

SOUTHERN COLORADO PLATEAU NETWORK

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

October 2004

Objective

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

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

Risk Assessment Methodology

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

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

Ozone-Sensitive Plant Species

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

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

Levels of Ozone Exposure

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

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

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

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

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

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

Soil Moisture Status

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

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

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

Site-Specific Assessment

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

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

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

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

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

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

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE SOUTHERN COLORADO PLATEAU NETWORK

Park	Code	State	Risk	O3 Data
Aztec Ruins NM	AZRU	NM	low	kriged
Bandelier NM	BAND	NM	low	kriged
Canyon de Chelly NM	CACH	AZ	low	kriged
Chaco Culture NHP	CHCU	NM	low	kriged
El Malpais NM	ELMA	NM	low	kriged
El Morro NM	ELMO	NM	low	kriged
Glen Canyon NRA	GLCA	UT	low	kriged
Grand Canyon NP	GRCA	AZ	low	monitored
Hubbell Trading Post NHS	HUTR	AZ	low	kriged
Mesa Verde NP	MEVE	CO	low	monitored
Navajo NM	NAVA	AZ	low	kriged
Petrified Forest NP	PEFO	AZ	moderate	kriged
Petroglyph NM	PETR	NM	low	kriged
Rainbow Bridge NM	RABR	UT	low	kriged
Salinas Pueblo Missions NM	SAPU	NM	low	kriged
Sunset Crater Volcano NM	SUCR	AZ	moderate	kriged
Walnut Canyon NM	WACA	AZ	moderate	kriged
Wupatki NM	WUPA	AZ	moderate	kriged
Yucca House NM	YUHO	CO	low	kriged

AZTEC RUINS NATIONAL MONUMENT (AZRU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for AZRU					
	1995	1996	1997	1998	1999
Sum06	6	15	8	10	16
W126	18.5	25.0	15.2	30.5	28.4
N60	171	345	184	518	423
N80	3	5	1	4	5
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, 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 AZRU					
	1995	1996	1997	1998	1999
Month 1	0.44	-4.19	2.31	-0.26	1.18
Month 2	-1.72	-0.70	1.86	-0.25	-0.21
Month 3	0.12	-1.79	1.42	3.53	3.55

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

Palmer Z Index data for the 7-month W126 period at AZRU					
	1995	1996	1997	1998	1999
April	1.87	-1.81	3.08	1.25	1.63
May	2.07	-4.19	1.19	-0.26	1.18
June	0.44	-0.70	2.31	-0.25	-0.21
July	-1.72	-1.79	1.86	3.53	3.55
August	0.12	-1.34	1.42	-0.52	5.05
September	0.47	1.98	2.06	-1.65	0.39
October	-2.43	1.40	-0.30	5.08	-2.51

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. 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 concentration greater than 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. Soil moisture conditions in the two years with the highest exposures, 1999 and 1996, were favorable and two months of mild and severe drought, respectively. The three years with lower levels of exposure had one month of mild drought among them. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The highest and second highest ozone years, 1998 and 1999, each had one month of mild or moderate drought. The mid-level ozone year 1996 had four months of mild and severe drought. There were two months of mild and moderate drought

in 1995, the year with the second lowest exposure, and soil moisture conditions were normal in 1997, the year with the lowest exposure.

The risk of foliar ozone injury to plants at Aztec Ruins National Monument is low. While the Sum06 exposures exceed the threshold levels for injury, the W126 do not since the N100 criterion is not satisfied. Hourly concentrations of ozone seldom exceed 80 ppb, and do not exceed 100 ppb. It is unlikely that these levels of exposure will produce foliar injury on plants.

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 skunkbush as a bioindicator.

BANDELIER NATIONAL MONUMENT (BAND)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	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. Index is in cumulative ppm-hr.

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

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

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

Ozone Exposure Data

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

Ozone air quality data for BAND					
	1995	1996	1997	1998	1999
Sum06	10	19	12	18	17
W126	17.8	23.8	18.9	25.4	26.6
N60	240	391	285	443	436
N80	17	12	9	14	21
N100	1	0	0	0	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BAND					
	1995	1996	1997	1998	1999
Month 1	0.30	-4.72	0.50	2.93	2.21
Month 2	2.14	0.53	1.76	-0.04	2.20
Month 3	4.26	0.20	0.40	-1.77	3.52

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

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

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value 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 one hour in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and similar levels of ozone exposure and the scarcity of drought. One month of severe and mild drought occurred in each of the two highest ozone years, 1996 and 1998, and soil moisture was normal in the other 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 highest ozone year, 1999, there was

one month of mild drought, while the second highest ozone year, 1998, had three months of mild and moderate and drought. The mid-level exposure year 1996 had two months of moderate and severe drought. The lowest ozone year, 1995, had one month of moderate drought while the second lowest year, 1997, had normal soil moisture.

The risk of foliar injury to plants at Bandelier National Monument is low. While the Sum06 exposure index is satisfied, the W126 index is not because the N100 criterion is not fulfilled. The number of hours of exposure greater than 80 ppb is low, and only one hour of exposure greater than 100 ppb occurred during the five-year period. The inverse relationship between exposure and soil moisture constrains the uptake of ozone at higher exposures and further reduces the likelihood of foliar injury.

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

CANYON DE CHELLEY NATIONAL MONUMENT (CACH)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Rudbeckia laciniata	Cut-leaf coneflower	Asteraceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
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	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

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

Ozone air quality data for CACH					
	1995	1996	1997	1998	1999
Sum06	8	17	11	17	20
W126	22.1	27.9	19.4	34.5	32.8
N60	253	428	269	616	540
N80	9	9	8	16	19
N100	1	0	0	0	0

Soil Moisture Status

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

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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 CACH					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	-3.23	1.25	-1.25
Month 2	-0.85	-3.23	-1.22	0.96	-1.53
Month 3	0.27	-1.22	-2.54	2.34	4.49

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

Palmer Z Index data for the 7-month W126 period at CACH					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and one year in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or the seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 exposure year, 1999, had two months of mild drought. The two years with the same second-highest exposure index, 1996 and 1998, had three months of mild and severe drought and normal moisture conditions, respectively. In 1997, the mid-level exposure year, there were three months of mild to severe drought. Soil moisture was normal in 1995, the year with the lowest exposure. Soil moisture levels associated with the W126 index also appear to be unrelated to ozone exposure levels. In the highest ozone year, 1998, there was one month of moderate drought, while the second highest ozone year, 1999, had three months

of mild and moderate drought. The mid-level exposure year, 1996, had five months of mild to severe drought. The two lowest ozone years, 1995 and 1997, each had one month of mild or moderate drought.

The risk of foliar ozone injury to plants at Canyon de Chelley National Monument is low. While the Sum06 exposures exceeded the threshold level for injury, the W126 did not since the N100 criteria were not satisfied. There are only a few hours of exposure to 80 ppb each year, and exposure to 100 ppb is rare. Although levels of exposure and drought are not associated, months of mild to severe drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: ponderosa pine, quaking aspen, skunkbush, and cut-leaf coneflower.

CHACO CULTURE NATIONAL HISTORIC PARK (CHCU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for CHCU					
	1995	1996	1997	1998	1999
Sum06	5	10	9	12	10
W126	17.8	23.8	17.6	27.5	26.3
N60	209	365	249	477	410
N80	10	9	6	9	13
N100	0	0	0	0	0

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the 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 CHCU					
	1995	1996	1997	1998	1999
Month 1	0.44	-4.19	2.31	-0.26	1.18
Month 2	-1.72	-0.70	1.86	-0.25	-0.21
Month 3	0.12	-1.79	1.42	3.53	3.55

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

Palmer Z Index data for the 7-month W126 period at CHCU					
	1995	1996	1997	1998	1999
April	1.87	-1.81	3.08	1.25	1.63
May	2.07	-4.19	1.19	-0.26	1.18
June	0.44	-0.70	2.31	-0.25	-0.21
July	-1.72	-1.79	1.86	3.53	3.55
August	0.12	-1.34	1.42	-0.52	5.05
September	0.47	1.98	2.06	-1.65	0.39
October	-2.43	1.40	-0.30	5.08	-2.51

Risk Analysis

- There are a few ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and uniform level of ozone exposure and the scarcity of drought. The highest ozone year, 1998, had normal soil moisture, while the lowest ozone year, 1995, had one month of mild drought. The other three years had two months of drought stress among them. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, had one month of mild and one month of moderate drought, while the two lowest ozone years, 1995 and 1997, experienced two months of mild and moderate drought and

normal moisture conditions, respectively. The intermediate ozone year 1996 had four months of mild to severe drought.

The low levels of ozone exposure at Chaco Culture Historic Park make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for foliar injury, but the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and no exposures greater than 100 ppb occur during the five-year period. Low soil moisture levels occur independently of the level of ozone exposure, and scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

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

EL MALPAIS NATIONAL MONUMENT (ELMA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for ELMA					
	1995	1996	1997	1998	1999
Sum06	9	16	11	17	14
W126	17.0	23.1	19.0	26.1	25.5
N60	228	373	285	462	414
N80	12	11	9	12	18
N100	0	0	0	0	0

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the 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 ELMA					
	1995	1996	1997	1998	1999
Month 1	0.57	-3.37	0.29	-0.20	-1.31
Month 2	-1.25	0.61	1.98	-0.62	-0.38
Month 3	0.30	1.10	0.35	4.66	3.48

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

Palmer Z Index data for the 7-month W126 period at ELMA					
	1995	1996	1997	1998	1999
April	0.16	-2.92	0.29	1.15	-0.73
May	0.87	-3.37	1.98	-0.20	-1.31
June	0.57	0.61	0.35	-0.62	-0.38
July	-1.25	1.10	1.78	4.66	3.48
August	0.30	0.76	-0.77	-0.99	3.67
September	0.30	1.78	2.99	-2.52	1.95
October	-2.63	3.22	0.09	3.15	-2.62

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 never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and uniform level of ozone exposure and the scarcity of drought. Three months of mild or severe drought occurred over the five-year period independent of the level of ozone, and soil moisture was generally normal. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. Four years each had one or two months of mild to moderate drought that occurred without any relationship to the level of ozone. One year had normal levels of soil moisture throughout.

The low levels of ozone exposure at El Malpais National Monument make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for foliar injury, but the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there are no hours of exposure greater than 100 ppb. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

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

EL MORRO NATIONAL MONUMENT (ELMO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for ELMO					
	1995	1996	1997	1998	1999
Sum06	8	15	11	16	14
W126	17.7	23.4	19.0	26.8	26.0
N60	232	374	285	473	420
N80	12	11	9	12	18
N100	1	0	0	0	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at ELMO					
	1995	1996	1997	1998	1999
Month 1	0.57	-3.37	0.29	-0.20	-1.31
Month 2	-1.25	0.61	1.98	-0.62	-0.38
Month 3	0.30	1.10	0.35	4.66	3.48

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

Palmer Z Index data for the 7-month W126 period at ELMO					
	1995	1996	1997	1998	1999
April	0.16	-2.92	0.29	1.15	-0.73
May	0.87	-3.37	1.98	-0.20	-1.31
June	0.57	0.61	0.35	-0.62	-0.38
July	-1.25	1.10	1.78	4.66	3.48
August	0.30	0.76	-0.77	-0.99	3.67
September	0.30	1.78	2.99	-2.52	1.95
October	-2.63	3.22	0.09	3.15	-2.62

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone reached 100 ppb on only one occasion, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and only one year in which concentration reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture because of the low and uniform level of ozone exposure and the scarcity of drought. Three months of mild or severe drought occurred over the five-year period independent of the level of ozone, and soil moisture was generally normal. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. Four years had one or two months of mild to moderate drought that occurred without any relationship to the level of ozone. One year had normal levels of soil moisture throughout.

The low levels of ozone exposure at El Morro National Monument make the risk of foliar ozone injury to plants low. The Sum06 index meets the criteria for foliar injury, but the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there is only one hour of exposure greater than 100 ppb. Scattered months of drought constrain the uptake of ozone and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: ponderosa pine and skunkbush

GLEN CANYON NATIONAL RECREATION AREA (GLCA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Oenothera elata</i>	Evening primrose	Onagraceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix goodingii</i>	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for GLCA					
	1995	1996	1997	1998	1999
Sum06	5	13	10	16	16
W126	28.0	40.1	26.4	46.5	41.3
N60	340	711	388	868	732
N80	11	25	7	29	23
N100	1	1	0	3	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, 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 GLCA					
	1995	1996	1997	1998	1999
Month 1	2.67	-2.18	0.76	0.39	2.28
Month 2	0.85	-1.90	1.31	-1.53	-0.77
Month 3	0.62	-2.50	1.75	-1.32	-0.64

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

Palmer Z Index data for the 7-month W126 period at GLCA					
	1995	1996	1997	1998	1999
April	1.97	-1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels associated with the 90-day Sum06 and seasonal W126 accumulation period levels of ozone appear to be inversely related to soil moisture, when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The two highest Sum06 ozone years, 1998 and 1999, experienced two months of mild drought and normal soil moisture, respectively. The mid-level exposure year 1996 had three months of mild and moderate drought, and the two lowest exposure years both had normal soil moisture. Soil moisture levels associated with the W126 index also appear

inversely related to ozone concentrations, but the pattern is again not consistent. In the three years with the highest levels of ozone, 1998, 1999, and 1996, there were three months of mild to moderate drought, one month of mild drought, and five months of mild to severe drought, respectively. The two lowest ozone years, 1997 and 1995, had normal moisture conditions and one month of mild drought, respectively.

The low levels of ozone exposure at Glen Canyon National Recreation Area make the risk of foliar ozone injury to plants low. While the Sum06 index generally meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and further reduces the likelihood of foliar injury.

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

GRAND CANYON NATIONAL PARK (GRCA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix goodingii</i>	Gooding's willow	Salicaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

Ambient concentrations of ozone 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).

	1995	1996	1997	1998	1999
Sum06	19	27	21	28	31
W126	47.2	47.5	38.8	52.5	51.2
N60	733	772	623	980	902
N80	0	8	0	0	18
N100	0	0	0	0	0

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the 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 GRCA					
	1995	1996	1997	1998	1999
Month 1	1.86	-3.96	0.06	1.25	-1.25
Month 2	1.32	-3.23	0.28	0.96	-1.53
Month 3	2.00	-1.22	-1.17	2.34	4.49

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

Palmer Z Index data for the 7-month W126 period at GRCA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index significantly exceeds the threshold for foliar injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- There are no associations between either the 90-day Sum06 or the seasonal W126 accumulation period levels of ozone and soil moisture conditions. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought. The second highest year, 1998, and the lowest ozone year, 1995, both had favorable conditions. The two intermediate years, 1996 and 1997, had three months of moderate and severe drought and one month of mild drought, respectively. Similarly, there is no pattern of association between the seasonal W126 index of exposure and soil moisture conditions. The highest, 1998, and the second highest, 1998, ozone years had one month of mild drought and three months of mild and moderate drought. Two years with the same mid-level of ozone, 1995 and 1996, experienced one month of mild drought and five months of mild to severe drought, respectively. The lowest ozone year 1997 had one month of mild drought.

The low levels of ozone exposure at Grand Canyon National Park make the risk of foliar ozone injury to plants low. The W126 criteria are not satisfied, and there are only a few hours above 80 ppb and none above 100 ppb. Months of moderate and severe drought constrain the uptake of ozone in some years and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, spreading dogbane, ponderosa pine, quaking aspen, skunkbush, and Scouler's willow.

HUBBELL TRADING POST NATIONAL HISTORIC SITE (HUTR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for HUTR					
	1995	1996	1997	1998	1999
Sum06	12	21	13	20	26
W126	25.8	30.1	23.7	42	40.9
N60	352	483	362	780	736
N80	32	30	21	51	46
N100	5	3	1	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, 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 HUTR					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	0.28	1.25	-1.25
Month 2	-0.85	-3.23	-1.17	0.96	-1.53
Month 3	0.27	-1.22	1.38	2.34	4.49

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

Palmer Z Index data for the 7-month W126 period at HUTR					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- No clear relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. The highest ozone year, 1999, experienced two months of mild drought. The two mid-level years, 1996 and 1998, had similar levels of exposure and experienced three months of mild and severe drought and normal soil moisture, respectively. The second lowest exposure year, 1997, had one month of mild drought, and the lowest year, 1995, had normal soil moisture. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced one month and two months of mild and one or moderate drought, while the three lowest ozone years, 1997 and 1995, had one month of

mild or moderate drought each. The year with mid-level ozone had five months of mild to severe drought.

The low levels of ozone exposure at Hubbell Trading Post National Historic Site make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. Soil moisture levels are variable, and months of drought constrain the uptake of ozone by plants and further reduce the likelihood of foliar injury. There are no bioindicator species at the site.

MESA VERDE NATIONAL PARK (MEVE)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

Ambient concentrations of ozone 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 MEVE					
	1995	1996	1997	1998	1999
Sum06	6	13	2	15	19
W126	26.1	29.7	13.9	33.5	37.5
N60	182	349	92	507	543
N80	0	0	0	0	0
N100	0	0	0	0	0

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the 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 MEVE					
	1995	1996	1997	1998	1999
Month 1	1.56	-0.39	1.98	-1.94	3.13
Month 2	5.61	-1.24	1.09	0.30	1.46
Month 3	2.71	0.26	0.70	1.69	1.00

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

Palmer Z Index data for the 7-month W126 period at MEVE					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show no years in which concentrations reached either 80 or 100 ppb. These levels of exposure are not likely to injure vegetation.
- There are no associations between the 90-day Sum06 accumulation period levels of ozone and soil moisture conditions. There were only two months of mild drought stress over the five-year period, and soil moisture was generally normal. 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. The highest ozone year, 1999, had one month of moderate drought, and the next two years, 1998 and 1996, each had three months of mild and mild to moderate drought, respectively. The two lowest ozone years had favorable conditions and one month of mild drought.

The low levels of ozone exposure at Mesa Verde National Park make the risk of foliar ozone injury to plants low. The W126 criteria are not satisfied, and there are no hours above 80 ppb and 100 ppb. Months of drought constrain the uptake of ozone in higher exposure years and further reduce the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, ponderosa pine, quaking aspen, and skunkbush.

NAVAJO NATIONAL MONUMENT (NAVA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Oenothera elata	Evening primrose	Onagraceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for NAVA					
	1995	1996	1997	1998	1999
Sum06	5	10	10	15	17
W126	33.2	41.0	29.9	53.7	51.2
N60	457	709	473	1023	952
N80	33	39	18	53	46
N100	5	3	1	2	1

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, 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 NAVA					
	1995	1996	1997	1998	1999
Month 1	2.00	-3.96	0.06	1.25	1.47
Month 2	2.08	-3.23	0.28	0.96	-1.25
Month 3	-0.85	-1.22	-1.17	2.34	-1.53

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

Palmer Z Index data for the 7-month W126 period at NAVA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than five hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The two highest ozone years, 1999 and 1998, experienced, respectively, two months of mild drought and normal soil moisture. One year with mid-level ozone had three months of mild and severe drought, while the other year had one month of mild drought. The lowest ozone year, 1995, had normal soil moisture. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced one month of mild drought and three months of mild and moderate drought, respectively, while

the two lowest ozone years, 1997 and 1995, had one month of mild or moderate drought each. The year with mid-level ozone, 1996, had five months of mild to severe drought.

The low levels of ozone exposure at Navajo National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index generally exceeds the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. Soil moisture is variable among years, and months of drought constrain the uptake of ozone by plants and further reduce the likelihood of foliar injury.

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

PETRIFIED FOREST NATIONAL PARK (PEFO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix gooddingii</i>	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for PEFO					
	1995	1996	1997	1998	1999
Sum06	22	27	19	32	39
W126	34.6	36.5	34.2	56.2	55.9
N60	565	633	593	1080	1091
N80	87	84	68	123	100
N100	14	9	5	5	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 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 PEFO					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	0.06	0.96	-2.92
Month 2	-0.85	-3.23	0.28	2.34	1.47
Month 3	0.27	-1.22	-1.17	-1.82	-1.25

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

Palmer Z Index data for the 7-month W126 period at PEFO					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for concentrations of 80 and 100 ppb are variable with counts high in some years and significantly lower in others. In some years, the levels of exposure could injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought, while the two mid-level years, 1998 and 1996, had one month of mild drought and three months of mild and severe drought, respectively. The lowest ozone years, 1995 and 1997, had normal soil moisture and one month of mild drought. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced one month of

mild and three months of mild and moderate drought. The three lowest ozone years had similar levels of ozone and experienced one month of mild, one month of moderate, and five months of mild to severe drought.

The risk of foliar ozone injury to plants at Petrified Forest National Park is moderate. The Sum06 exposure index meets the criteria for injury, while the W126 index does in two years. The numbers of hours of exposure greater than 80 and 100 ppb are variable, with two years having a higher number of hours above 100 ppb. The incidence of drought varies considerably among years and can significantly reduce the uptake of ozone and decrease the likelihood of foliar injury being produced. The year 1995 is an exception to this pattern and is characterized by higher levels of ozone exposure under generally normal soil moisture conditions. The co-occurrence of higher levels of ozone exposure and soil moisture conditions that favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or both of the following bioindicator species: tree-of-heaven and skunkbush.

PETROGLYPH NATIONAL MONUMENT (PETR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for PETR					
	1995	1996	1997	1998	1999
Sum06	9	17	11	17	14
W126	17.2	23.0	19.0	25.9	25.8
N60	236	375	287	460	423
N80	13	11	9	12	20
N100	0	0	0	0	0

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the 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 PETR					
	1995	1996	1997	1998	1999
Month 1	-2.13	4.94	1.48	6.08	-0.16
Month 2	-1.16	0.20	3.46	-2.03	-0.02
Month 3	1.08	0.20	-0.19	-3.45	3.60

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

Palmer Z Index data for the 7-month W126 period at PETR					
	1995	1996	1997	1998	1999
April	0.52	-1.99	2.85	2.65	-0.26
May	-0.67	-3.01	-0.27	-0.51	-0.16
June	-0.62	4.94	1.48	-0.78	-0.02
July	-2.13	0.20	3.46	6.08	3.60
August	-1.16	0.20	-0.19	-2.03	4.47
September	1.08	2.33	3.14	-3.45	-0.84
October	-2.50	2.01	-1.15	3.01	-1.49

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. In the Sum06 assessment, soil moisture was generally normal with only four months of drought over the five-year period. The two highest ozone years, 1998 and 1996, experienced, respectively, two months of mild drought and normal soil moisture, while the lowest ozone year, 1995, had two months of mild and moderate drought. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. Eight months of drought were distributed over the five years. The two highest ozone years, 1998 and 1999, experienced two months of moderate and severe drought and one month of mild drought, respectively. The

year with mid-level ozone had two months of mild and severe drought, and the two lowest ozone years, 1995 and 1997, had three months of mild and moderate drought and normal moisture conditions, respectively.

The low levels of ozone exposure at Petroglyph National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there are no exposures greater than 100 ppb. Soil moisture levels are variable, and scattered months of drought constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

If the level of risk increases in the future, skunkbush can be used as a bioindicator.

RAINBOW BRIDGE NATIONAL MONUMENT (RABR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae
Salix gooddingii	Gooding's willow	Salicaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for RABR					
	1995	1996	1997	1998	1999
Sum06	6	13	10	15	16
W126	31.7	41.6	29.2	50.7	47.1
N60	427	734	457	959	860
N80	18	32	11	37	33
N100	2	2	1	2	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at RABR					
	1995	1996	1997	1998	1999
Month 1	2.67	-2.18	0.76	0.39	2.28
Month 2	0.85	-1.90	1.31	-1.53	-0.77
Month 3	0.62	-2.50	1.75	-1.32	-0.64

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

Palmer Z Index data for the 7-month W126 period at RABR					
	1995	1996	1997	1998	1999
April	1.97	-1.75	2.06	0.39	2.28
May	5.04	-2.18	1.06	-1.53	-0.77
June	2.67	-1.90	0.76	-1.32	-0.64
July	0.85	-2.50	1.31	-0.42	1.39
August	0.62	-3.12	1.75	-2.65	3.49
September	-0.69	2.90	4.46	0.36	-0.20
October	-2.53	1.38	0.13	3.14	-3.02

Risk Analysis

- There are two ozone-sensitive species at the site, one of which is a bioindicator for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. 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.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. In the Sum06 assessment, the two highest ozone years, 1998 and 1999, experienced, respectively, two months of mild drought and normal soil moisture. One of the intermediate ozone years had three months of mild and moderate drought, while the other had normal conditions. The lowest ozone year, 1995, had normal soil moisture. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1998 and 1999, experienced three months of mild and moderate drought and one month of severe drought,

respectively. The two years with mid-level ozone had five months of mild to severe drought and normal soil moisture conditions, and the lowest ozone year, 1995, had one month of moderate drought.

The low levels of ozone exposure at Rainbow Bridge National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and exposures greater than 100 ppb are rare. Soil moisture levels are variable, and months of drought constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

If the level of risk increases in the future, skunkbush can be used as a bioindicator.

SALINAS PUEBLO MISSIONS NATIONAL MONUMENT (SAPU)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for SAPU					
	1995	1996	1997	1998	1999
Sum06	9	17	11	17	15
W126	17.4	22.8	18.5	26.0	25.3
N60	242	370	273	463	414
N80	13	11	8	12	18
N100	1	0	0	0	0

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAPU					
	1995	1996	1997	1998	1999
Month 1	0.54	-4.43	2.44	-0.81	0.23
Month 2	-1.34	2.98	1.43	-1.06	0.00
Month 3	-0.78	1.88	2.04	2.82	0.33

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

Palmer Z Index data for the 7-month W126 period at SAPU					
	1995	1996	1997	1998	1999
April	-0.23	-2.76	2.44	0.24	0.23
May	-0.90	-4.43	1.43	-0.81	0.00
June	0.54	2.98	2.04	-1.06	0.33
July	-1.34	1.88	-0.37	2.82	-0.13
August	-0.78	-0.33	-0.14	-1.03	2.28
September	1.51	1.45	2.91	-1.57	-0.69
October	-2.47	1.77	-0.34	3.77	-1.33

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 never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and only one hour in the five-year period during which the concentration of ozone reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. In the Sum06 assessment, soil moisture was generally normal with only three months of drought over the five-year period. The two highest ozone years, 1996 and 1998, experienced, respectively, one month of severe drought and one month of mild drought, while the lowest ozone year, 1995, had one month of mild drought. The remaining two years had normal moisture conditions. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. Months of

drought were distributed over four of the five years. The two highest ozone years, 1998 and 1999, experienced three months of mild and one month of mild drought, respectively. The two years with mid-level ozone had two months of mild and severe drought and normal conditions, and the lowest ozone year, 1995, had two months of mild and moderate drought.

The low levels of ozone exposure at Salinas Pueblo Missions National Monument make the risk of foliar ozone injury to plants low. While the Sum06 index meets the criteria for injury, the W126 exposure index does not. The number of hours of exposure greater than 80 ppb is low, and there is only one hour of exposure to levels greater than 100 ppb. Soil moisture is variable, and months of drought constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

If the risk increases in the future, ponderosa pine and skunkbush can be used as bioindicators.

SUNSET CRATER VOLCANO NATIONAL MONUMENT (SUCR)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for SUCR					
	1995	1996	1997	1998	1999
Sum06	6	11	17	25	33
W126	43.6	46.3	43.0	65.8	66.8
N60	737	835	781	1284	1329
N80	94	96	65	123	102
N100	16	9	5	6	2

Soil Moisture Status

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

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

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

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SUCR					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	1.13	1.53	-2.92
Month 2	-0.85	-3.23	0.06	1.25	1.47
Month 3	0.27	-1.22	0.28	0.96	-1.25

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

Palmer Z Index data for the 7-month W126 period at SUCR					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in three of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a number of hours every year. These levels of exposure may possibly injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought while second highest exposure year, 1998, had normal soil moisture. The mid-level year 1997 had normal soil moisture. The second lowest ozone year, 1996, had three months of mild to severe drought, and the lowest year, 1995, had normal soil moisture conditions. There is also no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1999 and

1998, experienced three months of mild and moderate drought and one month of mild drought, respectively. The mid-level exposure year 1996 had five months of mild to severe drought. The two years with the lowest and similar levels of ozone had one month of mild drought and one month of moderate drought.

The risk of foliar ozone injury to plants at Sunset Crater Volcano National Monument is moderate. The Sum06 and W126 exposure indices generally meet the criteria for injury. The number of hours of exposure greater than 80 and 100 ppb varies among years, and reaches levels that can injure vegetation. The relationships between levels of ozone and soil moisture show no association, and conditions constraining the uptake of ozone occur for one or more months during most years. It is anticipated that the risk of injury may be greatest in years such as 1995 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: ponderosa pine, quaking aspen, and skunkbush.

WALNUT CANYON NATIONAL MONUMENT (WACA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus ponderosa	Ponderosa pine	Pinaceae
Populus tremuloides	Quaking aspen	Salicaceae
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for WACA					
	1995	1996	1997	1998	1999
Sum06	5	10	18	27	37
W126	43.2	46.0	43.5	67.7	68.3
N60	740	840	799	1327	1371
N80	107	110	76	141	113
N100	18	10	6	7	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 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 WACA					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	1.13	1.53	-2.92
Month 2	-0.85	-3.23	0.06	1.25	1.47
Month 3	0.27	-1.22	0.28	0.96	-1.25

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

Palmer Z Index data for the 7-month W126 period at WACA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation. The W126 accumulative value exceeds the threshold each year and the N100 count generally meets the threshold requirement.
- The distribution of hourly concentrations of ozone varies considerably among years. In some 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 other years, the number of hours was significantly lower. In the higher ozone years, the levels of exposure could injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought, and the second lowest ozone year, 1996, had three months of mild and severe drought. The three remaining years had normal moisture conditions. Similarly, there is no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1999 and 1998, experienced three months

of mild and moderate drought and one month of mild drought, respectively. The mid-level ozone year 1996 had five months of mild to severe drought, and the two years with the lowest and similar levels of ozone each experienced a month of mild or moderate drought.

The risk of foliar ozone injury to plants at Walnut Canyon National Monument is moderate. The Sum06 and W126 exposure indices generally meet the criteria for injury. The number of hours of exposure greater than 80 and 100 ppb varies among years, and reaches levels that can injure vegetation. The relationships between levels of ozone and soil moisture show no association, and conditions limiting the uptake of ozone occur for one or more months during most years. It is anticipated that the risk of injury may be greatest in years such as 1995, 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: ponderosa pine, quaking aspen, and skunkbush.

WUPATKI NATIONAL MONUMENT (WUPA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae
Salix scouleriana	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for WUPA					
	1995	1996	1997	1998	1999
Sum06	6	11	16	23	30
W126	43.9	46.2	42.1	64.0	65.0
N60	731	822	752	1242	1277
N80	81	84	56	108	92
N100	14	8	4	5	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 WUPA					
	1995	1996	1997	1998	1999
Month 1	2.08	-3.96	0.06	1.25	-2.92
Month 2	-0.85	-3.23	0.28	0.96	1.47
Month 3	0.27	-1.22	-1.17	2.34	-1.25

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

Palmer Z Index data for the 7-month W126 period at WUPA					
	1995	1996	1997	1998	1999
April	1.32	-2.44	1.13	1.53	1.47
May	2.00	-3.96	0.06	1.25	-1.25
June	2.08	-3.23	0.28	0.96	-1.53
July	-0.85	-1.22	-1.17	2.34	4.49
August	0.27	-2.54	1.38	-1.82	2.48
September	1.01	3.24	2.32	1.01	2.76
October	-2.36	0.24	0.18	3.04	-2.64

Risk Analysis

- There are two ozone-sensitive species listed for the site.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had fourteen hours in which the concentration exceeded 100 ppb, but there were eight or fewer hours in the other years. These levels of exposure may possibly injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or seasonal W126 accumulation period levels of ozone and soil moisture. The highest Sum06 ozone year, 1999, experienced two months of mild and moderate drought, while the second highest year, 1998, had normal moisture conditions. The two mid-level exposure years, 1997 and 1996, experienced one month of mild and three months of mild and severe drought, respectively. The lowest exposure year, 1995, had normal soil moisture. There is also no association between the W126 level of ozone exposure and the incidence of drought. The two highest ozone years, 1999

and 1998, experienced three months of mild and moderate drought and one month of mild drought, respectively. The mid-level ozone year 1996 had five months of mild to severe drought, and the two years with the lowest and similar levels of ozone each experienced a month of mild or moderate drought.

The risk of foliar ozone injury to plants at Wupatki National Monument is moderate. The Sum06 index meets the criteria for injury, and the W126 exposure index meets the criteria in two years. The number of hours of exposure greater than 100 ppb is variable. The incidence of drought varies considerably among years, and can constrain the uptake of ozone by plants and reduce the likelihood of foliar injury. The year 1995 is an exception and is characterized by higher levels of ozone exposure under more normal soil moisture conditions. The co-occurrence of levels of ozone exposure above thresholds and soil moisture conditions that generally favor uptake increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use skunkbush as a bioindicator.

YUCCA HOUSE NATIONAL MONUMENT (YUHO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Rhus trilobata	Skunkbush	Anacardiaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

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

Ozone air quality data for YUHO					
	1995	1996	1997	1998	1999
Sum06	3	7	5	12	12
W126	23.7	29.9	16.0	33.5	32.9
N60	189	404	166	555	491
N80	2	2	1	2	3
N100	0	0	0	0	0

Soil Moisture Status

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

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

Palmer Z data were compiled for the site for both the 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 YUHO					
	1995	1996	1997	1998	1999
Month 1	1.56	-1.24	1.98	0.32	3.13
Month 2	5.61	0.26	1.09	-1.94	1.46
Month 3	2.71	-1.07	0.70	0.30	1.00

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

Palmer Z Index data for the 7-month W126 period at YUHO					
	1995	1996	1997	1998	1999
April	1.56	-0.39	2.93	0.32	3.13
May	5.61	-1.24	1.98	-1.94	1.46
June	2.71	0.26	1.09	0.30	1.00
July	2.25	-1.07	0.70	1.69	3.20
August	0.30	-2.78	2.39	-1.44	3.71
September	1.30	1.62	4.50	-1.69	0.40
October	-1.39	2.52	1.11	2.62	-2.46

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations rarely exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. Soil moisture was generally normal with only three months of drought over the five-year period. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. In the highest ozone years, 1998 and 1999, there were three months of mild and one month of moderate drought, respectively.

The next highest ozone year, 1996, had three months of mild and moderate drought, and the two lowest ozone years had one month of mild drought between them.

The low levels of ozone exposure at Yucca House National Monument make the risk of foliar ozone injury to plants low. Neither the Sum06 nor the W126 exposure indices meet the criteria for injury, the number of hours of exposure greater than 80 ppb is very low, and there are no exposures greater than 100 ppb. Soil moisture levels are variable, and years with higher ozone years are accompanied by months of drought that constrain the uptake of ozone by plants and reduce the likelihood of foliar injury.

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