-0.66
October	-2.12	1.68	-0.70	-0.55	-1.96

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone

- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two of the years. The levels of exposure in the highest ozone years can injure vegetation.

- During the assessment period for the 90-day Sum06 accumulative index of exposure, soil moisture levels were normal throughout and favored the uptake of ozone. Since there were no months of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and the Sum06 index of exposure. There does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. Soil moisture conditions were generally favorable, but in some years drought stress can significantly constrain uptake. There were four months of mild and moderate drought in 1997, the year with the lowest ozone exposure, while the other years had either a month of drought or favorable soil moisture conditions.

The risk of foliar ozone injury to plants at Yosemite National Park is high. The levels of ozone exposure create the potential for injury with Sum06 and W126 indices that exceed their thresholds, consistently high N80 values, and occasionally high N100 counts. There are no apparent relationships between the levels of ozone exposure and soil moisture conditions, and entire growing seasons appear to be characterized by either favorable or unfavorable soil moisture conditions. As a result, the levels of risk will vary among years. Dry soil conditions may reduce the likelihood of injury in any particular year,

while in years like 1995 and 1998, favorable soil moisture and high ozone exposures create conditions that can lead to foliar injury.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, mugwort, Jeffrey pine, ponderosa pine, quaking aspen, skunkbush, Scouler's willow, and blue elderberry.

SONORAN DESERT NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SONORAN DESERT NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its

determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations $\geq$ 100 ppb. Thus,

the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not anticipated it will occur regularly or frequently. Sites rated moderate are likely to

experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SONORAN DESERT NETWORK

Park	Code	State	Risk	O3 Data
Casa Grande Ruins NM	CAGR	AZ	low	kriged
Chiricahua NM	CHIR	AZ	low	monitored
Coronado NMEM	CORO	AZ	low	kriged
Fort Bowie NHS	FOBO	AZ	low	kriged
Gila Cliff Dwellings NM	GICL	NM	low	kriged
Montezuma Castle NM	MOCA	AZ	moderate	kriged
Organ Pipe Cactus NM	ORPI	AZ	moderate	kriged
Saguaro NP	SAGU	AZ	low	monitored
Tonto NM	TONT	AZ	moderate	kriged
Tumacacori NHP	TUMA	AZ	low	kriged
Tuzigoot NM	TUZI	AZ	low	kriged

CASA GRANDE RUINS NATIONAL MONUMENT (CAGR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CAGR					
	1995	1996	1997	1998	1999
Sum06	29	28	21	28	28
W126	36.9	36.0	31.2	37.0	38.9
N60	650	650	556	669	722
N80	111	104	63	90	79
N100	18	12	4	4	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CAGR					
	1995	1996	1997	1998	1999
Month 1	1.59	-2.41	-1.07	4.59	-1.93
Month 2	-2.58	-2.39	-2.27	1.33	-1.55
Month 3	0.99	-1.81	-1.59	-0.90	5.49

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CAGR					
	1995	1996	1997	1998	1999
April	1.45	-2.41	-1.07	2.35	1.54
May	1.75	-2.39	-2.27	4.57	-1.93
June	1.59	-1.81	-1.59	4.59	-1.55
July	-2.58	1.09	-2.61	1.33	5.49
August	0.99	-1.27	0.71	-0.90	-0.83
September	0.22	1.51	-0.47	0.08	1.05
October	-2.04	-1.22	-0.99	0.21	-2.28

Risk Analysis

- There is one ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in some years. The highest levels of exposure can injure vegetation.

- There is no apparent association between either the 90-day Sum06 or the seasonal W126 index of exposure and soil moisture. Evaluation of the relationships between the Sum06 and W126 indices and soil moisture is difficult because ozone exposure levels were relatively uniform over the five years, and soil moisture conditions showed frequent periods of mild to moderate drought stress. Except for 1998, the annual Sum06 accumulation periods were marked by between one and three months of mild to moderate drought each year. Similarly, except for 1998, the W126 index had two to five months of mild to moderate drought annually.

The risk of foliar ozone injury at Casa Grande Ruins National Monument is low. While the Sum06 exposures exceed the threshold level for injury, the W126 do not since the N100 criteria are not satisfied. Exposure to 80 and 100 ppb ozone varies considerably among years. The ability of low soil moisture to constrain the uptake of ozone is an important consideration at the site since there are often three or four months of mild and moderate drought in a year. These levels of soil moisture significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. While the year 1998 is characterized by normal soil moisture conditions, it experienced lower levels of ozone that are unlikely to result in foliar injury. The random co-occurrence of higher

levels of ozone exposure and soil moisture conditions that favor the uptake of ozone could increase the likelihood of injury in a particular year.

There are no ozone bioindicator species listed for the site.

CHIRICAHUA NATIONAL MONUMENT (CHIR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Salix gooddingii	Gooding's willow	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHIR					
	1995	1996	1997	1998	1999
Sum06	22	30	15	20	23
W126	25.1	33.3	21.2	31.3	29.6
N60	407	659	262	534	469
N80	2	1	0	2	8
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.
Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHIR					
	1995	1996	1997	1998	1999
Month 1	1.66	-2.23	-1.06	2.55	0.43
Month 2	3.14	-2.41	-0.84	1.63	-1.96
Month 3	2.46	-0.51	-1.94	2.99	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHIR					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show no concentrations of 100 ppb and only a few greater than 80 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. For the Sum06 exposures, three years, including those with the highest and lowest indices, each had two months of drought stress. The remaining two years had normal soil moisture. There also does not appear to be any association between the W126 index and soil moisture. Soil moisture levels in the years with the three highest levels of exposure, 1996, 1998 and 1999, experienced two, three and three months of mild to severe drought, respectively. The second lowest year, 1995, had two months of drought, and the lowest exposure year, 1997, had three months of mild and severe drought.

The levels of ozone exposure at Chiricahua National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb and do not reach 100 ppb. Each year has two or three months of mild to severe drought that constrain the uptake of ozone and reduce the effectiveness of the exposures. It is unlikely that foliar injury will be produced on plants under these exposure and environmental conditions.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, black cherry, skunkbush, cut-leaf coneflower and Scouler's willow.

CORONADO NATIONAL MEMORIAL (CORO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Prunus serotina	Black cherry	Rosaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CORO					
	1995	1996	1997	1998	1999
Sum06	17	17	12	16	14
W126	27.1	27.0	23.8	29.0	25.8
N60	448	490	376	525	430
N80	40	26	22	27	16
N100	3	1	1	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CORO					
	1995	1996	1997	1998	1999
Month 1	2.46	-2.23	-1.06	2.43	0.43
Month 2	-3.09	-2.41	-0.84	2.07	-1.96
Month 3	-0.43	-0.51	-1.94	-1.71	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CORO					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Evaluation of the relationships between ozone exposure and soil moisture is difficult since ozone exposure levels for the 90-day Sum06 and the seasonal W126 indices were relatively uniform over the five years, and soil moisture conditions showed frequent months of mild to severe drought stress. There is no apparent association between either the Sum06 or W126 index of ozone exposure and level of soil moisture. The Sum06 index was accompanied by one or two months of mild to severe drought each year. The W126 index was associated with two or three months of mild to severe drought annually.

The risk of foliar ozone injury at Coronado National Memorial is low. The Sum06 index satisfies the threshold for injury, the W126 does not, and the N-values indicate there are only rare exposures to concentrations of ozone greater than 100 ppb. Soil moisture conditions of frequent mild to severe drought significantly reduce the effectiveness of the exposures in most years. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often two or more consecutive months of mild to severe drought. These levels of soil moisture would significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced.

If the level of risk increases in the future, a program to assess the incidence of foliar

ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, black cherry, skunkbush and blue elderberry.

FORT BOWIE NATIONAL HISTORIC SITE (FOBO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOBO					
	1995	1996	1997	1998	1999
Sum06	19	24	13	18	19
W126	25.7	30.3	22.7	30.6	28.4
N60	419	576	318	535	462
N80	19	12	11	14	13
N100	1	1	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOBO					
	1995	1996	1997	1998	1999
Month 1	1.66	-2.23	-1.06	2.55	0.43
Month 2	3.14	-2.41	-0.84	1.63	-1.96
Month 3	2.46	-0.51	-1.94	2.99	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOBO					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than one hour in which the concentration exceeded 100 ppb, and in three years there were no hours above this level. These levels of exposure are not likely to injure vegetation.

- There were no apparent relationships between either the 90-day Sum06 or the seasonal W126 indices of exposure and soil moisture conditions. Soil moisture in the year with the highest Sum06 ozone exposure, 1996, showed two months of moderate drought, while the year with the lowest exposure, 1997, had two months of mild drought. The remaining three years had levels of ozone exposure that were similar in magnitude, but experienced normal moisture conditions in 1995 and 1998 and two months of mild drought in 1999. Similarly, there is no relationship between the W126 index of ozone and soil moisture with each year having two or three months of mild to severe drought. Soil moisture levels in the highest ozone years, 1996 and 1998, showed two months of moderate drought and three months of mild drought, respectively, while the lowest ozone year, 1997, had three months of mild and severe drought.

The levels of ozone exposure at Fort Bowie National Historic Site make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Since several months of mild to severe drought reduce the effectiveness of the exposures in most years, and hourly concentrations of ozone seldom exceed 80 ppb, it is unlikely that foliar injury will be produced on plants.

If the level of risk increases in the future, a program to assess the presence of ozone injury could employ skunkbush.

GILA CLIFF DWELLINGS NATIONAL MONUMENT (GICL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GICL					
	1995	1996	1997	1998	1999
Sum06	11	18	12	18	16
W126	21.5	24.1	20.9	28.5	25.9
N60	329	401	300	503	422
N80	25	22	17	22	20
N100	3	2	1	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GICL					
	1995	1996	1997	1998	1999
Month 1	0.57	-3.37	0.35	-0.62	-0.73
Month 2	-1.25	0.61	1.78	4.66	-1.31
Month 3	0.30	1.10	-0.77	-0.99	-0.38

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GICL					
	1995	1996	1997	1998	1999
April	0.16	-2.92	0.29	1.15	-0.73
May	0.87	-3.37	1.98	-0.20	-1.31
June	0.57	0.61	0.35	-0.62	-0.38
July	-1.25	1.10	1.78	4.66	3.48
August	0.30	0.76	-0.77	-0.99	3.67
September	0.30	1.78	2.99	-2.52	1.95
October	-2.63	3.22	0.09	3.15	-0.73

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Since ozone exposure levels for the 90-day Sum06 index were relatively uniform and there were only three months of drought over the five years, no relationships are apparent between levels of ozone and soil moisture. The W126 index of ozone exposure was also relatively consistent during the five-year period. One or two months of drought occurred in four of the years, and no association between ozone exposure and soil moisture is apparent.

The levels of ozone exposure at Gila Cliff Dwellings National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Since soil moisture conditions of mild to severe drought reduce the effectiveness of the exposures, and hourly concentrations of ozone only occasionally exceed 80 ppb, it is unlikely that foliar injury will be produced on plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine, skunkbush and cut-leaf coneflower.

MONTEZUMA CASTLE NATIONAL MONUMENT (MOCA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for MOCA					
	1995	1996	1997	1998	1999
Sum06	5	10	19	31	43
W126	42.5	46.3	43.9	70.9	70.1
N60	743	870	826	1414	1433
N80	131	134	89	164	122
N100	22	13	7	7	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at MOCA					
	1995	1996	1997	1998	1999
Month 1	1.89	-3.39	-1.50	0.19	0.83
Month 2	-2.18	-3.38	-3.65	1.01	-2.16
Month 3	-0.76	-3.14	-0.61	1.01	-1.83

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at MOCA					
	1995	1996	1997	1998	1999
April	0.73	-3.39	0.50	1.17	0.83
May	1.87	-3.38	-1.18	1.89	-2.16
June	1.89	-3.14	-1.50	1.68	-1.83
July	-2.18	-0.91	-3.65	3.16	3.41
August	-0.76	-2.47	-0.61	0.19	-2.17
September	1.51	1.55	4.23	1.01	4.95
October	-2.17	-1.39	-1.07	1.01	-2.01

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two years. These levels of ozone can injure vegetation in high exposure years.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Three years with high, moderate, and low Sum06 exposures, 1999, 1997 and 1996 respectively, had two, two and three months of mild to severe drought, respectively. The remaining two years, with the second highest and the lowest exposures, 1998 and 1995, had normal soil moisture and one month of moderate drought. Soil moisture levels in the two years with the highest seasonal W126 exposures, 1998 and 1999, showed normal soil moisture and four months of mild and moderate drought, respectively. The remaining three years had similar levels of ozone exposure, and each experienced two to five months of mild to severe drought.

The risk of foliar ozone injury to plants at Montezuma Castle National Monument is moderate. The Sum06 and W126 indices exceed the threshold levels for injury and hourly concentrations of ozone occasionally exceed 100 ppb. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often several consecutive months of mild and severe drought. These levels of soil moisture would significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. The year 1998 is an exception to this pattern and is characterized by moderate levels of ozone exposure under normal soil moisture conditions. There are

also relatively few months of drought in 1995 a year of high exposure and one in which the uptake of ozone is not severely restricted. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that generally favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: tree-of-heaven and skunkbush.

ORGAN PIPE CACTUS NATIONAL MONUMENT (ORPI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ORPI					
	1995	1996	1997	1998	1999
Sum06	11	13	17	21	21
W126	35.8	35.6	30.8	33.7	35.6
N60	639	648	562	619	666
N80	107	105	54	70	67
N100	17	12	2	3	4

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ORPI					
	1995	1996	1997	1998	1999
Month 1	2.46	-2.23	-0.84	2.43	0.43
Month 2	-3.09	-2.41	-1.94	2.07	-1.96
Month 3	-0.43	-0.51	-3.88	-1.71	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ORPI					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only two years, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb. Most years had four or fewer hours in which the concentration exceeded 100 ppb, but two years had 17 and 12 hours. These levels of ozone may possibly injure vegetation in the high exposure years.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 accumulative index and soil moisture. In the Sum06 assessment, one or two months of mild to severe drought stress occurred each year without any relationship to the level of exposure. The W126 index of ozone was also unrelated to soil moisture. Levels of exposure were similar among the five years and each year experienced periods of two or three months of mild to severe drought.

The risk of foliar ozone injury to plants at Organ Pipe Cactus National Monument is moderate. The Sum06 exposures exceed the threshold levels for injury, while the W126 exposures meet the criteria in two years. Soil moisture conditions of mild to severe drought reduce the effectiveness of the exposures for several months each year. However, in years in which hourly concentrations of ozone often exceed 100 ppb, 1995 and 1996, there are fewer months of drought than in other years. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush.

SAGUARO NATIONAL PARK (SAGU)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Oenothera elata	Evening primrose	Onagraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Salix gooddingii	Gooding's willow	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. The index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAGU					
	1995	1996	1997	1998	1999
Sum06	29	21	24	27	20
W126	41.1	28.7	39.2	39.2	27.9
N60	655	452	672	672	455
N80	84	29	45	45	11
N100	7	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.
Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAGU					
	1995	1996	1997	1998	1999
Month 1	2.46	-0.51	-1.06	1.63	0.43
Month 2	-3.09	-0.45	-0.84	2.99	-1.96
Month 3	-0.43	-0.38	-1.94	2.43	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAGU					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceed 60 and 80 ppb, and exceeded 100 ppb in one year. These levels of exposure may possibly injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. In 1995, the year with the highest Sum06 exposure, there was one month of severe drought. In both 1997, a mid-level exposure year, and 1999, the second lowest exposure year, there were two months of mild drought. Soil moisture was normal in 1998 and 1996, the second highest and lowest exposure years respectively. There also does not appear to be any association between the W126 index and soil moisture. In 1995 when ozone exposure was highest, there were two months of mild and severe drought. There were three months of mild and severe drought in 1997 and 1998, both of which had the second highest exposure index, and the years with the two lowest exposures, 1999 and 1998, experienced three and two months of mild and moderate drought, respectively.

The levels of ozone exposure at Saguaro National Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 exposures do not since the N100 criterion is not satisfied. There are frequent hours with concentrations of ozone above 80 ppb, but exposure to concentrations greater than 100 ppb occur in only one year. Each year experiences two or three months of mild

to severe drought that constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, evening primrose, ponderosa pine, quaking aspen, skunkbush, cut-leaf coneflower, Scouler's willow and blue elderberry.

TONTO NATIONAL MONUMENT (TONT)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Sambucus mexicana	Blue elderberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for TONT					
	1995	1996	1997	1998	1999
Sum06	32	32	23	38	45
W126	41.3	41.2	41.2	65.6	62.6
N60	721	742	748	1273	1250
N80	136	133	96	173	135
N100	23	15	7	7	5

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TONT					
	1995	1996	1997	1998	1999
Month 1	3.23	-1.29	-1.76	0.75	2.17
Month 2	0.18	-2.46	-3.68	0.42	-1.96
Month 3	0.91	-3.05	-1.82	1.00	-3.23

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at TONT					
	1995	1996	1997	1998	1999
April	0.09	-2.78	-0.76	0.63	2.17
May	0.97	-3.50	-1.07	0.75	-1.96
June	0.82	-3.29	-1.76	0.42	-3.23
July	-2.53	0.60	-3.68	1.00	4.41
August	-1.22	-3.03	-1.82	-1.24	-0.16
September	-0.31	2.48	-1.63	-0.43	1.28
October	-2.42	-1.37	-0.05	-0.59	-2.66

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and the W126 criteria were satisfied in the five years of data.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in two of the years. These levels of ozone can possibly injure vegetation in high exposure years.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the year with the highest Sum06 exposure, 1999, showed two months of mild and severe drought, while the second highest exposure year, 1998, had normal soil moisture. Years with mid-level ozone exposure, 1995 and 1996, experienced normal soil moisture and three months of mild to severe drought, respectively. The lowest exposure year, 1997, had three months of mild and moderate drought. Soil moisture levels associated with the seasonal W126 index also appear unrelated to the level of ozone exposure. While the year with the highest W126 exposure, 1998, experienced one month of mild drought, the other four years each had three to five months of mild to severe drought. There was no association between level of exposure and soil moisture conditions.

The risk of foliar ozone injury to plants at Tonto National Monument is moderate. The Sum06 and W126 indices exceed the threshold levels for injury, and hourly concentrations of ozone often exceed 100 ppb. Soil moisture conditions of several months of mild to severe drought each year significantly limit the uptake of ozone and reduce the effectiveness of the exposures. The year 1998 is an exception to this pattern and is characterized by moderate ozone exposure under generally normal soil moisture

conditions. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: skunkbush and blue elderberry.

TUMACACORI NATIONAL HISTORICAL PARK (TUMA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*

No species listed.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for TUMA					
	1995	1996	1997	1998	1999
Sum06	17	16	11	16	14
W126	26.9	25.4	22.9	26.9	24.1
N60	450	454	371	491	405
N80	43	28	22	25	14
N100	3	1	1	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TUMA					
	1995	1996	1997	1998	1999
Month 1	2.46	-2.23	-1.06	2.43	0.43
Month 2	-3.09	-2.41	-0.84	2.07	-1.96
Month 3	-0.43	-0.51	-1.94	-1.71	-1.56

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at TUMA					
	1995	1996	1997	1998	1999
April	1.66	-2.23	-1.06	1.63	0.43
May	3.14	-2.41	-0.84	2.99	-1.96
June	2.46	-0.51	-1.94	2.43	-1.56
July	-3.09	-0.45	-3.88	2.07	4.36
August	-0.43	-0.38	-0.43	-1.71	1.32
September	-0.48	1.31	-0.05	-1.37	-0.17
October	-1.55	0.33	-0.70	-1.38	-2.35

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are unlikely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Ozone exposure levels for the Sum06 and the W126 indices were both relatively uniform over the five years. For both indices of exposure, soil moisture conditions showed frequent months of mild to moderate drought throughout the five-year period, and there was no apparent association between either index of exposure and the level of soil moisture. The moderate and severe drought experienced each year would constrain the uptake of ozone and reduce the effectiveness of the exposures.

The levels of ozone exposure and the relatively dry soil moisture conditions at Tumacacori Historical Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Since annual soil moisture conditions of mild to severe drought reduce the effectiveness of the exposures for several months each year, and hourly concentrations of ozone only occasionally exceeded 80 ppb, it is unlikely that foliar injury will be produced on plants.

There are no ozone bioindicator species listed for the site.

TUZIGOOT NATIONAL MONUMENT (TUZI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for TUZI					
	1995	1996	1997	1998	1999
Sum06	5	14	21	30	41
W126	42.4	49.0	45.3	68.1	70.4
N60	739	939	875	1358	1443
N80	125	129	77	142	115
N100	21	11	5	7	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place. The level of soil moisture is an important environmental variable controlling the uptake of ozone. Understanding the soil moisture status can provide insight to how effective the exposure may have been in leading to foliar injury. The Palmer Z Index was used to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for that time period for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

Palmer Z data were compiled for the site for both the months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TUZI					
	1995	1996	1997	1998	1999
Month 1	1.89	-3.39	-1.50	0.19	0.83
Month 2	-2.18	-3.38	-3.65	1.01	-2.16
Month 3	-0.76	-3.14	-0.61	1.01	-1.83

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at TUZI					
	1995	1996	1997	1998	1999
April	0.73	-3.39	0.50	1.17	0.83
May	1.87	-3.38	-1.18	1.89	-2.16
June	1.89	-3.14	-1.50	1.68	-1.83
July	-2.18	-0.91	-3.65	3.16	3.41
August	-0.76	-2.47	-0.61	0.19	-2.17
September	1.51	1.55	4.23	1.01	4.95
October	-2.17	-1.39	-1.07	1.01	-2.01

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are often satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb every year. In two years the N100 values were greater than ten, while they were lower in the other three. These levels of ozone can possibly injure vegetation in the highest exposure years.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels during the year with the highest Sum06 value, 1999, showed two months of mild and moderate drought, while the second highest exposure year, 1998, had normal soil moisture conditions. The year with mid-level exposure, 1997, had two months of mild and severe drought. There were three months of severe drought in 1996, the year with the second lowest exposure, and the year with the lowest exposure, 1995, had one month of moderate drought. Soil moisture levels associated with the seasonal W126 index are similarly mixed. The two years with the highest exposures, 1999 and 1998, experiencing four months of mild and moderate drought and normal moisture conditions, respectively. The remaining three years had similar and lower levels of exposure, and each experienced between two and five months of moderate to severe drought.

The risk of foliar ozone injury at Tuzigoot National Monument is low. While the Sum06 and W126 indices generally satisfy their thresholds for injury, and the N-values indicate

there are occasional exposures to concentrations of ozone greater than 100 ppb, low soil moisture reduces the potential for foliar injury at the site. Most years experience two to five months of mild to severe drought that can significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. The year 1998 is an exception to this pattern and is characterized by a higher level of ozone exposure under consistently normal soil moisture conditions. The co-occurrence of somewhat higher levels of ozone exposure and soil moisture conditions that favor uptake could increase the likelihood of injury in a given year.

If the level of risk increases in the future, a program to assess the presence of ozone injury could employ tree-of-heaven and skunkbush.

SOUTHERN PLAINS NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHERN PLAINS NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHERN PLAINS NETWORK

Park	Code	State	Risk	O3 Data
Alibates Flint Quarries NM	ALFL	TX	low	kriged
Bent's Old Fort NHS	BEOL	CO	low	kriged
Capulin Volcano NM	CAVO	NM	low	kriged
Chickasaw NRA	CHIC	OK	high	kriged
Fort Larned NHS	FOLS	KS	low	kriged
Fort Union NM	FOUN	NM	low	kriged
Lake Meredith NRA	LAMR	TX	low	kriged
Lyndon B. Johnson NHP	LYJO	TX	moderate	kriged
Pecos NHP	PECO	NM	low	kriged

ALIBATES FLINT QUARRIES NATIONAL MONUMENT (ALFL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for ALFL					
	1995	1996	1997	1998	1999
Sum06	14	11	10	20	18
W126	25.1	22.9	24.1	39.5	30.4
N60	420	402	397	730	516
N80	56	28	33	81	62
N100	6	2	2	6	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ALFL					
	1995	1996	1997	1998	1999
Month 1	0.34	-3.45	2.27	-0.30	-0.52
Month 2	-0.66	-0.70	-0.38	-3.69	-0.04
Month 3	-1.52	2.86	-0.72	3.65	-1.65

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at ALFL					
	1995	1996	1997	1998	1999
April	-0.84	-2.43	8.34	-0.13	3.65
May	2.24	-3.45	1.20	-2.94	2.90
June	0.34	-0.70	2.45	-3.77	3.48
July	-0.66	2.86	1.83	-1.70	1.08
August	-1.52	3.55	2.27	-0.30	-0.52
September	2.86	1.46	-0.38	-3.69	-0.04
October	-1.33	-1.45	-0.72	3.65	-1.65

Risk Analysis

- There are a few ozone-sensitive species at the site, but none of them are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than six hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.

- No consistent relationship is apparent between 90-day Sum06 accumulation period indices of ozone and soil moisture. This is largely a consequence of similar levels of exposure and scattered months of drought. There was one month of mild or severe drought in four of the five years. There does not appear to be any association between the W126 level of ozone exposure and soil moisture status. The highest and lowest ozone years, 1998 and 1996, experienced four and three months, respectively, of mild to severe drought. The second highest ozone

year 1999 had one month of mild drought, the mid-exposure year 1995 had two months of mild drought and the second lowest ozone year 1997 had normal soil moisture. There were no associations between ozone and soil moisture for either the Sum06 or the W126 indices of exposure.

The low level of ozone exposure at Alibates Flint Quarries National Monument makes the risk of foliar ozone injury to plants low. While the Sum06 threshold is satisfied, the W126 criteria generally are not. The N100 counts are low with only two years having six hours of ozone greater than 100 ppb. Although there is no apparent association between ozone exposure and soil moisture, several years had three or four months of mild to severe drought that constrain the uptake of ozone and reduce the likelihood of foliar injury development.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use American sycamore.

BENT'S OLD FORT NATIONAL HISTORIC SITE (BEOL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus pennsylvanica	Green ash	Oleaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BEOL					
	1995	1996	1997	1998	1999
Sum06	8	12	8	12	10
W126	14.8	19.5	17.5	25.3	23.6
N60	203	313	261	426	378
N80	13	15	10	27	21
N100	1	1	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BEOL					
	1995	1996	1997	1998	1999
Month 1	6.75	2.21	-2.10	-2.20	7.76
Month 2	2.82	1.77	1.63	-0.29	3.50
Month 3	0.61	2.06	-0.15	7.21	2.70

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BEOL					
	1995	1996	1997	1998	1999
April	3.18	-1.39	3.26	1.36	7.76
May	6.11	-0.89	-2.10	-2.20	3.50
June	6.75	-0.24	1.63	-0.29	2.70
July	2.82	2.21	-0.15	7.21	3.84
August	0.61	1.77	5.87	2.44	5.00
September	1.33	2.06	0.25	-1.14	0.77
October	-1.26	-0.42	5.01	2.82	0.40

Risk Analysis

- There is one ozone-sensitive species at the site, but it is not a bioindicator for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation, but the values are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Only two months of drought occurred in the five-year period for the Sum06 index; one in one of the highest ozone years, 1998, and one in the lowest, 1997. For the W126 index, there were two months of drought in the highest ozone year, 1998, and none in the second highest year, 1999. One month of drought occurred in each of the remaining three years. No association with the level of ozone is evident from

this distribution of drought.

The risk of foliar ozone injury to plants at Bent's Old Fort National Historic Site is low. While the Sum06 threshold is marginally satisfied, the W126 criteria are not. Only a few hours of exposure to ozone concentrations greater than 80 ppb occur each year, while exposures to 100 ppb are rare.

If the level of risk increases in the future and an injury assessment becomes desirable, bioindicator species will have to be identified at the site.

CAPULIN VOLCANO NATIONAL MONUMENT (CAVO)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CAVO

	1995	1996	1997	1998	1999
Sum06	8	12	8	12	10
W126	14.8	19.5	17.5	25.3	23.6
N60	203	313	261	426	378
N80	13	15	10	27	21
N100	1	1	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CAVO					
	1995	1996	1997	1998	1999
Month 1	3.60	-4.72	0.50	-2.65	4.42
Month 2	0.31	0.53	1.76	-2.14	2.21
Month 3	-0.31	0.20	0.40	2.93	2.20

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CAVO					
	1995	1996	1997	1998	1999
April	2.14	-2.33	2.69	0.46	4.42
May	4.26	-4.72	0.50	-2.65	2.21
June	3.60	0.53	1.76	-2.14	2.20
July	0.31	0.20	0.40	2.93	3.52
August	-0.31	0.58	0.93	-0.04	3.56
September	1.51	0.13	2.02	-1.77	0.24
October	-2.28	1.55	-0.22	5.19	-1.25

Risk Analysis

- There are no ozone-sensitive species listed for the site.

- The Sum06 index exceeds the threshold for injury to vegetation, although the levels are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- The 90-day Sum06 accumulation period levels of ozone were relatively consistent over the five-year period making it difficult to assess relationships with soil moisture. There is some indication, however, that soil moisture levels during the 90-day periods may be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two years with the same high ozone exposure value, 1996 and 1998, experienced one and two months of moderate or severe drought, respectively. The remaining three years had favorable soil moisture conditions. However, the limited occurrence of drought makes the inverse nature of the association uncertain. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, although the pattern is not consistent. The highest ozone year, 1998, had three months of mild and moderate, while the second highest year, 1999, had one month of mild drought. There were two months of moderate and severe drought in the mid-level ozone year 1996. The lowest ozone year had one month of drought, and the second lowest year had normal conditions.

The risk of foliar ozone injury to plants at Capulin Volcano National Monument is low. While the Sum06 threshold is marginally satisfied, the W126 criteria are not. Exposure

to 80 ppb ozone is infrequent, and exposure to 100 ppb rare. Soil moisture is inversely related to ozone exposure and serves to constrain the uptake of ozone at higher exposure levels. This effect further reduces the likelihood of foliar injury development.

No ozone-sensitive or bioindicator species have been identified at the site.

CHICKASAW NATIONAL RECREATION AREA (CHIC)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Rhus trilobata	Skunkbush	Anacardiaceae.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CHIC					
	1995	1996	1997	1998	1999
Sum06	11	7	7	15	27
W126	40.4	30.3	31.8	50.8	40.1
N60	674	511	534	920	682
N80	155	84	93	168	131
N100	30	14	16	20	14

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHIC					
	1995	1996	1997	1998	1999
Month 1	1.07	0.32	0.04	-4.42	0.58
Month 2	1.56	-0.26	-2.42	-2.15	-0.67
Month 3	-0.09	-4.17	0.31	-2.25	-2.28

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CHIC					
	1995	1996	1997	1998	1999
April	1.46	-0.26	2.42	-0.71	1.06
May	2.84	-4.17	0.04	-3.75	0.08
June	1.07	-0.94	0.27	-2.54	1.27
July	1.56	1.68	-1.16	-4.42	-0.63
August	-0.09	5.11	0.04	-2.15	-1.35
September	1.83	2.62	-2.42	-2.25	0.58
October	-1.74	-0.18	0.31	0.72	-0.67

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.

- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. In the highest ozone year, 1999, there was one month of moderate drought, while in each of the two years with the lowest ozone, 1996 and 1997, there was one month of severe or moderate drought. Soil moisture levels associated with the seasonal W126 index give some indication of being inversely related to ozone concentrations: when ozone is high, soil moisture is low, however the inconsistencies in the pattern are significant. The year with the highest ozone level, 1998, had five months of moderate and severe drought. The remaining four years each had one or two months of mild to severe drought.

The risk of foliar ozone injury to plants at Chickasaw National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in some years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing is greatest during years such as 1995 and 1999 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: white ash, American sycamore, and skunkbush.

FORT LARNED NATIONAL HISTORIC SITE (FOLS)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOLS					
	1995	1996	1997	1998	1999
Sum06	21	15	15	28	20
W126	23.2	12.8	22.9	41.5	27.6
N60	438	278	378	788	478
N80	67	15	13	88	54
N100	8	1	0	6	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOLS					
	1995	1996	1997	1998	1999
Month 1	2.56	-1.44	2.31	1.59	2.55
Month 2	1.40	1.49	1.97	-1.77	-0.01
Month 3	1.79	4.09	4.00	-2.38	1.69

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOLS					
	1995	1996	1997	1998	1999
April	1.34	-1.40	2.10	-0.17	3.60
May	5.10	-1.53	0.14	-1.79	0.04
June	2.56	-1.44	2.31	-2.40	2.24
July	1.40	1.49	1.97	1.59	2.55
August	1.79	4.09	4.00	-1.77	-0.01
September	0.26	3.58	1.63	-2.38	1.69
October	-1.83	0.38	1.93	3.56	-1.67

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. The highest exposures may possibly injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The highest Sum06 exposure year, 1998, had two months of mild and moderate drought, while one of the lowest, 1996, had one month of mild drought. Soil moisture in the other three years was normal. The year with the highest W126 exposure index, 1998, had four months of mild and moderate drought, and the year with the lowest, 1996, had three months of mild drought. There were only two months of mild drought in the remaining three years.

The low levels of ozone exposure at Fort Larned National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 threshold criteria are satisfied, while the W126 criteria are generally not fulfilled. While there are some years with a significant number of hours of ozone above 80 ppb, hours of exposure to concentrations above100 ppb are generally low. Levels of ozone and soil moisture conditions are unrelated, and the number of months of drought varies widely among years. In some years, such as 1995, exposures reach injury thresholds while soil moisture conditions foster the uptake of ozone. The opportunity for foliar injury to occur is greatest when these conditions coincide.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use common milkweed or redbud.

FORT UNION NATIONAL MONUMENT (FOUN)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for FOUN					
	1995	1996	1997	1998	1999
Sum06	9	17	11	16	14
W126	16.5	23.1	18.7	25.6	25.8
N60	219	376	282	448	420
N80	13	12	9	13	20
N100	1	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOUN					
	1995	1996	1997	1998	1999
Month 1	3.60	-4.72	0.50	-0.04	2.21
Month 2	0.31	0.53	1.76	-1.77	2.20
Month 3	-0.31	0.20	0.40	5.19	3.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at FOUN					
	1995	1996	1997	1998	1999
April	2.14	-2.33	2.69	0.46	4.42
May	4.26	-4.72	0.50	-2.65	2.21
June	3.60	0.53	1.76	-2.14	2.20
July	0.31	0.20	0.40	2.93	3.52
August	-0.31	0.58	0.93	-0.04	3.56
September	1.51	0.13	2.02	-1.77	0.24
October	-2.28	1.55	-0.22	5.19	-1.25

Risk Analysis

- There are a few ozone-sensitive species at the site, none of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and one year in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only two months of drought over the five-year period. However, the two months occurred in the years with the highest ozone exposures. While this suggests an inverse relationship, when ozone is high, soil moisture is low, additional data are required to confirm such a conclusion. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the three highest ozone years, 1999, 1998 and 1996, there were one, three, and two months of mild and severe

drought, respectively. The two years with the lowest ozone experienced one month of moderate drought between them.

The low levels of ozone exposure at Fort Union National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours with concentrations of ozone above 80 ppb, but only one hour above 100 ppb during the assessment period. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

There are no ozone bioindicator species at the site.

LAKE MEREDITH NATIONAL RECREATION AREA (LAMR)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Platanus occidentalis	American sycamore	Platanaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LAMR					
	1995	1996	1997	1998	1999
Sum06	14	11	10	19	17
W126	24.5	22.3	23.9	39.3	30.2
N60	412	393	393	726	511
N80	54	26	32	80	60
N100	5	2	2	6	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LAMR					
	1995	1996	1997	1998	1999
Month 1	0.34	-3.45	2.27	-0.30	-0.52
Month 2	-0.66	-0.70	-0.38	-3.69	-0.04
Month 3	-1.52	2.86	-0.72	3.65	-1.65

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LAMR					
	1995	1996	1997	1998	1999
April	-0.84	-2.43	8.34	-0.13	3.65
May	2.24	-3.45	1.20	-2.94	2.90
June	0.34	-0.70	2.45	-3.77	3.48
July	-0.66	2.86	1.83	-1.70	1.08
August	-1.52	3.55	2.27	-0.30	-0.52
September	2.86	1.46	-0.38	-3.69	-0.04
October	-1.33	-1.45	-0.72	3.65	-1.65

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than six hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. For the Sum06 index, there was one month of mild or severe drought in four of the five years. With the W126 index, there were three months of moderate and severe drought in the highest ozone year, 1998, and three months of mild to severe drought in the lowest year, 1996. Distribution of months of drought in the intermediate years shows no association with exposure.

The low level of ozone exposure at Lake Meredith National Recreation Area makes the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a few hours of exposure above 80 ppb, but exposures above 100 ppb are generally rare. One year, 1998, had exposures that satisfied the Sum06 and W126 criteria, but dry soil conditions during several months that year would significantly constrain the uptake of ozone and reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use American sycamore.

LYNDON B. JOHNSON NATIONAL HISTORIC PARK (LYJO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LYJO					
	1995	1996	1997	1998	1999
Sum06	13	4	10	15	20
W126	36.4	13.4	22.1	25.7	32.0
N60	594	205	372	443	539
N80	161	41	74	79	128
N100	26	7	8	12	18

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LYJO					
	1995	1996	1997	1998	1999
Month 1	-1.28	-0.94	5.60	6.87	-2.41
Month 2	-0.98	-1.15	1.64	-1.81	-2.94
Month 3	0.39	-3.47	-1.51	0.45	-1.22

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LYJO					
	1995	1996	1997	1998	1999
April	0.27	-1.15	2.93	-1.77	-0.71
May	1.74	-3.47	0.74	-3.70	-1.45
June	0.33	-2.73	5.60	-2.31	0.28
July	-1.28	-2.09	1.64	-2.72	-0.80
August	-0.98	2.96	-1.51	6.87	-2.41
September	0.39	1.06	-2.24	-1.81	-2.94
October	-1.98	0.14	-0.54	0.45	-1.22

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.

- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The highest Sum06 exposure was in 1999 when there were three months of mild and moderate drought, while the lowest exposure was in 1996 when there were two months of mild and severe drought. The remaining intermediate ozone years each had one month of drought. With the W126 index, the highest ozone year, 1995, had two months of mild drought. The second highest year, 1999, had four months of mild and moderate drought while the two intermediate years had five and two months of drought. The lowest year, 1996, four months of mild to severe drought. Overall, no association between ozone exposure and drought is apparent for either

index.

The risk of foliar ozone injury to plants at Lyndon B. Johnson National Historic Park is moderate. While the levels of ozone exposure consistently create the potential for injury, periods of low soil moisture may reduce the likelihood of injury developing in particular years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use redbud.

PECOS NATIONAL HISTORIC PARK (PECO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PECO					
	1995	1996	1997	1998	1999
Sum06	9	17	11	16	14
W126	17.2	23.8	19.0	25.9	26.4
N60	229	391	288	453	432
N80	15	12	10	14	21
N100	1	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PECO					
	1995	1996	1997	1998	1999
Month 1	3.60	-4.72	0.50	-0.04	2.21
Month 2	0.31	0.53	1.76	-1.77	2.20
Month 3	-0.31	0.20	0.40	5.19	3.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PECO					
	1995	1996	1997	1998	1999
April	2.14	-2.33	2.69	0.46	4.42
May	4.26	-4.72	0.50	-2.65	2.21
June	3.60	0.53	1.76	-2.14	2.20
July	0.31	0.20	0.40	2.93	3.52
August	-0.31	0.58	0.93	-0.04	3.56
September	1.51	0.13	2.02	-1.77	0.24
October	-2.28	1.55	-0.22	5.19	-1.25

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had one hour in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only two months of drought over the five-year period. One month of drought occurred in each of the two years with the highest ozone exposures. While this suggests an inverse relationship, when ozone is high, soil moisture is low, additional data are required to confirm such a relationship. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, although the pattern is not consistent. This relationship reduces the uptake of ozone and the

effectiveness of the higher exposures in producing foliar injury. In the three highest ozone years, 1999, 1998 and 1996, there were one, three, and two months of mild and severe drought, respectively. The two years with the lowest ozone experienced one month of moderate drought between them.

The low levels of ozone exposure at Pecos National Historic Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours with concentrations of ozone above 80 ppb, but only one hour above 100 ppb. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or skunkbush.

SOUTHWEST ALASKA NETWORK

OCTOBER 2004

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHWEST ALASKA NETWORK

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern

of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus,

the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

It was not possible to assess risk for sites in the Southwest Alaska Network since ozone was neither monitored nor kriged for them, and Palmer Z values are not calculated for the state.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHWEST ALASKA NETWORK

Park	Code	State	Risk	O3 Data
Alagnak Wild River	ALAG	AK	cannot eval	no data
Aniakchak NM & PRES	ANIA	AK	cannot eval	no data
Katmai NP & PRES	KATM	AK	cannot eval	no data
Kenai Fjords NP	KEFJ	AK	cannot eval	no data
Lake Clark NP & PRES	LACL	AK	cannot eval	no data

ALAGNAK WILD RIVER
(ALAG)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Alagnak Wild River cannot be assessed due to the lack of information on ozone exposure at the site.

ANIAKCHAK NATIONAL MONUMENT AND PRESERVE (ANIA)

Plant Species Sensitive to Ozone

No ozone-sensitive species have been identified at the site.

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Aniakchak National Monument and Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

KATMAI NATIONAL PARK AND PRESERVE (KATM)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Physocarpus capitatus	Ninebark	Rosaceae
Salix scouleriana	Scouler's willow	Saliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Katmai National Park and Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

KENAI FJORDS NATIONAL PARK
(KEFJ)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Kenai Fjords National Park cannot be assessed due to the lack of information on ozone exposure at the site.

LAKE CLARK NATIONAL PARK AND PRESERVE (LACL)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Ozone Exposure Data

No ozone exposure data are available for the site.

Soil Moisture Status

The US Department of Agriculture's Palmer Z Index that was selected to indicate soil moisture status is not calculated for Alaska.

Risk Analysis

The risk of ozone injury on foliage of vegetation at Lake Clark National Park and Preserve cannot be assessed due to the lack of information on ozone exposure at the site.

UPPER COLUMBIA BASIN NETWORK

October 2004

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE UPPER COLUMBIA BASIN NETWORK

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United

States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone $\geq$ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations $\geq$ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in

producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to –4.0, a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

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SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE UPPER COLUMBIA BASIN NETWORK

Park	Code	State	Risk	O3 Data
Big Hole NB	BIHO	MT	low	kriged
City of Rocks N RES	CIRO	ID	moderate	kriged
Craters of the Moon NHP	CRMO	ID	low	monitored
Hagerman Fossil Beds NM	HAFO	ID	low	kriged
John Day Fossil Beds NM	JODA	OR	low	kriged
Lake Roosevelt NRA	LARO	WA	low	kriged
Nez Perce NHP	NEPE	ID	low	kriged
Whitman Mission NHS	WHMI	WA	low	kriged

BIG HOLE NATIONAL BATTLEFIELD (BIHO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicacea

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BIHO					
	1995	1996	1997	1998	1999
Sum06	5	13	7	13	13
W126	13.6	19.5	13.2	22.1	20.8
N60	130	267	137	296	274
N80	13	22	6	26	8
N100	2	3	1	4	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BIHO					
	1995	1996	1997	1998	1999
Month 1	-1.20	-0.18	1.57	-0.86	-1.61
Month 2	3.04	2.69	0.34	-0.51	-1.81
Month 3	2.82	3.10	0.76	4.18	-1.48

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BIHO					
	1995	1996	1997	1998	1999
April	3.76	0.19	1.27	0.43	-0.25
May	1.84	3.87	0.15	0.07	1.20
June	2.83	-2.69	1.89	4.35	-0.26
July	4.77	-1.51	3.81	1.95	-2.53
August	2.44	-2.21	2.95	-0.40	1.55
September	0.59	-1.27	0.20	-1.48	-2.24
October	1.76	-0.44	2.10	-0.81	-2.63

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Three years, 1996, 1998 and 1999, had the same highest Sum06 index of exposure. Soil moisture was normal in 1996 and 1998, and there were three months of mild drought in 1999. The remaining two years had one month of mild drought between them. No relationship is apparent between the W126 index of exposure and soil moisture. The year with the highest exposure, 1998, experienced one month of mild drought, while the second highest year, 1999, had three months of moderate drought. The mid-level exposure year 1996 had four months of mild

and moderate drought, and the two lowest exposure years had normal soil moisture conditions.

The risk of foliar ozone injury at Big Hole National Battlefield is low. The threshold levels for injury are not consistently satisfied by the Sum06 and not satisfied by the W126 index of exposure. The N-value counts indicate there are a few hours of exposure to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. Soil moisture levels are not associated with ozone exposure, however some years have periods of drought that significantly constrain uptake and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: ponderosa pine and quaking aspen.

CITY OF ROCKS NATIONAL RESERVE (CIRO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CIRO					
	1995	1996	1997	1998	1999
Sum06	9	19	10	17	16
W126	18.8	28.1	16.4	28.5	24.4
N60	247	470	246	449	388
N80	28	57	16	76	31
N100	4	7	2	12	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CIRO					
	1995	1996	1997	1998	1999
Month 1	0.19	-2.20	0.21	3.20	0.83
Month 2	2.43	-0.51	0.47	2.83	0.88
Month 3	2.00	-2.41	3.63	2.05	1.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CIRO					
	1995	1996	1997	1998	1999
April	0.19	-0.22	0.90	-0.14	1.85
May	2.43	4.64	0.21	3.20	2.45
June	2.00	-2.20	0.47	2.83	0.83
July	2.37	-0.51	3.63	2.05	0.88
August	0.46	-2.41	2.75	0.21	1.35
September	-0.93	-0.24	2.12	1.60	-1.12
October	-0.68	-0.25	0.47	-0.14	-1.84

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had twelve hours in which the concentration exceeded 100 ppb. The highest levels of exposure may injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the Sum06 assessment, there were two months of moderate drought stress in the year with the highest exposure, 1996, while the remaining four years had normal soil moisture. No associations between ozone and soil moisture can be discerned from these observations. Soil moisture levels associated with the seasonal W126 index of exposure were generally normal and favored the uptake of ozone. In

1996 and 1998, years with similar high exposures, there were two months of moderate drought and normal soil moisture conditions, respectively. The mid-level exposure year 1999 had two months of mild drought, and the lowest exposure years 1995 and 1997 had normal soil moisture. No clear relationship between ozone exposure and soil moisture can be derived from this pattern.

The risk of foliar ozone injury at City of Rocks National Reserve is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, and there are a few years in which the W126 criteria are fulfilled. Since there is no association between levels of ozone and soil moisture, conditions favorable for the uptake of ozone can occur at all levels of exposure. This creates the opportunity for reaching the threshold for injury at both high and more moderate levels of ambient ozone. The risk of injury is greatest in years such as 1998 when the ambient level of ozone is high, and soil moisture conditions favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use the following bioindicator species: quaking aspen and Scouler's willow.

CRATERS OF THE MOON NATIONAL HISTORIC PARK (CRMO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CRMO					
	1995	1996	1997	1998	1999
Sum06	1	12	2	10	11
W126	12.2	19.9	9.8	22.7	5.4
N60	20	223	40	267	234
N80	0	5	0	0	2
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CRMO					
	1995	1996	1997	1998	1999
Month 1	1.12	-1.49	-0.05	3.52	1.91
Month 2	4.49	-0.21	1.05	3.11	1.12
Month 3	7.03	-1.66	3.38	2.15	1.52

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CRMO					
	1995	1996	1997	1998	1999
April	1.12	0.30	1.04	-0.26	2.33
May	4.49	2.95	-0.05	3.52	3.61
June	7.03	-1.49	1.05	3.11	1.91
July	5.41	-0.21	3.38	2.15	1.12
August	3.05	-1.66	3.01	-0.99	1.52
September	-0.15	0.41	1.59	1.92	-1.66
October	-0.71	-0.55	0.60	-0.70	-1.57

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value generally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show only two years in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels were generally normal and favored the uptake of ozone. Four months of mild drought were distributed among two of the years. With this incidence of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and either the 90-day cumulative Sum06 or the seasonal W126 index of exposure.

The low levels of ozone exposure at Craters of the Moon National Historic Park make the risk of foliar ozone injury to plants low. The Sum06 exposures intermittently exceed the threshold for injury, but the W126 exposures do not since the N100 criterion is not satisfied. While soil moisture levels are generally favorable for the uptake of ozone, ambient levels of exposure are such that the threshold for foliar injury is not likely to be reached.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen, and Scouler's willow.

HAGERMAN FOSSIL BEDS NATIONAL MONUMENT (HAFO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Rhus trilobata	Skunkbush	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for HAFO					
	1995	1996	1997	1998	1999
Sum06	7	17	8	15	14
W126	16.8	25.8	14.8	27.1	24.7
N60	177	398	192	402	350
N80	19	43	12	56	24
N100	2	5	1	9	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

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Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HAFO					
	1995	1996	1997	1998	1999
Month 1	0.40	1.24	0.01	6.72	1.70
Month 2	4.41	1.59	2.75	3.71	1.48
Month 3	5.76	-0.74	2.18	3.27	1.01

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at HAFO					
	1995	1996	1997	1998	1999
April	0.40	0.19	1.56	-0.28	2.30
May	4.41	3.91	0.01	6.72	2.04
June	5.76	1.24	2.75	3.71	1.70
July	4.57	1.59	2.18	3.27	1.48
August	1.04	-0.74	1.02	0.10	1.01
September	-0.10	-0.94	1.43	2.39	-1.39
October	-0.63	0.16	0.31	-1.40	-1.47

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb; the second highest year had five hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods were generally normal and favored the uptake of ozone. In the five-year Sum06 assessment, there were no months of drought. Soil moisture levels during the W126 accumulation periods were also generally normal. In the five-year period, soil moisture was at mild drought for one month in the highest ozone year 1998, and for two months in a mid-level ozone year 1999.

The risk of foliar ozone injury at Hagerman Fossil Beds National Monument is low. The threshold level for injury is satisfied by the Sum06 index, and there is one year in which

the W126 criteria are fulfilled. Since there is no association between levels of ozone and soil, conditions favorable for the uptake of ozone can occur at all levels of exposure. The risk of injury is greater in years such as 1998 when ambient levels of ozone are high, and soil moisture conditions favor uptake by the plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator species skunkbush.

JOHN DAY FOSSIL BEDS NATIONAL MONUMENT (JODA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Pinus ponderosa	Ponderosa pine	Pinaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for JODA					
	1995	1996	1997	1998	1999
Sum06	3	9	3	6	4
W126	6.7	11.2	4.9	6.6	5.9
N60	85	152	47	87	69
N80	10	37	1	16	3
N100	2	9	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JODA					
	1995	1996	1997	1998	1999
Month 1	0.60	1.10	-1.42	1.66	-0.70
Month 2	2.16	1.15	1.82	4.03	-0.56
Month 3	3.04	-0.32	-0.47	0.10	-0.12

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JODA					
	1995	1996	1997	1998	1999
April	2.61	0.87	1.82	0.43	0.51
May	0.60	2.62	-0.47	7.10	-0.70
June	2.16	1.10	0.70	1.66	-0.56
July	3.04	1.15	1.94	4.03	-0.12
August	0.26	-0.32	0.28	0.10	2.16
September	-0.75	-0.19	0.41	0.52	-1.69
October	-1.33	-0.17	-0.15	-1.11	-0.17

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.

- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value marginally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had nine hours in which the concentration exceeded 100 ppb; the second highest year had three hours. These levels of exposure are not likely to injure vegetation.

- Soil moisture levels during the 90-day Sum06 accumulation periods were normal and favored the uptake of ozone. In the five-year assessment period, soil moisture was at mild drought for one month. Soil moisture levels during the seasonal W126 accumulation periods were also generally normal. One month of mild drought occurred in each of three years without any association with the level of ozone exposure.

The low levels of ozone exposure at John Day Fossil Beds National Monument make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. Concentrations over 100 ppb are rare, but one year has a higher number of hours. Since there is no association between levels of ozone and soil, conditions favorable for the uptake of ozone can occur at all levels of exposure. The risk of injury is greatest in years such as 1998 when ambient levels of ozone are higher, and soil moisture conditions favor uptake by plants.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator ponderosa pine.

LAKE ROOSEVELT NATIONAL RECREATION AREA (LARO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus banksiana	Jack pine	Pinaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Salix scouleriana	Scouler's willow	Saliaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for LARO					
	1995	1996	1997	1998	1999
Sum06	4	8	3	8	4
W126	9.9	10.2	7.6	11.5	7.6
N60	106	129	66	159	88
N80	5	8	4	9	2
N100	0	1	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LARO					
	1995	1996	1997	1998	1999
Month 1	-1.20	0.82	0.85	2.49	-1.12
Month 2	2.06	0.54	0.90	-1.28	-0.03
Month 3	0.40	-0.58	2.27	-2.05	0.83

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at LARO					
	1995	1996	1997	1998	1999
April	-0.23	2.30	1.24	-0.43	-1.12
May	-1.20	3.69	0.85	5.17	-0.03
June	2.06	0.82	0.90	1.10	0.83
July	0.40	0.54	2.27	2.49	0.89
August	-0.01	-0.58	0.05	-1.28	-0.14
September	0.74	-0.28	2.01	-2.05	-2.03
October	1.15	2.90	0.49	-0.43	-0.65

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is generally above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.

- The N-values for the site show concentrations frequently exceed 80 ppb for only a few hours each year. Two years had two hours in which the concentration exceeded 100 ppb, and there were three years in which concentrations did not reach 100 ppb. These levels of exposure are unlikely to injure vegetation.

- The low and consistent exposure indices and the limited occurrence of drought make it difficult to assess relationships between ozone exposure and soil moisture. However, there appear to be no associations between either the Sum06 or the W126 index of exposure and soil moisture conditions. There were only four months of drought over the five-year Sum06 assessment period; their occurrence was unrelated to the level of ozone exposure. The three years with the highest and similar W126 exposure, 1995, 1996 and 1998, had one, none and two months of drought, respectively. The lowest exposure years, 1997 and 1999, had normal

soil moisture and two months of drought, respectively. Overall, there is no association between the W126 index of exposure and soil moisture.

The low levels of ozone exposure at Lake Roosevelt National Recreation Area make the risk of foliar ozone injury to plants low. While there is no association between exposure and soil moisture, months of mild and moderate drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, Scouler's willow and common snowberry.

NEZ PERCE NATIONAL HISTORIC PARK (NEPE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Amelanchier alnifolia	Saskatoon serviceberry	Rosaceae
Artemisia douglasiana	Mugwort	Asteraceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for NEPE					
	1995	1996	1997	1998	1999
Sum06	2	5	1	5	5
W126	8.9	11.7	7.3	11.4	10.1
N60	82	141	57	142	113
N80	6	13	3	9	3
N100	1	2	0	2	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at NEPE					
	1995	1996	1997	1998	1999
Month 1	1.96	-1.51	-0.97	2.75	-0.32
Month 2	-0.40	-1.07	-0.83	-0.18	0.47
Month 3	1.86	-1.60	3.60	1.47	-2.07

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at NEPE					
	1995	1996	1997	1998	1999
April	1.96	3.41	3.34	0.51	-0.85
May	-0.40	4.08	-0.97	3.85	-0.52
June	1.86	-1.51	-0.83	1.09	0.61
July	4.77	-1.07	3.60	2.75	-0.32
August	3.90	-1.60	1.24	-0.18	0.47
September	-0.07	0.09	1.03	1.47	-2.07
October	3.42	0.99	0.85	-0.37	0.01

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The low and similar levels of ozone during the 90-day Sum06 and the seasonal W126 accumulation periods and the infrequent occurrence of low soil moisture make it impossible to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. During the five-year W126 assessment period, there were four months of drought; three in one year and one in another. The periods of drought were not associated with the levels of ozone exposure in these years.

The low levels of ozone exposure at Nez Perce National Park make the risk of foliar

ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. There are some hours of exposure to concentrations of ozone above 80 ppb, however the numbers are not high. Exposure to concentrations over 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, mugwort, ponderosa pine, and common snowberry.

WHITMAN MISSION NATIONAL HISTORIC SITE (WHMI)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Platanus occidentalis	American sycamore	Platanaceae
Populus tremuloides	Quaking aspen	Salicaceae
Robinia pseudoacacia	Black locust	Fabaceae
Symphoricarpos albus	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
Tree Seedlings	10 - 16 ppm-hr	(1-2% reduction in growth)
Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	W126	N100
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for WHMI					
	1995	1996	1997	1998	1999
Sum06	2	5	1	5	4
W126	7.8	10.3	6.4	8.2	7.7
N60	93	137	59	110	91
N80	9	21	4	13	3
N100	1	4	0	3	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WHMI					
	1995	1996	1997	1998	1999
Month 1	1.92	2.09	0.82	-1.50	-0.84
Month 2	3.02	2.94	1.15	0.59	-1.87
Month 3	3.86	-0.63	2.52	-1.35	-0.72

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at WHMI					
	1995	1996	1997	1998	1999
April	3.17	1.32	1.15	-1.24	-1.92
May	1.92	2.75	2.52	0.86	-0.84
June	3.02	2.09	2.23	-1.50	-1.87
July	3.86	2.94	3.14	0.59	-0.72
August	0.76	-0.63	0.45	-1.35	0.12
September	1.54	-0.18	0.50	-1.40	-1.76
October	0.42	1.88	2.40	-1.58	-0.51

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

- The Sum06 index is below the threshold for injury. While the W126 accumulative value is marginally above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.

- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.

- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Low and similar levels of ozone during the Sum06 accumulation periods and only three months of mild drought over five years make it difficult to assess relationships between the levels of ozone and soil moisture, and no pattern is evident. In the W126 assessment period, drought was concentrated in two years: five months in 1998, the second highest year, and three months in 1999, the second lowest year. Ozone exposures over the five-year period were relatively similar, and no association between ozone and drought can be discerned.

The low levels of ozone exposure at Whitman Mission National Historic Site make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. There are some hours of exposure to concentrations of ozone above 80 ppb, however the numbers are not high. Exposure to concentrations over 100 ppb is rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: American sycamore, quaking aspen, and common snowberry.

Appendix: Network Risk Assessment Summary

NETWORK RISK ASSESSMENT SUMMARY					
Network / Park	**#**	**Code**	**State**	**Risk**	**O3 Data**
Southwest Alaska Network / No.1	5				
Alagnak Wild River		ALAG	AK	cannot eval	no data
Aniakchak NM & PRES		ANIA	AK	cannot eval	no data
Katmai NP & PRES		KATM	AK	cannot eval	no data
Kenai Fjords NP		KEFJ	AK	cannot eval	no data
Lake Clark NP & PRES		LACL	AK	cannot eval	no data
Arctic Alaska Network / No. 2	5				
Bering Land Bridge N PRES		BELA	AK	cannot eval	no data
Cape Krusenstern NM		CAKR	AK	cannot eval	no data
Gates of the Arctic NP & PRES		GAAR	AK	cannot eval	no data
Kobuk Valley NP		KOVA	AK	cannot eval	no data
Noatak N PRES		NOAT	AK	cannot eval	no data
Central Alaska Network / No.3	3				
Denali NP & Preserve		DENA	AK	low	monitored
Wrangell-St Elias NP & PRES		WRST	AK	cannot eval	no data
Yukon-Charley Rivers N PRES		YUCH	AK	cannot eval	no data
Southeast Alaska Network / No. 4	3				
Glacier Bay NP & PRES		GLBA	AK	cannot eval	no data
Klondike Gold Rush NHP		KLGO	AK	cannot eval	no data
Sitka NHP		SITK	AK	cannot eval	no data
Great Lakes Network / No. 5	10				
Apostle Islands NL		APIS	WI	low	kriged
Grand Portage NM		GRPO	MN	low	kriged
Indiana Dunes NL		INDU	IN	high	monitored
Isle Royale NP		ISRO	MI	low	kriged
Mississippi NRRA		MISS	MN	low	kriged
Missouri NRA		MNRR	NB/SD	low	kriged
Pictured Rocks NL		PIRO	MI	moderate	kriged

Saint Croix/Lower St. Croix NSR		SACN	WI	low	kriged
Sleeping Bear Dunes NL		SLBE	MI	high	kriged
Voyageurs NP		VOYA	MN	low	monitored
Heartland Network/ No. 6	16				
Arkansas Post NM		ARPO	AR	moderate	kriged
Buffalo NR		BUFF	AR	low	kriged
Cuyahoga Valley NRA		CUVA	OH	high	kriged
Effigy Mounds NM		EFMO	IA	low	kriged
Fort Scott NHS		FOSC	KS	moderate	kriged
George Washington Carver NM		GWCA	MO	moderate	kriged
Herbert Hoover NHS		HEHO	IA	low	kriged
Homestead NM of America		HOME	NB	low	kriged
Hopewell Culture NHP		HOCU	OH	high	kriged
Hot Springs NP		HOSP	AR	low	kriged
Lincoln Boyhood NM		LIBO	IN	high	kriged
Ozark NSR		OZAR	MO	high	kriged
Pea Ridge NMP		PERI	AR	low	kriged
Pipestone NM		PIPE	MN	low	kriged
Tallgrass Prairie NP		TAPR	KS	moderate	kriged
Wilson's Creek NB		WICR	MO	low	kriged
Northern Great Plains Network / No.7	13				
Agate Fossil Beds NM		AGFO	NB	low	kriged
Badlands NP		BADL	SD	low	kriged
Devils Tower NM		DETO	WY	low	kriged
Fort Laramie NHS		FOLA	WY	low	kriged
Fort Union Trading Post NHS		FOUS	ND	low	kriged
Jewel Cave NM		JECA	SD	low	kriged
Knife River Indian Village NHS		KNRI	ND	low	kriged
Missouri NNR		MNRR	SD	low	kriged
Mount Rushmore N MEM		MORU	SD	low	kriged
Niobrara NSR		NIOB	NB	low	kriged
Scotts Bluff NM		SCBL	NB	low	kriged
Theodore Roosevelt NP		THRO	ND	low	monitored
Wind Cave NP		WICA	SD	low	kriged
Mid-Atlantic Network / No. 8	10				
Appomattox Court House NHP		APCO	VA	moderate	kriged
Booker T. Washington NM		BOWA	VA	moderate	kriged
Eisenhower NHS		EISE	PA	high	kriged
Fredericksburg & Spotsylvania NMP		FRSP	VA	high	kriged
Gettysburg NMP		GETT	PA	high	kriged

Hopewell Furnace NHS		HOFU	PA	high	kriged
Petersburg NB		PETE	VA	moderate	kriged
Richmond NBP		RICH	VA	moderate	kriged
Shenandoah NP		SHEN	VA	moderate	monitored
Valley Forge NHP		VAFO	PA	high	kriged
Eastern Rivers and Mountains Network / No. 9	9				
Allegheny Portage Railroad NHS		ALPO	PA	moderate	kriged
Bluestone NSR		BLUE	WV	moderate	kriged
Delaware Water Gap NRA		DEWA	PA	high	kriged
Fort Necessity NB		FONE	PA	high	kriged
Friendship Hill NHS		FRHI	PA	high	kriged
Gauley River NRA		GARI	WV	moderate	kriged
Johnstown Flood N MEM		JOFL	PA	moderate	kriged
New River Gorge NR		NERI	WV	moderate	kriged
Upper Delaware Scenic and Recreational River		UPDE	PA	high	kriged
Northeast Coastal and Barrier Network / No. 10	8				
Assateague Island NS		ASIS	MD	high	kriged
Cape Cod NS		CACO	MA	high	monitored
Colonial NHP		COLO	VA	high	kriged
Fire Island NS		FIIS	NY	high	kriged
Gateway NRA		GATE	NY	high	kriged
George Washington Birthplace NM		GEWA	VA	high	kriged
Sagamore Hill NHS		SAHI	NY	high	kriged
Thomas Stone NHS		THST	MD	high	kriged
Northeast Temperate Network / No. 11	10				
Acadia NP		ACAD	ME	moderate	monitored
Boston Harbor Islands NRA		BOHA	MA	moderate	kriged
Marsh-Billings NHP		MABI	VT	low	kriged
Minute Man NHP		MIMA	MA	moderate	kriged
Morristown NHP		MORR	NJ	high	kriged
Roosevelt-Vanderbilt Headquarters		ROVA	NY	high	kriged
Saint-Gaudens NHS		SAGA	NH	low	kriged
Saratoga NHP		SARA	NY	low	kriged
Saugus Iron Works NHS		SAIR	MA	moderate	kriged
Weir Farm NHS		WEFA	CT	high	kriged
National Capital Network / No. 12	12				
Antietam NB		ANTI	MD	high	kriged

Appalachian NST		APPA	WV	various	krig/monit
Catoctin Mountain Park		CATO	MD	high	kriged
Chesapeake & Ohio Canal NHP		CHOH	MD	high	kriged
George Washington Memorial PKWY		GWMP	VA	high	kriged
Harpers Ferry NHP		HAFE	WV	high	kriged
Manassas NBP		MANA	VA	high	kriged
Monocacy NB		MONO	MD	high	kriged
National Capital Parks-East		NACE	DC	high	kriged
Prince William Forest Park		PRWI	VA	high	kriged
Rock Creek Park		ROCR	DC	high	kriged
Wolf Trap Farm Park		WOTR	VA	high	kriged
Cumberland/Piedmont Network / No. 13	14				
Abraham Lincoln Birthplace NHS		ABLI	KY	moderate	kriged
Carl Sandburg Home NHS		CARL	NC	moderate	kriged
Chickamauga & Chattanooga NMP		CHCH	GA	high	kriged
Cowpens NB		COWP	SC	high	monitored
Cumberland Gap NHP		CUGA	KY	high	kriged
Fort Donelson NB		FODO	TN	high	kriged
Guilford Courthouse NMP		GUCO	NC	high	kriged
Kings Mountain NMP		KIMO	SC	high	kriged
Little River Canyon NPRES		LIRI	AL	high	kriged
Mammoth Cave NP		MACA	KY	high	monitored
Ninety Six NHS		NISI	SC	low	kriged
Russell Cave NM		RUCA	AL	moderate	kriged
Shiloh NMP		SHIL	TN	high	kriged
Stones River NB		STRI	TN	high	kriged
Southeast Coast Network / No. 14	17				
Canaveral NS		CANA	FL	low	kriged
Cape Hatteras NS		CAHA	NC	moderate	kriged
Cape Lookout NS		CALO	NC	moderate	kriged
Castillo de San Marcos NM		CASA	FL	low	kriged
Chattahoochee River NRA		CHAT	GA	high	kriged
Congaree Swamp NM		COSW	SC	low	monitored
Cumberland Island NS		CUIS	GA	low	kriged
Fort Caroline NM		FOCA	FL	low	kriged
Fort Frederica NM		FOFR	GA	low	kriged
Fort Matanzas NM		FOMA	FL	low	kriged
Fort Pulaski NM		FOPU	GA	low	kriged
Fort Sumter NM		FOSU	SC	low	kriged
Horseshoe Bend NMP		HOBE	AL	moderate	kriged
Kennesaw Mountain NBP		KEMO	GA	high	kriged
Moores Creek NB		MOCR	NC	moderate	kriged

Ocmulgee NM		OCMU	GA	high	kriged
Timucuan Ecological & Hist Preserve		TIMU	FL	low	kriged
Gulf Coast Network / No. 15	8				
Big Thicket N PRES		BITH	TX	high	kriged
Gulf Islands NS		GUIS	FL	low	kriged
Jean Lafitte NHP & PRES		JELA	LA	moderate	kriged
Natchez Trace NST		NATR	MS	various	krig/monit
Padre Island NS		PAIS	TX	low	kriged
Palo Alto Battlefield NHS		PAAL	TX	low	kriged
San Antonio Missions NHP		SAAN	TX	moderate	kriged
Vicksburg NMP		VICK	MS	low	kriged
Appalachian Highlands Network / No. 16	4				
Big South Fork NRRA		BISO	TN	high	kriged
Blue Ridge PKWY		BLRI	NC	low	kriged
Great Smoky Mountains NP		GRSM	TN	high	monitored
Obed Wild and Scenic River		OBRI	TN	high	kriged
South Florida/Caribbean Network / No. 17	6				
Big Cypress N PRES		BICY	FL	low	kriged
Biscayne NP		BISC	FL	low	kriged
Buck Island Reef NM		BUIS	VI	low	kriged
Dry Tortugas NP		DRTO	FL	cannot eval	no data
Everglades NP		EVER	FL	low	monitored
Virgin Islands NP		VIIS	VI	low	monitored
Northern Colorado Plateau Network / No. 18	16				
Arches NP		ARCH	UT	low	kriged
Black Canyon of the Gunnison NM		BLCA	CO	low	kriged
Bryce Canyon NP		BRCA	UT	low	kriged
Canyonlands NP		CANY	UT	low	monitored
Capitol Reef NP		CARE	UT	low	kriged
Cedar Breaks NM		CEBR	UT	low	kriged
Colorado NM		COLM	CO	low	kriged
Curecanti NRA		CURE	CO	low	kriged
Dinosaur NM		DINO	CO	low	kriged
Fossil Butte NM		FOBU	WY	moderate	kriged
Golden Spike NHS		GOSP	UT	moderate	kriged
Hovenweep NM		HOVE	CO	low	kriged
Natural Bridges NM		NABR	UT	low	kriged
Pipe Spring NM		PISP	AZ	low	kriged

Timpanogos Cave NM		TICA	UT	moderate	kriged
Zion NP		ZION	UT	low	kriged
Rocky Mountain Network / No. 19	6				
Florissant Fossil Beds NM		FLFO	CO	low	kriged
Glacier NP		GLAC	MT	low	monitored
Grant-Kohrs Ranch NHS		GRKO	MT	low	kriged
Great Sand Dunes NM		GRSA	CO	low	kriged
Little Bighorn Battlefield NM		LIBI	MT	low	kriged
Rocky Mountain NP		ROMO	CO	low	monitored
Greater Yellowstone Network / No. 20	3				
Bighorn Canyon NRA		BICA	MT	low	kriged
Grand Teton NP		GRTE	WY	low	kriged
Yellowstone NP		YELL	WY	low	monitored
Southern Colorado Plateau Network / No. 21	19				
Aztec Ruins NM		AZRU	NM	low	kriged
Bandelier NM		BAND	NM	low	kriged
Canyon de Chelly NM		CACH	AZ	low	kriged
Chaco Culture NHP		CHCU	NM	low	kriged
El Malpais NM		ELMA	NM	low	kriged
El Morro NM		ELMO	NM	low	kriged
Glen Canyon NRA		GLCA	UT	low	kriged
Grand Canyon NP		GRCA	AZ	low	monitored
Hubbell Trading Post NHS		HUTR	AZ	low	kriged
Mesa Verde NP		MEVE	CO	low	monitored
Navajo NM		NAVA	AZ	low	kriged
Petrified Forest NP		PEFO	AZ	moderate	kriged
Petroglyph NM		PETR	NM	low	kriged
Rainbow Bridge NM		RABR	UT	low	kriged
Salinas Pueblo Missions NM		SAPU	NM	low	kriged
Sunset Crater Volcano NM		SUCR	AZ	moderate	kriged
Walnut Canyon NM		WACA	AZ	moderate	kriged
Wupatki NM		WUPA	AZ	moderate	kriged
Yucca House NM		YUHO	CO	low	kriged
Southern Plains Network / No. 22	9				
Alibates Flint Quarries NM		ALFL	TX	low	kriged
Bent's Old Fort NHS		BEOL	CO	low	kriged
Capulin Volcano NM		CAVO	NM	low	kriged
Chickasaw NRA		CHIC	OK	high	kriged

Fort Larned NHS		FOLS	KS	low	kriged
Fort Union NM		FOUN	NM	low	kriged
Lake Meredith NRA		LAMR	TX	low	kriged
Lyndon B. Johnson NHP		LYJO	TX	moderate	kriged
Pecos NHP		PECO	NM	low	kriged
Sonoran Desert Network / No. 23	11				
Casa Grande Ruins NM		CAGR	AZ	low	kriged
Chiricahua NM		CHIR	AZ	low	monitored
Coronado NMEM		CORO	AZ	low	kriged
Fort Bowie NHS		FOBO	AZ	low	kriged
Gila Cliff Dwellings NM		GICL	NM	low	kriged
Montezuma Castle NM		MOCA	AZ	moderate	kriged
Organ Pipe Cactus NM		ORPI	AZ	moderate	kriged
Saguaro NP		SAGU	AZ	low	monitored
Tonto NM		TONT	AZ	moderate	kriged
Tumacacori NHP		TUMA	AZ	low	kriged
Tuzigoot NM		TUZI	AZ	low	kriged
Chihuahuan Desert Network / No. 24	7				
Amistad NRA		AMIS	TX	moderate	kriged
Big Bend NP		BIBE	TX	low	monitored
Carlsbad Caverns NP		CAVE	NM	low	kriged
Chamizal NM		CHAM	TX	low	monitored
Fort Davis NHS		FODA	TX	low	kriged
Guadalupe Mountains NP		GUMO	TX	low	kriged
White Sands NM		WHSA	NM	low	kriged
North Coast and Cascades Network / No. 25	8				
Ebey's Landing NH Reserve		EBLA	WA	low	kriged
Fort Clatsop NM		FOCL	OR	low	kriged
Fort Vancouver NHS		FOVA	WA	low	kriged
Lake Roosevelt NRA		LARO	WA	low	kriged
Mount Rainier NP		MORA	WA	low	monitored
North Cascades NP		NOCA	WA	low	monitored
Olympic NP		OLYM	WA	low	monitored
San Juan Island NHP		SAJH	WA	low	kriged
Northern Semi-Arid Network / No. 26	7				
Big Hole NB		BIHO	MT	low	kriged
City of Rocks N RES		CIRO	ID	moderate	kriged
Craters of the Moon NHP		CRMO	ID	low	monitored

Hagerman Fossil Beds NM		HAFO	ID	low	kriged
John Day Fossil Beds NM		JODA	OR	low	kriged
Nez Perce NHP		NEPE	ID	low	kriged
Whitman Mission NHS		WHMI	WA	low	kriged
San Francisco Bay Area Network / No. 27	5				
Golden Gate NRA		GOGA	CA	low	kriged
John Muir NHS		JOMU	CA	high	kriged
Muir Woods NM		MUWO	CA	moderate	kriged
Pinnacles NM		PINN	CA	high	monitored
Point Reyes NS		PORE	CA	low	kriged
Mojave Desert Network / No. 28	6				
Death Valley NP		DEVA	CA	low	monitored
Great Basin NP		GRBA	NV	low	monitored
Joshua Tree NP		JOTR	CA	high	monitored
Lake Mead NRA		LAME	NV	low	kriged
Manzanar NHS		MANZ	CA	high	kriged
Mojave N PRES		MOJA	CA	high	kriged
Mediterranean Coast Network / No. 29	3				
Cabrillo NM		CABR	CA	low	kriged
Channel Islands NP		CHIS	CA	low	monitored
Santa Monica Mountains NRA		SAMO	CA	high	kriged
Sierra Nevada Network / No. 30	3				
Devils Postpile NM		DEPO	CA	high	kriged
Sequoia & Kings Canyon NP		SEKI	CA	high	monitored
Yosemite NP		YOSE	CA	high	monitored
Pacific Island Network / No. 31	9				
American Memorial Park		AMME	MP	cannot eval	no data
Haleakala NP		HALE	HI	cannot eval	no data
Hawaii Volcanoes NP		HAVO	HI	cannot eval	no data
Kalaupapa NHP		KALA	HI	cannot eval	no data
Kaloko-Honokohau NHP		KAHO	HI	cannot eval	no data
National Park of American Samoa		NPSA	AS	cannot eval	no data
Pu'uhonua o Honaunau NHP		PUHO	HI	cannot eval	no data
Puukohola Heiau NHS		PUHE	HI	cannot eval	no data
War in the Pacific NHP		WAPA	GU	cannot eval	no data

Klamath Network / No. 32	6				
Crater Lake NP		CRLA	OR	moderate	kriged
Lassen Volcanic NP		LAVO	CA	low	monitored
Lava Beds NM		LABE	CA	moderate	kriged
Oregon Caves NM		ORCA	OR	moderate	kriged
Redwood NP		REDW	CA	moderate	kriged
Whiskeytown-Shasta-Trinity NRA		WHIS	CA	high	kriged
Appalachian National Scenic Trail	30				
Dawsonville			GA	moderate	monitored
Great Smokey Mountain NP		GRSM	NC	high	monitored
Bryson City			NC	low	monitored
Mount Mitchell			NC	moderate	monitored
Lenoir			NC	moderate	monitored
Kingsport			TN	high	monitored
Blountville			TN	moderate	monitored
Rural Retreat			VA	low	monitored
Bluestone NSR		BLUE	WV	moderate	kriged
Vinton			VA	low	monitored
Glenwood-Pedlar Ranger Station			VA	low	monitored
Shenandoah NP		SHEN	VA	moderate	monitored
Rest			VA	low	monitored
Harpers Ferry NHP		HAFE	WV	high	kriged
Catoctin Mountain Park		CATO	MD	high	kriged
Gettysburg NMP		GETT	PA	high	kriged
Little Buffalo State Park			PA	moderate	monitored
Kutztown University			PA	moderate	monitored
Kunkletown			PA	moderate	monitored
Delaware Water Gap NRA		DEWA	PA	high	kriged
Montgomery			NY	high	monitored
Roosevelt-Vanderbilt Headquarters		ROVA	NY	high	kriged
Torrington			CT	high	monitored
Mount Greylock			MA	low	monitored
Bennington			VT	low	monitored
Marsh-Billings NHP		MABI	VT	low	kriged
Saint-Gaudens NHS		SAGA	VT	low	kriged
Haverhill			NH	low	monitored
Mount Washington			NH	low	monitored
Greenville			ME	low	monitored
Natchex Trace National Scenic Trail	9				
Natchez			MS	low	monitored
Vicksburg NMP		VICK	MS	low	kriged

Jackson			MS	low	monitored
Ackerman			MS	low	monitored
Tupelo			MS	high	monitored
Shiloh NMP		SHIL	TN	high	kriged
Busby			TN	moderate	monitored
Fairview			TN	low	monitored
Stones River NB		STRI	TN	high	kriged