

HEARTLAND NETWORK

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

October 2004

Objective

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

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

Risk Assessment Methodology

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

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

Ozone-Sensitive Plant Species

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

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

Levels of Ozone Exposure

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

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

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 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 HEARTLAND NETWORK

Park	Code	State	Risk	O3 Data
Arkansas Post NM	ARPO	AR	moderate	kriged
Buffalo NR	BUFF	AR	low	kriged
Cuyahoga Valley NRA	CUVA	OH	high	kriged
Effigy Mounds NM	EFMO	IA	low	kriged
Fort Scott NHS	FOSC	KS	moderate	kriged
George Washington Carver NM	GWCA	MO	moderate	kriged
Herbert Hoover NHS	HEHO	IA	low	kriged
Homestead NM of America	HOME	NB	low	kriged
Hopewell Culture NHP	HOCU	OH	high	kriged
Hot Springs NP	HOSP	AR	low	kriged
Lincoln Boyhood NM	LIBO	IN	high	kriged
Ozark NSR	OZAR	MO	high	kriged
Pea Ridge NMP	PERI	AR	low	kriged
Pipestone NM	PIPE	MN	low	kriged
Tallgrass Prairie NP	TAPR	KS	moderate	kriged
Wilson's Creek NB	WICR	MO	low	kriged

ARKANSAS POST NATIONAL MEMORIAL (ARPO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

	<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 ARPO					
	1995	1996	1997	1998	1999
Sum06	27	19	20	27	30
W126	35.4	24.8	27.7	37.6	39.6
N60	632	429	513	683	719
N80	95	52	46	107	123
N100	8	5	4	8	10

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ARPO					
	1995	1996	1997	1998	1999
Month 1	-0.65	1.18	-0.28	-2.58	-1.39
Month 2	0.50	2.26	-0.30	-1.14	-2.86
Month 3	-2.20	0.08	-0.04	-2.16	-1.85

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

Palmer Z Index data for the 7-month W126 period at ARPO					
	1995	1996	1997	1998	1999
April	1.04	-1.16	3.95	-0.92	0.61
May	-0.90	-0.55	-0.10	-2.53	-0.77
June	-0.65	1.18	2.01	-3.08	1.47
July	0.50	2.26	-0.28	-2.58	-1.39
August	-2.20	0.08	-0.30	-1.14	-2.86
September	-2.17	2.04	-0.04	-2.16	-1.85
October	-0.87	2.00	0.91	-0.35	0.07

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a number of hours every year. The higher levels of exposure can injure vegetation.
- Soil moisture levels during the 90-day Sum06 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the three years with the highest ozone exposure values, 1999 and 1998 each had three months of mild and moderate drought, and 1995 had one month of moderate drought. The two years with lower ozone exposures, 1996 and 1997, had normal soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure, although the relationship is not consistent. In the two highest ozone years, 1999 and 1998, there were three and five months,

respectively, of mild to severe drought. The mid-level ozone year, 1995, had two months of moderate drought. The two years with the lowest exposure, 1996 and 1997, had one month of mild drought between them.

The risk of foliar ozone injury at Arkansas Post National Memorial is moderate. The threshold level for injury is consistently satisfied by the Sum06 index and generally satisfied for the W126 index. The N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb, and there are a number of hours of exposure to 100 ppb in some years. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone levels are reduced but still exceed the thresholds, and soil moisture levels are normal most of the growing season with drought occurring late in the year.

A program to assess the incidence of foliar ozone injury on plants at the site could use the bioindicator species redbud and American sycamore.

BUFFALO NATIONAL RIVER (BUFF)

Plant Species of Interest

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Vitis labrusca</i>	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.

	<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 BUFF					
	1995	1996	1997	1998	1999
Sum06	16	12	11	17	23
W126	25.9	24.1	25.7	34.4	38.5
N60	406	388	431	598	706
N80	37	26	19	43	55
N100	4	2	1	2	4

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BUFF					
	1995	1996	1997	1998	1999
Month 1	0.90	-2.25	1.56	-1.33	-1.60
Month 2	0.26	0.26	0.39	-1.29	-1.33
Month 3	-2.66	100	0.12	0.62	-2.03

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

Palmer Z Index data for the 7-month W126 period at BUFF					
	1995	1996	1997	1998	1999
April	2.27	1.00	-0.34	-1.52	0.88
May	0.70	-2.06	-1.11	-1.49	1.08
June	0.90	-0.82	0.13	-2.75	2.41
July	0.26	0.09	0.34	-2.42	-0.77
August	-2.66	-0.75	1.56	-1.33	-1.60
September	-0.21	3.92	0.39	-1.29	-1.33
October	-0.11	-0.39	0.12	0.62	-2.03

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 4 hours in which the concentration exceeded 100 ppb.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The Sum06 index was highest in 1999 when there were three months of mild and moderate drought, and second highest in 1998 when there were two months of mild drought. There was one month of moderate drought in both 1995 and 1997 the mid-level exposure years, and soil moisture was normal in 1997, the lowest exposure year. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the year with the highest W126

index, 1999, there were three months of mild and moderate drought, while the second highest exposure year, 1998, had six months of mild to moderate drought. The three remaining years had lower levels of exposure and each had one month of mild or moderate drought.

The risk of foliar ozone injury at Buffalo National River is low. The threshold level for injury is satisfied only by the Sum06 index, and the N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb while exposure to 100 ppb is rare. The inverse relationship between exposure and soil moisture further reduces the likelihood of injury developing in the high ozone years.

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

CUYAHOGA VALLEY NATIONAL PARK (CUVA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Aster umbellatus</i>	Flat-topped aster	Asteraceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
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Ozone air quality data for CUVA					
	1995	1996	1997	1998	1999
Sum06	29	27	24	29	31
W126	30.7	31.3	27.5	39.6	35.7
N60	521	523	464	669	610
N80	119	117	85	159	138
N100	15	7	5	21	13

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CUVA					
	1995	1996	1997	1998	1999
Month 1	-1.47	2.03	1.82	-1.46	-1.77
Month 2	0.57	0.54	-3.01	0.43	-2.70
Month 3	-2.30	-0.89	1.72	-2.72	0.53

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

Palmer Z Index data for the 7-month W126 period at CUVA					
	1995	1996	1997	1998	1999
April	0.62	3.33	-0.62	3.88	0.80
May	0.81	0.68	2.63	-3.47	-1.77
June	-1.47	2.03	1.82	0.44	-2.70
July	0.57	0.54	-3.01	-1.46	0.53
August	-2.30	-0.89	1.72	0.43	-0.65
September	-2.57	6.70	0.05	-2.72	1.11
October	2.04	3.04	-1.13	-0.58	0.31

Risk Analysis

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

exposure in producing foliar injury. The years with the highest and similar ozone exposure values, 1999, 1995 and 1998, each show two months of mild and moderate drought. The two years with the lowest ozone exposures had one month of moderate drought, between them. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone concentrations, although the pattern is not consistent. In the two highest ozone years, 1998 and 1999, there were three and two months of mild to severe drought, respectively. The mid-ozone years 1996 and 1997 experienced normal soil moisture and three months of mild and moderate drought, respectively, while there was one month of severe drought in 1997, the year with the lowest ozone.

The risk of foliar ozone injury to plants at Cuyahoga Valley National Park is high. While the levels of ozone exposure consistently create the potential for injury, months with low soil moisture may reduce the likelihood of injury developing in some years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 or 1999 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under limited drought.

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

EFFIGY MOUNDS NATIONAL MONUMENT (EFMO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Asclepias exaltata</i>	Tall milkweed	Asclepiadaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

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

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

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

	<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 EFMO					
	1995	1996	1997	1998	1999
Sum06	13	8	10	11	15
W126	16.0	13.9	14.4	17.4	22.0
N60	265	203	224	270	365
N80	27	22	13	17	43
N100	2	1	0	0	2

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at EFMO					
	1995	1996	1997	1998	1999
Month 1	5.48	8.66	1.79	-0.09	0.00
Month 2	-0.25	-1.31	-0.14	3.27	0.05
Month 3	0.75	-0.70	-0.49	-1.00	-1.25

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

Palmer Z Index data for the 7-month W126 period at EFMO					
	1995	1996	1997	1998	1999
April	3.16	-0.95	0.19	1.68	2.24
May	5.48	8.66	1.79	-0.09	0.00
June	-0.25	-1.31	-0.14	3.27	0.05
July	0.75	-0.70	-0.49	-1.00	-1.25
August	-0.18	-0.88	1.33	1.09	-0.80
September	0.05	-0.83	-0.76	0.16	-0.04
October	-0.91	-0.71	1.39	4.28	-1.51

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 2 hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture levels were generally normal to high and favored the uptake of ozone. During the five-year W126 assessment period, two years had one month of mild drought each, and one year had two months of mild drought.

The risk of foliar ozone injury at Effigy Mounds National Monument is low. The threshold level for injury is satisfied by the Sum06 index, but the criteria for W126 index are not since the requisite number of hours of exposure to 100 ppm is not attained. The

N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, while exposure to 100 ppb is rare. While soil moisture conditions are generally favorable for the uptake of ozone during most of the growing season, the levels of exposure are low and should be below the threshold for foliar injury.

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

FORT SCOTT NATIONAL HISTORIC SITE (FOSC)

Plant Species Sensitive to Ozone

No ozone-sensitive species are listed for the site.

Representative Ozone Injury Thresholds

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

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

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

	<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 FOSC					
	1995	1996	1997	1998	1999
Sum06	26	19	15	23	21
W126	32	24.7	23.4	31.8	33.1
N60	533	430	383	589	584
N80	101	46	46	64	53
N100	14	4	6	9	3

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FOOSC					
	1995	1996	1997	1998	1999
Month 1	-	-	-	-2.85	-0.43
Month 2	-	-	-	-0.92	-1.01
Month 3	-	-	-	0.94	1.33

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

Palmer Z Index data for the 7-month W126 period at FOOSC					
	1995	1996	1997	1998	1999
April	1.09	-0.70	0.37	0.61	3.43
May	4.08	-1.49	0.86	-2.85	1.65
June	3.54	-0.97	1.63	-0.92	2.89
July	0.72	0.17	0.87	0.94	-0.43
August	1.55	2.28	1.61	-1.68	-1.01
September	-1.44	1.83	0.66	1.51	1.33
October	-2.57	0.32	0.41	4.76	-1.31

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index exceeded the threshold for injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years although concentrations exceeded 100 ppb every year. Thus, both the Sum06 and W126 thresholds are satisfied intermittently at the site.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Relationships between the 90-day Sum06 index of exposure and soil moisture cannot be assessed because moisture data can only be obtained for two of the five years. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The three years with the highest and similar ozone exposures, 1999, 1995 and 1998, each had two months of mild or moderate drought. The two years with the lowest exposures, 1996 and 1997, had one month of mild drought between them.

The risk of foliar ozone injury at Fort Scott National Historic Site is moderate. The threshold for injury is satisfied for the Sum06 index, and is occasionally satisfied for the W126 index. The N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb, with several hours of exposure to 100 ppb each year. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone. While the level of risk under the conditions of exposure is moderate, there are no ozone-sensitive species listed for the site. Until sensitive species are identified either through plant surveys at the site or as a result of further ozone research, the risk of injury remains potential rather than actual.

GEORGE WASHINGTON CARVER NATIONAL MONUMENT (GWCA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

	<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 GWCA					
	1995	1996	1997	1998	1999
Sum06	12	10	6	24	17
W126	31.5	26.2	21.0	33.2	32.3
N60	526	454	347	601	571
N80	82	46	23	62	58
N100	11	3	2	6	4

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GWCA					
	1995	1996	1997	1998	1999
Month 1	2.90	-0.73	0.07	2.67	-1.16
Month 2	-0.99	0.67	1.60	-0.58	-1.28
Month 3	-1.83	-0.84	0.41	0.17	-1.36

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

Palmer Z Index data for the 7-month W126 period at GWCA					
	1995	1996	1997	1998	1999
April	3.39	1.24	-0.87	-0.85	2.15
May	2.72	-0.87	0.46	-1.18	1.18
June	2.90	-0.73	-0.17	-0.52	1.33
July	-0.99	0.67	0.07	2.67	-1.16
August	-1.83	-0.84	1.60	-0.58	-1.28
September	-1.60	3.52	0.41	0.17	-1.36
October	-2.30	0.85	-0.09	1.52	-2.43

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is generally below the required number and thus the criteria for injury are not consistently satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally 80 ppb, and exceeded 100 ppb a few times every year. These levels of exposure can injure vegetation.
- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture status. Soil moisture conditions were favorable in the highest and lowest Sum06 ozone years. The year with the second highest Sum06 exposure, 1999, had three months of mild drought, and a mid-ozone year, 1995, had one month of mild drought. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not fully consistent. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The three years with the highest

ozone exposures, 1998, 1999 and 1995, each had, respectively, one, four and three months of mild or moderate drought stress. The two years with the lowest exposures, 1996 and 1997, both had normal soil moisture levels.

The risk of foliar ozone injury at George Washington Carver National Monument is moderate. The threshold for injury is occasionally satisfied for both the Sum06 and the W126 indices. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and between two and eleven hours of exposure to 100 ppb each year. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

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

HERBERT HOOVER NATIONAL HISTORIC SITE (HEHO)

Plant Species Sensitive to Ozone

<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
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

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

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

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

	<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 HEHO					
	1995	1996	1997	1998	1999
Sum06	10	7	6	8	13
W126	11.3	10.9	10.1	11.9	20.1
N60	176	160	143	174	333
N80	15	15	4	9	35
N100	1	1	0	0	1

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HEHO					
	1995	1996	1997	1998	1999
Month 1	-1.31	-0.71	2.25	-0.90	3.11
Month 2	-0.65	-1.17	-0.63	3.33	-0.24
Month 3	-2.36	-0.96	-2.38	-2.03	0.37

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

Palmer Z Index data for the 7-month W126 period at HEHO					
	1995	1996	1997	1998	1999
April	4.30	-0.95	-1.35	0.56	3.11
May	2.92	7.54	2.25	-0.90	-0.24
June	-1.31	-0.56	-0.63	3.33	0.37
July	-0.65	-0.71	-2.38	-2.03	1.16
August	-2.36	-1.17	0.66	2.26	-0.13
September	-1.62	-0.96	-0.64	0.08	-0.87
October	-1.05	1.24	0.24	5.04	-1.51

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only one year in which concentrations reached 100 ppb, and relatively few hours in which concentrations exceeded 80 ppb. These levels of exposure are unlikely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. The Sum06 indices were low and consistent over the five years. The distribution of the five months of drought over the period is such that no relationship between ozone and soil moisture is apparent. Similarly, here does not appear to be any association between the W126 accumulative index and soil moisture. In 1999 when ozone concentrations were high, there was one month of mild drought. The four

remaining years had similar levels of ozone exposure, and each had one to four months of mild and moderate drought, including two months of drought in 1997, the lowest exposure year.

The levels of ozone exposure at Herbert Hoover National Historic Site make the risk of foliar ozone injury to plants low. The Sum06 index intermittently exceeds the threshold while W126 index does not satisfy the thresholds for injury. The number of hours of exposure greater than 80 ppb is low, and no year had more than one hour of exposure greater than 100 ppb.

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

HOMESTEAD NATIONAL MONUMENT OF AMERICA (HOME)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

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

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

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

	<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 HOME					
	1995	1996	1997	1998	1999
Sum06	11	6	8	8	8
W126	14.9	9.9	12.7	14.0	13.6
N60	225	138	184	220	211
N80	39	14	23	26	21
N100	5	1	3	4	1

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOME					
	1995	1996	1997	1998	1999
Month 1	-1.23	-	-	-	-
Month 2	-0.08	-	-	-	-
Month 3	-0.67	-	-	-	-

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

Palmer Z Index data for the 7-month W126 period at HOME					
	1995	1996	1997	1998	1999
April	1.46	-0.27	1.86	0.85	3.85
May	6.34	6.41	-0.12	-2.62	2.88
June	-1.23	-1.57	0.57	1.58	0.92
July	-0.08	1.39	0.92	3.18	-0.49
August	-0.67	1.47	-0.39	-0.72	-0.96
September	-1.25	0.31	-0.35	-1.20	-1.74
October	-1.23	-0.08	2.28	0.35	-2.45

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 5 hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.
- Relationships between the 90-day Sum06 index of exposure and soil moisture cannot be assessed since only one year of moisture data were obtained. The low and consistent seasonal W126 indices of exposure make it difficult to assess associations between the levels of ozone and soil moisture, however an inverse relationship appears to exist: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The three years with the highest ozone exposures, 1995, 1998 and 1999, each had two or three months of mild and

moderate drought. The two years with the lowest exposures, 1996 and 1997, had one month of mild drought between them.

The risk of foliar ozone injury at Homestead National Monument of America is low. The threshold for injury is exceeded by the Sum06 index, but is not satisfied by the W126 index of exposure. The N-value counts indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposures and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, skunkbush and American elder.

HOPEWELL CULTURE NATIONAL HISTORICAL PARK (HOCU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

	<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 HOCU					
	1995	1996	1997	1998	1999
Sum06	29	23	35	36	29
W126	35.1	31.7	28.2	47.0	48.1
N60	602	525	485	795	808
N80	138	128	91	203	218
N100	19	14	8	35	24

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOCU					
	1995	1996	1997	1998	1999
Month 1	-0.73	1.45	2.53	-0.66	-2.49
Month 2	-1.12	1.86	-0.17	-1.60	-3.22
Month 3	0.52	-0.85	1.27	-2.44	-2.76

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

Palmer Z Index data for the 7-month W126 period at HOCU					
	1995	1996	1997	1998	1999
April	-1.27	0.80	-1.80	2.88	-1.78
May	3.87	4.62	0.25	0.00	-2.49
June	-0.73	1.45	2.53	5.52	-3.22
July	-1.12	1.86	-0.17	-0.66	-2.76
August	0.52	-0.85	1.27	-1.60	0.87
September	-0.67	2.08	-0.99	-2.44	-2.38
October	2.01	0.04	-0.63	0.19	0.06

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone that can produce foliar injury.
- There does not appear to be any association between the 90-day Sum06 index of ozone exposure and soil moisture status. The two years with the highest Sum06 indices, 1998 and 1997, had two months of mild and moderate drought and favorable moisture conditions, respectively. Two mid-ozone years, 1995 and 1999, with the same exposure had three and one month of drought, respectively. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This

relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the two years with the highest ozone indices, 1999 and 1998, there were, respectively, six months of mild to severe drought and two months of mild and moderate drought. The two years with mid-level exposures, 1995 and 1996, had two months of mild drought and normal soil moisture conditions, respectively. There was one month of drought in 1997, the year with the lowest exposure.

The risk of foliar ozone injury to plants at Hopewell Culture National Historic Park is high. While the levels of ozone exposure consistently create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1997 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

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

HOT SPRINGS NATIONAL PARK (HOSP)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Rhus copallina</i>	Flameleaf sumac	Anacardiaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

	<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 HOSP					
	1995	1996	1997	1998	1999
Sum06	21	10	14	24	25
W126	26.4	15.0	22.0	30.6	30.8
N60	464	240	392	558	559
N80	56	20	31	64	82
N100	3	1	1	3	5

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the three months associated with the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for

the site's Sum06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOSP					
	1995	1996	1997	1998	1999
Month 1	-0.63	-0.26	2.27	-2.60	-2.17
Month 2	0.47	2.93	-1.15	-2.27	-1.66
Month 3	-2.09	-0.08	-0.41	-0.86	0.01

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

Palmer Z Index data for the 7-month W126 period at HOSP					
	1995	1996	1997	1998	1999
April	0.40	-0.21	2.85	-1.81	0.69
May	-0.28	-0.28	-0.98	-2.03	-0.75
June	-0.63	-0.26	2.27	-2.60	0.64
July	0.47	2.93	-1.15	-2.27	-1.43
August	-2.09	-0.08	-0.41	-0.86	-2.17
September	-0.90	1.89	-0.44	-0.07	-1.66
October	-0.44	1.68	1.43	1.11	0.01

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 5 hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of

ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1999 and 1998, both show two months of mild and moderate drought. Two years with lower ozone exposures had one month of moderate drought, and the lowest exposure year had favorable conditions throughout. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, there were three and four months, respectively, of mild and moderate drought. The two mid-ozone years, 1995 and 1997, each had one month of mild or moderate drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury at Hot Springs National Park is low. While the threshold for injury is satisfied by the Sum06 index, the W126 criteria are not met. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, but rare exposures to 100 ppb. The inverse relationship between the level of ozone and soil moisture constrains the uptake of ozone and further reduces the likelihood the higher exposures will produce foliar injury.

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

LINCOLN BOYHOOD NATIONAL MEMORIAL (LIBO)

Plant Species Sensitive to Ozone

<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 americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Pinus rigida</i>	Pitch pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

	<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 LIBO					
	1995	1996	1997	1998	1999
Sum06	27	21	19	27	30
W126	39.4	34.3	31.5	42.8	39.0
N60	694	586	545	750	679
N80	154	129	101	159	155
N100	17	11	11	21	17

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at LIBO					
	1995	1996	1997	1998	1999
Month 1	0.56	1.73	2.21	1.30	1.58
Month 2	-0.56	0.75	-1.79	0.29	-0.33
Month 3	0.42	-1.23	0.98	-2.21	-1.88

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

Palmer Z Index data for the 7-month W126 period at LIBO					
	1995	1996	1997	1998	1999
April	1.30	5.86	-0.22	4.15	0.85
May	5.47	2.52	2.19	1.07	-0.97
June	0.56	1.73	2.21	2.70	1.58
July	-0.56	0.75	-1.79	1.30	-0.33
August	0.42	-1.23	0.98	0.29	-1.88
September	-2.20	4.80	-1.36	-2.21	-2.64
October	-1.41	0.65	-1.07	0.82	-0.68

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Soil moisture conditions during the Sum06 accumulation periods showed that one month of mild or moderate drought occurred in four of the five years, and were unrelated to the level of ozone exposure. Both the W126 exposure indices and soil moisture conditions were relatively consistent over the five-year period making it difficult to assess their relationships. The highest ozone year 1998 had one month of moderate drought. Two mid-ozone years, 1995 and 1999, had

similar levels of exposure and each had two months of mild and moderate drought stress. The second lowest year had one month of mild drought, while the lowest year, 1997, had three months of mild drought. There was no apparent relationship between the W126 index of ozone exposure and soil moisture conditions.

The risk of foliar ozone injury to plants at Lincoln Boyhood National Memorial is high. The levels of ozone exposure consistently create the potential for injury, and soil conditions generally favor uptake, although dry conditions can reduce the uptake from one to several months in any particular year. Since the site is subject to potentially harmful levels of ozone annually, the probability of foliar injury developing may be greatest during years such as 1996 and 1998 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

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

OZARK NATIONAL SCENIC RIVERWAYS (OZAR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Aster macrophyllus</i>	Big-leaf aster	Asteraceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<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>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

	<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 OZAR					
	1995	1996	1997	1998	1999
Sum06	17	20	14	21	24
W126	28.7	29.9	23.2	33.6	40.0
N60	472	512	396	585	693
N80	101	92	45	89	140
N100	13	8	4	11	19

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at OZAR					
	1995	1996	1997	1998	1999
Month 1	1.42	-0.47	-0.39	4.88	-1.68
Month 2	0.91	1.11	0.66	-0.79	-0.90
Month 3	-1.48	-1.12	0.29	-1.14	-2.30

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

Palmer Z Index data for the 7-month W126 period at OZAR					
	1995	1996	1997	1998	1999
April	0.30	2.75	-0.20	-0.16	1.91
May	2.96	0.51	1.30	-1.65	-1.22
June	1.42	-0.47	1.13	2.45	-0.24
July	0.91	1.11	-0.39	4.88	-1.68
August	-1.48	-1.12	0.66	-0.79	-0.90
September	-0.82	3.75	0.29	-1.14	-2.30
October	-0.94	0.79	-0.18	0.86	-1.50

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement. The Sum06 and W126 indices both exceed the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 exposure value, 1999, had two months of mild and moderate drought; the lowest ozone year, 1997, had favorable moisture conditions. The intervening years each have one month of mild drought. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the highest ozone years, 1999 and 1998, there were

four and two months, respectively, of mild and moderate drought. The two mid-ozone years, 1996 and 1995, each had one month of mild drought. In the lowest ozone year, 1997, soil moisture conditions were favorable throughout.

The risk of foliar ozone injury to plants at Ozark National Scenic Riverways is high. While the levels of ozone exposure create the potential for injury, the inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. Since the site is subject to potentially harmful levels of ozone in most years, the probability of foliar injury developing may be greatest during years such as 1995 and 1996 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under mild drought and do not significantly constrain the uptake of ozone.

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

PEA RIDGE NATIONAL MILITARY PARK (PERI)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

	<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 PERI					
	1995	1996	1997	1998	1999
Sum06	13	10	7	23	16
W126	29.4	24.6	22.0	35.2	32.5
N60	482	414	365	633	580
N80	64	36	19	60	53
N100	8	2	1	4	4

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PERI					
	1995	1996	1997	1998	1999
Month 1	0.90	-0.82	1.56	-2.42	-1.60
Month 2	0.26	0.09	0.39	-1.33	-1.33
Month 3	-2.66	-0.75	0.12	-1.29	-2.03

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

Palmer Z Index data for the 7-month W126 period at PERI					
	1995	1996	1997	1998	1999
April	2.27	1.00	-0.34	-1.52	0.88
May	0.70	-2.06	-1.11	-1.49	1.08
June	0.90	-0.82	0.13	-2.75	2.41
July	0.26	0.09	0.34	-2.42	-0.77
August	-2.66	-0.75	1.56	-1.33	-1.60
September	-0.21	3.92	0.39	-1.29	-1.33
October	-0.11	-0.39	0.12	0.62	-2.03

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows the required number of hours was met in only one year although concentrations exceeded 100 ppb every year. The Sum06 index generally satisfies while the W126 index does not satisfy the criteria necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. Years generally had 4 or fewer hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the highest Sum06 ozone exposure values, 1998 and 1999, each had three months of mild and moderate drought. The remaining three years with lower

levels of ozone exposure had one month of moderate drought among them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In the two highest ozone years, 1998 and 1999, there were six and three months, respectively, of mild and moderate drought. The three years with lower levels of ozone each had one month of mild or moderate drought.

The risk of foliar ozone injury at Pea Ridge National Military Park is low. The threshold level for injury is satisfied mainly by the Sum06 index, while the criteria for the W126 index are satisfied in only one year. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, with rare exposure to 100 ppb. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone exposure exceeds the thresholds, and soil moisture levels moderately constrain the uptake of ozone.

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

PIPESTONE NATIONAL MONUMENT (PIPE)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Asclepias syriaca</i>	Common milkweed	Asclepiadaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Philadelphus coronarius</i>	Sweet mock-orange	Hydrangeaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

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

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

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

	<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 PIPE					
	1995	1996	1997	1998	1999
Sum06	2	1	2	3	4
W126	11.0	7.0	10.7	12.5	10.2
N60	154	74	151	180	130
N80	22	4	8	11	5
N100	3	0	0	0	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PIPE					
	1995	1996	1997	1998	1999
Month 1	-1.47	1.61	0.14	-0.43	3.06
Month 2	3.09	0.73	-0.27	-2.71	0.32
Month 3	0.31	-0.15	0.76	0.26	0.36

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

Palmer Z Index data for the 7-month W126 period at PIPE					
	1995	1996	1997	1998	1999
April	4.05	-1.74	0.44	-0.43	3.06
May	2.04	1.61	0.14	-2.71	0.32
June	-1.47	0.73	-0.27	0.26	0.36
July	3.09	-0.15	0.76	0.63	-0.36
August	0.31	2.16	-0.46	1.45	-1.04
September	1.36	0.17	-1.55	-3.00	-1.92
October	2.10	1.74	-0.60	3.55	-1.20

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and only one year in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture status. Low levels of Sum06 exposures and only two months of drought over five years make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. The W126 index also shows no relationship with soil moisture. The highest exposure year, 1998, had two months of moderate and severe drought. The three mid-ozone years, 1995, 1997 and 1999, had similar indices of exposure and experienced one, one and three months of mild drought, respectively. The lowest exposure year, 1996, had one month of mild drought.

No association between the W126 levels of ozone and soil moisture is apparent in these observations.

The levels of ozone exposure at Pipestone National Monument make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 criteria are satisfied. While there were some hours with concentrations of ozone above 80 ppb, the numbers were not high and concentrations of 100 ppb are rare.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed and American elder.

TALLGRASS PRAIRIE NATIONAL PRESERVE (TAPR)

Plant Species Sensitive to Ozone

<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
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

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

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

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

	<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 TAPR					
	1995	1996	1997	1998	1999
Sum06	14	12	14	16	17
W126	25.1	20.3	28.8	35.4	28.2
N60	452	393	492	664	498
N80	85	36	52	68	46
N100	11	3	5	8	3

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at TAPR					
	1995	1996	1997	1998	1999
Month 1	0.92	1.87	2.27	-0.02	5.29
Month 2	-0.22	0.96	-1.15	-4.08	1.92
Month 3	0.30	1.07	0.15	0.76	0.88

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

Palmer Z Index data for the 7-month W126 period at TAPR					
	1995	1996	1997	1998	1999
April	0.55	-1.34	1.60	-0.02	5.29
May	7.92	1.87	2.27	-4.08	1.92
June	0.92	0.96	-1.15	0.76	0.88
July	-0.22	1.07	0.15	2.83	-1.72
August	0.30	3.38	0.79	-1.17	-0.94
September	-0.69	0.94	-0.44	2.63	2.84
October	-2.48	0.62	0.52	3.50	-1.63

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years although concentrations exceeded 100 ppb every year. Thus, the criteria for the W126 index are not consistently satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. Concentrations exceeded 100 ppb generally less than 10 times each year. These levels of exposure may possibly injure vegetation.
- Low levels of ozone during the 90-day Sum06 accumulation periods and only two months of drought over five years make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. Soil moisture levels associated with the seasonal W126 index appear inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. In the year with the highest ozone index, 1998, there were two months of mild and severe drought. The two years with the second highest and

similar exposures, 1997 and 1999, had one and two months, respectively, of mild drought. There was one month of drought each year in 1995 and 1996, the years with the lowest exposure indices.

The risk of foliar ozone injury at Tallgrass Prairie National Preserve is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, while the W126 index are satisfied on occasion. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and a few hours of exposure to 100 ppb. The inverse relationship between exposure and soil moisture reduces the likelihood of injury developing in the highest ozone years. The probability of foliar injury developing may be greatest during years such as 1995 when ozone levels are somewhat reduced but still exceed the thresholds, and soil moisture levels are normal or under short-term drought that does not significantly constrain the uptake of ozone.

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

WILSON'S CREEK NATIONAL BATTLEFIELD (WICR)

Plant Species Sensitive to Ozone

<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 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>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Vitis labrusca</i>	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.

	<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 WICR					
	1995	1996	1997	1998	1999
Sum06	18	15	6	18	20
W126	29.3	25.0	15.7	24.7	28.9
N60	501	439	228	427	510
N80	50	38	10	25	41
N100	5	1	1	2	3

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at WICR					
	1995	1996	1997	1998	1999
Month 1	2.90	-0.73	-0.17	2.67	-1.16
Month 2	-0.99	0.67	0.07	-0.58	-1.28
Month 3	-1.83	-0.84	1.60	0.17	-1.36

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

Palmer Z Index data for the 7-month W126 period at WICR					
	1995	1996	1997	1998	1999
April	3.39	1.24	-0.87	-0.85	2.15
May	2.72	-0.87	0.46	-1.18	1.18
June	2.90	-0.73	-0.17	-0.52	1.33
July	-0.99	0.67	0.07	2.67	-1.16
August	-1.83	-0.84	1.60	-0.58	-1.28
September	-1.60	3.52	0.41	0.17	-1.36
October	-2.30	0.85	-0.09	1.52	-2.43

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceed 60 ppb and occasionally exceed 80 ppb. No year had more than 5 hours in which the concentration exceeded 100 ppb. These levels of exposure may possibly injure vegetation.
- Soil moisture levels during both the 90-day Sum06 and the seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure, 1999, has three months of mild drought. The remaining years experienced only one month of mild drought among them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. Soil moisture levels in the two highest ozone years, 1995 and 1999, show three and four months, respectively, of mild to

moderate drought. When the ozone index was slightly lower in 1998 and 1996, there was one month of mild drought and normal soil moisture, respectively. Soil moisture was normal in 1997 when the index was the lowest.

The risk of foliar ozone injury at Wilson's Creek National Battlefield is low. The threshold level for injury is satisfied only by the Sum06 index, the N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and rare exposure to 100 ppb. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone during high exposure years and further reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: common milkweed, redbud, white ash, American sycamore, black cherry, American elder and northern fox grape.