

ROCKY MOUNTAIN NETWORK

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

Park	Code	State	Risk	O3 Data
Florissant Fossil Beds NM	FLFO	CO	low	kriged
Glacier NP	GLAC	MT	low	monitored
Grant-Kohrs Ranch NHS	GRKO	MT	low	kriged
Great Sand Dunes NM	GRSA	CO	low	kriged
Little Bighorn Battlefield NM	LIBI	MT	low	kriged
Rocky Mountain NP	ROMO	CO	low	monitored

FLORISSANT FOSSIL BEDS NATIONAL MONUMENT (FLFO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
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 FLFO					
	1995	1996	1997	1998	1999
Sum06	8	11	7	11	8
W126	13.5	16.1	15.6	25.5	19.2
N60	191	250	229	403	287
N80	14	24	13	51	21
N100	1	1	0	7	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 FLFO					
	1995	1996	1997	1998	1999
Month 1	5.31	0.86	-0.65	0.67	1.58
Month 2	1.79	1.08	3.47	5.84	1.70
Month 3	0.89	0.32	3.35	1.81	3.00

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

Palmer Z Index data for the 7-month W126 period at FLFO					
	1995	1996	1997	1998	1999
April	3.79	-0.69	3.50	2.92	7.48
May	7.46	1.38	-0.65	-0.85	1.58
June	5.31	0.86	3.47	0.67	1.70
July	1.79	1.08	3.35	5.84	3.00
August	0.89	0.32	6.34	1.81	5.30
September	3.10	3.91	2.47	-0.80	2.21
October	-0.26	-0.55	3.49	2.04	-0.11

Risk Analysis

- There are two ozone-sensitive species at the site, both of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation although the values are marginal. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than seven hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels during the 90-day Sum06 and the seasonal W126 accumulation periods were normal and favored the uptake of ozone. In the five-year assessment period, there were no months of drought.

The risk of foliar ozone injury to plants at Florissant Fossil Beds National Monument is low. While the Sum06 threshold is marginally satisfied, W126 exposure criteria are not. Soil moisture conditions are consistently normal. Even when moisture conditions do not

constrain the uptake of ozone, the levels of exposure are below those likely to produce foliar injury. The occurrence of somewhat higher levels of ozone exposure, such as in 1998, could increase the possibility of injury in a given year.

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 spreading dogbane and quaking aspen.

GLACIER NATIONAL PARK (GLAC)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae
<i>Symphoricarpos albus</i>	Common snowberry	Caprifoliaceae

Representative Ozone Injury Thresholds

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

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

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

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

Ozone Exposure Data

Ambient concentrations of ozone 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 GLAC					
	1995	1996	1997	1998	1999
Sum06	0	2	0	1	1
W126	2.7	5.4	2.3	5.6	9.7
N60	4	30	0	23	20
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 GLAC					
	1995	1996	1997	1998	1999
Month 1	-	2.69	-	-0.86	-1.61
Month 2	-	3.10	-	-0.51	-1.81
Month 3	-	-1.06	-	4.18	-1.48

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

Palmer Z Index data for the 7-month W126 period at GLAC					
	1995	1996	1997	1998	1999
April	0.09	2.69	1.57	-0.51	-1.81
May	-1.20	3.10	0.34	4.18	-1.48
June	3.04	-1.06	0.76	3.18	-0.07
July	2.82	-0.70	1.82	3.01	-0.68
August	1.28	-0.88	0.68	0.04	-0.20
September	1.13	0.03	0.18	-1.15	-2.05
October	2.86	0.08	0.97	-1.30	0.46

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index is below the threshold for injury. While the W126 accumulative value exceeds the threshold in one year, 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 both below the levels considered necessary for injury to vegetation.
- The N-values for the site show no concentrations greater than 60 ppb. These levels of exposure are unlikely to injure vegetation.
- The low levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of low soil moisture make it difficult to assess relationships between the levels of ozone and soil moisture, and no patterns are evident. Although the W126 indices of exposure are low, soil moisture levels appear inversely related to the ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the seasonal exposure in producing foliar injury. The highest ozone year, 1999, had three months of mild and moderate drought, and the second highest year, 1998, had two months of mild drought. Two intermediate years, 1996 and 1995, each had one month of mild drought, and the lowest ozone year, 1997, had favorable conditions. While an inverse relationship appears to exist, the limited range of the W126 ozone indices and the relatively few months of drought make the analysis uncertain.

The low levels of ozone exposure at Glacier National Park make the risk of foliar ozone injury to plants low. The Sum06 and W126 exposures indices do not exceed the threshold levels for injury, and there are no hours of exposure greater than 60 ppb.

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

GRANT-KOHR'S RANCH NATIONAL HISTORIC SITE (GRKO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
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 GRKO					
	1995	1996	1997	1998	1999
Sum06	2	8	3	7	9
W126	11.9	17.2	12.2	19.8	19.1
N60	109	225	120	255	250
N80	11	16	5	19	6
N100	1	2	0	3	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 GRKO					
	1995	1996	1997	1998	1999
Month 1	-1.20	-0.18	1.57	-0.86	-1.61
Month 2	3.04	2.69	0.34	-0.51	-1.81
Month 3	2.82	3.10	0.76	4.18	-1.48

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

Palmer Z Index data for the 7-month W126 period at GRKO					
	1995	1996	1997	1998	1999
April	0.09	2.69	1.57	-0.51	-1.81
May	-1.20	3.10	0.34	4.18	-1.48
June	3.04	-1.06	0.76	3.18	-0.07
July	2.82	-0.70	1.82	3.01	-0.68
August	1.28	-0.88	0.68	0.04	-0.20
September	1.13	0.03	0.18	-1.15	-2.05
October	2.86	0.08	0.97	-1.30	0.46

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The 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.
- The low levels of ozone during the 90-day Sum06 accumulation periods and the infrequent occurrence of low soil moisture make it difficult to assess relationships between ozone and soil moisture. Although there were three months of mild drought in the highest ozone year 1999, there was only one month of drought among the other four years. No association between ozone and drought is apparent from this pattern of distribution. Relationships between the seasonal W126 index of exposure and soil moisture are also difficult to assess because the levels of ozone were relatively similar over the five-year period. There is, however, some indication of an inverse relationship: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the

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

The risk of foliar ozone injury to plants at Grant-Kohrs Ranch National Historic Site is low. The Sum06 and W126 exposure criteria are not satisfied, and there are only a few hours of exposure each year to ozone concentrations greater than 80 ppb. Soil moisture conditions generally favor the uptake of ozone and months of drought are rare and mild. Even with these favorable soil conditions, the levels of exposure are unlikely to produce foliar ozone injury.

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

GREAT SAND DUNES NATIONAL MONUMENT (GRSA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Oenothera elata</i>	Evening primrose	Onagraceae
<i>Pinus ponderosa</i>	Ponderosa pine	Pinaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rhus trilobata</i>	Skunkbush	Anacardiaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<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 GRSA					
	1995	1996	1997	1998	1999
Sum06	7	11	8	11	9
W126	14.9	19.4	17.3	29.2	23.3
N60	194	301	254	499	372
N80	12	21	11	48	23
N100	1	1	0	6	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 GRSA					
	1995	1996	1997	1998	1999
Month 1	4.95	-1.34	1.38	-1.00	4.22
Month 2	2.83	-1.12	2.40	-0.19	3.32
Month 3	1.48	-0.05	1.46	3.61	2.88

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

Palmer Z Index data for the 7-month W126 period at GRSA					
	1995	1996	1997	1998	1999
April	1.32	-0.80	1.07	0.68	4.22
May	2.98	-3.06	1.38	-1.00	3.32
June	4.95	1.23	2.40	-0.19	2.88
July	2.83	-1.34	1.46	3.61	5.04
August	1.48	-1.12	1.90	0.38	5.61
September	1.94	-0.05	4.45	-0.59	2.33
October	-2.17	1.83	1.00	5.09	-1.71

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index generally exceeds the threshold for injury to vegetation, although the levels are marginal. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between both the 90-day Sum06 and seasonal W126 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years and the occurrence of drought limited. The two years with the highest ozone levels, 1998 and 1996, had one and two months of mild drought. Soil moisture was normal in the other years. There does not appear to be any association between the seasonal W126 accumulative index and soil moisture conditions. This is a consequence of the scattered

distribution of months of drought over the five-year period. In 1998 when ozone exposure was highest and in 1995 when ozone was the lowest, there was one month of mild or moderate drought each year. The second highest ozone year, 1999, also had one month of drought. The mid-level ozone years, 1996 and 1997, had, respectively, three months of mild and severe drought and normal soil moisture. Overall, there is no association between the W126 index of exposure and soil moisture.

The risk of foliar ozone injury to plants at Great Sand Dunes National Monument is low. While the Sum06 threshold is marginally satisfied, the W126 exposure criteria are not. There are only a few hours of exposure each year to ozone concentrations greater than 80 ppb, and exposure to 100 ppb is generally rare. There is no apparent relationship between ozone exposure and soil moisture, and most years have generally favorable soil moisture conditions. When soil moisture is favorable and ozone exposures levels are slightly elevated, such as in 1998, the possibility of foliar ozone injury, while still low, is greatest.

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, evening primrose, ponderosa pine, quaking aspen, skunkbush, cut-leaf coneflower, and Scouler's willow.

LITTLE BIGHORN BATTLEFIELD NATIONAL MONUMENT (LIBI)

Plant Species Sensitive to Ozone

Very Sensitive Species

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Apocynum androsaemifolium	Spreading dogbane	Apocynaceae
Asclepias syriaca	Common milkweed	Asclepiadaceae
Fraxinus pennsylvanica	Green ash	Oleaceae
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 LIBI					
	1995	1996	1997	1998	1999
Sum06	4	10	8	10	12
W126	14.2	20.3	18.0	26.8	23.1
N60	123	279	199	390	309
N80	7	7	4	13	3
N100	1	0	0	1	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 LIBI					
	1995	1996	1997	1998	1999
Month 1	2.56	-1.74	-0.29	1.32	-2.52
Month 2	2.03	-0.15	2.26	-0.55	2.25
Month 3	4.97	-2.09	0.71	-2.70	-0.75

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

Palmer Z Index data for the 7-month W126 period at LIBI					
	1995	1996	1997	1998	1999
April	3.08	0.23	2.26	-0.55	2.25
May	2.56	4.88	0.71	-2.70	-0.75
June	2.03	-1.74	2.52	3.42	-0.90
July	4.97	-0.15	6.60	1.71	-1.50
August	2.45	-2.09	4.23	0.65	1.11
September	0.10	0.13	-0.32	-1.29	-0.66
October	1.67	0.13	1.38	0.23	-2.13

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied. The Sum06 and W126 indices are both below the levels considered necessary for injury to vegetation.
- The N-values for the site show only a few hours in which concentrations exceeded 80 ppb and two years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Relationships between the 90-day Sum06 accumulation periods ozone level and soil moisture are difficult to assess because ozone exposure was relatively similar over the five years. However, soil moisture levels during the 90-day periods appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the exposure in producing foliar injury. The years with the three highest ozone exposure values, 1999, 1996 and 1998, experienced one, two and one month of mild to severe drought, respectively. The two years with the lowest ozone exposure, 1996 and 1997, had favorable soil moisture conditions. Soil

moisture levels associated with the seasonal W126 index also appear inversely related to ozone exposure. The three highest ozone years, 1998, 1999 and 1996, each had two months of mild and moderate drought. The two lowest ozone years had normal soil moisture throughout.

The low levels of ozone exposure at Little Bighorn Battlefield National Monument make the risk of foliar ozone injury to plants low. The Sum06 exposure index exceeds the threshold for injury, but the W126 index does not. The number of hours of exposure greater than 80 ppb is very low, and only two hours of exposure greater than 100 ppb occur during the five-year period. Soil moisture conditions in the higher exposure years 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: spreading dogbane, common milkweed, and skunkbush.

ROCKY MOUNTAIN NATIONAL PARK (ROMO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Rudbeckia laciniata</i>	Cut-leaf coneflower	Asteraceae
<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).

Ozone air quality data for ROMO					
	1995	1996	1997	1998	1999
Sum06	15	24	10	28	13
W126	29.1	37.0	28.7	47.0	6.9
N60	331	566	388	843	431
N80	21	21	8	36	15
N100	0	0	0	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. 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 ROMO					
	1995	1996	1997	1998	1999
Month 1	5.31	0.86	3.50	-0.85	1.58
Month 2	1.79	1.08	-0.65	0.67	1.70
Month 3	0.89	0.32	3.47	5.84	3.00

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

Palmer Z Index data for the 7-month W126 period at ROMO					
	1995	1996	1997	1998	1999
April	3.79	-0.69	3.50	2.92	7.48
May	7.46	1.38	-0.65	-0.85	1.58
June	5.31	0.86	3.47	0.67	1.70
July	1.79	1.08	3.35	5.84	3.00
August	0.89	0.32	6.34	1.81	5.30
September	3.10	3.91	2.47	-0.80	2.21
October	-0.26	-0.55	3.49	2.04	-0.11

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. No year had more than two hours in which the concentration exceeded 100 ppb, and three years had no hours at this level. These levels of exposure are not likely to injure vegetation.
- During the five-year assessment period, soil moisture levels were normal to high and favored the uptake of ozone. Since there were no months of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and either the 90-day cumulative Sum06 or the seasonal W126 index of exposure.

The risk of foliar ozone injury at Rocky Mountain National Park is low. The threshold for injury is satisfied by the Sum06 index, but not by the W126 index. The N-values indicate there are occasional exposures to concentrations of ozone greater than 80 ppb, and exposures to 100 ppb are rare. While soil moisture levels are favorable for the uptake of ozone, ambient levels of exposure are low and the threshold for foliar injury is not likely to be reached.

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, quaking aspen, cut-leaf coneflower, and Scouler's willow.