

SOUTHERN PLAINS NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE SOUTHERN PLAINS NETWORK

October 2004

Objective

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

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

Risk Assessment Methodology

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

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

Ozone-Sensitive Plant Species

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

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

Levels of Ozone Exposure

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

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

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

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

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

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

Soil Moisture Status

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

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

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

Site-Specific Assessment

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

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

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

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

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

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

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 SOUTHERN PLAINS NETWORK

Park	Code	State	Risk	O3 Data
Alibates Flint Quarries NM	ALFL	TX	low	kriged
Bent's Old Fort NHS	BEOL	CO	low	kriged
Capulin Volcano NM	CAVO	NM	low	kriged
Chickasaw NRA	CHIC	OK	high	kriged
Fort Larned NHS	FOLS	KS	low	kriged
Fort Union NM	FOUN	NM	low	kriged
Lake Meredith NRA	LAMR	TX	low	kriged
Lyndon B. Johnson NHP	LYJO	TX	moderate	kriged
Pecos NHP	PECO	NM	low	kriged

ALIBATES FLINT QUARRIES NATIONAL MONUMENT (ALFL)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Robinia pseudoacacia</i>	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.

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

Ozone Exposure Data

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

Ozone air quality data for ALFL					
	1995	1996	1997	1998	1999
Sum06	14	11	10	20	18
W126	25.1	22.9	24.1	39.5	30.4
N60	420	402	397	730	516
N80	56	28	33	81	62
N100	6	2	2	6	2

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ALFL					
	1995	1996	1997	1998	1999
Month 1	0.34	-3.45	2.27	-0.30	-0.52
Month 2	-0.66	-0.70	-0.38	-3.69	-0.04
Month 3	-1.52	2.86	-0.72	3.65	-1.65

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

Palmer Z Index data for the 7-month W126 period at ALFL					
	1995	1996	1997	1998	1999
April	-0.84	-2.43	8.34	-0.13	3.65
May	2.24	-3.45	1.20	-2.94	2.90
June	0.34	-0.70	2.45	-3.77	3.48
July	-0.66	2.86	1.83	-1.70	1.08
August	-1.52	3.55	2.27	-0.30	-0.52
September	2.86	1.46	-0.38	-3.69	-0.04
October	-1.33	-1.45	-0.72	3.65	-1.65

Risk Analysis

- There are a few ozone-sensitive species at the site, but none of them are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than six hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.
- No consistent relationship is apparent between 90-day Sum06 accumulation period indices of ozone and soil moisture. This is largely a consequence of similar levels of exposure and scattered months of drought. There was one month of mild or severe drought in four of the five years. There does not appear to be any association between the W126 level of ozone exposure and soil moisture status. The highest and lowest ozone years, 1998 and 1996, experienced four and three months, respectively, of mild to severe drought. The second highest ozone

year 1999 had one month of mild drought, the mid-exposure year 1995 had two months of mild drought and the second lowest ozone year 1997 had normal soil moisture. There were no associations between ozone and soil moisture for either the Sum06 or the W126 indices of exposure.

The low level of ozone exposure at Alibates Flint Quarries National Monument makes the risk of foliar ozone injury to plants low. While the Sum06 threshold is satisfied, the W126 criteria generally are not. The N100 counts are low with only two years having six hours of ozone greater than 100 ppb. Although there is no apparent association between ozone exposure and soil moisture, several years had three or four months of mild to severe drought that constrain the uptake of ozone and reduce the likelihood of foliar injury development.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use American sycamore.

BENT'S OLD FORT NATIONAL HISTORIC SITE (BEOL)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for BEOL					
	1995	1996	1997	1998	1999
Sum06	8	12	8	12	10
W126	14.8	19.5	17.5	25.3	23.6
N60	203	313	261	426	378
N80	13	15	10	27	21
N100	1	1	0	2	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BEOL					
	1995	1996	1997	1998	1999
Month 1	6.75	2.21	-2.10	-2.20	7.76
Month 2	2.82	1.77	1.63	-0.29	3.50
Month 3	0.61	2.06	-0.15	7.21	2.70

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

Palmer Z Index data for the 7-month W126 period at BEOL					
	1995	1996	1997	1998	1999
April	3.18	-1.39	3.26	1.36	7.76
May	6.11	-0.89	-2.10	-2.20	3.50
June	6.75	-0.24	1.63	-0.29	2.70
July	2.82	2.21	-0.15	7.21	3.84
August	0.61	1.77	5.87	2.44	5.00
September	1.33	2.06	0.25	-1.14	0.77
October	-1.26	-0.42	5.01	2.82	0.40

Risk Analysis

- There is one ozone-sensitive species at the site, but it is not a bioindicator for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation, but the values are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Only two months of drought occurred in the five-year period for the Sum06 index; one in one of the highest ozone years, 1998, and one in the lowest, 1997. For the W126 index, there were two months of drought in the highest ozone year, 1998, and none in the second highest year, 1999. One month of drought occurred in each of the remaining three years. No association with the level of ozone is evident from

this distribution of drought.

The risk of foliar ozone injury to plants at Bent's Old Fort National Historic Site is low. While the Sum06 threshold is marginally satisfied, the W126 criteria are not. Only a few hours of exposure to ozone concentrations greater than 80 ppb occur each year, while exposures to 100 ppb are rare.

If the level of risk increases in the future and an injury assessment becomes desirable, bioindicator species will have to be identified at the site.

CAPULIN VOLCANO NATIONAL MONUMENT (CAVO)

Plant Species Sensitive to Ozone

No sensitive species are listed for the site.

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for CAVO					
	1995	1996	1997	1998	1999
Sum06	8	12	8	12	10
W126	14.8	19.5	17.5	25.3	23.6
N60	203	313	261	426	378
N80	13	15	10	27	21
N100	1	1	0	2	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CAVO					
	1995	1996	1997	1998	1999
Month 1	3.60	-4.72	0.50	-2.65	4.42
Month 2	0.31	0.53	1.76	-2.14	2.21
Month 3	-0.31	0.20	0.40	2.93	2.20

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

Palmer Z Index data for the 7-month W126 period at CAVO					
	1995	1996	1997	1998	1999
April	2.14	-2.33	2.69	0.46	4.42
May	4.26	-4.72	0.50	-2.65	2.21
June	3.60	0.53	1.76	-2.14	2.20
July	0.31	0.20	0.40	2.93	3.52
August	-0.31	0.58	0.93	-0.04	3.56
September	1.51	0.13	2.02	-1.77	0.24
October	-2.28	1.55	-0.22	5.19	-1.25

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation, although the levels are marginal. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than two hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- The 90-day Sum06 accumulation period levels of ozone were relatively consistent over the five-year period making it difficult to assess relationships with soil moisture. There is some indication, however, that soil moisture levels during the 90-day periods may be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two years with the same high ozone exposure value, 1996 and 1998, experienced one and two months of moderate or severe drought, respectively. The remaining three years had favorable soil moisture conditions. However, the limited occurrence of drought makes the inverse nature of the association uncertain. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, although the pattern is not consistent. The highest ozone year, 1998, had three months of mild and moderate, while the second highest year, 1999, had one month of mild drought. There were two months of moderate and severe drought in the mid-level ozone year 1996. The lowest ozone year had one month of drought, and the second lowest year had normal conditions.

The risk of foliar ozone injury to plants at Capulin Volcano National Monument is low. While the Sum06 threshold is marginally satisfied, the W126 criteria are not. Exposure

to 80 ppb ozone is infrequent, and exposure to 100 ppb rare. Soil moisture is inversely related to ozone exposure and serves to constrain the uptake of ozone at higher exposure levels. This effect further reduces the likelihood of foliar injury development.

No ozone-sensitive or bioindicator species have been identified at the site.

CHICKASAW NATIONAL RECREATION AREA (CHIC)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Rhus trilobata</i>	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.

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

Ozone Exposure Data

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

Ozone air quality data for CHIC					
	1995	1996	1997	1998	1999
Sum06	11	7	7	15	27
W126	40.4	30.3	31.8	50.8	40.1
N60	674	511	534	920	682
N80	155	84	93	168	131
N100	30	14	16	20	14

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CHIC					
	1995	1996	1997	1998	1999
Month 1	1.07	0.32	0.04	-4.42	0.58
Month 2	1.56	-0.26	-2.42	-2.15	-0.67
Month 3	-0.09	-4.17	0.31	-2.25	-2.28

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

Palmer Z Index data for the 7-month W126 period at CHIC					
	1995	1996	1997	1998	1999
April	1.46	-0.26	2.42	-0.71	1.06
May	2.84	-4.17	0.04	-3.75	0.08
June	1.07	-0.94	0.27	-2.54	1.27
July	1.56	1.68	-1.16	-4.42	-0.63
August	-0.09	5.11	0.04	-2.15	-1.35
September	1.83	2.62	-2.42	-2.25	0.58
October	-1.74	-0.18	0.31	0.72	-0.67

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- There does not appear to be any association between the 90-day Sum06 accumulative index and soil moisture conditions. In the highest ozone year, 1999, there was one month of moderate drought, while in each of the two years with the lowest ozone, 1996 and 1997, there was one month of severe or moderate drought. Soil moisture levels associated with the seasonal W126 index give some indication of being inversely related to ozone concentrations: when ozone is high, soil moisture is low, however the inconsistencies in the pattern are significant. The year with the highest ozone level, 1998, had five months of moderate and severe drought. The remaining four years each had one or two months of mild to severe drought.

The risk of foliar ozone injury to plants at Chickasaw National Recreation Area is high. The Sum06 and W126 threshold criteria are both satisfied, and the N80 and N100 counts are high. While the levels of ozone exposure consistently create the potential for injury, low soil moisture may reduce the likelihood of injury developing in some years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing is greatest during years such as 1995 and 1999 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

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

FORT LARNED NATIONAL HISTORIC SITE (FOLS)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for FOLS					
	1995	1996	1997	1998	1999
Sum06	21	15	15	28	20
W126	23.2	12.8	22.9	41.5	27.6
N60	438	278	378	788	478
N80	67	15	13	88	54
N100	8	1	0	6	2

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOLS					
	1995	1996	1997	1998	1999
Month 1	2.56	-1.44	2.31	1.59	2.55
Month 2	1.40	1.49	1.97	-1.77	-0.01
Month 3	1.79	4.09	4.00	-2.38	1.69

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

Palmer Z Index data for the 7-month W126 period at FOLS					
	1995	1996	1997	1998	1999
April	1.34	-1.40	2.10	-0.17	3.60
May	5.10	-1.53	0.14	-1.79	0.04
June	2.56	-1.44	2.31	-2.40	2.24
July	1.40	1.49	1.97	1.59	2.55
August	1.79	4.09	4.00	-1.77	-0.01
September	0.26	3.58	1.63	-2.38	1.69
October	-1.83	0.38	1.93	3.56	-1.67

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than eight hours in which the concentration exceeded 100 ppb. The highest exposures may possibly injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The highest Sum06 exposure year, 1998, had two months of mild and moderate drought, while one of the lowest, 1996, had one month of mild drought. Soil moisture in the other three years was normal. The year with the highest W126 exposure index, 1998, had four months of mild and moderate drought, and the year with the lowest, 1996, had three months of mild drought. There were only two months of mild drought in the remaining three years.

The low levels of ozone exposure at Fort Larned National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 threshold criteria are satisfied, while the W126 criteria are generally not fulfilled. While there are some years with a significant number of hours of ozone above 80 ppb, hours of exposure to concentrations above 100 ppb are generally low. Levels of ozone and soil moisture conditions are unrelated, and the number of months of drought varies widely among years. In some years, such as 1995, exposures reach injury thresholds while soil moisture conditions foster the uptake of ozone. The opportunity for foliar injury to occur is greatest when these conditions coincide.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use common milkweed or redbud.

FORT UNION NATIONAL MONUMENT (FOUN)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Robinia pseudoacacia</i>	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.

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

Ozone Exposure Data

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

Ozone air quality data for FOUN					
	1995	1996	1997	1998	1999
Sum06	9	17	11	16	14
W126	16.5	23.1	18.7	25.6	25.8
N60	219	376	282	448	420
N80	13	12	9	13	20
N100	1	0	0	0	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOUN					
	1995	1996	1997	1998	1999
Month 1	3.60	-4.72	0.50	-0.04	2.21
Month 2	0.31	0.53	1.76	-1.77	2.20
Month 3	-0.31	0.20	0.40	5.19	3.52

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

Palmer Z Index data for the 7-month W126 period at FOUN					
	1995	1996	1997	1998	1999
April	2.14	-2.33	2.69	0.46	4.42
May	4.26	-4.72	0.50	-2.65	2.21
June	3.60	0.53	1.76	-2.14	2.20
July	0.31	0.20	0.40	2.93	3.52
August	-0.31	0.58	0.93	-0.04	3.56
September	1.51	0.13	2.02	-1.77	0.24
October	-2.28	1.55	-0.22	5.19	-1.25

Risk Analysis

- There are a few ozone-sensitive species at the site, none of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and one year in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only two months of drought over the five-year period. However, the two months occurred in the years with the highest ozone exposures. While this suggests an inverse relationship, when ozone is high, soil moisture is low, additional data are required to confirm such a conclusion. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the three highest ozone years, 1999, 1998 and 1996, there were one, three, and two months of mild and severe

drought, respectively. The two years with the lowest ozone experienced one month of moderate drought between them.

The low levels of ozone exposure at Fort Union National Monument make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours with concentrations of ozone above 80 ppb, but only one hour above 100 ppb during the assessment period. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

There are no ozone bioindicator species at the site.

LAKE MEREDITH NATIONAL RECREATION AREA (LAMR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Robinia pseudoacacia</i>	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.

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

Ozone Exposure Data

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

Ozone air quality data for LAMR					
	1995	1996	1997	1998	1999
Sum06	14	11	10	19	17
W126	24.5	22.3	23.9	39.3	30.2
N60	412	393	393	726	511
N80	54	26	32	80	60
N100	5	2	2	6	2

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LAMR					
	1995	1996	1997	1998	1999
Month 1	0.34	-3.45	2.27	-0.30	-0.52
Month 2	-0.66	-0.70	-0.38	-3.69	-0.04
Month 3	-1.52	2.86	-0.72	3.65	-1.65

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

Palmer Z Index data for the 7-month W126 period at LAMR					
	1995	1996	1997	1998	1999
April	-0.84	-2.43	8.34	-0.13	3.65
May	2.24	-3.45	1.20	-2.94	2.90
June	0.34	-0.70	2.45	-3.77	3.48
July	-0.66	2.86	1.83	-1.70	1.08
August	-1.52	3.55	2.27	-0.30	-0.52
September	2.86	1.46	-0.38	-3.69	-0.04
October	-1.33	-1.45	-0.72	3.65	-1.65

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than six hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. For the Sum06 index, there was one month of mild or severe drought in four of the five years. With the W126 index, there were three months of moderate and severe drought in the highest ozone year, 1998, and three months of mild to severe drought in the lowest year, 1996. Distribution of months of drought in the intermediate years shows no association with exposure.

The low level of ozone exposure at Lake Meredith National Recreation Area makes the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a few hours of exposure above 80 ppb, but exposures above 100 ppb are generally rare. One year, 1998, had exposures that satisfied the Sum06 and W126 criteria, but dry soil conditions during several months that year would significantly constrain the uptake of ozone and reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use American sycamore.

LYNDON B. JOHNSON NATIONAL HISTORIC PARK (LYJO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for LYJO					
	1995	1996	1997	1998	1999
Sum06	13	4	10	15	20
W126	36.4	13.4	22.1	25.7	32.0
N60	594	205	372	443	539
N80	161	41	74	79	128
N100	26	7	8	12	18

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LYJO					
	1995	1996	1997	1998	1999
Month 1	-1.28	-0.94	5.60	6.87	-2.41
Month 2	-0.98	-1.15	1.64	-1.81	-2.94
Month 3	0.39	-3.47	-1.51	0.45	-1.22

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

Palmer Z Index data for the 7-month W126 period at LYJO					
	1995	1996	1997	1998	1999
April	0.27	-1.15	2.93	-1.77	-0.71
May	1.74	-3.47	0.74	-3.70	-1.45
June	0.33	-2.73	5.60	-2.31	0.28
July	-1.28	-2.09	1.64	-2.72	-0.80
August	-0.98	2.96	-1.51	6.87	-2.41
September	0.39	1.06	-2.24	-1.81	-2.94
October	-1.98	0.14	-0.54	0.45	-1.22

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours in several years. These levels of exposure can injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The highest Sum06 exposure was in 1999 when there were three months of mild and moderate drought, while the lowest exposure was in 1996 when there were two months of mild and severe drought. The remaining intermediate ozone years each had one month of drought. With the W126 index, the highest ozone year, 1995, had two months of mild drought. The second highest year, 1999, had four months of mild and moderate drought while the two intermediate years had five and two months of drought. The lowest year, 1996, four months of mild to severe drought. Overall, no association between ozone exposure and drought is apparent for either

index.

The risk of foliar ozone injury to plants at Lyndon B. Johnson National Historic Park is moderate. While the levels of ozone exposure consistently create the potential for injury, periods of low soil moisture may reduce the likelihood of injury developing in particular years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1995 when ozone levels exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use redbud.

PECOS NATIONAL HISTORIC PARK (PECO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for PECO					
	1995	1996	1997	1998	1999
Sum06	9	17	11	16	14
W126	17.2	23.8	19.0	25.9	26.4
N60	229	391	288	453	432
N80	15	12	10	14	21
N100	1	0	0	0	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PECO					
	1995	1996	1997	1998	1999
Month 1	3.60	-4.72	0.50	-0.04	2.21
Month 2	0.31	0.53	1.76	-1.77	2.20
Month 3	-0.31	0.20	0.40	5.19	3.52

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

Palmer Z Index data for the 7-month W126 period at PECO					
	1995	1996	1997	1998	1999
April	2.14	-2.33	2.69	0.46	4.42
May	4.26	-4.72	0.50	-2.65	2.21
June	3.60	0.53	1.76	-2.14	2.20
July	0.31	0.20	0.40	2.93	3.52
August	-0.31	0.58	0.93	-0.04	3.56
September	1.51	0.13	2.02	-1.77	0.24
October	-2.28	1.55	-0.22	5.19	-1.25

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. One year had one hour in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because there were only two months of drought over the five-year period. One month of drought occurred in each of the two years with the highest ozone exposures. While this suggests an inverse relationship, when ozone is high, soil moisture is low, additional data are required to confirm such a relationship. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations, although the pattern is not consistent. This relationship reduces the uptake of ozone and the

effectiveness of the higher exposures in producing foliar injury. In the three highest ozone years, 1999, 1998 and 1996, there were one, three, and two months of mild and severe drought, respectively. The two years with the lowest ozone experienced one month of moderate drought between them.

The low levels of ozone exposure at Pecos National Historic Park make the risk of foliar ozone injury to plants low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. There are a number of hours with concentrations of ozone above 80 ppb, but only one hour above 100 ppb. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use ponderosa pine or skunkbush.