MID-ATLANTIC NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE MID-ATLANTIC NETWORK

October 2004

Objective

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

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

Risk Assessment Methodology

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

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

Ozone-Sensitive Plant Species

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

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

Levels of Ozone Exposure

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

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

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

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

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

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

Soil Moisture Status

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

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

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

Site-Specific Assessment

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

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

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

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

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

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

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 MID-ATLANTIC NETWORK

Park	Code	State	Risk	O3 Data
Appomattox Court House NHP	APCO	VA	moderate	kriged
Booker T. Washington NM	BOWA	VA	moderate	kriged
Eisenhower NHS	EISE	PA	high	kriged
Fredericksburg & Spotsylvania NMP	FRSP	VA	high	kriged
Gettysburg NMP	GETT	PA	high	kriged
Hopewell Furnace NHS	HOFU	PA	high	kriged
Petersburg NB	PETE	VA	moderate	kriged
Richmond NBP	RICH	VA	moderate	kriged
Shenandoah NP	SHEN	VA	moderate	monitored
Valley Forge NHP	VAFO	PA	high	kriged

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

APPOMATTOX COURT HOUSE NATIONAL HISTORIC PARK (APCO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for APCO					
	1995	1996	1997	1998	1999
Sum06	17	16	21	26	30
W126	34.6	27.9	42.1	57.2	41.5
N60	643	523	758	1040	750
N80	77	50	114	212	131
N100	5	4	9	27	9

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was

estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at APCO					
	1995	1996	1997	1998	1999
Month 1	6.78	0.26	-2.18	-0.88	-2.56
Month 2	-0.32	-0.32	0.60	-2.82	-1.22
Month 3	-2.45	1.89	-0.09	-0.71	-1.80

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

Palmer Z Index data for the 7-month W126 period at APCO					
	1995	1996	1997	1998	1999
April	-2.57	-1.21	1.43	1.98	-0.55
May	1.17	1.53	-2.18	2.25	-1.93
June	6.78	0.26	0.60	-0.88	-2.56
July	-0.32	-0.32	-0.09	-2.82	-1.22
August	-2.45	1.89	-1.19	-0.71	-1.80
September	-0.68	7.05	0.42	-2.84	5.84
October	2.76	0.16	-0.62	-2.38	-0.64

Risk Analysis

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

with the highest Sum06 ozone exposure value, 1999, experienced three months of mild and moderate drought. The three intermediate ozone years had one month of moderate drought each, and the year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of moderate drought. The next two lower exposure years, 1997 and 1999, had two and four months of mild and moderate drought, respectively. The second lowest exposure year had two months of moderate drought, and the lowest year had one month of mild drought.

The risk of foliar ozone injury at Appomattox Court House National Historic Park is moderate. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in some years, and considerably reduced exposure in other years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

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

BOOKER T. WASHINGTON NATIONAL MONUMENT (BOWA)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for BOWA					
	1995	1996	1997	1998	1999
Sum06	19	17	23	24	26
W126	35.4	29.1	42.5	60.8	43.5
N60	677	527	769	1089	812
N80	66	51	108	232	137
N100	3	5	6	29	10

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BOWA					
	1995	1996	1997	1998	1999
Month 1	-0.32	1.53	0.60	-2.82	-2.56
Month 2	-2.45	0.26	-0.09	-0.71	-1.22
Month 3	-0.68	-0.32	-1.19	-2.84	-1.80

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

Palmer Z Index data for the 7-month W126 period at BOWA					
	1995	1996	1997	1998	1999
April	-2.57	-1.21	1.43	1.98	-0.55
May	1.17	1.53	-2.18	2.25	-1.93
June	6.78	0.26	0.60	-0.88	-2.56
July	-0.32	-0.32	-0.09	-2.82	-1.22
August	-2.45	1.89	-1.19	-0.71	-1.80
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October	2.76	0.16	-0.62	-2.38	-0.64

Risk Analysis

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

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

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

- Soil moisture levels during both the 90-day Sum06 and seasonal W126 accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, experienced three months of mild and moderate drought. The year with the lowest ozone exposure, 1996, had favorable soil moisture conditions. The three intermediate ozone years had one or

two months of mild and moderate drought each. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, although the pattern is not consistent. In the highest ozone year, 1998, there were three months of moderate drought. The three intermediate ozone years, 1997, 1999 and 1995, had two to four months of mild and moderate drought. In the lowest ozone year, 1996, there was one month of mild drought.

The risk of foliar ozone injury at Booker T. Washington National Monument is moderate. The threshold level for injury is consistently satisfied by the Sum06 index, and intermittently by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in some years, and considerably reduced levels of exposure in other years. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood that the exposures will produce foliar injury. The probability of foliar injury developing may be greatest during years such as 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

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

EISENHOWER NATIONAL HISTORIC SITE (EISE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Prunus serotina	Black cherry	Rosaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

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Ozone air quality data for EISE					
	1995	1996	1997	1998	1999
Sum06	20	20	25	32	33
W126	39.5	32.1	44.2	59.4	48.5
N60	651	573	749	1007	812
N80	168	87	160	270	199
N100	23	6	21	32	23

Soil Moisture Status

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

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Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

- Soil moisture levels associated with both the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1999, had three months of moderate drought. The three intermediate years covered a wide range of exposure values, but each had only one month of drought. The lowest exposure year, 1996, had favorable conditions. Soil moisture levels associated with the W126 index also appear inversely related to ozone exposure, and the pattern is again not consistent.

The highest ozone year, 1998, experienced one month of moderate drought. The next two highest ozone years, 1999 and 1997, had similar levels of exposure and three months of mild and moderate drought each. There were two months of drought in the second lowest year, and the lowest ozone year, 1996, had favorable soil moisture conditions.

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

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

FREDERICKSBURG & SPOTSYLVANIA NATIONAL MILITARY PARK (FRSP)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for FRSP					
	1995	1996	1997	1998	1999
Sum06	24	26	30	37	38
W126	34.7	31.0	38.6	49.1	46.6
N60	613	567	660	831	777
N80	121	79	141	212	215
N100	16	3	17	36	26

Soil Moisture Status

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

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

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

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at FRSP					
	1995	1996	1997	1998	1999
Month 1	0.11	-0.73	-0.02	-2.74	-1.80
Month 2	-2.62	1.51	0.79	-2.87	-0.95
Month 3	-0.54	0.72	-1.63	-2.28	-1.34

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

Palmer Z Index data for the 7-month W126 period at FRSP					
	1995	1996	1997	1998	1999
April	-1.62	-0.63	1.01	1.37	-0.75
May	1.57	0.66	-2.03	0.29	-1.51
June	3.93	-0.73	-0.02	0.24	-1.80
July	0.11	1.51	0.79	-2.74	-0.95
August	-2.62	0.72	-1.63	-2.87	-1.34
September	-0.54	3.99	-0.88	-2.28	7.71
October	3.44	2.23	-0.19	-2.46	-0.22

Risk Analysis

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

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

The risk of foliar ozone injury at Fredericksburg and Spotsylvania National Military Park is high. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are significant exposures to concentrations of ozone greater than 80 and 100 ppb in most years, and considerably reduced exposure in others. The inverse relationship between ozone exposure and soil moisture constrains the uptake of ozone at higher exposures and reduces the likelihood the exposures will produce foliar injury. Annual variations in ozone exposure and soil moisture interact to create highly variable levels of risk. The probability of foliar injury developing is greatest during years such as 1995 and 1997 when ozone levels exceed thresholds, and soil moisture levels do not place long-term constrains on the uptake of ozone.

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

GETTYSBURG NATIONAL MILITARY PARK (GETT)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

HOPEWELL FURNACE NATIONAL HISTORIC SITE (HOFU)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for HOFU					
	1995	1996	1997	1998	1999
Sum06	29	25	28	29	32
W126	34.6	28.1	34.5	42.5	41.1
N60	556	485	524	686	647
N80	173	106	170	215	206
N100	36	13	38	28	45

Soil Moisture Status

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

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

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

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at HOFU					
	1995	1996	1997	1998	1999
Month 1	-1.51	1.51	-1.33	-1.18	-2.41
Month 2	0.10	3.68	-0.12	-1.24	-4.16
Month 3	-3.35	0.21	-0.50	-2.27	-0.58

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

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

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value and the N100 count are significantly greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for concentrations of 60, 80, and 100 ppb are all elevated and show there are a significant number of hours during which plants are exposed to levels of ozone likely to produce foliar injury.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day

accumulation periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, but the pattern in not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The year with the highest Sum06 ozone exposure value experienced two months of mild and severe drought. The two years with the same, second highest exposure, 1995 and 1998, had two months of mild and severe and three months of mild and moderate drought, respectively. The year with the second lowest exposure, 1997, had one month of mild drought, and the lowest exposure year, 1996, had favorable soil moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear to be inversely related to ozone exposure. The two years with the highest exposure levels, 1998 and 1999, experienced three sequential months of mild and moderate drought. The two intermediate ozone years, 1995 and 1997, had three months of intermittent mild or severe drought, while the lowest ozone year, 1996, had favorable soil moisture conditions throughout.

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

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

PETERSBURG NATIONAL BATTLEFIELD (PETE)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for PETE					
	1995	1996	1997	1998	1999
Sum06	25	24	35	38	35
W126	32.6	28.5	44.0	48.7	42.6
N60	570	514	745	843	711
N80	97	65	174	187	180
N100	11	3	24	27	26

Soil Moisture Status

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

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

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

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PETE					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

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

Palmer Z Index data for the 7-month W126 period at PETE					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours almost every year. These levels of exposure can injure vegetation.
- Ozone exposure levels for the 90-day Sum06 accumulation periods were high and relatively uniform over the five years, and soil moisture conditions showed scattered months of mild to severe drought stress. There was no apparent

association between the Sum06 index of ozone exposure and soil moisture. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone year, 1998, there were four months of mild and moderate drought. The two next highest ozone years, 1997 and 1999, had four and two months of mild and moderate drought, respectively. The lowest ozone year had favorable conditions, but the second lowest year, 1995, had three months of mild and severe drought.

The risk of foliar ozone injury to plants at Petersburg National Battlefield is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The generally inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. However, years such as 1999, in which high levels of exposure occur under conditions of less severe drought, may have the potential to produce foliar injury. The probability of foliar injury developing may greatest during years such as this when ozone levels are elevated, and soil moisture levels are under mild drought and do not create a long-term constraint on the uptake of ozone.

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

RICHMOND NATIONAL BATTLEFIELD PARK (RICH)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Pinus virginiana	Virginia pine	Pinaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Verbesina occidentalis	Crownbeard	Asteraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for RICH					
	1995	1996	1997	1998	1999
Sum06	26	27	36	40	37
W126	33.9	29.9	44.3	50.6	44.8
N60	588	540	739	860	743
N80	111	74	183	209	201
N100	13	3	26	34	31

Soil Moisture Status

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

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

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

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at RICH					
	1995	1996	1997	1998	1999
Month 1	0.65	1.68	-1.25	0.99	-1.18
Month 2	-1.60	4.40	0.98	0.04	-0.87
Month 3	-3.52	1.67	-2.69	-2.05	-0.97

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

Palmer Z Index data for the 7-month W126 period at RICH					
	1995	1996	1997	1998	1999
April	-1.31	0.58	1.17	0.53	-0.26
May	0.63	0.55	-1.61	0.99	-2.33
June	0.65	1.68	-1.25	0.04	-1.18
July	-1.60	4.40	0.98	-2.05	-0.87
August	-3.52	1.67	-2.69	-2.06	-0.97
September	-0.40	1.93	-2.29	-1.42	4.84
October	1.69	3.11	0.28	-2.31	3.15

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours almost every year. These levels of exposure can injure vegetation.
- There was no apparent association between the 90-day Sum06 index of ozone exposure and soil moisture. Ozone exposure levels for the Sum06 accumulation periods varied moderately among the five years, and soil moisture conditions

showed scattered months of mild to severe drought stress. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone year, 1998, there were four months of mild and moderate drought. The two next highest ozone years, 1997 and 1999, had four and two months of mild and moderate drought, respectively. The lowest ozone year had favorable conditions, but the second lowest year, 1995, had three months of mild and severe drought.

The risk of foliar ozone injury to plants at Richmond National Battlefield Park is moderate. The Sum06 threshold for injury is consistently satisfied, and the W126 index criteria are generally fulfilled. The N80 and N100 counts are high, but significantly lower in one year. The generally inverse relationship between ozone exposure and soil moisture is a significant factor affecting the potential for injury at the site. The years in which exposures exceed the injury thresholds are also ones in which there are two to four months of mild to severe drought. These moisture conditions constrain the uptake of ozone and reduce the likelihood that the exposures will produce foliar injury. However, years such as 1999, in which high levels of exposure occur under conditions of less extensive drought, have the greatest potential to produce foliar injury. The probability of injury developing may greatest during years when ozone levels are elevated, and soil moisture levels are under limited drought and do not produce long-term constraints on the uptake of ozone.

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

SHENANDOAH NATIONAL PARK (SHEN)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

VALLEY FORGE NATIONAL HISTORIC PARK (VAFO)

Plant Species Sensitive to Ozone

Latin Name	*Common Name*	*Family*
Ailanthus altissima	Tree-of-heaven	Simaroubaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Cercis canadensis	Redbud	Fabaceae
Fraxinus americana	White ash	Oleaceae
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Philadelphus coronarius	Sweet mock-orange	Hydrangeaceae
Platanus occidentalis	American sycamore	Platanaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Robinia pseudoacacia	Black locust	Fabaceae
Rubus allegheniensis	Allegheny blackberry	Rosaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Vitis labrusca	Northern fox grape	Vitaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for VAFO					
	1995	1996	1997	1998	1999
Sum06	31	26	27	29	32
W126	35.8	28.8	34.0	41.5	40.7
N60	574	498	512	670	633
N80	187	122	170	211	209
N100	44	17	39	30	52

Soil Moisture Status

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

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

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

the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to –4.0 (extreme drought) with ±0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VAFO					
	1995	1996	1997	1998	1999
Month 1	-1.51	1.51	-1.33	-1.18	-2.41
Month 2	0.10	3.68	-0.12	-1.24	-4.16
Month 3	-3.35	0.21	-0.50	-2.27	-0.58

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

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

Risk Analysis

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

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

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

- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day periods appear to be inversely related to ozone concentrations: when ozone is high, soil

moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the three highest ozone exposure values, 1999, 1995 and 1998, experienced two, two and three months of mild to severe drought, respectively. The two years with the lowest ozone exposure, 1996 and 1997, had one month of mild drought between them. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. In each of the two highest ozone years, 1998 and 1999, there were three consecutive months of mild to severe drought. The two mid-level ozone years, 1995 and 1997, had three interspersed months of mild to severe drought. In the lowest ozone year, 1996, soil moisture conditions were favorable throughout.

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

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