APPALACHIAN NATIONAL SCENIC TRAIL (APPL)

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

Objective

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

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

Risk Assessment Methodology

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

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

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

Appalachian National Scenic Trail Assessment Sites and Data Availability

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

Ozone-Sensitive Plant Species

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

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

Levels of Ozone Exposure

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

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

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

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

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

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

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

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

Soil Moisture Status

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

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

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

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

Site-Specific Assessment

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

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

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

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

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

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

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

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 SITES ALONG THE APPALACHIAN NATIONAL SCENIC TRAIL

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

GEORGIA

Dawsonville, Dawson County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

Great Smokey Mountains National Park (GRSM)

Plant Species Sensitive to Ozone

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

Sambucus canadensis	American elder	Caprifoliaceae
Verbesina occidentalis	Crownbeard	Asteraceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Lookout Rock

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

Cade's Cove

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

Cove Mountain

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

Clingman's Dome

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

NORTH CAROLINA

Bryson City, Swain County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

Mount Mitchell, Yancey County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

Lenoir, Caldwell County

Plant Species Sensitive to Ozone

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

Robinia pseudoacacia	Black locust	Fabaceae
Sassafras albidum	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

TENNESSEE

Kingsport, Sullivan County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

Blountville, Sullivan County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

moisture status and its change throughout the growing season.

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

VIRGINIA

Rural Retreat, Wythe County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

WEST VIRGINIA

Bluestone National Scenic River (BLUE)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

VIRGINIA

Vinton, Roanoke County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

Glenwood-Pedlar Ranger District, Rockbridge County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

Shenandoah National Park (SHEN)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

Rest, Frederick County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

WEST VIRGINIA

Harpers Ferry National Historical Park (HAFE)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

MARYLAND

Catoctin Mountain Park (CATO)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

PENNSYLVANIA

Gettysburg National Military Park
(GETT)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

Little Buffalo State Park, Perry County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

Kutztown University, Berks County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

moisture status and its change throughout the growing season.

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

Kunkletown, Monroe County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

Delaware Water Gap National Recreation Area (DEWA)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

of exposure can injure vegetation.

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

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

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

NEW YORK

Montgomery, Orange County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

Roosevelt-Vanderbilt Headquarters (ROVA)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

CONNECTICUT

Torrington, Litchfield County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

MASSACHUSETTS

Mount Greylock Summit, Berkshire County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

observations.

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

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

VERMONT

Bennington, Bennington County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

Marsh-Billings National Historic Park (MABI)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

Saint-Gaudens National Historic Site (SAGA)

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

NEW HAMPSHIRE

Haverhill, Grafton County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

Mount Washington, Coos County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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

MAINE

Greenville, Piscataquis County

Plant Species Sensitive to Ozone

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

Representative Ozone Injury Thresholds

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

Natural Ecosystems	8 - 12 ppm-hr	(foliar injury)
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Crops	15 - 20 ppm-hr	(10% reduction in 25-35% of crops)

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

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

Ozone Exposure Data

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

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

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

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

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

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

Risk Analysis

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

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

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

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

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

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

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