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.

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 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.