FINAL REPORT

STATUS OF AIR QUALITY AND EFFECTS OF ATMOSPHERIC POLLUTANTS ON ECOSYSTEMS IN THE PACIFIC NORTHWEST REGION OF THE NATIONAL PARK SERVICE

Submitted by

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to the

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EXECUTIVE SUMMARY

The National Park Service (NPS), Air Quality Division, initiated this project to evaluate the information needs for air quality related issues in NPS class I areas of the Pacific Northwest. To protect sensitive aquatic and terrestrial resources in class I areas, the following specific objectives were identified:

1. Conduct comprehensive analyses of documented and potential ecological effects of various atmospheric pollutants and exposures (chronic, episodic) on terrestrial and aquatic systems.

2. Compile inventories of pollution-sensitive components or receptors of ecosystems, and the critical or target loading of pollutants that would cause changes in the sensitive receptors.

3. Prepare assessments of key knowledge deficits and additional information required to adequately protect resources sensitive to potential degradation by poor air quality.

The National Park Service class I areas within the Pacific Northwest region (Oregon, Washington, and Idaho) that were included in this project are Crater Lake National Park (CRLA), Craters of the Moon National Monument (CRMO), Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM). This report addresses the above objectives by providing a summary of current and historical monitoring data for pollutants, a synthesis of knowledge on ecological effects from atmospheric pollutants, and to the extent feasible, a park-specific assessment of pollution vulnerability. Guidelines presented in this report should also be applicable to similar ecosystems or areas with similar resources.

The air quality in the region generally is very good compared to other areas of the United States. The principal air masses are derived from the atmosphere over the Pacific Ocean, and as a consequence, accumulated air pollutant loads are low. Emissions of principal air pollutants within the Pacific Northwest are low relative to other regions, and trends in some air quality indicators seem to be stable or improving. Although precipitation quality in the region generally is high, it is not uniform. Nonmarine sulfate and hydrogen ion concentrations in precipitation for at least portions of the Washington Cascades are slightly elevated above background concentrations (background concentrations are approximated by precipitation measured on the west side of OLYM) and are cause for concern in MORA and NOCA. Limited data on ozone

indicate that concentrations are elevated and may even periodically exceed NAAQS values on the western slopes of the Washington Cascades to the east and southeast of urban centers near Puget Sound.

Monitoring and research programs in the Pacific Northwest were reviewed to determine existing research needs, particularly with respect to reviewing PSD permits. There are several monitoring and research programs currently in operation or being developed in the region that can provide information relevant to air quality issues and the NPS. Major monitoring and research programs are operated by the U.S. Forest Service, U.S. Environmental Protection Agency, U.S. Geological Survey, universities, and private industry. NPS staff have already taken actions to coordinate with these organizations, although opportunities remain for the NPS to supplement efforts with the Cooperative Park Studies Units and park staff in developing a better understanding of air pollution-related effects in the parks.

The park-specific studies were reviewed to assess the need for additional monitoring and research regarding effects of air pollution. The major needs for the five class I areas are summarized below:

CRLA: The most sensitive receptor in the park to air pollution is Crater Lake. The lake is N-limited and the major nutrient inputs to the lake are from atmospheric deposition. The principal monitoring need is to measure deposition chemistry at the lake.

CRMO: The threat from air pollution to the monument is currently low. The most sensitive receptors are lichens. The lichen populations should be monitored on a systematic basis to detect signs of air pollution stress, as warranted by new emissions sources.

MORA: This park is potentially at greatest risk from air pollution stress (SO_x, NO_x, O_3) in the region. Monitoring efforts by the NPS for lakes, biota, and deposition have been accelerated in recent years. The geographic emphasis of the deposition and effects monitoring programs needs to be reoriented to the west side of the park, and at higher elevations.

NOCA: This park potentially is also at risk from air pollution (SO_x, NO_x, O_3) and has the greatest information needs with respect to basic characterization of park resources. The lakes and associated aquatic biota are resources that are particularly sensitive to damage from air pollution. A plan to study lakes in the park will be extremely useful and should be implemented.

OLYM: Most of this park currently is at low risk from air pollution stress. Few data are available, however, on the east side of the park to assess the possible impacts from air pollution sources in the Puget Sound area.

The NPS Federal land managers have a responsibility under the Clean Air Act to review proposed increases in emissions for potential impacts to class I areas. We reviewed available data to determine what guidance could be provided to the NPS regarding critical loads of pollutants to the parks.

Quantification of sulfur and nitrogen dose-response functions is difficult for the national parks considered in this report. Limited availability of data precludes rigorous quantitative assessment in most cases. In particular, data are scarce in the following categories:

- •Stream and lake chemistry during snowmelt and precipitation events.
- •Seasonal surface water chemistry data, particularly for nitrogen and aluminum.
- •Model input parameters (especially soils characteristics) for watersheds.
- •Deposition (wet and dry) data, particularly at high-elevation sites.
- •Dose-response functions for plants and aquatic biota in natural ecosystems.

Based on data available within the parks and results of more detailed studies elsewhere, however, we offer a preliminary evaluation of critical loads of atmospheric sulfur and nitrogen deposition, below which sensitive resources will be protected from adverse effects. For protection of sensitive lakes and streams in MORA and NOCA, we recommend an interim nonmarine sulfur deposition guideline of 20 meq/m^2/yr (about 3 kg S/ha/yr; 9 kg SO_4^{2-}/ha/yr). This recommended critical load is based to a large degree on studies of European systems which have precipitation generally about 1 m. The recommended critical load for S in the Pacific Northwest should be adjusted upward to account for precipitation greater than 1 m. For example, areas in the Pacific Northwest which receive 2 m of annual precipitation require double the annual S load to experience surface water concentrations comparable to similar areas receiving only 1 m of precipitation. In this way, the natural dilution afforded by high precipitation amounts is incorporated into the computation of critical load.

Note that this recommendation for maximum S loading to these two parks is predicated on the following:

- •The recommended S loading will not necessarily protect all sensitive aquatic resources at all times. This recommended loading is adequate for protecting at least 95% of the resources from chronic acidification, but it may not be adequate for long-term protection of the most sensitive resources.
- •The recommended S loading may not protect aquatic resources from episodic acidification from either S or N deposition. Episodic acidification will precede chronic acidification in many of the systems, particularly in view of the importance of snow to the hydrologic budgets of the alpine lakes.
- •The recommended S loading does not address possible accumulation of N in low temperature lakes that remain ice covered for most of the year.

Recommendation of guidelines for N loading to the parks is even more problematic than for S loading. There is no evidence that chronic N accumulation has occurred in lakes within the region, and what little information has been collected suggests that episodic acidification from NO_3^- is probably not occurring. We suspect that critical loads for N deposition in class I national parks in the Pacific Northwest are considerably lower than estimates often cited for forests of Europe and the northeastern United States (e.g., 7-10 kg/ha/yr). As an interim guideline, we suggest a value of 5 kg N ha/yr for the protection of aquatic resources against chronic acidification. Total N deposition in precipitation for the Pacific Northwest ranged from 0.5 to 2.4 kg N ha/yr in 1992 (NADP/NTN 1993). To protect resources from episodic acidification, the critical N load for this region may be even lower than the 5 kg N/ha/yr value we recommend for protection of aquatic resources from chronic acidification. Forest ecosystems in the Pacific Northwest may be more sensitive to smaller additions of N than forests in other regions because forests in the Pacific Northwest have not been subjected to intensive forest management practices, soils are shallow, and snowmelt is an important component of runoff. Moreover, low levels of N deposition may have important influences on the species composition of plant communities via subtle alterations in plant competition. Currently, the most important form of N deposition to these forests may be acidic components in fog, especially in higher elevation sites of MORA and NOCA. Given that emissions of S in the Pacific Northwest have declined and are expected to decline further whereas emissions of N are expected to eventually increase, a greater focus on the effects of N deposition seems warranted.

Ozone is the pollutant of most concern with respect to air pollution effects on vegetation in class I national parks of the Pacific Northwest, mainly because of the expanding urban centers and vehicular traffic. Ozone concentrations at levels higher than 80 ppb per hour occur in the Washington Cascades during the summer months. Available data indicate that forests close to large urban centers are more likely to receive high ozone exposures than other forests in the region. National parks on the western slopes of the Cascades at higher elevations in Oregon and Washington are particularly vulnerable. MORA faces the highest risk, followed by NOCA, and possibly the eastern portion of OLYM. Additional monitoring sites, however, would be needed to confirm the spatial pattern of ozone exposure. The adequacy of NAAQS values (based on extreme ozone concentrations) for protecting vegetation from injury is controversial. Past research in both the laboratory and field indicates that ozone concentrations < 70 ppb (7-h growing season mean) or < 80-100 ppb maximum hourly values may be adequate to protect most tree species, but not some herbaceous plants, lichens, and bryophyte species. The cumulative nature of ozone effects would suggest a more conservative standard such as the SUM06 or SUM08 air quality indicator together with a maximum hourly value may be more appropriate for protecting park resources. Additional research and monitoring efforts are needed to better understand ozone effects on vegetation in the

Pacific Northwest before threshold values for ozone exposure may be adequately evaluated. Cooperation with other agencies which share NPS concerns would likely be the most productive and efficient approach to accomplish the recommended research and monitoring activities.

ACRONYMS AND ABBREVIATIONS

Al	Aluminum
ANC	Acid Neutralizing Capacity
As	Arsenic
AQD	Air Quality Division (of the National Park Service)
AQRV	Air Quality Related Values
CAEC	Center for Analysis of Environmental Change
Ca^{2+}	Calcium
Cd	Cadmium
Cl^-	Chloride
CO	Carbon Monoxide
CRLA	Crater Lake National Park
CRMO	Craters of the Moon National Monument
Cu	Copper
DOE	Department of Energy
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
ERL-C	Environmental Research Laboratory-Corvallis
F^-	Fluoride
Fe	Iron
GCRP	Global Change Research Program
GIS	Geographic Information System
H^+	Hydrogen
Hg	Mercury
HJA	H.J. Andrews Experimental Forest
IMPROVE	Interagency Monitoring of Protected Visual Environments
K^+	Potassium
LTER	Long Term Ecological Research Program
Mg^{2+}	Magnesium
MORA	Mount Rainier National Park
N	Nitrogen
Na^+	Sodium
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NAPAP	National Acid Precipitation Assessment Program
NAWQA	National Water Quality Assessment
NBS	National Biological Survey
NCASI	National Council of the Paper Industry for Air and Stream Improvement
NDDN	National Dry Deposition Network
NH_3	Ammonia
NH_4^+	Ammonium
NITREX	Nitrogen Saturation Experiments
NOCA	North Cascades National Park
NO_x	Nitrogen Oxides
NO_3^-	Nitrate
NPS	National Park Service
NSF	National Science Foundation
ODEQ	Oregon Department of Environmental Quality
OAQPS	Office of Air Quality Planning and Standards

OLYM	Olympic National Park
O_3	Ozone
P	Phosphorus
Pb	Lead
PM_{10}	Particulate Matter, 10 microns
PREVENT	Pacific Northwest Regional Visibility Experiments Using Natural Tracers
PSD	Prevention of Significant Deterioration
S	Sulfur
SO_2	Sulfur Dioxide
SO_4^{2-}	Sulfate
SWAPCA	Southwest Air Pollution Control Association, Washington
TIME	Temporally Integrated Monitoring of Ecosystems
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
VMT	Vehicular Miles Traveled
WDOE	Washington Department of Ecology
WRD	Water Resources Division (of the NPS)
Zn	Zinc

Units

cm	centimeter
ha	hectare
in.	inches
kg	kilogram
km	kilometer
L	liter
lat.	latitude
m	meter
m^2	square meter
meq	milliequivalent
mg	milligram
ppb	parts per billion
ppm	parts per million
yr	year
µeq	microequivalents

I. INTRODUCTION

A. BACKGROUND

National parks in the Pacific Northwest include lands of exceptional ecological and cultural significance. The National Park Service (NPS) maintains the world's most admired and imitated system of parks. However, increasing demands on park usage and pollutant emissions outside park boundaries potentially threaten ecological integrity within the parks. Most of the parks in this region receive generally low levels of atmospheric pollutants (Bormann et al. 1989, Sisterson et al. 1990, Smith 1990). Nevertheless, sensitive aquatic and terrestrial ecosystems, especially those at high elevations, can potentially be degraded by existing or future pollution (Peterson et al. 1992a).

Recognizing the valuable role that scientific research can play in proper management of the parks, the NPS Director commissioned the National Research Council to review the agency's research program. The review committee (National Research Council 1992) concluded that there was an urgent need to accelerate research in the parks to:

•inventory, protect, and manage natural resources, and detect changes;

•better understand the natural ecosystems in the parks; and

•assess specific threats to the parks.

In response to these recommendations, the Air Quality Division (AQD) of the NPS initiated a project in 1993 to assess air quality issues on their lands. This project, led by scientists from E&S Environmental Chemistry, Inc. and the Pacific Northwest Research Station, U.S. Forest Service, is taking a proactive position in researching potential threats from air pollution to national parks in the Pacific Northwest.

The Clean Air Act (42 USC 7470), as amended in August 1977, provides one of the most important mandates for protecting air resources in NPS areas. In section 160 of the Act, Congress states that one of the purposes of the Act is to "preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value." According to the Clean Air Act and subsequent amendments (Public Laws 95-95, 101-549), Federal land managers have "... an affirmative responsibility to protect the air quality related values (AQRVs)...within a class I area." A class I designation allows only small increments of pollution above already existing levels within the area. Class I areas are designated as national parks over 6,000 acres and national wilderness areas over 5,000 acres that were in existence before August of 1977. The NPS class I areas within the Pacific Northwest region (Oregon, Washington and Idaho) include (in alphabetical order) Crater

Lake National Park (CRLA), Craters of the Moon National Monument (CRMO), Mount Rainier National Park (MORA), North Cascades National Park (NOCA), and Olympic National Park (OLYM). There are also several U.S. Forest Service class I areas in these states.

Criteria air pollutants are pollutants for which the U.S. Environmental Protection Agency (EPA) has established National Ambient Air Quality Standards (NAAQS) as directed by the Clean Air Act. Standards were established for the pollutants that are emitted in greatest quantities throughout the country and that may be a danger to public health and welfare. Primary standards protect human health, and secondary standards protect public welfare. The standards also are defined in terms of deposition averaging times, such as annual or hourly, depending on the type of exposure associated with health and welfare effects. For some pollutants, there are both short-and long-term standards (O'Leary 1988, Table 1). Criteria air pollutants include ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, and lead. Baseline data on criteria pollutants determined by the NPS criteria pollutants monitoring system are used to determine if deterioration in air quality exceeds NAAQS values and to track pollutant trends.

To maintain healthy ecosystems, it is increasingly imperative that land managers be prepared to monitor and assess levels of atmospheric pollutants and ecological effects in national parks of the Pacific Northwest. Knowledge of emissions inventories, coupled with scientific understanding of dose-response functions and critical loads assessments, will provide land managers with a framework with which to protect sensitive resources within the parks from degradation due to atmospheric deposition of pollutants.

Air quality within class I lands of the National Park Service system is subject to the "prevention of significant deterioration (PSD)" provisions of the Clean Air Act. The primary objective of the PSD provisions is to prevent substantial degradation of air quality in areas that comply with NAAQS, and yet maintain a margin for industrial growth. An application for a PSD permit from the appropriate air regulatory agency is required before construction of a new or modification of an existing major air pollution source (Bunyak 1993). A permit application is required to demonstrate that the proposed polluting facility will (1) not violate national or state ambient air quality standards, (2) use the best available control technology to limit emissions, (3) not violate either class I or class II PSD increments for sulfur dioxide, nitrogen dioxide, and particulates, and (4) not cause or contribute to adverse impacts to AQRVs in any class I area (Peterson et al. 1992a).

As discussed by Peterson et al. (1992a), the PSD increments are allowable pollutant concentrations that can be added to existing concentrations. The values chosen as PSD increments by Congress were not selected on the basis of concentration limits relative to specific resources. Therefore, it may be possible to exceed the legal class I increments without causing damage to a class I area. It is also possible that a class I area could be affected without exceeding the increments. The role of the Federal land manager is to determine if there is potential for additional air pollution to cause damage to a sensitive receptor whether or not the PSD increments have been exceeded. Even if a proposed facility is not expected to violate class I increments, the Federal land manager can still recommend denial of a permit by demonstrating that there will be adverse impacts in the class I area. Provisions for mitigation can be recommended by the Federal land manager or the agency that regulates permits.

The following questions must be answered in response to PSD permit applications:

- What are the identified sensitive receptors within AQRVs in each class I area that could be affected by the new source?
- What are the critical doses for the identified sensitive receptors?
- Will the proposed facility result in pollutant concentrations or atmospheric deposition that will cause the identified critical dose to be exceeded?

The first two questions are land management issues that should be answered on the basis of management goals and objectives for the class I areas. The third is a technical question that must be answered on the basis of analyses of emissions from the proposed facility and forecasts of environmental response at a given pollutant concentration (Peterson et al. 1992a). The staff in the NPS Air Quality Division has implemented a program to better meet the needs of the agency in the PSD review process by reviewing air quality related issues in the Pacific Northwest. This report represents one step toward addressing the questions identified above.

B. OBJECTIVES

The major goal of this project is to evaluate the information needs for air quality related issues in NPS class I areas in the Pacific Northwest. To accomplish the NPS mandate to protect AQRVs in class I areas, the following specific objectives have been identified for the project:

1. Conduct comprehensive analyses of documented and potential ecological effects of various atmospheric pollutants and exposures (chronic, episodic) on terrestrial and aquatic systems.

2. Compile inventories of pollution-sensitive components or receptors of ecosystems, and the critical or target loading of pollutants that would cause changes in the sensitive receptors.

3. Prepare assessments of key knowledge deficits and additional information required to adequately protect resources sensitive to potential degradation by poor air quality.

This report addresses these objectives by providing a summary of current and historical monitoring data for pollutants, a synthesis of knowledge on ecological effects from atmospheric pollutants, and to the extent feasible, a park-specific assessment of pollution vulnerability.

The material presented in this report is based on a compilation of published and unpublished information. We are grateful to the many individuals who kindly provided access to relevant information. A list of people contacted during the process of compiling information for this report is provided in Appendix A.

C. SCOPE AND ORGANIZATION

The thrust of this report is based on a concern for the ecological integrity of the class I areas, thus the scope was limited to addressing potential threats to aquatic and terrestrial resources primarily from deposition of N and S, as well as exposure to ozone and gaseous forms of N and S. Exposure to trace metals and F is covered in less detail, particulate matter is briefly mentioned, and radionuclides and organic toxins are not addressed. With regard to trace metals, an extensive analysis of the topic was not justified because at present, the problem is localized in close proximity to industrial smelters. Also, information is lacking with which to evaluate the dispersal of trace metals in the Pacific Northwest via airborne particulates.

Although the report attempts to address many of the critical issues facing each park, partial coverage of some topics should not be interpreted as a judgement that these topics are not important or relevant to the issue of air pollution effects. For example, little mention is made of fish or other important taxonomic groups. These omissions often reflect the lack of information on these topics rather than any reflection on their ecological significance.

It was hoped that this report would serve several audiences including staff with the NPS Air Quality Division, regional air quality officers, individual park staff, and organizations dealing with PSD issues in the Pacific Northwest. The report was structured to present relevant information on individual NPS class I areas within the five park sections (IV A-E) and to discuss regional issues in other sections of the report. Consequently, the report is intentionally repetitive in some areas, especially with respect to partially redundant reference sections.

Some aspects of measuring air pollution and air pollution effects are evolving, and scientists remain divided with respect to appropriate assessment techniques. We have not attempted to resolve these issues in this report but have noted some of the more controversial ones. Among these topics are:

(1)Deposition monitoring: The estimation of deposition of atmospheric pollutants in high-elevation areas in the western United States is problematic because all components of the deposition (e.g., rain, snow, cloudwater, dryfall, and gases) have seldom been measured concurrently. Even measurement of wet deposition remains a problem because of the logistical difficulties in operating a site above 1500 m. Portions of the wetfall have been measured by using snow cores (or snow pits), bulk deposition, and automated sampling devices such as those used at the NADP/NTN sites. All of these approaches suffer from limitations that cause problems with respect to developing annual deposition estimates. The snow sampling includes results for only a portion of the year and may seriously underestimate the load for that period if there is a major rain-on-snow event. Bulk deposition samplers are subject to contamination problems from birds and litterfall and AeroChem-Metric samplers have insufficient capacity to measure snowfall events in the Cascades.

Cloudwater, dryfall, and gaseous deposition monitoring further complicate the difficult task of measuring total deposition. Cloudwater can be an important portion of the hydrologic budget in forests on the west side of the Cascades (cf. Harr 1982), and failure to capture this portion of the deposition input could lead to substantial underestimates of annual deposition. Furthermore, cloudwater chemistry has the potential to be much more acidic than rainfall. Dryfall from wind-borne soil can constitute a major input to the annual deposition load, particularly in arid environments. Aeolian inputs can provide a major source of acid neutralization, not generally measured in other forms of deposition. Gaseous deposition is calculated from the product of ambient air concentrations and estimated deposition velocities. The derivation of deposition velocities is subject to considerable debate. In brief, there is great uncertainty in current deposition of atmospheric pollutants in the class I areas and throughout much of the mountainous regions of the western United States.

(2)Aquatic Biological Effects: Specific information about the sensitivity of aquatic taxa in the Pacific Northwest are poorly known both because of the inadequate characterization of the taxa in the Cascades and the lack of extensive testing of the response of western taxa to acidic conditions. Furthermore, many of the lakes historically lacked fish. The fish, including nonnative eastern species such as brook trout, were introduced and are suspected of altering the nonfish biota. These three issues, (1) characterization, (2) evaluation of sensitivity, and (3) evaluation of the effects of stocking need to be resolved before a more complete assessment of biological effects can occur. As a consequence, most of the discussions of aquatic effects covered in this report focus on aquatic chemistry rather than aquatic biota.

(3)Ozone Effects. Ozone damage to plants is among the major concerns relating to terrestrial effects from air pollution in the Pacific Northwest. Existing data indicate that the current NAAQS for ozone (125 ppb maximum 1-h average, Table 1) may not adequately protect the more sensitive terrestrial vegetation. One of the difficulties in assessing the risk to vegetation, however, is using an appropriate measure that best reflects the response of plants to O_3 exposure. The controversy hinges on whether plants are impacted to a greater degree by short-term exposures to high concentrations or long-term exposure to lower concentrations of ozone. Lefohn (1992) presents a detailed analysis of the strengths and limitations of different ozone summary statistics used to quantify ambient ozone levels (see summary, Appendix D).

We have not resolved these issues but want to alert the reader to these and other issues that cannot be addressed in this report.

II. REGIONAL CHARACTERISTICS

The Pacific Northwest is a diverse region comprised of a coastal zone, the Cascade Range, and the Columbia Plateau provinces. We have followed the regionalization scheme of Fenneman (1946) shown in Figure 1, based on broad patterns in precipitation, vegetation, soils, and geology. These patterns reflect the major distinction in the region between the wet, mountainous areas in the west and the more arid climate to the east. The following sections provide a brief description of these physiographic provinces relevant to air quality issues.

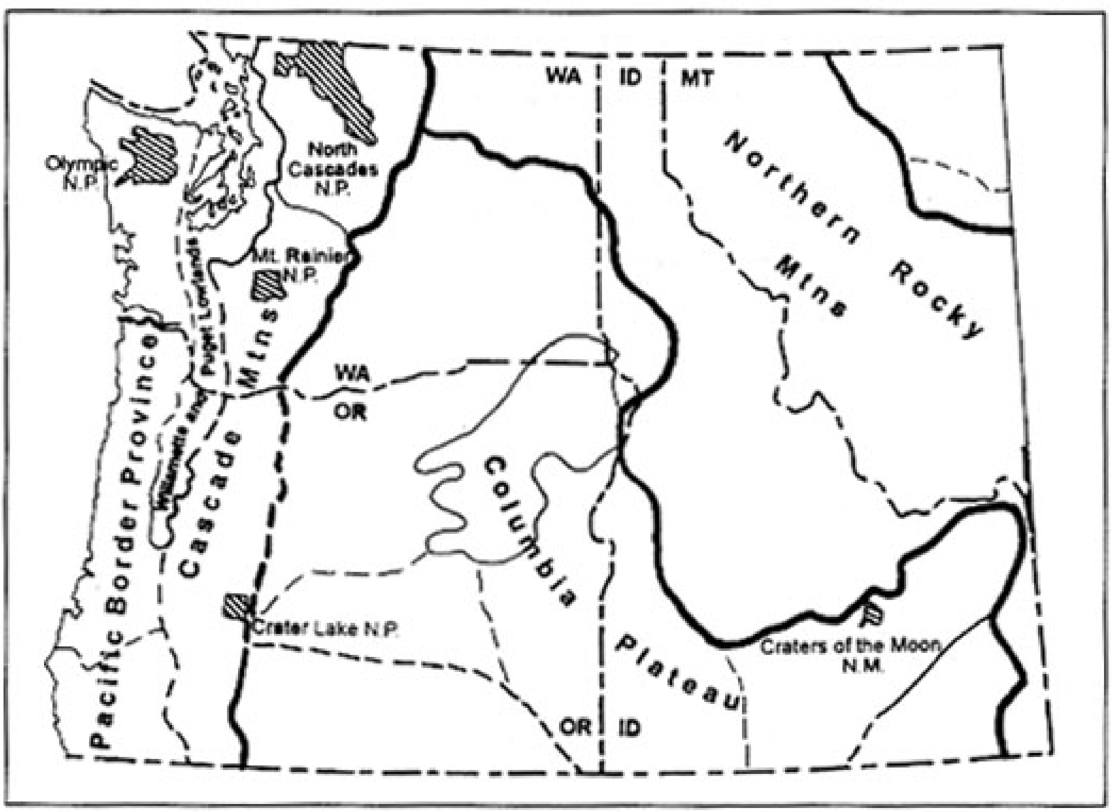

Figure 1. Physiographic provinces of the Pacific Northwest (Fenneman 1946) and location of class I national parks and monuments.

Figure 1.Physiographic provinces of the Pacific Northwest (Fenneman 1946) and location of class I national parks and monuments.

A. CASCADES/OLYMPIC

1.Regional Deposition and Air Quality

The air quality in Oregon and Washington generally is very good compared to other areas of the United States. The principal air masses are derived from the Pacific Ocean, and accumulated air pollutant loads entering the region are low. Emissions of principal air pollutants generated within the region are low relative to other regions (Table 2) and trends in some air quality indicators seem to be stable or improving (Washington Department of Ecology [WDOE] 1993, Oregon Department of Environmental Quality [ODEQ] 1993). A major reduction in sulfur dioxide (SO_2) emissions occurred in 1985 when the ASARCO smelter in Tacoma discontinued operation, thereby resulting in a reduction of 143,000 tons SO_2 per year (WDOE 1993). Air quality nonattainment areas within the region generally are confined to the major metropolitan areas of Seattle, Tacoma, and Portland, with the major exception of particulate matter (PM_{10}) exceedances in some smaller communities (WDOE 1993, ODEQ 1993). Because of measures to reduce air emissions, the number of air quality exceedances of Federal and state standards have declined appreciably over the last decade.

Table 2. Annual emissions (in thousands tons/yr) for Oregon and Washington.

	PM_{10}	SO_2	NO_x	NH_3	VOC	CO
Oregon[a]	201	70	213	19 [b]	220	1,538
Washington[c]	270	141	358	23 [c]	472	3,104
Total	471	211	571	42	692	4,642
As % of National[c]	NA	15	2	2	NA	NA

[a] ODEQ (1993)
[b] EPA (1989)
[c] WDOE (1993)
NA - data not available

The average concentrations of sulfur (S) and nitrogen (N) species in precipitation throughout the Pacific Northwest are low (Figure 2). Although the concentrations of pollutants in precipitation generally are low in the region, they are not uniform. Sulfate (SO_4^{2-}) and hydrogen ion concentrations in snow along the Cascades increase with increasing latitude, thereby suggesting that the deposition quality in the Washington Cascades may have been degraded relative to precipitation in the Oregon Cascades (Figures 3 and 4). Although some of the increased SO_4^{2-} can be attributed to marine aerosols, as represented by chloride (Cl^-) (Figure 5), most of the increased SO_4^{2-} is probably nonmarine and may be attributable to anthropogenic sources.

Although parameters such as S and N are comparatively low, ozone concentrations are high near some class I national parks in the Pacific Northwest. Ozone concentrations higher than 80 ppb[1] occur in the Washington Cascades during the summer months. In particular, national parks on the western slopes of the Cascades at higher elevations in Washington are particularly vulnerable. Basabe et al. (1989a) recorded peak hourly ozone concentrations ranging from 90-196 at six sites in forested areas of western Washington. Based on existing dose-response data, these O_3 concentrations may pose a threat to forest vegetation in Washington (Hogsett et al. 1989; Bytnerowicz and Grulke 1992; Peterson et al. 1992a,b; also see section IV).

Summaries of selected air quality and deposition data for the region are provided in Appendix B.

2. Emission Trends

Trends in emissions of most atmospheric pollutants in the region have shown a decline in recent years. The nature of the changes and expected future emissions, however, are highly dependent on assumptions regarding population growth and forecasts in economic development. Emissions of NO_x, VOC, and CO are very dependent on population projections. Emissions of

[1] Ozone values are expressed on an hourly basis throughout this report.

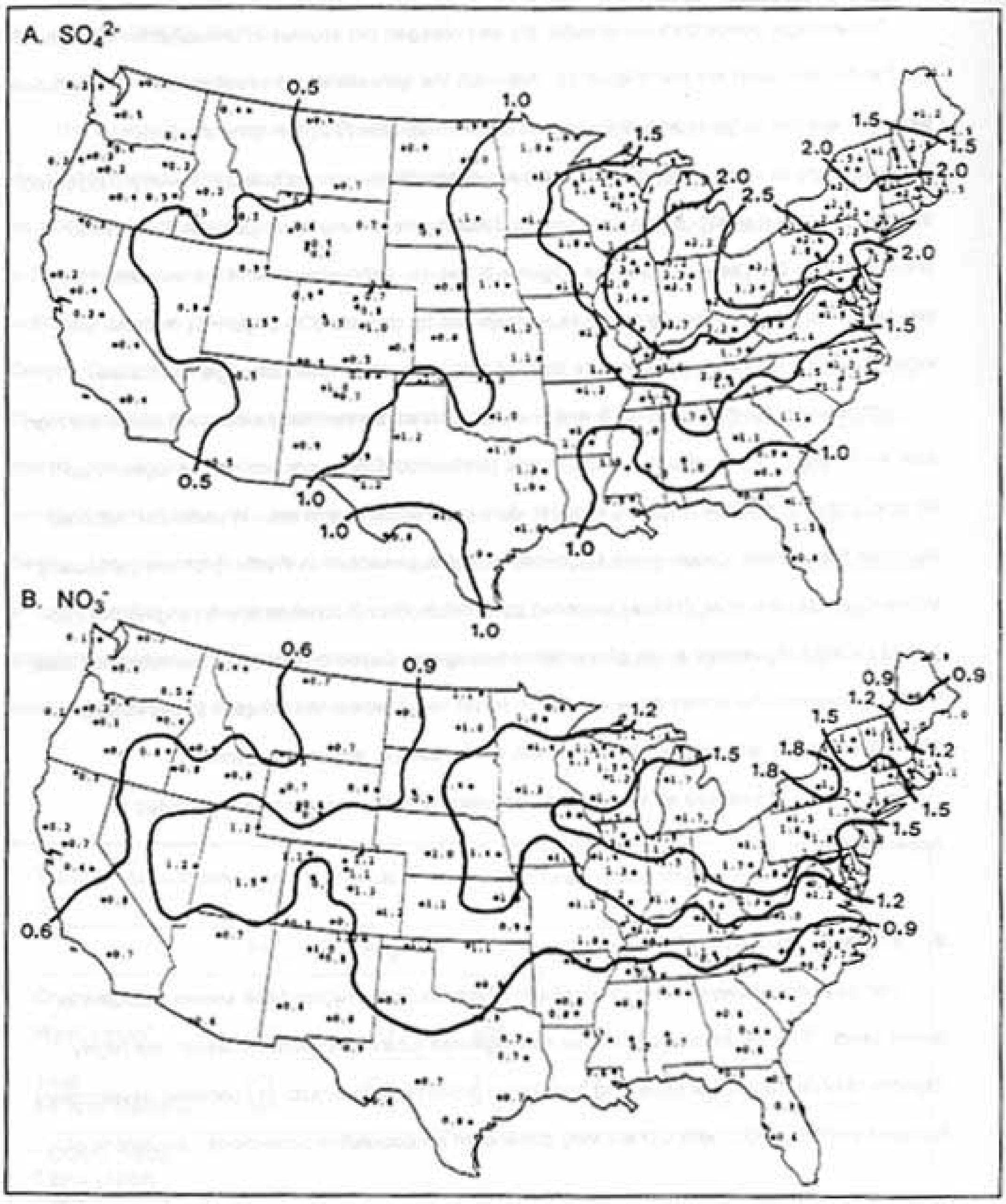

Figure 2. Precipitation-weighted concentrations of sulfate (SO_4^{2-}) and nitrate (NO_3^-) ions (both in mg/L) for the United States for 1992 (Source: NADP/NTN 1993).

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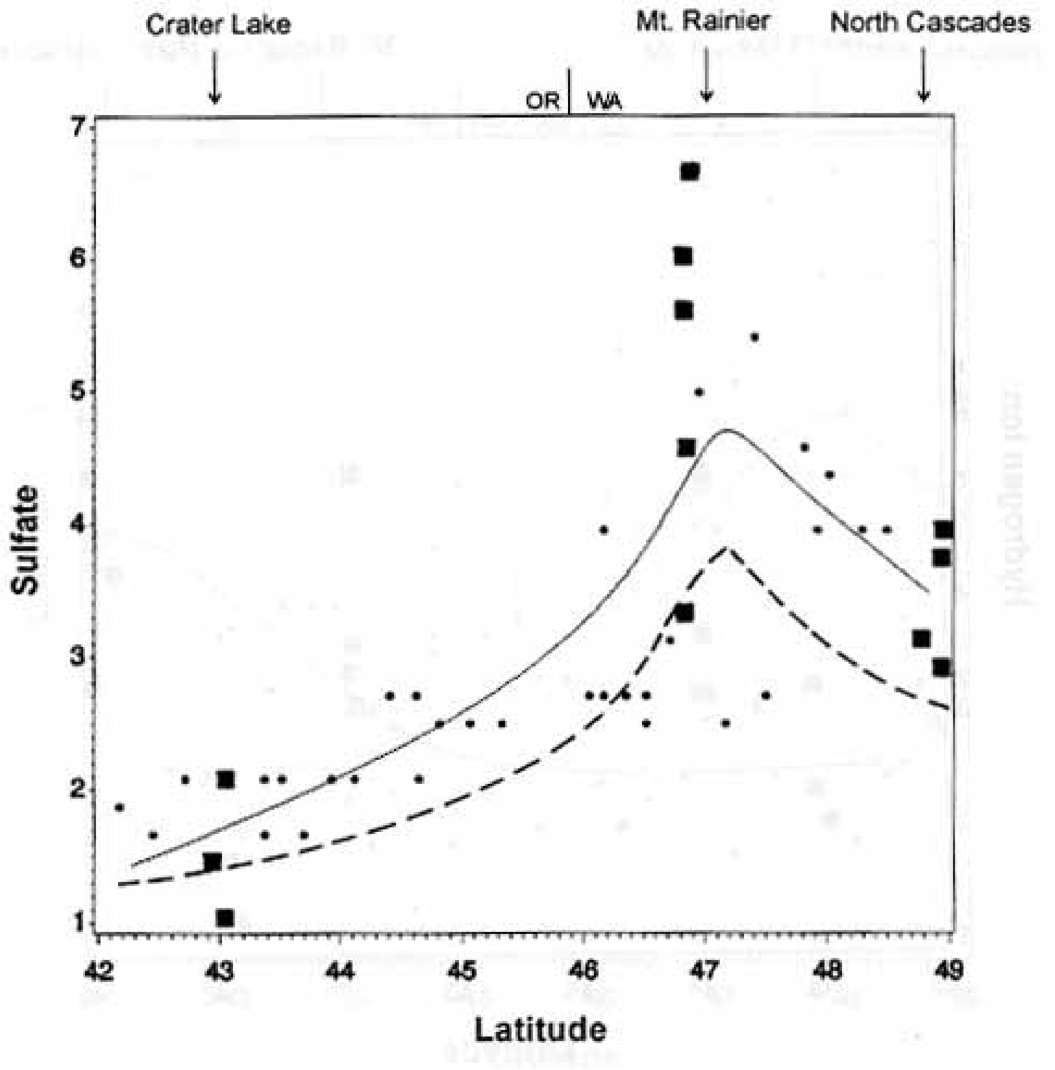

Figure 3. Concentration of sulfate (μeq/L) in snow versus latitude (degrees) for 1983 from the Oregon/California border (lat. 42°) to the Washington/Canada border (lat. 49°) as reported by Laird et al. (1986). The solid line is a cubic spline fit of the raw data. The dashed line represents the cubic spline fit of nonmarine sulfate. The rectangles represent samples collected within the national parks.

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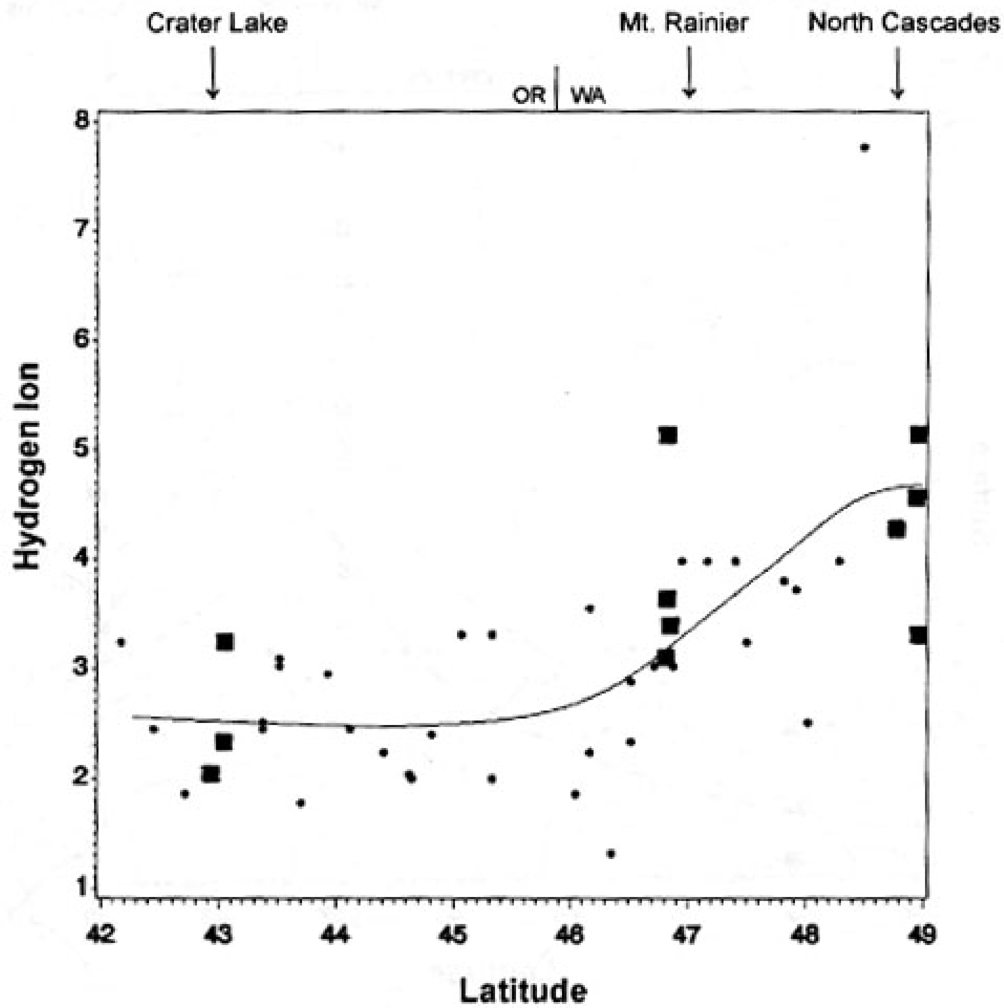

Figure 4. Concentration of hydrogen ion (μeq/L) in snow versus latitude (degrees) for 1983 from the Oregon/California border (lat. 42°) to the Washington/Canada border (lat. 49°) as reported by Laird et al. (1986). The line is a cubic spline fit of the raw data. The rectangles represent samples collected within the national parks.

Figure 4.Concentration of hydrogen ion (μeq/L) in snow versus latitude (degrees) for 1983 from the Oregon/California border (lat. 42°) to the Washington/Canada border (lat. 49°) as reported by Laird et al. (1986). The line is a cubic spline fit of the raw data. The rectangles represent samples collected within the national parks.

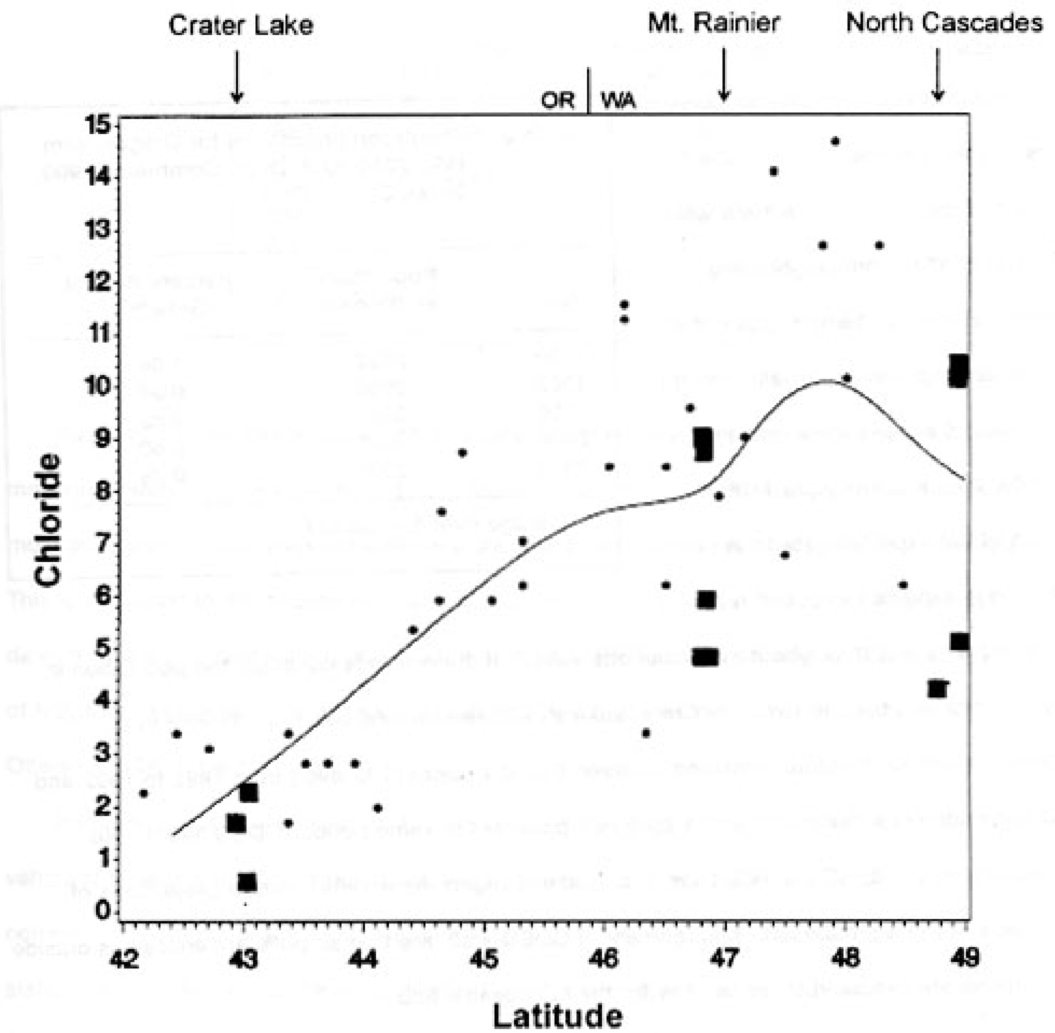

Figure 5. Concentration of chloride (µeq/L) in snow versus latitude (degrees) for 1983 from the Oregon/California border (lat. 42°) to the Washington/Canada border (lat. 49°) as reported by Laird et al. (1986). The line is a cubic spline fit of the raw data. The rectangles represent samples collected within the national parks.

Figure 5.Concentration of chloride (µeq/L) in snow versus latitude (degrees) for 1983 from the Oregon/California border (lat. 42°) to the Washington/Canada border (lat. 49°) as reported by Laird et al. (1986). The line is a cubic spline fit of the raw data. The rectangles represent samples collected within the national parks.

other pollutants such as SO_2 are more sensitive to assumptions in industrial activity and natural sources. These trends are best summarized by state.

a. Oregon

Population projections for Oregon assume an average state-to-state migration trend from 1975-1988 with declining influx from neighboring states. Recent patterns suggest that these assumptions are invalid and that Oregon will experience a growth rate greater than that shown in Table 3. Much of the expected growth in Oregon is expected to occur in the Portland area and throughout the Willamette Valley. If these trends continue, the population in the communities upwind (west) of Crater Lake should remain relatively low. Trends in O_3 concentrations for Medford remained between 0.07-0.11 ppm (1 hr avg.) from 1982 to 1992 and CO concentrations declined from 13 ppm to 8 ppm for the same period (ODEQ 1993). No exceedances of Pb, SO_2, or NO_2 have occurred in Oregon since 1984. Future trends in emissions for Oregon based on judgement of ODEQ staff is that air pollutant emissions outside of Portland are expected to remain low for the foreseeable future.

Table 3. Population projections for Oregon from 1990-2010 (U.S. Dept. Commerce 1990, Series C).

Year	Population (in millions)	Percent Annual Growth[a]
1990	2822	1.04
1995	2960	0.98
2000	3086	0.85
2005	3209	0.80
2010	3335	0.79

[a] Average over 5-yr period.

b. Washington

Population projections for Washington (Table 4) are subject to the same problems affecting those for Oregon. These population projections should be viewed as underestimates that nevertheless provide a framework for assessing future changes.

Table 4. Population projections for Washington from 1990-2010 (U.S. Dept. Commerce 1990, Series C).

Year	Population (in millions)	Percent Annual Growth[a]
1990	4796	1.63
1995	5157	1.51
2000	5477	1.24
2005	5775	1.09
2010	6060	0.99

[a] Average over 5-yr period

Washington also has experienced an overall decline in air pollutant emissions. Ambient air monitoring stations for sites with sufficient records show stable or declining concentrations of most pollutants. Sulfur emissions, in particular, have declined dramatically in the last decade. This is attributed to the decline in natural emissions of S from Mt. St. Helens (USGS, unpublished data) from 1980 to present and the closure of the ASARCO copper smelter in Tacoma. Emissions of NO_x from mobile sources are expected to continue their decline until the year 2005 (S. Otterson, WDOE, pers. comm.).

Emissions of NO_x are expected to begin increasing again in the year 2005 as increases in vehicular miles travelled outstrip reductions achieved in emissions controls (S. Otterson, pers. comm.). The single largest SO_2 source in Washington, the Centralia coal-fired power generating station, is expected to reduce its emissions from the current level of 60,000 tons/yr to a new allowance closer to 40,000 tons/yr by the year 2000 (L. Stookey, Southwest Air Pollution Control Association [SWAPCA], pers. comm.). This schedule is contingent on completion, review, and approval of the new acid rain regulations currently being drafted by SWAPCA under contract to WDOE through the authority of Title IV, 1990 Federal Clean Air Act.

3. Environmental Setting

Oregon and Washington are characterized by diverse climate and landforms. The states encompass wet coastal and dry interior mountain ranges, extensive coastline, interior valleys and basins, and high desert plateaus. Physiographic units that encompass class I national parks in this region include the Pacific Border Province (Olympics) and the Sierra-Cascade Range (Fenneman 1946). Diverse environmental conditions result in large part from the complex interaction between maritime and continental air masses and the mountain ranges that divide the states into western and eastern parts. The western region is influenced by the Pacific air masses which create mild year-round temperatures with persistent cloudcover and seasonally heavy rainfall. The eastern region combines features of both the maritime and continental climates, depending on location. Compared to the maritime climate, the continental climate has greater temperature fluctuations, colder winters, warmer summers, and less precipitation. Landforms range from level river valleys and lava plains to precipitous mountain slopes. Elevation extends from sea level to over 4200 m. Much of the landscape has been shaped by volcanism, although sedimentary and metamorphic geologic materials also are common. Soils in mountainous areas tend to be poorly developed, especially in areas subject to recent glaciation.

4. Vegetation

Natural vegetation in Oregon and Washington ranges from dense coastal rain forests through woodland and savanna to shrub steppe. Vegetation patterns respond in a large degree to sharp gradients in temperature and moisture extending from the coast to the interior plateaus. Forests of the western slopes and valleys are principally mesic temperate forests. Dominant tree species such as Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Sitka spruce (*Picea sitchensis*) attain their maximum size development there. Forests of the central and eastern regions are primarily Rocky Mountain types where the dominant species include ponderosa pine (*Pinus ponderosa*) at lower elevations and subalpine fir (*Abies amabilis*) at higher elevations. Detailed descriptions of the ecology, vegetation, and natural resources of the Cascade/Olympic Ranges can be found in Sierra Club (1985), Franklin and Dyrness (1988), Ruggiero (1991), and Matthews (1992). Olson et al. (1992) provides a broad overview of the physiography and forest types of the western Coast Ranges and Cascade Ranges. A partial species list for vascular plants in each national park is available in the NPFLORA database (Waggoner 1989). Additional vascular and nonvascular species lists for each class I national park are presented by Esserlieu and Olson (1986).

5. Aquatic Resources

In general, the aquatic resources of the region, particularly in the high-elevation areas, have been inadequately characterized. We are unaware of any systematic, comprehensive treatments of the aquatic biota in the Cascade Range. Some taxonomic groups such as amphibians (Leonard et al. 1993) and fishes (Wyodoski and Whitney 1979) are well described; however, the distributions of other important groups have not been characterized on a regional basis. Some fauna are described from studies of individual lakes or streams, although their representation elsewhere in the region awaits further investigation.

One generalization regarding the aquatic fauna that can be made is that diversity of most taxonomic groups in the Cascades is probably low relative to lowland areas in the region and elsewhere in the United States. This lowered diversity is a response, in part, to the harsh and extended winter conditions at high elevation, the low nutrient availability in many high-elevation lakes and streams, and restricted habitats. For example, fish historically were not present in most high-elevation lakes in the Cascades. They were introduced and continue to be stocked in hundreds of lakes in the region. Molluscs, which are very abundant in freshwaters throughout much of the eastern United States, are relatively uncommon throughout the Cascades. Aquatic macrophytes often are absent in Cascades lakes or restricted to a few species. Aquatic insects and other macroinvertebrates also tend to be less diverse than in other areas, although some orders such as Ephemeroptera, Trichoptera, and Plecoptera may be both abundant and diverse.

Selected water-quality data and references for relevant ecological data are presented in Appendix C.

B. COLUMBIA PLATEAU

1. Regional Deposition and Air Quality

The air quality in the Idaho portion of the Columbia Plateau generally is excellent. Areas in Idaho that do not meet air quality standards are restricted to two sites in the southern portion and two sites in the Panhandle. The four sites exceed PM_{10} standards, and one of the four exceeds carbon monoxide (CO) standards.

Wet deposition of pollutants in the region is also low for S and N (Figure 2), although concentrations of pollutants can be quite high in the arid environment. As is the case with much of the western United States, pollutant concentrations in precipitation are low on a regional basis and generally are high only at the local level.

2. Emission Trends

Population projections for Idaho are quite low and also indicate a declining trend (Table 5). There are no population centers in the vicinity of CRMO, and population trends do not suggest cause for immediate concern related to increased emissions associated with population growth.

Table 5.Population projections for Idaho from 1990-2010 (U.S. Dept. Commerce 1990, Series C).

Year	Population (in millions)	Percent Annual Growth[a]
1990	1012	0.50
1995	1036	0.47
2000	1056	0.39
2005	1076	0.38
2010	1097	0.39

[a] Average over 5-yr period

Table 6. Annual emissions (in thousands tons/yr) for Idaho.[a]

	SO_2	NO_x	NH_3
Idaho	36	88	20
% of National	<1	<1	<1

[a] EPA (1989)

Emissions of SO_2, CO, and lead decreased in 1985 to 1987 and have since remained stable at the levels provided in Table 6. Because Idaho's air quality meets National Ambient Air Quality Standards (with the exception of four nonattainment areas for PM_{10}), no published values are available on emission projections. Air quality in Idaho is expected to remain high for the foreseeable future.

3. Environmental Setting

The Columbia Plateau is one of three distinctive physiographic regions separating the Rocky Mountains from the Sierra-Cascade Range in the Intermontane Plateaus and Basins Province. This region consists of a massive lava plain in eastern Washington, eastern Oregon, and southern Idaho ranging from 1830-2150 m in elevation. The Snake River Plain in Idaho exhibits relatively flat terrain as it slopes from 1830 m at the northeastern end to 1000 m in south-central Idaho. The geology of the central Snake River Plain is dominated by volcanism, including large lava flows, cinder cones, lava caves, and canyons. Soil development is limited except in cracks in the surface of lava flows.

Annual precipitation averages 42.6 cm and has a bimodal distribution, with the major peak from snow in December-January, and a second peak from rain in May. The average monthly maximum temperature ranges from $-1.7\,^{o}$C in January to $28.7\,^{o}$C in July.

4. Vegetation

The vegetation of this region is dominated by big sagebrush (*Artemisia tridentata*)/grass/bitterbush (*Purshia tridentata*) associations (Blakesley and Wright 1988). Forested lands have limited range and are concentrated in microsites with deeper soil accumulations, higher moisture and moderate temperatures. Forest plant associations include Douglas-fir (*Pseudotsuga menziesii*)/mountain snowberry (*Symphoricarpos oreophilus*), limber pine (*Pinus flexilis*)/antelope bitterbush (*Purshia tridentata*), and quaking aspen (*Populus tremuloides*). Relevant descriptions of the ecology, vegetation, and natural resources of this region can be found in Blakesley and Wright (1988). Olson et al. (1992)

provided a broad overview of the physiography and forest types of the western intermontane plateaus and basins. A partial species list for vascular plants in each national park is available in the NPFLORA database (Waggoner 1989). Additional species lists for vascular and nonvascular plants in each class I national park are presented by Esserlieu and Olson (1986).

5. Aquatic Resources

The aquatic resources in the Columbia Plateau are limited because of the scarcity of lakes and streams. Precipitation in large portions of the region is only 25-50 cm/yr (10-20 in/yr) (Daly 1993), resulting in a desert biome. Biota in ephemeral streams and ponds is highly adapted to drought conditions and elevated water temperatures. Where water is available and nonsaline, aquatic biota can be very productive. Unlike the Cascades/Olympics, however, where water is abundant, water in the Columbia Basin is so limiting that its quality generally is secondary to its availability.

Selected water quality data and references for relevant ecological data are presented in Appendix C.

III.REGIONAL ECOLOGICAL MONITORING AND RESEARCH PROGRAMS

A.USDA FOREST SERVICE

1. Forest Health Monitoring Program

The Forest Health Monitoring Program and Air Resource Management Program are conducting research on the adverse effects of air pollutants on forest resources. Currently, the two programs are combining efforts to document and monitor responses of sensitive plant species to ozone and to identify ozone-sensitive plants as bioindicators of excessive ozone exposure in the western United States. Already underway on the east coast, the work is now being expanded to include western states. The use of bioindicators in western forests has not been possible because only a few species, such as coastal ponderosa pine (*Pinus ponderosa*), are known to exhibit definitive symptoms of ozone injury. The new ozone initiative is designed to identify common western plant species, including those of alpine communities, that show characteristic symptoms when exposed to phytotoxic doses of ozone. This data will be compiled to determine specific dose-response functions. The information will be useful in detecting ozone impact in the land management planning process, in the new source review process, and in developing state implementation plans.

In Phase I of the project, seeds will be collected from target species in the national forests, germinated and tested for ozone exposure at the Center for Forest Environmental Studies in Dry Branch, Georgia. In Phase II, western researchers including EPA in Corvallis, will conduct sensitivity studies in the field by using species identified in Phase I.

2. Forest Response Program

The Forest Response Program was developed in 1985 as part of the National Acid Precipitation Assessment Program (NAPAP). A joint effort of EPA and the U.S. Forest Service, the Forest Response Program evaluated the effects of acid rain and associated pollutants on forests. Research was conducted within four regional cooperatives, and coniferous forests in the 11 western states were under the jurisdiction of the Western Conifers Research Cooperative, which operated from 1986 to 1990. In addition, scientists from 11 universities, state agencies, and industry groups worked within the cooperative. The cooperative conducted studies across a range of scales from small open-top chambers to large regional comparative growth studies, and at various biological levels, including seedlings, trees, and stands. As a final product, the cooperative produced a book entitled, *The Response of Western Forests to Air Pollution* (Olson et al. 1992). The program formally ended in 1990.

3. Global Climate Change Program

The Forest Service's Global Climate Change Program (FSGCP) is part of the U.S. Government's Global Change Research Program, developed under the direction of the Office of Science and Technology Policy in the Office of the President. The FSGCP addresses potential changes in Earth's environment and associated effects on forest ecosystems, including reference to the management of forests and range lands. Air pollution and acidic deposition are two of the many factors addressed as part of global change.

An important objective of the FSGCP is the provision of scientific information to policy makers and land use managers. In particular, FSGCP provides the scientific basis to address three broad questions concerning global change and forest ecosystems:

1. What processes in forest ecosystems are sensitive to physical and chemical changes in the atmosphere?
2. How will future physical and chemical climate changes influence the structure, function, and productivity of forest and related ecosystems, and to what extent will forest ecosystems change in response to atmospheric changes?
3. What are the implications for forest management and how must forest management activities be altered to sustain forest productivity, health, and diversity?

All global change projects fall into one or more major program elements: (1) atmosphere/ biosphere gas and energy exchange, (2) disturbance ecology, (3) ecosystem dynamics, and (4) human activities and natural resource interactions. The first of these program elements examines the way in which climate and atmospheric chemistry shape and are shaped by the biological world, including greenhouse gas exchange with terrestrial ecosystems, and ozone concentrations and acidic deposition at many locations. As part of the second program element, smoke emissions and pollution are being mapped at the state level. The third program element is directed at understanding basic ecosystem processes, plant and animal viability, water quality and quantity, and vegetation and soil responses to global change. The main objective of this third element is to anticipate the ecosystem changes that will result from altered environmental conditions and to understand the sensitivity of key ecosystem components to different levels of stress. Species migration, changes in ecosystem composition, and threshold limits of ecosystem stability and diversity will be investigated partly using air pollution model scenarios. The fourth program element attempts to predict the effects of ecosystem change on communities and society, to evaluate forest policy options, and to reassess forest management decisions in light of these effects. In addition to research, development, and application activities, modeling, monitoring, and quality assurance also are important activities of the FSGCP.

The FSGCP is conducted through five regions (Pacific, Interior West, Northern, Southern, and the Forest Products Laboratory), and a national coordinating office. The Pacific region includes Alaska, California, Hawaii, Oregon, Washington, and the Pacific Islands. Air quality research in this region has focused on (1) measurement, remote sensing, and inventory of the role of wildfires and managed fires in the exchange of greenhouse gases and carbon to the atmosphere, (2) understanding the physiological response of stressed vegetation to acidic deposition, ozone, and carbon dioxide to predict future distribution and structure of western species and ecosystems, and (3) measurement and prediction of the role of forest soils as sources and sinks of greenhouse gases. Idaho is part of the Interior West Region. Atmospheric research in this region has focused primarily on greenhouse gas exchange.

Within the FSGCP, modeling will be used to represent current atmospheric conditions and to predict changes that could occur because of pollution. Combined with risk assessment, models will be used to evaluate alternative human activities and select appropriate strategies to minimize negative effects of changing air quality.

Monitoring will provide the baseline information for describing current resource conditions and trends. Ongoing monitoring within the Forest Service, primarily the Forest Inventory and Analysis, Forest Health Monitoring Program, and Long-Term Ecological Research (LTER) Program provide relevant information to the FSGCP. Forest Inventory and Analysis conducts comprehensive statewide inventories of forest resource conditions at 10-year intervals. Forest Health Monitoring also examines forest condition at finer scales. LTER sites conduct long-term intensive monitoring of forest conditions at yet a higher level of resolution.

B. CENTER FOR ANALYSIS OF ENVIRONMENTAL CHANGE

The Center for Analysis of Environmental Change (CAEC) was established in 1991 as a focal point for developing and coordinating long-term interdisciplinary environmental research. The CAEC is housed at Oregon State University and is supported by four organizations that involve more than 2,000 researchers and teachers in environmental and ecological sciences: Oregon State University, the U.S. Environmental Protection Agency, Corvallis, OR; the U.S. Forest Service, Pacific Northwest Research Station; and Battelle-Pacific Northwest Laboratories.

One of the six research areas for CAEC focuses on the effects of global and regional environmental change, especially the greenhouse effect, acid rain, and industrial pollution.

C. NATIONAL SCIENCE FOUNDATION

The LTER network of 17 sites was initiated in 1980 by the National Science Foundation to support long-term ecological research. The sole LTER site in the Pacific Northwest is on the H.J. Andrews Experimental Forest in the western Cascade Range of central Oregon. This site maintains a meteorological station, as well as a National Atmospheric Deposition Program (NADP/NTN) monitoring site.

D.U.S. ENVIRONMENTAL PROTECTION AGENCY

1. Temporal Integrated Monitoring of Ecosystems

The Temporal Integrated Monitoring of Ecosystems (TIME) program is under the direction of EPA at the Environmental Research Laboratory in Corvallis. The program is an outgrowth of EPA's Long-Term Monitoring program which was established as a lake and stream monitoring program to assess long-term changes in the acid-base chemistry of selected sensitive aquatic systems in selected portions of the United States (Newell et al. 1987). A series of manuscripts was recently published in *Water, Air, and Soil Pollution* (1993, Vol. 67) describing interim results from the project. Monitoring sites are located in New York, Maine, Vermont, Wisconsin, Minnesota, Michigan, and Colorado. There currently are no long-term monitoring or TIME sites in the Pacific Northwest, nor are we aware of any sites planned for this region.

2. Environmental Monitoring and Assessment Program

The goal of the Environmental Monitoring and Assessment Program (EMAP), in EPA's Office of Research and Development, is to monitor the ecological status and trends that would identify emerging environmental problems before they reach crisis proportions. The EMAP data are intended to provide a baseline against which future condition of resources can be measured and the overall effectiveness of environmental policies and programs can be evaluated. The scope of EMAP is comprehensive, both in spatial coverage (nationwide) and in subject coverage (all ecological resources).

The EMAP has four major organizational elements: resource monitoring, coordination, integration, and developmental research. Resource monitoring focuses on the collection and interpretation of field data on the ecological condition of eight resource categories: agroecosystems, arid lands, forests, estuaries, the Great Lakes, coastal waters, surface waters (lakes and streams), and wetlands. Coordination activities ensure standardized methods in data collection, network design and statistical analysis, logistics, quality assurance, technology transfer, and coordination/liaison with the international community, other agencies, states, and EPA regions. Integration activities serve to facilitate the acquisition, management, and interpretation of monitoring data.

Several groups in EMAP's resource monitoring program are engaged in activities that complement interests of the National Park Service with regard to characterizing and protecting ecological resources from deterioration of air quality. The Forest Resource group in EMAP is working with the U.S. Forest Service to implement a long-term interagency monitoring effort to assess the condition of forests. In the Surface Waters Resource group in EMAP, efforts are underway to sample fish, macroinvertebrates, amphibians, and diverse indicators of biotic integrity in many aquatic systems. A major activity of this group is the development of procedures for sampling surface waters to provide comparable, high-quality data for use in trend analysis. The statistically based design, if implemented on a national scale, would include monitoring selected lakes and streams in the Pacific Northwest.

As part of EMAP integration, the Air and Deposition group is developing a framework to consolidate existing air quality and deposition monitoring networks and new EMAP monitoring programs into a cooperative network to meet demand for information on deposition levels and environmental effects as required by amendments to the Clean Air Act. As part of this effort, the Air and Deposition group provided quality assurance support and partial funding to help maintain the National Atmospheric Deposition Program's (NADP) National Trends Network (NTN). Another priority for the group has been to evaluate existing network capabilities to provide air quality and deposition data for determining exposure levels to ecological resources located in nonurban environments. A master database incorporating information from several monitoring networks is being developed to facilitate analyses on spatial and temporal trends that will identify where monitoring sites are needed or where redundancies occur.

EMAP Air and Deposition is part of a multiagency group that oversees the cooperative monitoring network. Other members of the network include the U.S. Geological Survey, the U.S. Forest Service, the National Oceanic and Atmospheric Administration, the National Park Service, and state agencies from California, Wisconsin, Michigan, New

York, and Vermont. Canadian participants from Environment Canada and the Ontario Ministry of the Environment are also included.

Of particular interest in the coordination category is the Indicators group. One activity of this group has been to develop an approach to: (1) describe ecological condition, (2) integrate among resource categories, and (3) compile data and expertise to characterize spatial and temporal variability of proposed ecological indicators. As part of the landscape approach, the data on indicators of ecological condition will be measured in the field and stored in a GIS format along with remote-sensed data. The GIS technology will permit the assessment of trends, or changes in ecological indicators over time and at various spatial resolutions.

Although EMAP has not yet been implemented on a national scale, regional pilot studies have been undertaken. The EMAP Surface Waters and related field activities in the western United States include studies underway at Oregon State University to evaluate approaches for assessing the physical, chemical, and biological status of streams (Kaufmann, pers. comm.) and Regional EMAP ("REMAP") surveys undertaken in cooperation with the water quality agencies of Oregon and Washington to evaluate the biological integrity, physical habitat, and water chemistry in Coast Range and Yakima Valley streams (EPA Region 10, Seattle; and Oregon State University).

3.Biodiversity Consortium

To identify sensitive species as biomonitors of pollution, the NPS may benefit from coordination with the new Biodiversity Research Consortium at the EPA's Environmental Research Laboratory in Corvallis (ERL-C). The Biodiversity Research Consortium was created to foster cooperation among research groups concerned with biodiversity. Currently, the Consortium consists of the U.S. Fish and Wildlife Service, the U.S. Forest Service, the U.S. Geological Survey, the Nature Conservancy, and the U.S. EPA. As part of the newly formed Consortium, the EPA Habitat/Biodiversity Research program is developing a strategy for identifying areas in the United States that are at risk of further reduction in native species. This objective overlaps with NPS interests in identifying sensitive aquatic and terrestrial species at risk from air pollution. The researchers are identifying the groups of species that contribute the highest genetic diversity in specific areas and the types of landscapes associated with these groups of species. The goal of the Consortium is to develop the technical information, databases, and methods necessary to quantify the relative risks to biodiversity from environmental stressors.

An initial effort, now being tested at a pilot scale, is to categorize and map vertebrate diversity for 12,500 sampling units covering the conterminous United States. This effort will utilize the Nature Conservancy's data on the distribution of vertebrate species in relation to anthropogenic stressors. At present, the Biodiversity Research Consortium is the only peer-reviewed U.S. EPA-sponsored program that is ranking habitat and biodiversity resources by using a risk-based framework (EPA 1993a).

4.Tropospheric Ozone Program

The Ecological Effects of Tropospheric Ozone Research program addresses the needs of EPA and the Office of Air Quality Planning and Standards in establishing the NAAQS (primary and secondary) for tropospheric ozone. Four policy-related questions are relevant to assessing the current NAAQS for forest trees in the United States:

1. What is the nature, magnitude, and extent of ozone injury in forests of the United States?
2. What are the functional and empirical relations between ozone exposure and tree response?
3. What are the primary harmful effects of ozone exposure on forest trees?
4. What are the probable long-term consequences of ozone exposure on forest resources in the United States?

Because the existing data were judged by EPA to be insufficient to answer these policy questions, the following six program objectives have been formulated:

1. Identify forest tree species most at risk from ozone exposure, based on current information.
2. Determine the physiological sensitivity and variation in response for several important tree species.
3. Develop dose-response functions over a range of tree ages and sizes.
4. Determine the relation between components of ozone exposure and tree response. Those components include concentration, frequency, duration of episodes and respite times, and seasonal sensitivity. Once the components are quantified, develop ozone exposure indices that are biologically meaningful for a long-lived species.
5. Develop process-based models that incorporate the effects of changing ozone air quality on trees and, in particular, incorporate the output from growth models into stand models to investigate long-term effects on forest communities.
6. Characterize the risk of ozone levels on long-term growth of tree species and forest species composition, including variability due to environment, age/size, and genetic factors.

The program focuses on the whole-tree level of biological complexity. These investigations examine ozone effects at all life stages (seedling, sapling, and mature tree) and in relation to the interactive role of environment (biotic and abiotic) and genetics in the response. Presently, the research covers three regions (Southeast, North, and Pacific Northwest) and three species from each region. Tree species studied in the Pacific Northwest include ponderosa pine (*Pinus ponderosa*), red alder (*Alnus rubra*), and Douglas-fir (*Pseudotsuga menziesii*).

Data on tree physiological response are input to the TREGRO model (Appendix D.3) to determine carbon gain, allocation, and the long-term effect on tree productivity. Because of the long-lived nature of trees and the wide variation in growing environments, the mechanistic and exposure-response studies must be linked to the process-based model, TREGRO, and the stand-level model (ZELIG; Appendix D.3), using a risk characterization approach and GIS. The result will be a spatial integration of the species response functions and simulated response functions with ambient ozone exposure, species/stand/habitat distribution, and relevant environmental factors for risk characterization.

The GIS-based assessment has been developed as an interactive tool to predict the vulnerability of tree species/forest types/habitats to current and predicted ambient ozone levels, across different site conditions and climatic scenarios, and under different control strategies for regulation of volatile organic compounds (VOCs) and nitrogen oxides (NO_x).

5.Miscellaneous Atmospheric Impact-Related Research

EPA (ERL-C) is currently conducting research in the Alaska arctic on long-range transport of airborne contaminants. Lake sediments and bryophytes are the primary receptors being monitored. The emphasis of the study is on accumulation of organochlorines and trace metals. Consideration is being given to extending the study area southward into Canada (in cooperation with the University of Alberta) and the conterminous United States, although no funds have been committed as yet (D. Landers, pers. comm.).

EPA (ERL-C) and the California Air Resources Board are funding a study of impacts of atmospheric deposition on snowpack accumulation of pollutants and its contribution to episodic acidification in the Sierra Nevada. Snow and runoff chemistry were collected in 1993 and 1994 (J. Stoddard, pers. comm.).

E. U.S. DEPARTMENT OF ENERGY

The U.S. Department of Energy (DOE) is funding projects to provide greater predictive capability in modeling the long-term effects of acidic deposition on surface waters. Recent advances in this area include an assessment of the importance of organic acids in forecasting the response of surface waters to acidic inputs (Driscoll et al. 1994, Sullivan et al. in review). Additional studies to evaluate the influence of watershed land use changes on acid-base chemistry are in progress, although research plans do not include analysis of sites in the Pacific Northwest.

F. U.S. GEOLOGICAL SURVEY

The U.S. Geological Survey (USGS) is the primary Federal agency responsible for collection of stream discharge data in the United States and operates a number of stream gauging sites in or near the national parks. The USGS historically has played an active role in various data collection efforts in the national parks, including snow sampling in NOCA, MORA, and CRLA (Laird et al. 1986) and hydrologic investigations at the various parks. The USGS has initiated a national program for assessing water quality in the United States involving detailed studies of major river basins. The National Water Quality Assessment (NAWQA) program has five study sites in the Pacific Northwest: Willamette River Basin, Oregon; Puget Sound Drainages, Washington; Yakima River Basin, Washington; Mid-Columbia Basin, Washington; and the Upper Snake River Basin, Idaho. Of these NAWQA study areas, the Puget Sound Drainages area is potentially relevant to OLYM, MORA, and NOCA. This is the first year of a six-year program, and data collection will not begin until 1995. A coordination meeting involving NPS and USGS staff was held in March 1994 (W. Staubitz, pers. comm.). The Yakima River Basin also drains the eastern portion of MORA. The CRMO is wholly within the Upper Snake River Basin area. The USGS and NPS have signed an agreement coordinating water quality work at national parks relevant to NAWQA. Under the agreement, the two agencies will increase their efforts in planning, collecting, analyzing, and interpreting water quality data from the national parks. The NPS will help locate and monitor pristine sites for ecological assessment. The USGS will provide scientists and technical personnel to conduct the water quality work (U.S. Geological Survey News Release, March 1994). A Federal position is being established at the USGS office in Reston, Virginia, to facilitate coordination between the two agencies (T. Maniero, pers. comm.).

G. U.S. FISH AND WILDLIFE SERVICE

The primary involvement of the U.S. Fish and Wildlife Service (USFWS) in air quality issues is through its interaction with the NPS. The NPS and USFWS signed a memorandum of understanding in which the NPS, Air Quality Division, and USFWS Air Quality Branch provide technical review of PSD applications that may affect USFWS class I areas (none located in the Pacific Northwest) (Bunyak 1993). The USFWS is responsible for administration of the Endangered Species Act and development of recovery plans associated with threatened and endangered species. Three major activities are involved in protecting endangered species: (1) list the species, (2) define critical habitat, and (3) create recovery plans. Of these activities, the process of defining critical habitat and developing recovery plans often can involve park service personnel. We are unaware of species listings at this time in the Pacific Northwest that are related to atmospheric impacts.

The USFWS has been involved in research related to environmental contaminants and species health and diversity. The GAP analysis of biological diversity is a research effort within the newly established NBS designed to estimate species richness and potential habitats of plants, vertebrates, and invertebrates (Scott et al. 1990). It is conceivable that future developments in the GAP program may aid the NPS in identifying critical areas for species sensitive to air pollution.

H. STATE AGENCIES

The state governments of Idaho, Oregon, and Washington are responsible for monitoring air and water quality and enforcing regulations to maintain these resources. Because states have primacy for their respective air quality programs, permit applications for PSD actions are approved or disapproved at the state level. The NPS reviews PSD applications for proposed emission sources which may have the potential to impact class I areas managed by the NPS or USFWS. The state agencies maintain a network of air quality monitoring stations that provide potentially useful information on local air quality and trends in air quality. For the most part, the state monitoring networks concentrate on urban areas. Currently, there are no acid precipitation or deposition research programs operated by these states, although the Washington Department of Ecology formerly designated a coordinator for such activities and funded several investigations on lake response to atmospheric deposition. Current research conducted by these state agencies that is most relevant to this study concerns the status of aquatic biota, especially fish. The state fish and game agencies are responsible for supervising fish stocking programs and historically have been proactive in furthering stocking programs, particularly in the Cascades.

Oregon and Washington are conducting joint projects with EPA to develop biological indicators of water quality. These Regional Environmental Monitoring and Assessment Program (REMAP) projects are coordinated through EPA Region 10 (Seattle) in conjunction with EPA research scientists in Corvallis.

I. AMPHIBIAN DECLINE

The current status of amphibian populations recently has become a major concern to biologists worldwide. Various hypotheses have been proposed to explain recent loss of amphibian populations, including predation by exotics (e.g., fish stocking), loss of habitat, increased UV radiation, widespread use of pesticides, acidification, and atmospheric contaminants. The Declining Amphibian Task Force (a component of the Survival Commission of the World Conservation Union) has been established at the EPA-Environmental Research Laboratory in Corvallis, Oregon.

The Pacific Northwest is an important region for some of the research in this field, with projects being conducted in NOCA (Liss et al. 1991), MORA (B. Samora, pers. comm.), and OLYM. The study by Liss et al. (1991) is testing the hypothesis that fish stocking is impacting other biological resources in the lakes, including amphibian populations. The amphibian project in MORA is being conducted by park staff and involves identification of amphibian species and measurement of field chemistry (pH, alkalinity, conductivity, dissolved oxygen, and temperature) and major ions at selected potential breeding sites in the park.

J. INDUSTRY

1. National Council of the Paper Industry for Air and Stream Improvement

The National Council of the Paper Industry for Air and Stream Improvement (NCASI) is a nonprofit environmental research group initially formed in 1943 by individuals in the pulp and paper industry. It has since expanded to cover several environmental quality and management interests of the forest products industry. Project areas include (1) effluent and ambient air impacts; (2) emission and effluent control and monitoring; (3) solid and hazardous waste management; (4) impacts of forestry practices on the quality of water, air, and wildlife habitat; (5) influence of air pollution on productivity of forests; and (6) workplace air quality monitoring. NCASI is geared to respond in a timely manner to urgent questions.

Products include technical bulletins (600 to date), special reports, forestry program news (published monthly), regional meetings (held annually), and special technical sessions (as needed, regionally and nationally).

NCASI maintains four regional offices and three aquatic biology research stations. Briefly, the program goals are to (1) provide a strong technical database to the forest products industry on the design and operation of waste control systems and on regulatory proposals; (2) aid industry in the development of environmental protection programs consistent with current technological and economic realities; (3) respond to current questions on environmental impact; and (4) provide quick response to new issues and concerns on environmental impact and protection.

Program areas relevant to air quality are as follows:

Emission Quality Program Elements
- Emission monitoring
- Emission control

Forestry Practices Program Elements
- Water quality protection
- Air quality impact protection
- Wildlife management

Environmental Effects Program Elements
- Experimental stress
- Fresh water bioassay procedures
- Marine water bioassay procedures
- Dispersion modeling

NCASI does not sponsor independent monitoring of air quality except for emissions near discrete industrial point sources, such as mill sites (NCASI 1974). They have, however, summarized and reviewed air quality data from established monitoring stations. For example, ambient ozone monitoring data from around the United States during the period 1978 to 1983 were summarized in NCASI Technical Bulletin 502. Ozone levels in the western United States were summarized in Van Haren (1987, NCASI Technical Bulletin 495).

Air quality research efforts at NCASI during the past 12 years have focused on data summary and interpretation, policy review, and method evaluation (NCASI 1964, 1982, 1987, and 1989). Of special interest to western forests, the forest products industry through NCASI, began to assess the effects of regional air pollution on forest health and productivity in the Northwest in 1985. The particular area of concern was Puget Sound, near Seattle, Washington. The NCASI, in cooperation with the Western Conifers Research Cooperative of NAPAP, supported research on temporal patterns of tree growth at low-to-mid elevation forests in western Washington. Study sites included the northwestern Cascades and the Olympic Mountains, with several sites in Mount Rainier and Olympic National Parks (Brubaker and Ford 1993).

NCASI also has studied the movement of industrial pollutants into aquatic sediments and effects on aquatic invertebrates (NCASI 1984).

2. Weyerhaeuser Paper Co.

Weyerhaeuser Paper Company is funding a five-year study on the acid-base chemistry of two lakes in the Goat Rocks Wilderness located southeast of MORA and a companion study of snow sampling at six sites in the Washington Cascades. Lake sampling was initiated in August 1993 and snow sampling began in April 1994. This is required by Washington DOE as a condition for a PSD permit to increase emissions at their Longview, Washington facility. One of the snow sampling sites is located at Paradise in MORA. The lake sampling was initiated in 1993 and the snow sampling in 1994. Study plans include use of the MAGIC model to simulate the response of lake and soil chemistry to changes in acidic deposition (J. Yount, pers. comm.).