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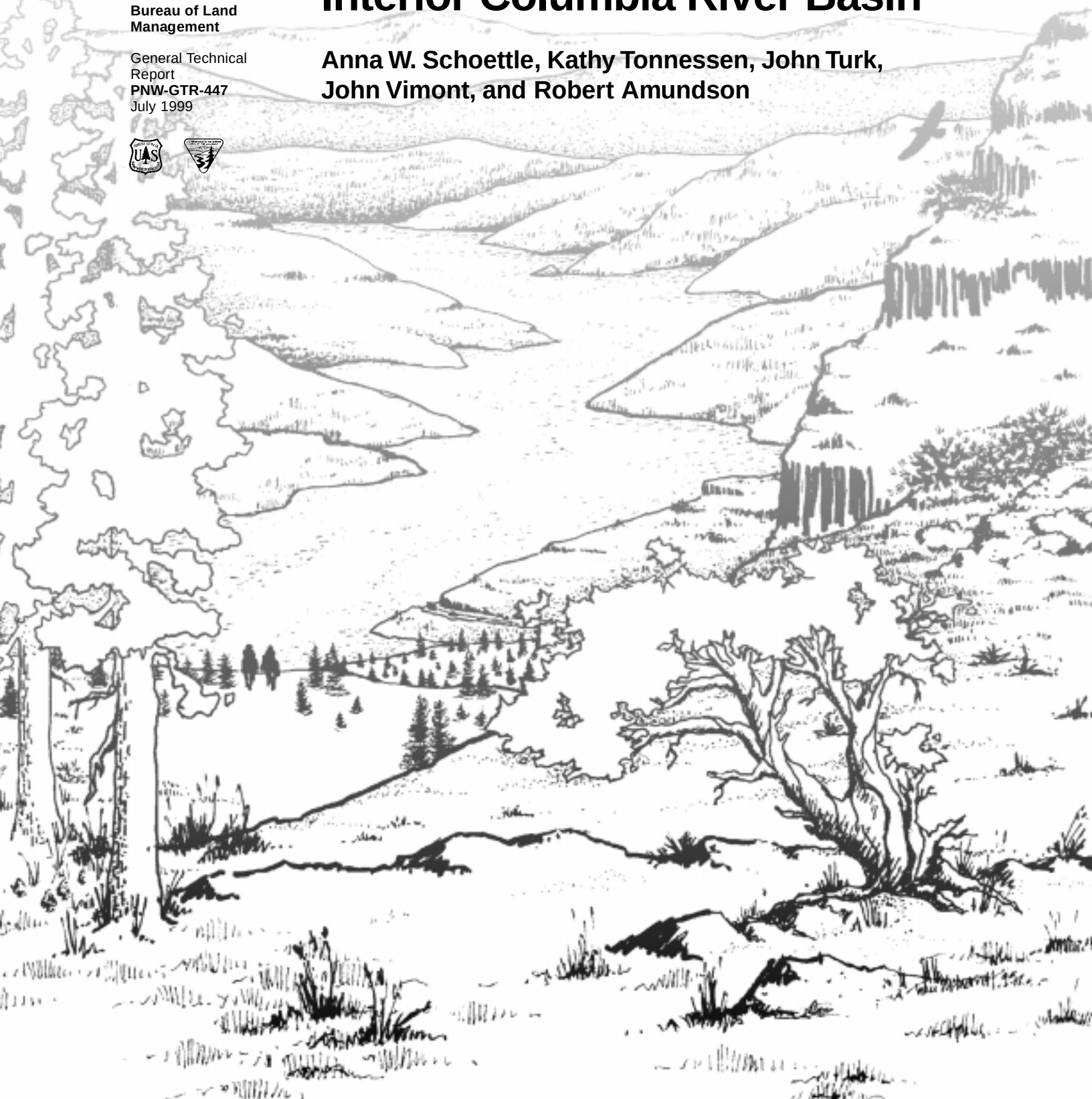
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An Assessment of the Effects of Human-Caused Air Pollution on Resources Within the Interior Columbia River Basin

**Anna W. Schoettle, Kathy Tonnessen, John Turk,
John Vimont, and Robert Amundson**



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An Assessment of Effects of Human-Caused Air Pollution on Resources Within the Interior Columbia River Basin

Anna W. Schoettle, Kathy Tonnessen, John Turk, John Vimont, and
Robert Amundson

Ann Acheson and Janice Peterson, Technical Editors

Interior Columbia Basin Ecosystem Management Project: Scientific Assessment

Thomas M. Quigley, Editor

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Abstract

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An assessment of existing and potential impacts to vegetation, aquatics, and visibility within the Columbia River basin due to air pollution was conducted as part of the Interior Columbia Basin Ecosystem Management Project. This assessment examined the current situation and potential trends due to pollutants such as ammonium, nitrogen oxides, sulfur oxides, particulates, carbon, and ozone. Ecosystems and resources at risk are identified, including certain forests, lichens, cryptogamic crusts, high-elevation lakes and streams, arid lands, and class I areas. Current monitoring data are summarized and air pollution sources identified. The assessment also includes a summary of data gaps and suggestions for future research and monitoring related to air pollution and its effects on resources in the interior Columbia River basin.

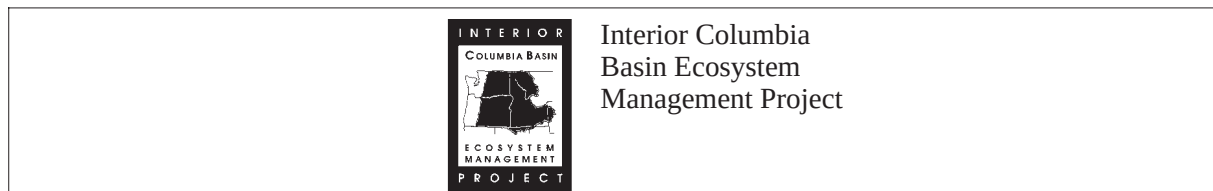
Keywords: Atmospheric deposition, acid rain, air pollution, aquatic effects, class I areas, terrestrial effects, sensitive species, visibility.

Preface

The Interior Columbia Basin Ecosystem Management Project was initiated by the Forest Service and the Bureau of Land Management to respond to several critical issues including, but not limited to, forest and rangeland health, anadromous fish concerns, terrestrial species viability concerns, and the recent decline in traditional commodity flows. The charter given to the project was to develop a scientifically sound, ecosystem-based strategy for managing the lands of the interior Columbia River basin administered by the Forest Service and the Bureau of Land Management. The Science Integration Team was organized to develop a framework for ecosystem management, and assessment of the socioeconomic and biophysical systems in the basin, and an evaluation of alternative management strategies. This paper is one in a series of papers developed as background material for the framework, assessment, or evaluation of alternatives. It provides more detail than was possible to disclose directly in the primary documents.

The Science Integration Team, although organized functionally, worked hard at integrating the approaches, analyses, and conclusions. It is the collective effort of team members that provides depth and understanding to the work of the project. The Science Integration Team leadership included deputy team leaders Russel Graham and Sylvia Arbelbide; landscape ecology—Wendel Hann, Paul Hessburg, and Mark Jensen; aquatic—Jim Sedell, Kris Lee, Danny Lee, Jack Williams, Lynn Decker; economic—Richard Haynes, Amy Horne, and Nick Reyna; social science—Jim Burchfield, Steve McCool, and Jon Bumstead; terrestrial—Bruce Marcot, Kurt Nelson, John Lehmkuhl, Richard Holthausen, and Randy Hickenbottom; spatial analysis—Becky Gravenmier, John Steffenson, and Andy Wilson.

Thomas M. Quigley
Editor



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Introduction

One of the building blocks of any ecosystem, at any scale, is air and its condition or quality. As human populations increase, they have an effect on air quality, which has an effect on ecosystems. It is appropriate, therefore, to evaluate as part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP), the current condition and expected trends in air quality and its effects to resources within the Columbia River basin (also referred to as “the basin”).

A team of scientists gathered to conduct such an evaluation. The team was familiar with the resources within the ICBEMP, and their expertise encompassed the areas of climate, atmospheric deposition, aquatic ecosystems, vegetation, and visibility (visual effects). They focused their work on assessing the effects of human-caused air pollution on natural resources. This pollution is normally associated with industry and urban lifestyles, such as power plants or traffic emissions, but can include agricultural and silvicultural practices. The team omitted an evaluation of human health effects to limit the scope so that a product could be delivered within the time allotted. A different team performed an extensive analysis of smoke effects generated from wildland fire. The climate and meteorology of the interior Columbia River basin are discussed by Ferguson (1997, 1998).

The evaluation of air quality and its effects within the basin was conducted through review of existing data (national databases where possible) about emissions, atmospheric deposition, snow and lake chemistry, vegetation, and visibility; development of tools to analyze weather and climate patterns affecting the basin; literature reviews; and conversations with other experts in the field. A geographic information system (GIS) was used as a mapping tool to identify areas potentially impacted by air pollution based on a resource’s sensitivity to air pollution, its proximity to emissions sources, and meteorology. Other politically designated areas sensitive to air pollution, such as class I or nonattainment areas (table 1, appendices 1 and 2; defined in “Definitions of Terms Used”), also were mapped (fig. 1). The prevention of significant deterioration of air quality

within class I areas is mandated by the 1977 and reinforced by the 1990 Clean Air Act amendments (U.S. Laws, Statutes 1977, Public Law 95-95, and U.S. Laws, Statutes 1990, Public Law 101-549, respectively). Federal land managers of class I areas have an affirmative responsibility to protect the air-quality-related values of these areas from adverse effects of air pollution. This report is organized into discussions of atmosphere-biosphere interactions, aquatic ecosystems, terrestrial ecosystems, and visibility.

Data Used to Evaluate Air Quality Condition

Emissions and monitoring data from within and around the basin were used to assess the current and predicted condition of air quality and its effects on resources. The emissions data for point and area sources (excluding silvicultural and agricultural burning) were from 1990 and were the same data compiled for the Grand Canyon Visibility Transport Commission (legislated by Congress to assess visibility and causes of impairment in national parks and wilderness areas of the Colorado Plateau). These data have been extensively reviewed and validated by the air regulatory agencies of the affected states. In general, emissions of air pollutants in the basin are less than in the Eastern United States or California (Environmental Protection Agency [EPA] 1994b), so basin air quality can be assumed to be relatively cleaner; however, long-term air-quality monitoring data for the basin do not exist (Böhm 1992, Lefohn and Lucier 1991).

This air-quality team focused primarily on the effects of the EPA “criteria” pollutants of particulate matter (PM-10), nitrogen oxides, and sulfur oxides, but also considered volatile organic compounds, ammonium, and ozone and some hazardous air pollutants. Other pollutants were considered based mainly on their effects to water or vegetation.

Ambient air monitoring data from national, state, or local monitoring were obtained through either the national EPA emissions inventory database or individual state agencies. The most recent year of data used was 1991, 1992, or 1993. Specifics of other monitoring data used in this report are described later.

Table 1—Potential air quality threats to vegetation in class I areas in the interior Columbia River basin assessment area

Class I area	State	Elevation		Potential threat			SO ₂ emissions within 25km ^a
		Low	High	Ozone	SO _x	NO _x	
		--Meters--					Tons per year
Alpine Lakes	WA	500	2408	yes ^b		yes ^b	<1000
Anaconda Pintlar	MT	1597	3290				<1000
Bob Marshall	MT	1257	2825				<500
Cabinet Mountains	MT	940	2663				<1000
Caribou	CA	2000	2553				<1500
Crater Lake							
National Park	OR	1433	2486				<500
Craters of the Moon							
National Monument	ID	1625	2356				0
Eagle Cap	OR	853	2999				<5500
Flathead	MT	768	2762				<5000
Gates of the Mountain	MT	1174	2425		yes		<21,000 ^c
Gearhart Mountain	OR	1798	2528	yes ^b			<500
Glacier National Park	MT	975	3190				<28,500
Glacier Peak	WA	600	2679	yes ^b		yes ^b	<500
Goat Rocks	WA	885	2500	yes ^b		yes ^b	0
Grand Teton							
National Park	WY	1951	4197				0
Hells Canyon	ID,OR	244	2863				<2500
Jarbridge	NV	2134	3304				0
Lassen Volcanic							
National Park	CA	1634	2652				<1500
Lava Beds	CA	1231	1616				<500
Marble Mountain	CA	244	2530				<500
Mission Mountain	MT	1409	2799				<2500
Mount Adams	WA	1300	3751	yes ^b		yes ^b	0
Mount Hood	OR	1250	3424	yes ^b		yes ^b	<6000
Mount Rainier							
National Park	WA	512	4392	yes		yes	0
Mount Washington	OR	945	2376	yes ^b		yes ^b	<1500

Table 1—Potential air quality threats to vegetation in class I areas in the interior Columbia River basin assessment area (continued)

Class I area	State	Elevation		Potential threat			SO ₂ emissions within 25km ^a
		Low	High	Ozone	SO _x	NO _x	
		– –Meters– –			Tons per year		
North Cascades							
National Park	WA	600	2703	yes		yes	<500
Pasayten	WA	366	2721	yes ^b		yes ^b	<500
Red Rock Lake	MT	2012	3048				0
Sawtooth	ID	1219	3353				0
Scapegoat	MT	1566	2857				<500
Selway Bitterroot	MT	501	3088				<3000
South Warner	CA	1402	3015	yes ^d			<1000
Strawberry Mountain	OR	1463	2755				<1500
Three Sisters	OR	610	3157	yes ^b		yes ^b	<4500
Yellowstone							
National Park	WY, MT	1676	3220				<1000

^a Point source SO₂ emissions only.

^b Peterson and others 1992b.

^c Nonattainment area.

^d Peterson and others 1992a.

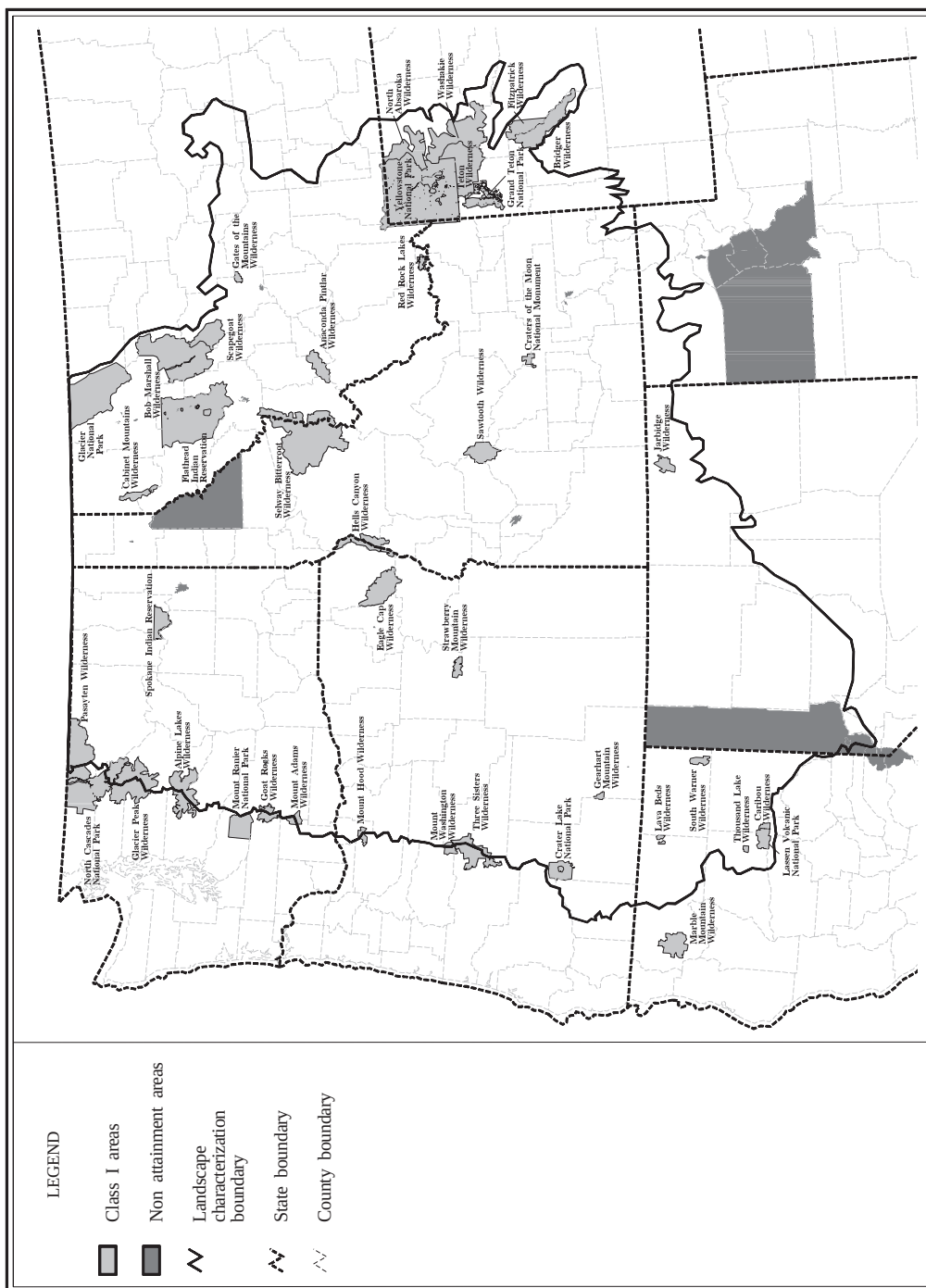


Figure 1—Class I and nonattainment areas within or near the interior Columbia River basin. See appendices 1 and 2 for specific information regarding class I and nonattainment areas.

Atmosphere-Biosphere Interactions

Air Pollutants of Concern

The need for abundant and reliable new energy sources, minerals, timber, and agricultural production will result in increased atmospheric emissions of pollutants in the basin and other western areas. To use these resources without damaging nearby wilderness areas and other Federal lands, land management decisions need to be based on an understanding of the present status of the basin's resources and the potential risk associated with atmospheric emissions.

Sulfur oxides (SO_x)—Sulfur is of concern because of its transformation to secondary pollutants such as sulfuric acid and sulfate particles, which affect vegetation, certain lakes and streams, and visibility. Globally, the major inputs of sulfur to the atmosphere come from seasalt (42.1 percent), human emissions (27.2 percent) biogenic gases (19.0 percent), volcanic emissions (5.8 percent), and gypsum dust (5.8 percent) (Brimblecombe and others 1989). Human-caused sulfur emissions are in the form of sulfur dioxide (Charlson and others 1992, Moller 1984). Charlson and others (1992) note that sulfur dioxide is converted to sulfate at a rate of about 1 percent per hour and that once converted to sulfate, the sulfur generally returns to Earth's surface as wet or dry deposition in about 2 days. Sulfur emissions are viewed as a regional issue because the sulfur may travel 1000 km¹ in a few days. Significant environmental effects are usually apparent within about 4 to 20 km of the source (Ludwig and others 1980).

Air arriving on the western shore of North America is relatively free of human-caused sulfur after traveling thousands of kilometers over open ocean. Human-caused sulfur found in the basin is probably from the large area and point sources located both outside and within the assessment boundary. The largest point sources, emitting more than 5,000 tons of sulfur per year, are in

the counties of Spokane, WA, Morrow, OR, Humboldt, NV, Bannock, ID, Caribou, ID, Lewis and Clark, MT, and Sublette, WY (fig. 2; see fig. 3 for a map of all counties within the basin). Area sources are aggregated by county. The counties within the basin having SO_x emissions between 1,000 and 5,000 tons per year are associated with the cities of Boise, Lewiston, and Idaho Falls, ID; Spokane, WA; and Bend, OR (fig. 4).

Nitrogen oxides (NO_x)—Human-caused alterations of N-cycling in managed and unmanaged ecosystems are of concern because nitrogen often limits primary productivity (Aber and others 1989, Field and Mooney 1986, Schulze and others 1994), and increased inputs of nitrogen to forest ecosystems have been associated with changes in plant community structure (Ellenberg 1988). Human-caused sources of nitrogen within the basin are associated primarily with combustion of fossil fuels for energy production and transportation and with changes in land use (agricultural and forestry practices).

Area sources for NO_x are more dispersed than for SO_x but still are associated with urban areas within the basin and on its western edge (fig. 5). The areas with the largest NO_x emission inventory are Portland, OR, and Seattle-Tacoma, WA, with emissions exceeding 20,000 tons per year. It is likely that most of these emissions are from vehicles.

The area emissions data available for this assessment did not include emissions of nitrogen oxides derived from soil microbial activity or fertilized agricultural land. The actual area emissions of nitrogen in the basin probably are higher than reported here.

Ozone (O₃)—Ozone is a colorless, odorless gas that is a secondary pollutant produced when emissions of volatile organic compounds combine with NO_x emissions in the presence of sunlight. Volatile organic compounds (VOCs) are emitted by both human and natural sources (vegetation for example). Ozone is formed in the atmosphere under hot, dry conditions and can be transported long distances from the source of the precursor emissions.

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¹ Units of measure shown in this document may be either metric or English, depending on the most frequently used convention for the particular parameter described. See the "Conversion Table" at the end of the text.

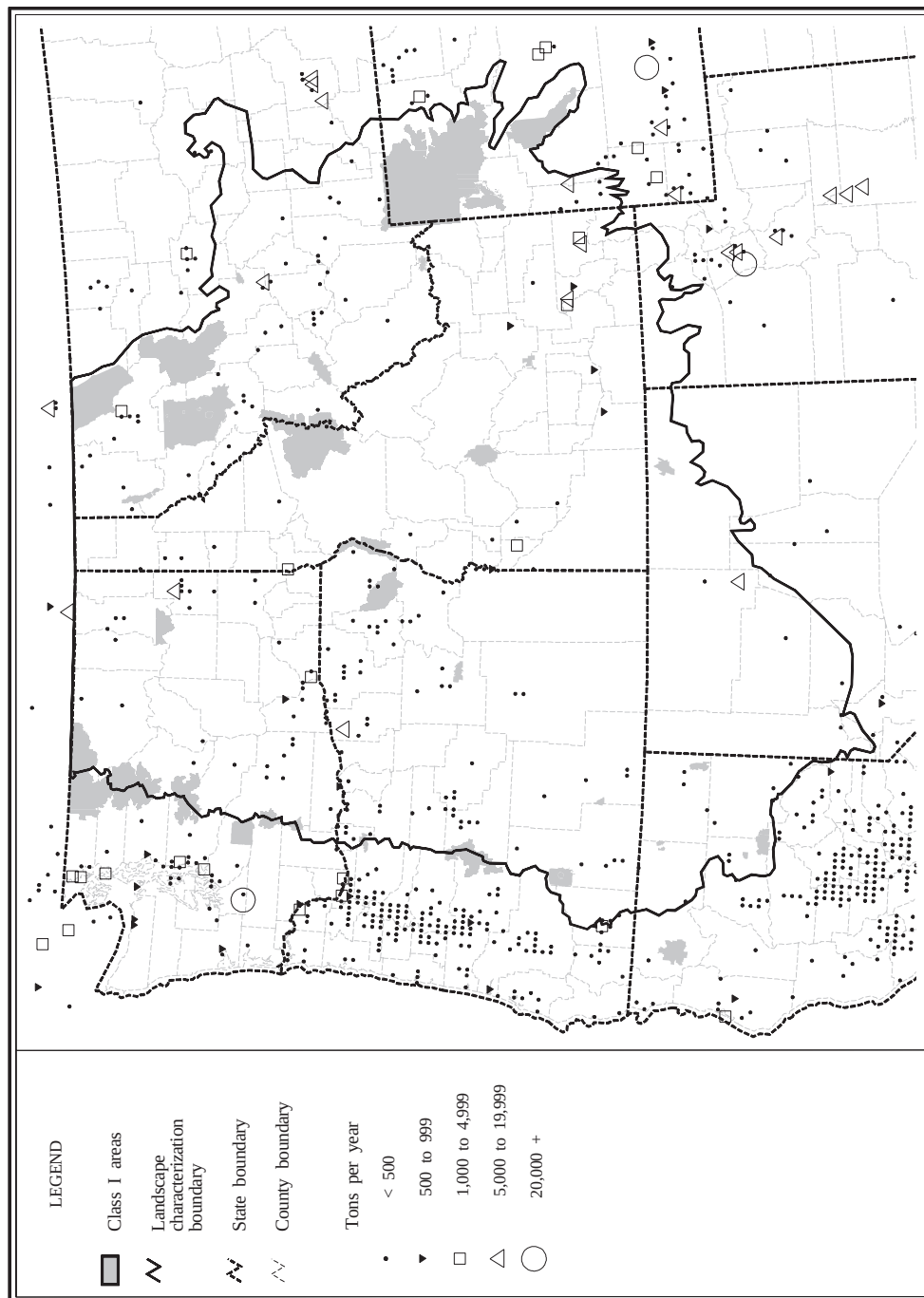
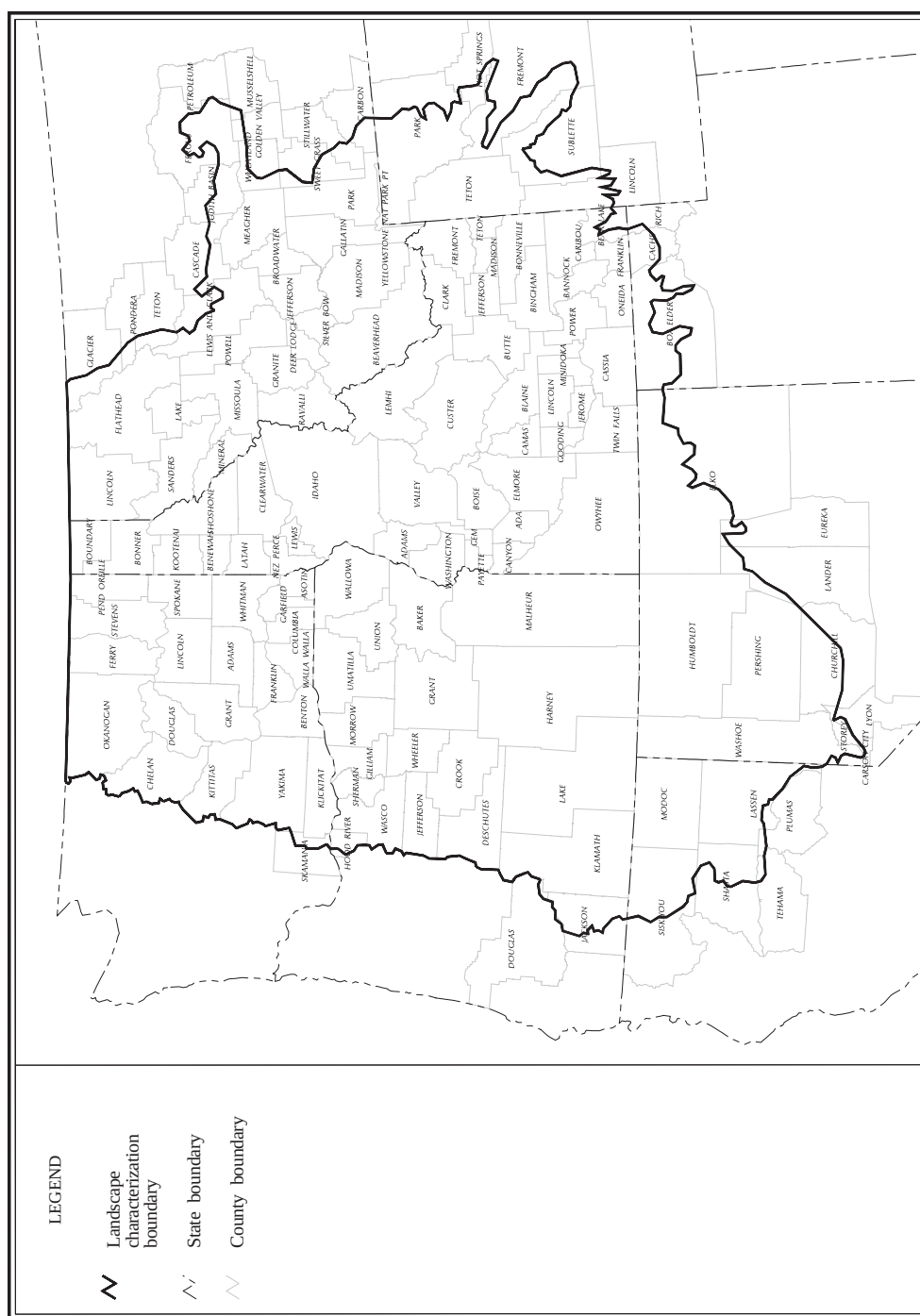


Figure 2—Sulfur oxide (SO_x) point source emissions within or around the interior Columbia River basin.



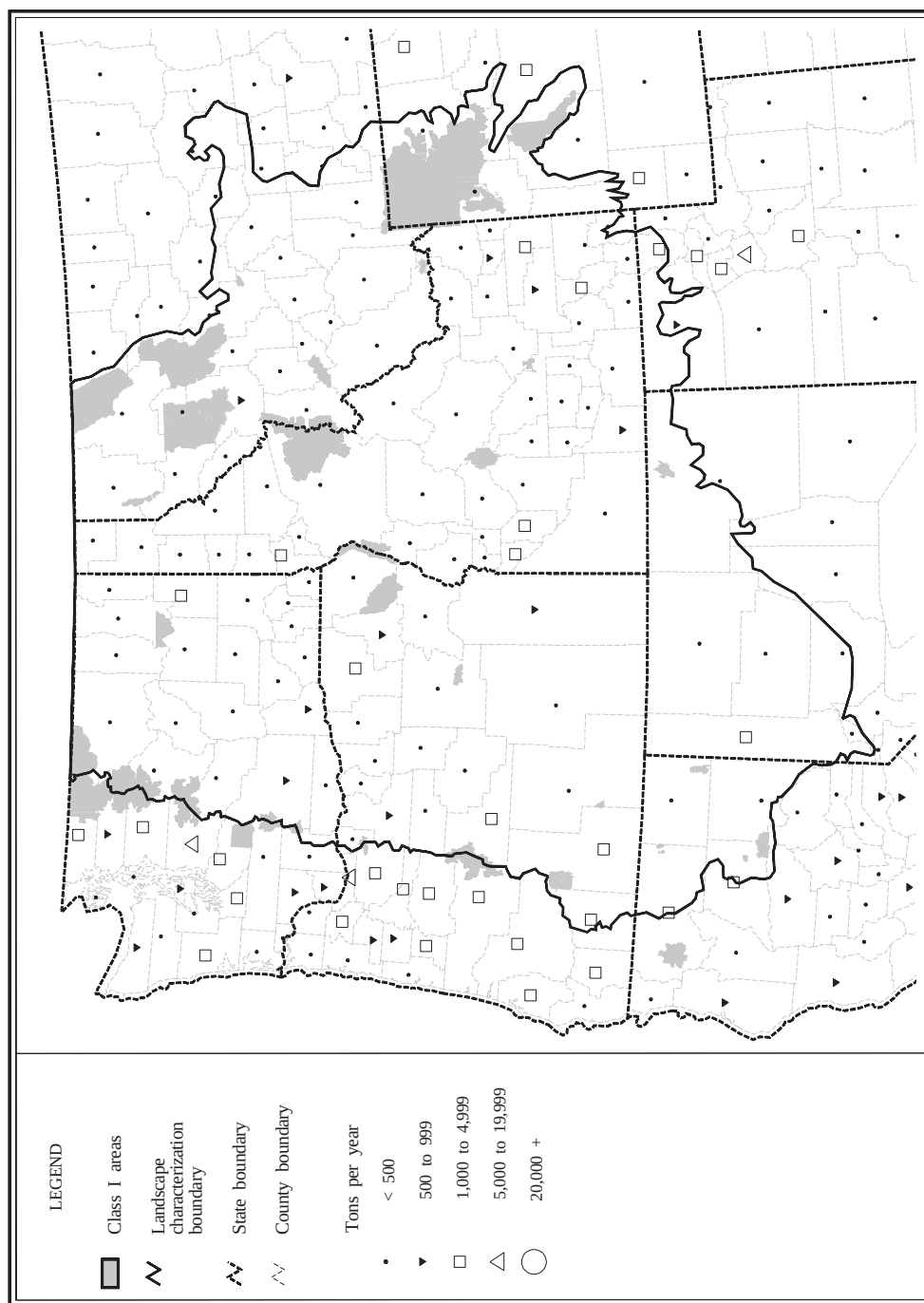


Figure 4—Sulfur oxide (SO_x) area source emissions within or around the interior Columbia River basin.

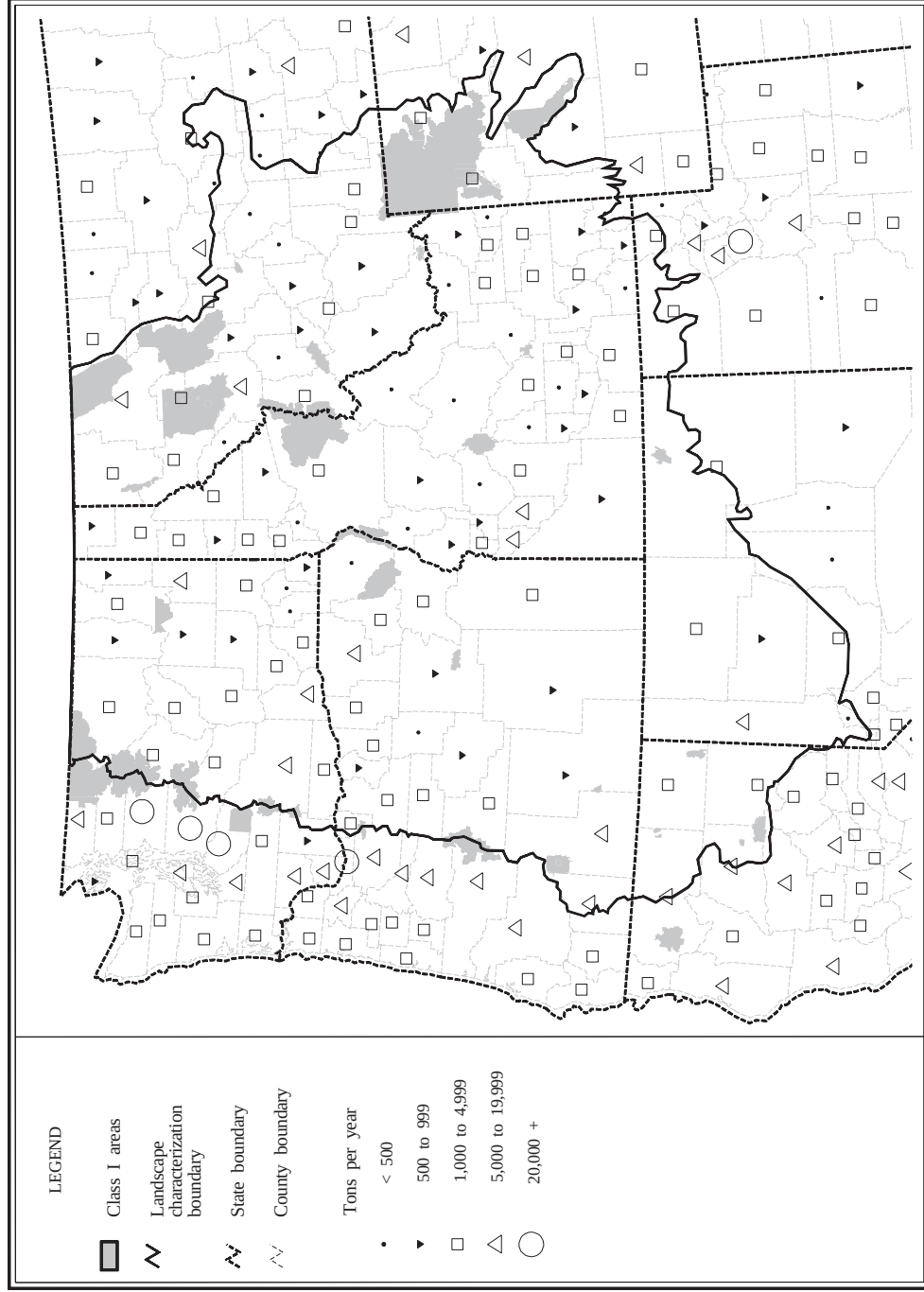


Figure 5—Nitrogen oxide (NO_x) area source emissions within or around the interior Columbia River basin.

Ozone is degraded by reacting with other air contaminants and biotic and abiotic surfaces that it contacts. Ozone production and destruction therefore can be rapid in urban areas and result in low ambient concentrations. Conversely, ozone destruction is less in rural areas, which contributes to the potential of high ambient ozone concentrations in rural locations. Ozone can threaten remote ecosystems and resources far from pollutant sources.

Ozone is highly phytotoxic to plants and is likely to affect vegetation in the basin because (1) it is found globally in elevated concentrations, and (2) ozone precursors, for example NO_x , are increasing within and upwind of the basin. Our assessment of ozone effects on vegetation was limited, however, both by inadequate monitoring data (Böhm 1992, Böhm and others 1995) and uncertainties in area emission estimates of NO_x within the basin. Ozone does not affect aquatic resources.

The EPA and state and local air agencies monitor ozone concentrations in many urban areas. Ozone concentrations measured near The Dalles, OR, increase (1 hour maximum, 92 parts per billion [ppb]) when winds move NO_x and ozone from the Portland area through the Columbia River Gorge. Unfortunately, ozone monitoring for The Dalles began only in 1992. More information on ozone concentrations produced by polluted air masses moving into the basin from the Vancouver, BC, to Eugene, OR, urban corridor is needed to assess the impacts on forests closest to this large source of ozone and its precursors (Edmonds and Basabe 1989). Ozone concentrations also are elevated around Spokane, WA (Böhm and others 1995) and likely are elevated in other basin urban areas (Boise, ID; and the Richland, Pasco, and Kennewick, WA vicinity). For a review of ozone levels found in parts of Oregon, Washington, and Idaho, refer to Eilers and others (1994).

Particles—Small airborne particles may originate from road dust, agricultural and silvicultural burning, volcanic eruptions, or atmospheric transformation of NO_x and SO_x to ammonium nitrate and ammonium sulfate particles, respectively. In remote areas, particles have potential effects on air quality-related values such as visibility. Small particles (0.1- to 1.0-micron category) can reduce

visibility to the point of obscuring views (Malm 1992). Results of a 1990 National Park Service study of visibility in national parks in the Washington Cascade Range (Malm and others 1994) indicate that carbon contributes about 60 percent of the total impairment, with 30 percent from sulfates, 5 percent from nitrates, and 5 percent from soil-related particles. These parks are on the edge of the basin, but information on particle composition and source regions should be relevant to that watershed. (See the “Visibility” section of this report for more information.)

Radionuclides and hazardous air pollutants—Two nuclear technology facilities are within the basin: Hanford Nuclear Reservation in southeastern Washington and Idaho National Engineering Lab in south-central Idaho. At the Hanford site, extensive air monitoring for both hazardous air pollutants (HAPs) and radionuclides has led to the conclusion that air concentrations at the site perimeter meet all applicable standards (Gray 1995). There will be risk of release of both radionuclides and HAPs to the air during the period of site cleanup, which is expected to last for the next 30 years or more. The greatest risk of airborne radionuclides and HAPs from these facilities is bioaccumulation in aquatic and terrestrial biota, which might cause physiological effects in top predators, including humans.

Mercury is the hazardous air pollutant now receiving attention due to its potential for long-distance transport and bioaccumulation, especially in aquatic systems (Watras and Huckabee 1994). Airborne mercury is present in the elemental form; most of the deposited mercury is in the oxidized form (inorganic or methylmercury). Human-mediated release of mercury to the air is through coal combustion, incineration operations, smelting, and landfill emissions. Microbes convert inorganic mercury to methylmercury, the compound that can then bioaccumulate in fish and piscivores, including humans. Methylmercury is a potent neurotoxin in vertebrates.

Because the transport of mercury via the air pathway is a regional and global phenomena, it is difficult to determine source-receptor relations for mercury within the interior Columbia River basin. Because this part of the Northwestern United States has a relatively low population density and

sparse industrial development, it is unlikely that the region is a significant contributor to mass fluxes of this toxic air contaminant. The degree to which the basin is accumulating mercury in soils, water, and biota is not known at this time. Two states within the basin (Oregon and Montana) have issued fish consumption advisories for specific water bodies to warn consumers about mercury-contaminated fish and shellfish (EPA 1994c). These advisories may be associated with specific point sources of mercury contamination rather than long-distance transport of elemental mercury.

Persistent organic pollutants, which include such compounds as PCBs (polychlorinated biphenyls), dioxins (2,3,7,8 TCDD), and chlordane, are included among the 189 hazardous air pollutants named by the EPA. These byproducts of industrial activities and pesticide applications can travel via the air pathway and deposit on terrestrial and aquatic surfaces. When these chemicals make their way into water bodies, they are not easily degraded and are concentrated in biota, where they can then accumulate up the food chain. These toxins may accumulate in lake trout, salmon and the higher predators, wading birds, eagles, and humans to levels that can result in deformities, reproductive disruption, and death. Many of these organic hazardous air pollutants can be revolatilized from the water bodies and transported via the air pathway to other sensitive receptors. Much of what we know about the transport and biomagnification of these chemicals comes from the Great Waters Program (EPA 1994a, 1994c), required by the Clean Air Act amendments of 1990 (U.S. Laws, Statutes 1990, Public Law 101-549).

Little information on sources and receptors of persistent organic pollutants is available for the basin. Under the 1990 Clean Air Act amendments, many of the industries emitting hazardous air pollutants are required to deploy maximum achievable control technology to prevent toxic emissions. The technology standards developed to prevent or ameliorate effects on human health and ecosystems in the more polluted areas (for example the Great Lakes basin) therefore will benefit the Northwestern United States, which currently does not have as many local sources or potential for regional transport of hazardous air pollutants to remote ecosystems.

Deposition of Air Pollutants²

Wet deposition—Wet deposition includes rain, snow, rime ice, sleet and hail, along with “occult” deposition (fogwater and cloudwater). Chemical species of interest in determining the dose to the ecosystem include sulfate (SO_4^-), nitrate (NO_3^-), ammonium (NH_4^+), and hydrogen ion (H^+). Acidity in wet deposition can directly affect vegetation by interactions with leaf or needle surfaces, especially as concentrated cloudwater. In general, acidity in rain and snow can affect soil fertility and nutrient cycling processes. Soils affected by acids often have high concentrations of aluminum in soilwater, which in turn affects root function. Acidity in rain and snow can result in chronic or episodic acidification of sensitive lakes and streams.

Dry deposition—Dry deposition is the term used for the removal of gaseous and particulate species from the atmosphere to terrestrial and aquatic systems. The species of interest with respect to “loadings” to natural ecosystems include sulfur dioxide, sulfate particles, sulfuric acid aerosol, nitric acid aerosol, nitrate ammonium particles, and nitrogen oxide gas. The uptake of ozone by vegetation also is considered a dry deposition process.

An important anion in acid deposition is nitrate. Vegetation can be impacted directly by increased inputs of nitrogen via either wet or dry deposition (Aber and others 1989, Fenn and Bytnerowicz 1993) or indirectly through NO_x mediated increases in ozone (Hogsett and others 1993). Additional indirect effects of NO_x on vegetation can be through changes in climate by increases in the global warming gas and nitrous oxide (N_2O) (Mooney and others 1987) or through nitric oxide (NO) destruction of stratospheric ozone, leading to increased UV-B-mediated mutagenicity (Davidson 1991). Deposition of excess nitrogen species (nitrate and ammonium) to both terrestrial and aquatic systems can result in fertilization or eutrophication and episodic acidification of streams and lakes (Stoddard 1994).

² A thorough discussion of regional wet and dry deposition and its effects on watersheds and surface waters can be found in Charles (1991); information on areas containing sensitive lakes in the Cascade Range and the Rocky Mountains can be found in Nelson (1991) and Turk and Spar (1991), respectively.

The reaction of nitric acid with ammonia gas emitted from feedlots and fertilized fields results in ammonium nitrate particles. When this buffered compound reaches soils and surface waters, the ammonium is preferentially taken up by biota, thus generating acidity. Most counties within the basin have some level of ammonia emissions, primarily less than 500 tons per year (fig. 6). It is possible, however, for ammonium nitrate transformation and transport to deliver nitrogen species to parks and wilderness areas in the basin, depending on the pattern of local ammonia emissions relative to the supply of nitric acid vapor.

Monitoring Data

Wet deposition monitoring—Wet deposition is measured in the United States by a national network of about 200 sites coordinated by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). Currently the only wet deposition network sites operating in the interior Columbia River basin are NADP/NTN sites at nine locations in Oregon, Washington, Idaho, Wyoming, and Montana (fig. 7):

NADP/NTN site	Elevation
	<i>Meters</i>
Idaho:	
Craters of the Moon National Monument	1807
Reynolds Creek	1198
Smiths Ferry	1442
Oregon:	
Silver Lake Ranger Station	1336
Starkey Experimental Forest	1253
Washington:	
Palouse Conservation Farm	766
Montana:	
Glacier National Park	968
Lost Trail Pass	2414
Wyoming:	
Yellowstone National Park	1912

The 1992 NADP/NTN data for the nine interior Columbia River basin sites are displayed in figures 8 and 9. The solutes of interest in this data set include nitrate, sulfate, ammonium, and pH (or hydrogen ion). The annual precipitation-weighted pH of wetfall measured at these nine sites ranges from 5.3 at Glacier National Park to

6.0 at Reynolds Creek (fig. 8). The pH of wetfall seems to correlate with annual amounts of precipitation, with the Reynolds Creek site receiving about 17 cm of wetfall and Glacier National Park receiving about 70 cm in 1992 (fig. 8). The Lost Trail site received the highest precipitation amount in 1992 (78 cm) and is also the highest elevation site of the nine monitored.

In general, wet deposition samples at these nine sites showed that nitrate exceeds sulfate and ammonium, with concentration peaks observed in the summer (fig. 9). The precipitation-weighted mean concentrations in the basin are lower than those recorded in the Eastern United States; for example, the highest annual average nitrate concentration for the two southern Idaho sites is 0.8 mg/l compared to maximum values in 1992 of 1.8 mg/l recorded at sites in Pennsylvania (fig. 10) (NADP 1993). Comparisons of annual concentrations of sulfate show a large difference between Eastern and Western sites, with the highest annual sulfate concentration of 0.5 mg/l for southern Idaho contrasted with the maximum sulfate concentration of 3.2 mg/l at Indiana Dunes National Lakeshore (fig. 11).

Wet deposition estimates reflect both the concentrations of solutes in wetfall and the total amount of wet deposition that fell during the year (fig. 12). These values can be used to estimate total loading of pollutants to ecosystems ($\text{kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) when combined with other sources of inputs, such as dry deposition and occult deposition. As with concentration data, the 1992 deposition values for the nine NADP stations in the basin show higher loadings for nitrate than sulfate. The stations with the highest snowfall, Glacier National Park, Yellowstone National Park, and Lost Trail Pass, have the highest annual loading of nitrate, all in the range of 2 to 3 kg/ha. This is still low compared to the highest value of 29 kg/ha in upstate New York (fig. 13). The annual sulfate deposition is close to the loadings for nitrate at two sites (Glacier National Park and Palouse Conservation Farm) in the basin. These values would be higher but snow deposition is not measured accurately. The NADP/NTN samplers are poor collectors of snow due to wind scour, overtopping the bucket, and mechanical malfunctions.

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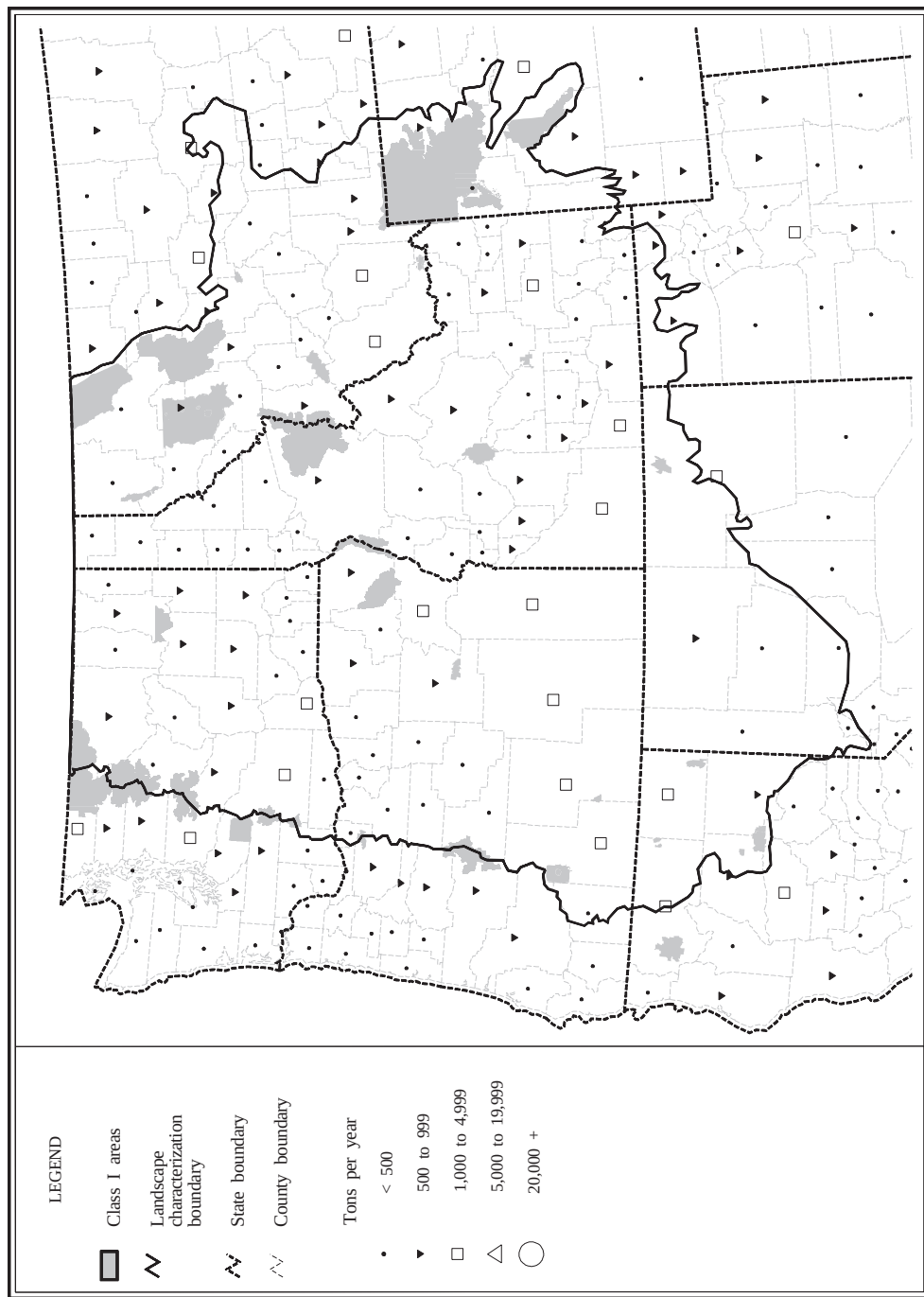


Figure 6—Ammonia (NH₃) area source emissions within or around the interior Columbia River basin.

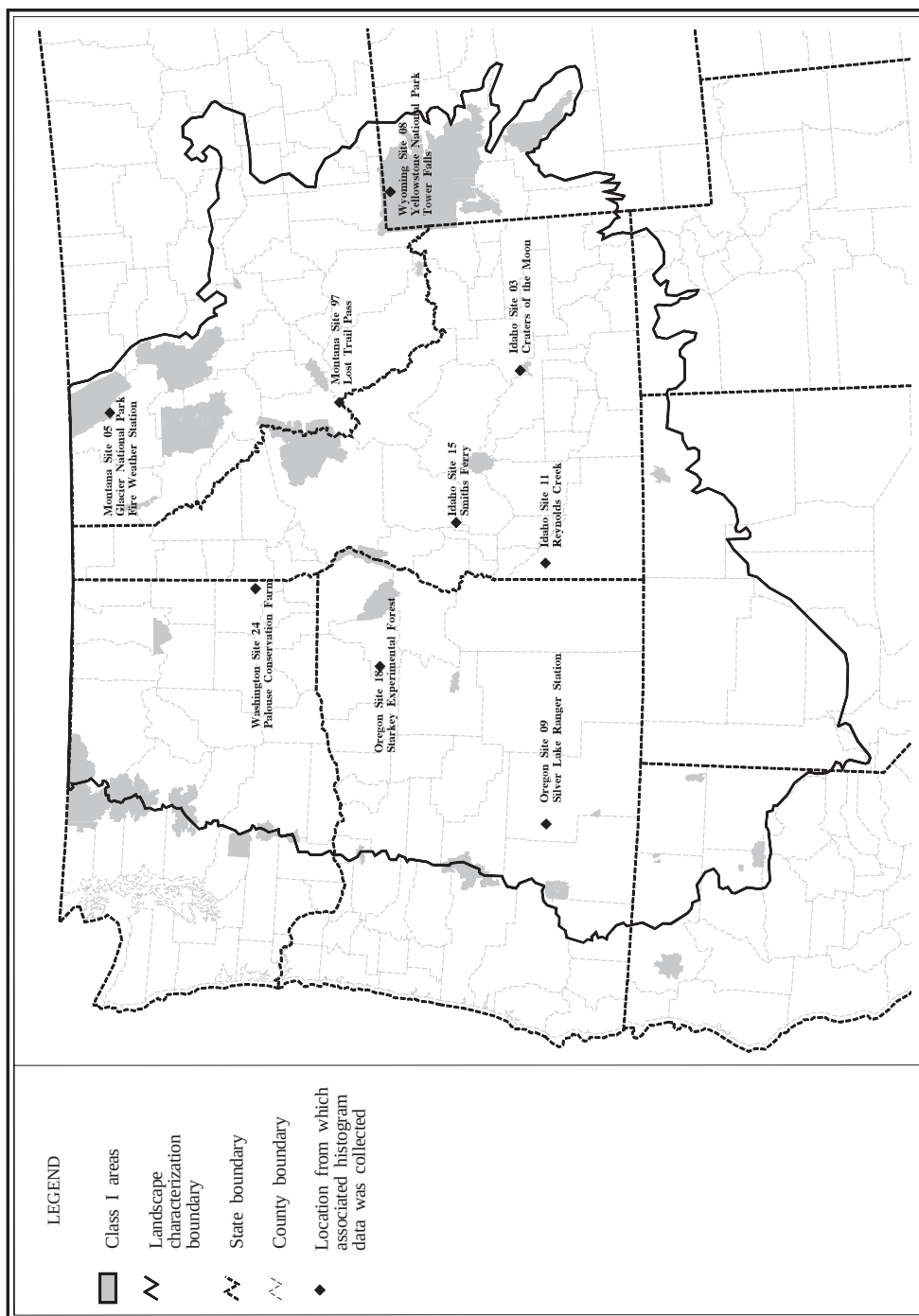


Figure 7—1992 National Atmospheric Deposition Program (NADP) monitoring sites.

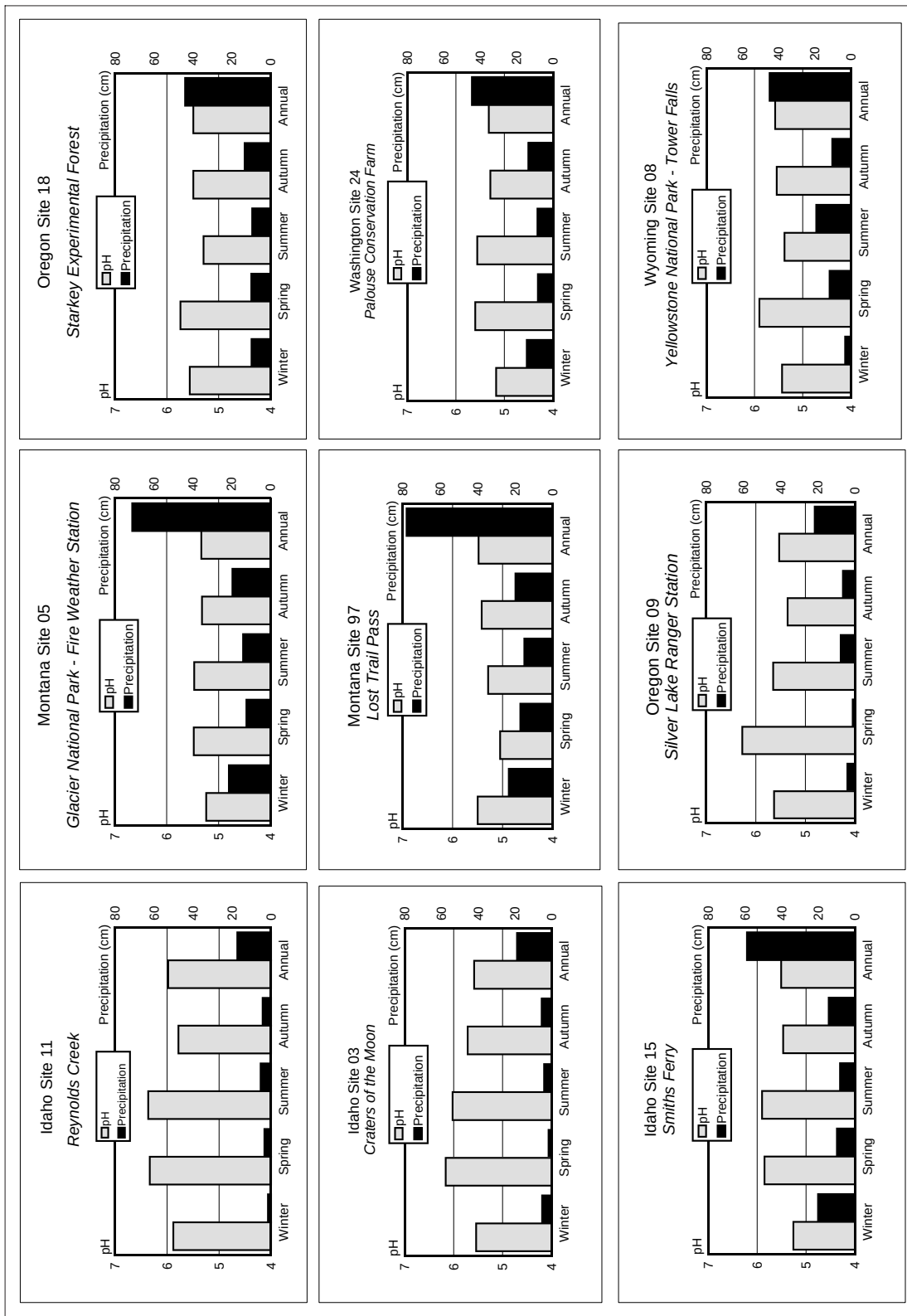


Figure 8—National Atmospheric Deposition Program (NADP) seasonal and annual pH and precipitation from sites within the interior Columbia River basin.

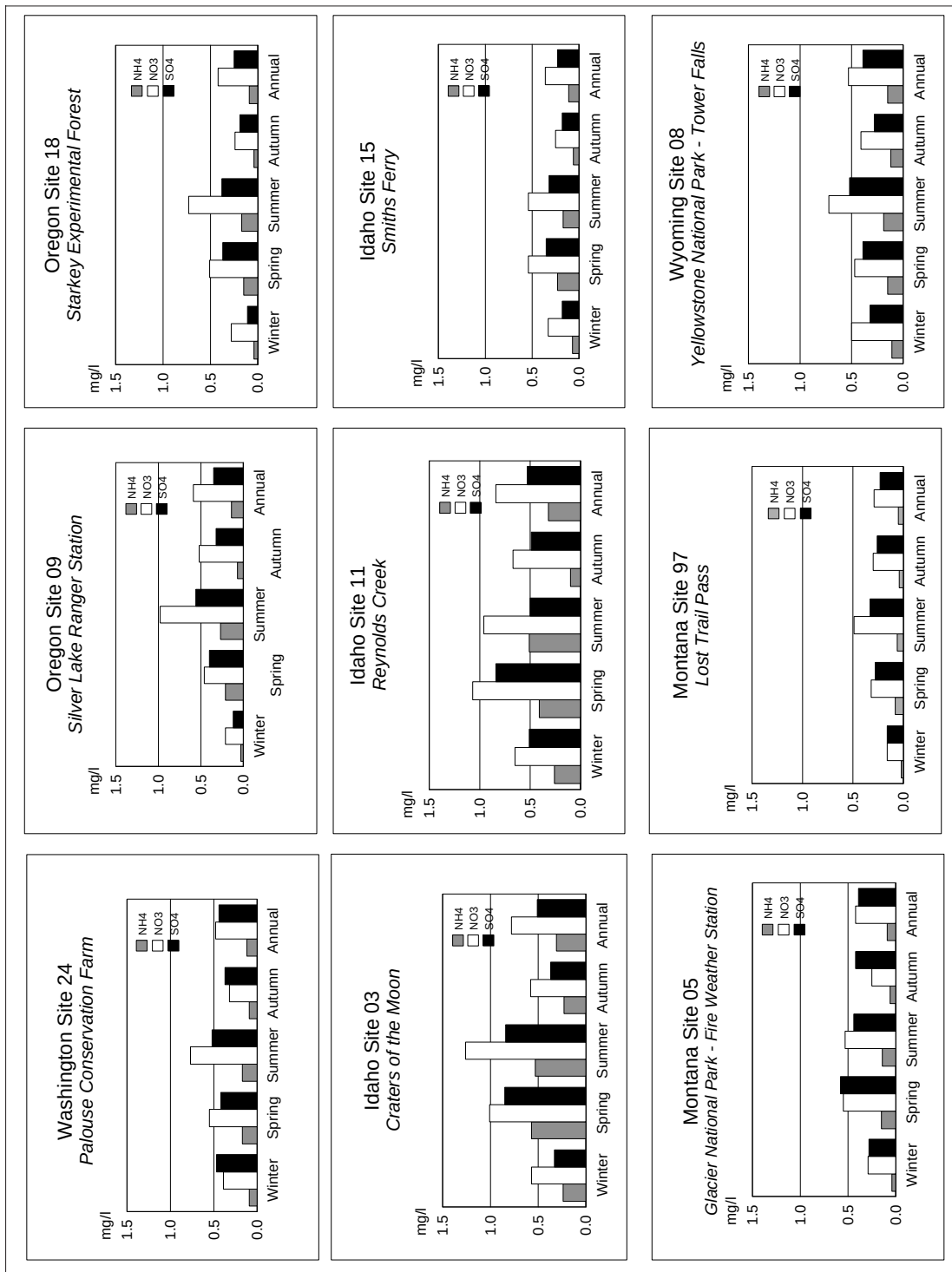


Figure 9—National Atmospheric Deposition Program (NADP) seasonal and annual average concentrations from sites within the interior Columbia River basin.

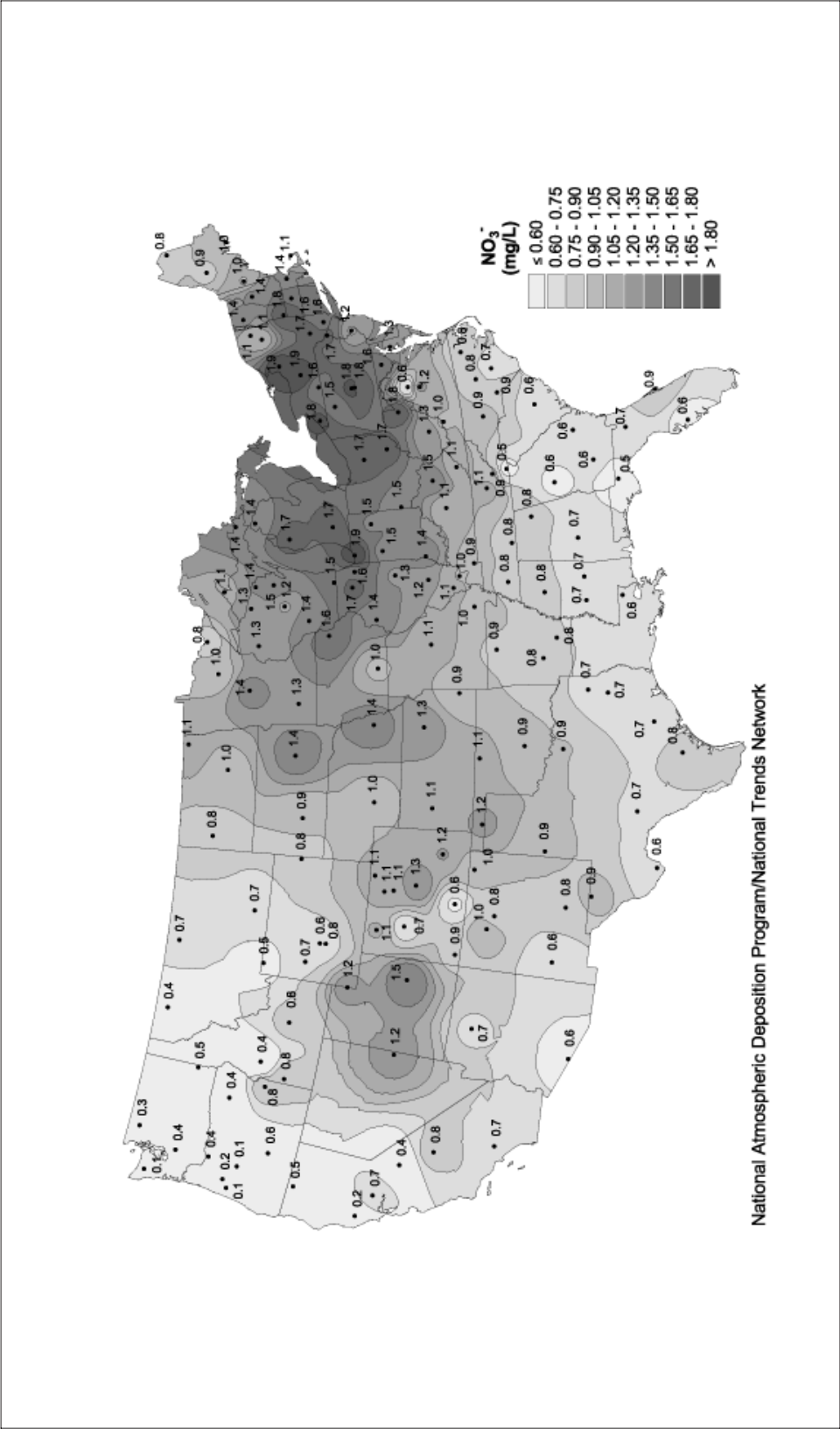


Figure 10—Annual precipitation-weighted mean nitrate ion concentrations for 1992 (milligrams per liter) (NADP 1993).

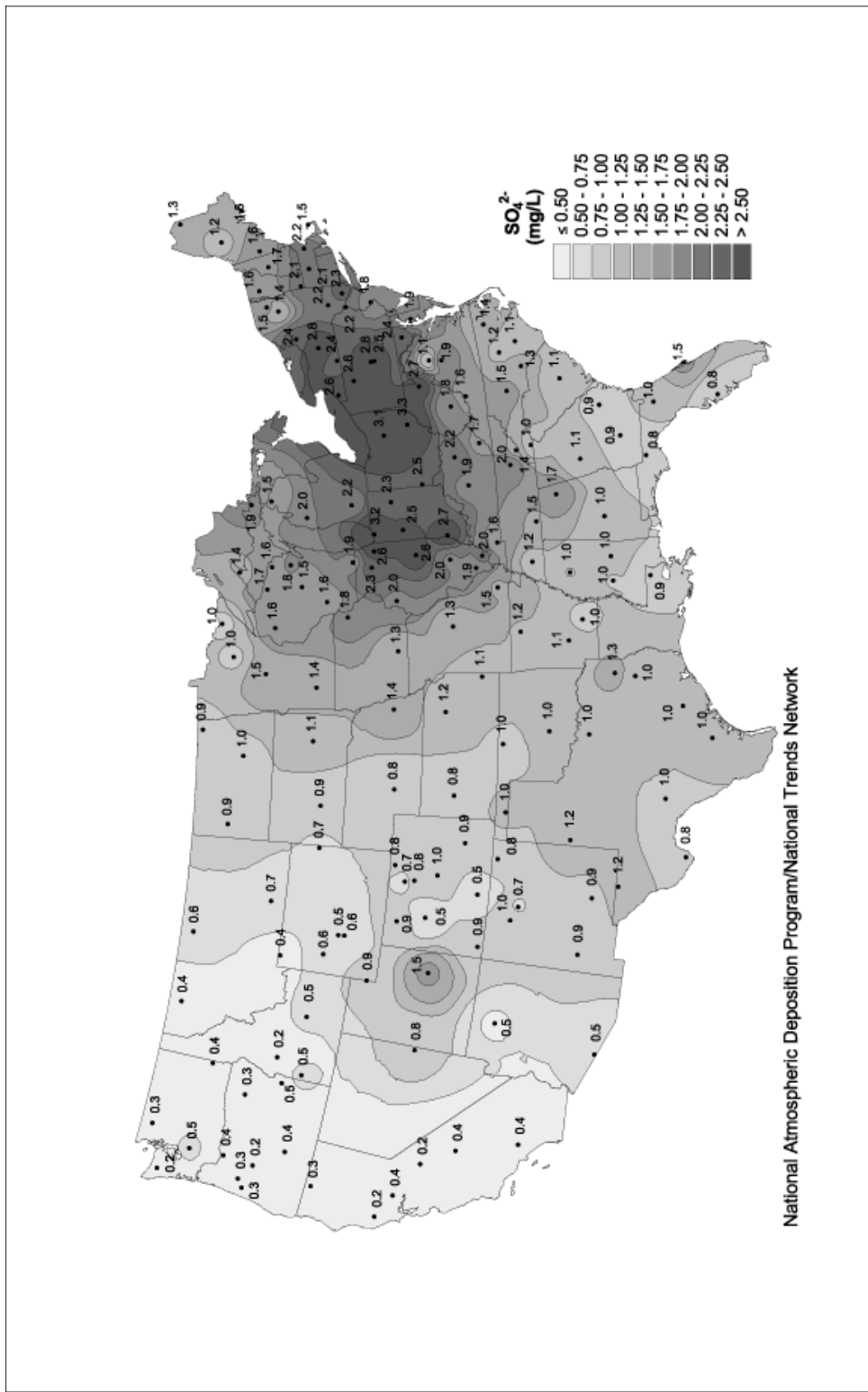


Figure 11—Annual precipitation-weighted mean sulfate ion concentrations for 1992 (milligrams per liter) (NADP 1993).

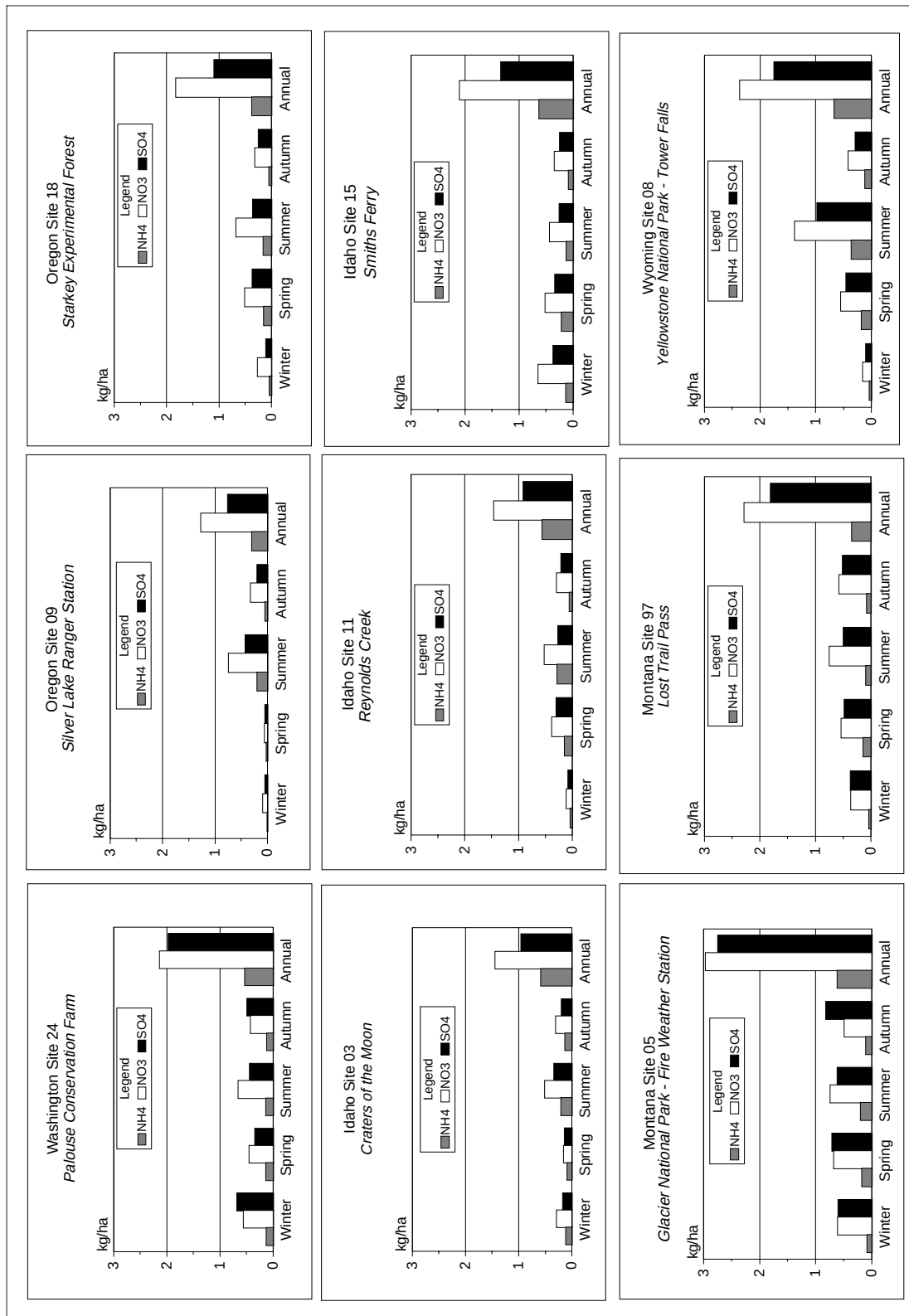


Figure 12—National Atmospheric Deposition Program (NADP) seasonal and annual deposition from sites within the interior Columbia River basin.

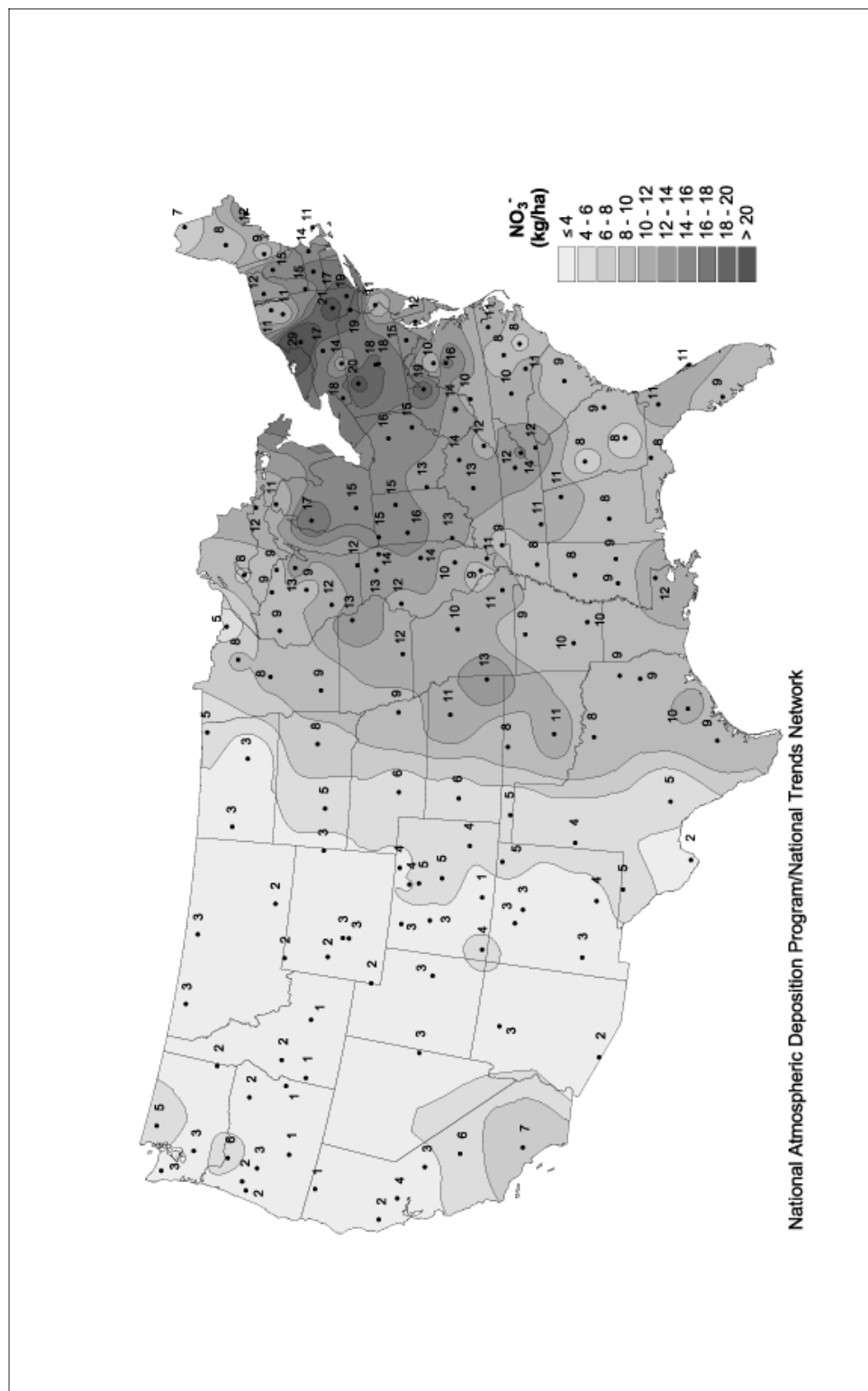


Figure 13—Estimated nitrate ion deposition for 1992 (kilograms per hectare) (NADP 1993).

Additional analysis of wet chemistry data (1980 to 1992) for selected NADP sites throughout the United States was performed by Lynch and others (1995) to look for statistically significant trends in average concentrations. Three sites in the basin were included in this analysis (Glacier National Park, Yellowstone National Park, and Craters of the Moon National Monument; fig. 14). During these 12 years, sulfate, base cation, and hydrogen ion concentrations significantly decreased at all three sites, with a measured increase in nitrate concentrations at two of the three sites (although not statistically significant), and no change in ammonium concentrations. This result agrees with the trends in estimated emissions, with decreasing SO_x emissions and increasing NO_x emissions in the basin.

Dry deposition monitoring—Dry deposition is measured by monitoring ambient concentrations of gases and particles and then using models to infer deposition. Air concentrations have been measured by the EPA as part of the 50-site National Dry Deposition Network and by the National Oceanic and Atmospheric Administration (NOAA) network of filter packs.³ There are three National Dry Deposition Network sites located within the basin, two colocated with NADP sites (fig. 15): Reynolds Creek in Idaho, Glacier National Park in Montana, and Saval Ranch in Nevada. These sites have operated since 1988 or 1989, with data reported as weekly-average concentrations of SO₂, particulate-sulfate, nitric acid, particulate nitrate, and ammonia. For details of sampling protocols, see Clarke and Edgerton (1992).

The dry deposition estimates for 1990 for the three National Dry Deposition Network sites for 1990 show that nitric acid had the highest loading of all the dry species at all three sites, with a range of 1 kg/ha at the Glacier National Park site to about 2.5 kg/ha at the two more southerly sites (fig. 16). Deposition of particle nitrate was extremely low at all three sites, with a maximum value of about 0.2 kg/ha. Because 1990 is one of the first years of data reporting for these sites, the variability of dry deposition is unknown.

³ National Acid Precipitation Assessment Program. 1995. Draft 1994 report to Congress of the National Acid Precipitation Assessment Program. Washington, DC. [pages unknown]. On file with: [unknown].

Only two sites within the interior Columbia River basin currently monitor ozone, and they both report elevated ozone concentrations. More ozone monitoring should be done within the basin, particularly near class I areas and sensitive forests. A more concerted effort to estimate dry deposition of nitrogen species and ozone in the basin is needed, particularly near sensitive forests and watersheds.

Snowpack monitoring—Regional snow deposition along the Continental Divide in Montana, Wyoming, Colorado, and New Mexico is being sampled by the U.S. Geological Survey, in cooperation with the U.S. Department of Agriculture-Forest Service, State of Colorado, and National Park Service (Turk 1995). An earlier synoptic snow monitoring project along the Cascade Range and Sierra Nevada crest is reported in Laird and others (1986).

Snowpacks in the basin tend to have dilute chemistry. During the survey by Laird and others (1986) of February through March 1983, the pH of the snowpack along the Washington, Oregon, and northern California Cascade Range ranged from 5.11 to 5.88, nitrate concentrations ranged from 0.007 to 0.12 mg/l, and sulfate ranged from 0.05 to 0.32 mg/l. The pH of snowpack recorded in the Rocky Mountains during 1993 was mostly above 5.0, except for sites in the vicinity of the Mount Zirkel Wilderness Area, where researchers have suggested that emissions from power facilities in the Yampa Valley are influencing snow chemistry (Ingersoll 1995).

Cloudwater and fogwater monitoring—

Cloudwater and fogwater can contribute significantly to total loading of solutes in certain types of environments. In high-elevation areas of eastern North America, cloudwater impaction can account for as much loading of sulfate and nitrate as do other forms of wet precipitation (for example at Noland Divide in Great Smoky Mountains National Park, [Johnson and Lindberg 1992]). Böhm (1992) summarizes what is known about the contribution of cloudwater to high-elevation areas in the vicinity of the basin, including the Washington Cascade Range and Mount Werner in northwest Colorado. Cloudwater pH ranged from 3.1 to 5.9 in the Washington Cascade Range and from 3.0 to 5.2 at Mount Werner. Cloudwater collected at these sites had higher concentrations of all ions

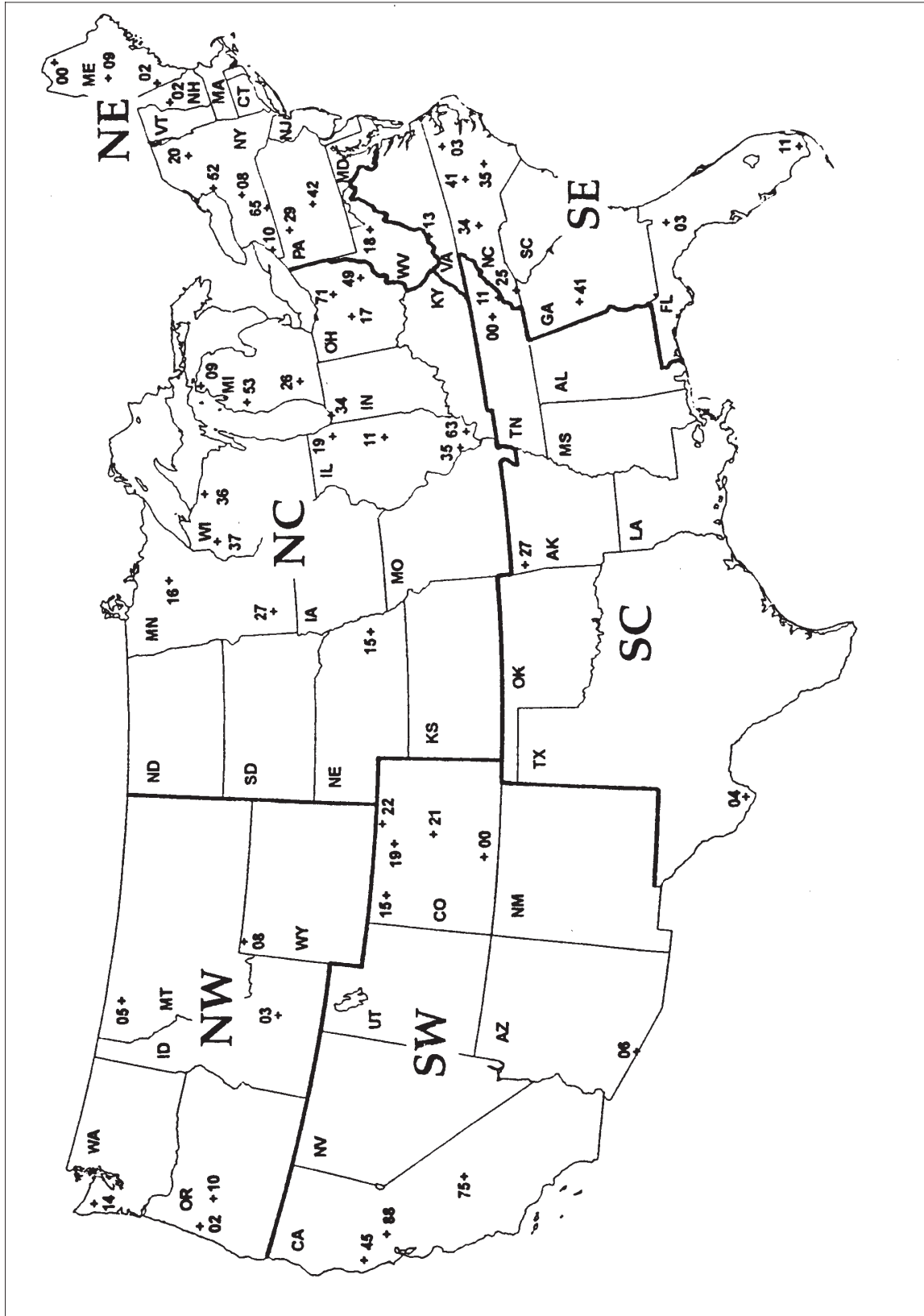


Figure 14—National Atmospheric Deposition Program (NADP) sites included in national precipitation trends analysis (from Lynch and others 1995).

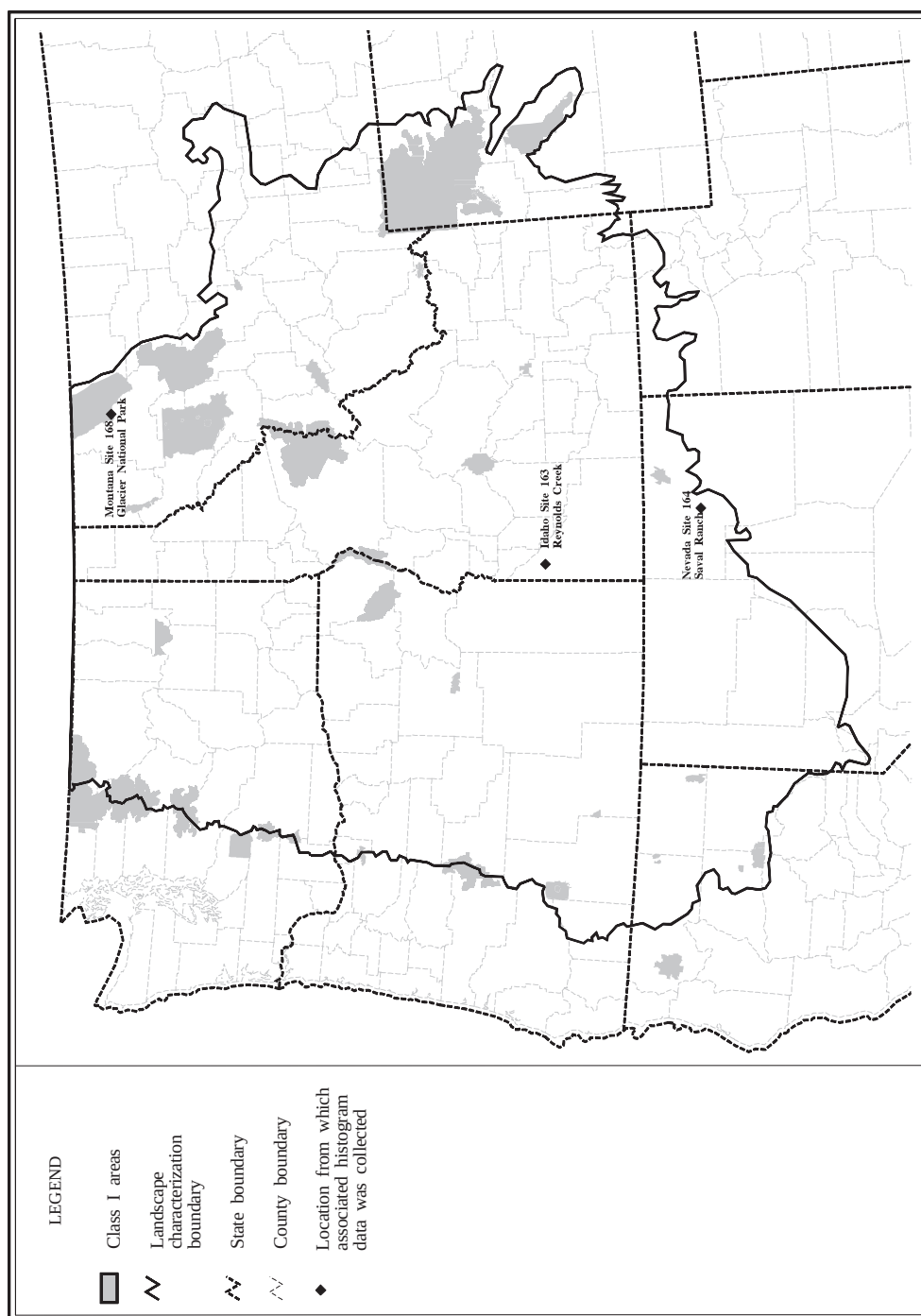


Figure 15—National Dry Deposition Network (NDDN) monitoring sites within the interior Columbia River basin in 1990.

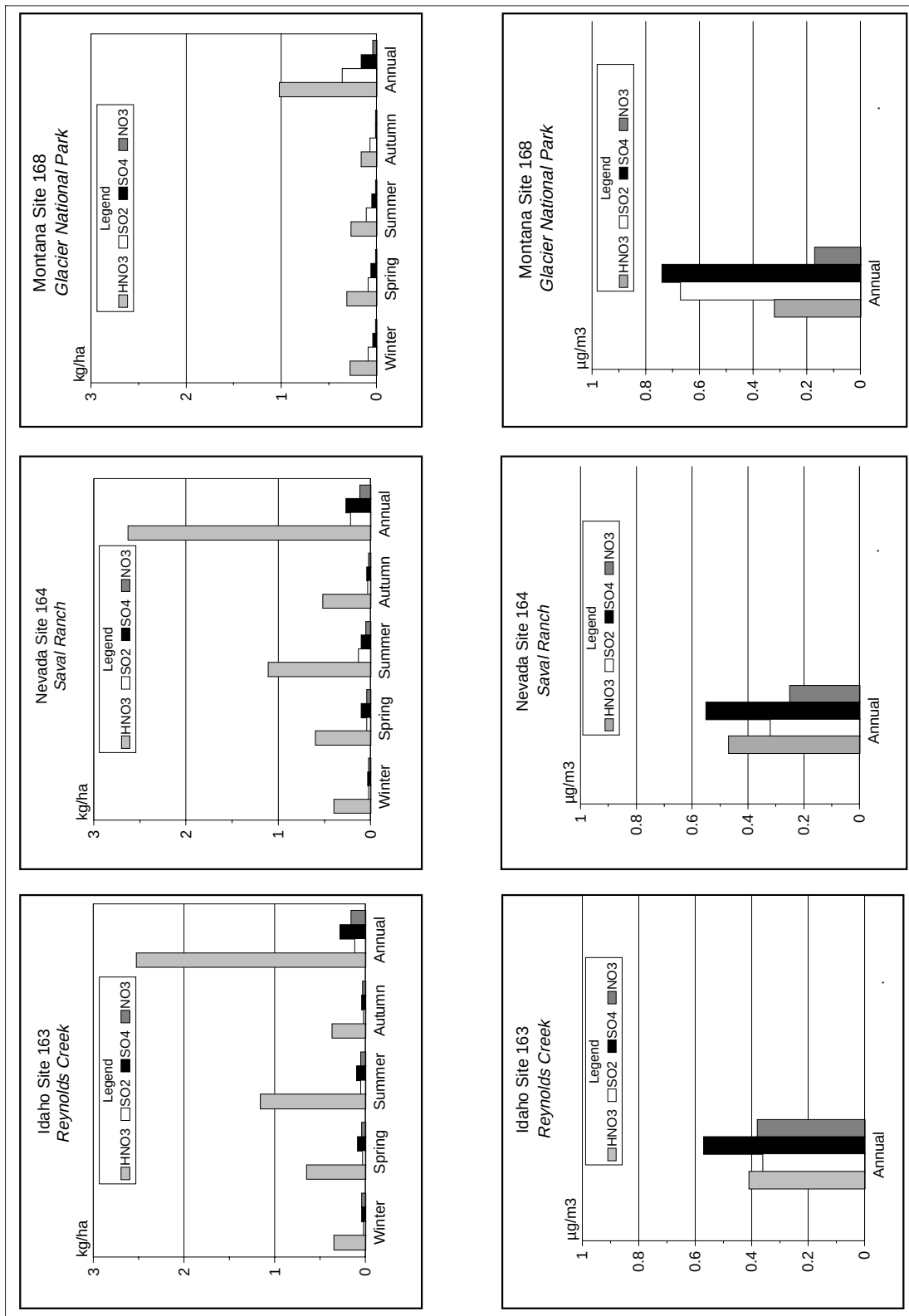


Figure 16—Deposition and average concentrations from National Dry Deposition Network (NDDN) monitoring sites within the interior Columbia River basin in 1990.

than did precipitation. The total loading of such species of nitrate, sulfate, and ammonium are likely, however, to be lower owing to the small volume of water that these samples represent.

Aquatic Ecosystems

Predicting Response of Aquatic Ecosystems to Air Pollutants

Aquatic ecosystems include the obvious hydrologic components of lakes, streams, and ground water and the rain, snow, and fog that replenish them. Other critical components include bedrock and surficial materials, soils, and terrestrial and aquatic communities that define much of the ecosystem's character and the movement of water, nutrients, and toxic materials through the ecosystem. Unfortunately, consideration of the many possible complex interactions of all these components with air pollutants would be difficult at best in intensively studied watersheds and impossible in the many remote wilderness areas and other Federal lands in the interior Columbia River basin. This section presents a regionally oriented approach to help the reader determine the present status of aquatic ecosystems and assess the risk of future threats to aquatic ecosystems from air pollutants in the basin. Most of this discussion uses existing data on lakes, snowpack, and rain plus snow (wetfall). These hydrologic components integrate many of the complex interactions of their respective ecosystems and allow the reader to rank the degree of threat and sensitivity to that threat.

One useful approach to predicting response of aquatic ecosystems to air pollutants is to consider:

1. Present status of aquatic ecosystems with respect to critical levels of some measure of ecosystem health, for example, pH.
2. Ability of aquatic ecosystems to respond to additional threats to ecosystem health, for example, acid neutralizing capacity.
3. Present geographic distribution of air pollutant concentrations.
4. Location of aquatic ecosystems already affected by air pollutants or having very little ability to respond to increased air pollutants in the future.

Aquatic resources at low elevation tend to be less sensitive to acid rain than high-elevation aquatic ecosystems; however, aquatic ecosystems at any elevation could be sensitive to other atmospheric pollutants owing to the same chemical and biological processes and characteristics that determine sensitivity to acid rain; for example, low pH and small acid neutralizing capacity would tend to make a lake sensitive to many toxic metals whose solubility is increased at low pH. Further, the short hydrologic flow paths and thin soils typical of lakes sensitive to acid rain provide minimal opportunity to remove inorganic and organic air pollutants by sorption to soil or by biological uptake or degradation. Thus, knowledge gained from acid rain studies can be used to select aquatic resources that may be sensitive to other air pollutants.

Sources of Historical Data and Background Information

Lakes—Most knowledge of the present status of aquatic resources of the interior Columbia River basin and risk from air pollutants has been summarized by Turk and Spahr (1991), Nelson (1991), and Melack and Stoddard (1991). These references discuss the 1985 EPA Western Lake Survey (Landers and others 1987)—the only lake study including the entire basin—and numerous smaller studies.

Atmospheric deposition—Current atmospheric deposition in the basin has been measured by the National Atmospheric Deposition Program as discussed above in this paper. Atmospheric deposition as characterized by snowpack chemistry was surveyed during 1983 by the U.S. Geological Survey (USGS) throughout the Cascade Range and the Sierra Nevada (Laird and others 1986). In 1993, another survey of snowpack chemistry throughout the Rocky Mountains was conducted by the USGS (Turk 1995).

Watershed processes—A collaborative effort by six Federal agencies recently resulted in published results from the 10-year National Acid Precipitation Assessment Program (NAPAP 1991). Although the NAPAP focus was primarily on the Eastern United States, much of what we know about the effects of air pollution on aquatic ecosystems and watershed processes is a result of NAPAP and related work.

Present Status of Aquatic Ecosystems

The only geographically extensive historical data are for lakes sampled as part of the Western Lakes Survey (Landers and others 1987). In the interior Columbia River basin, most lakes sampled as part of this survey have pH between 6 and 8 and only two have pH less than 6 (fig. 17). The pH data typically represent conditions during summer and fall, although lower pH is expected to occur during snowmelt, for which data are unavailable. Mortality in amphibians common to lakes and ephemeral pools in alpine areas occurs at pH values as high as 5 to 6 (Corn and Vertucci 1992, Harte and Hoffman 1989). Thus, pH of lakes typically is not at a critical level for the basin during the summer and fall sample period.

Seasonal snowmelt supplies most of the water in sensitive lakes, ephemeral breeding pools, and low order streams, all tending to occur in alpine and subalpine areas of the basin. At times, this snowmelt may totally or largely displace more alkaline water that typically would occupy such systems during periods other than snowmelt. Thus, surveys conducted during summer and fall, the case for all lake surveys referenced above, may provide a poor estimate of worst-case acidification of aquatic systems. The chemical nature of this snowmelt, and aquatic systems most influenced by it, may be a more appropriate measure of aquatic chemistry than is the chemistry of lakes reported by the surveys above. It is possible that areas having lakes with insufficient acid neutralizing capacity to buffer acidity released during snowmelt may experience episodic pH low enough to result in biological damage, but data are not available to determine whether this occurs in the basin.

Ability of Aquatic Ecosystems to Respond to Additional Threats

Lakes are ranked in sensitivity to acidification based on their acid neutralizing capacity (ANC.) To be able to buffer atmospheric deposition as acidic as that commonly observed in the Eastern

United States, and to retain a moderate amount of acid neutralizing capacity to provide stability in pH, an acid neutralizing capacity of 200 micro-equivalents per liter ($\mu\text{eq/L}$) is often used to divide sensitive ($\text{ANC} < 200 \mu\text{eq/L}$) and non-sensitive ($\text{ANC} > 200 \mu\text{eq/L}$) lakes (Hendrey and others 1980, Turk and Adams 1983). Many lakes in the interior Columbia River basin have acid neutralizing capacity less than $200 \mu\text{eq/L}$, and numerous clusters of lakes have acid neutralizing capacity much less than $200 \mu\text{eq/L}$ (fig. 18); however, no acidic ($\text{ANC} < 0$) lakes have been identified in the basin.

Geographic Distribution of Air Pollutant Concentrations

Air pollutants can directly enter aquatic ecosystems as solutes in wetfall and from the snowpack. The present geographic distribution of areas of greater concentration of air pollutants in snowpack can be seen for pH (fig. 19), nitrate, (fig. 20) and sulfate (fig. 21). Generally, the smallest concentrations of air pollutants in the snowpack are in the Cascade Range, the Sierra Nevada, and in Montana. Concentrations are greatest in Wyoming and a small area within Montana near the junction with Idaho and Wyoming. Some of the largest concentrations of sulfate, nitrate, and acidity were measured at sites in this area west of Yellowstone National Park.

The present geographic distribution of areas of greater concentration of air pollutants in wetfall can be seen for pH, sulfate, and nitrate (figs. 8 and 9). Generally the wetfall sites near snowpack sampling sites, shown in figures 19, 20, and 21, have values comparable to the snowpack values. Wetfall sites at lower elevation, however, have somewhat greater concentrations than do the higher elevation snowpack sites. Much of this difference is caused by a seasonal pattern with greatest concentration of air pollutants in the summer and smallest concentration in the winter, when the snowpack accumulates.

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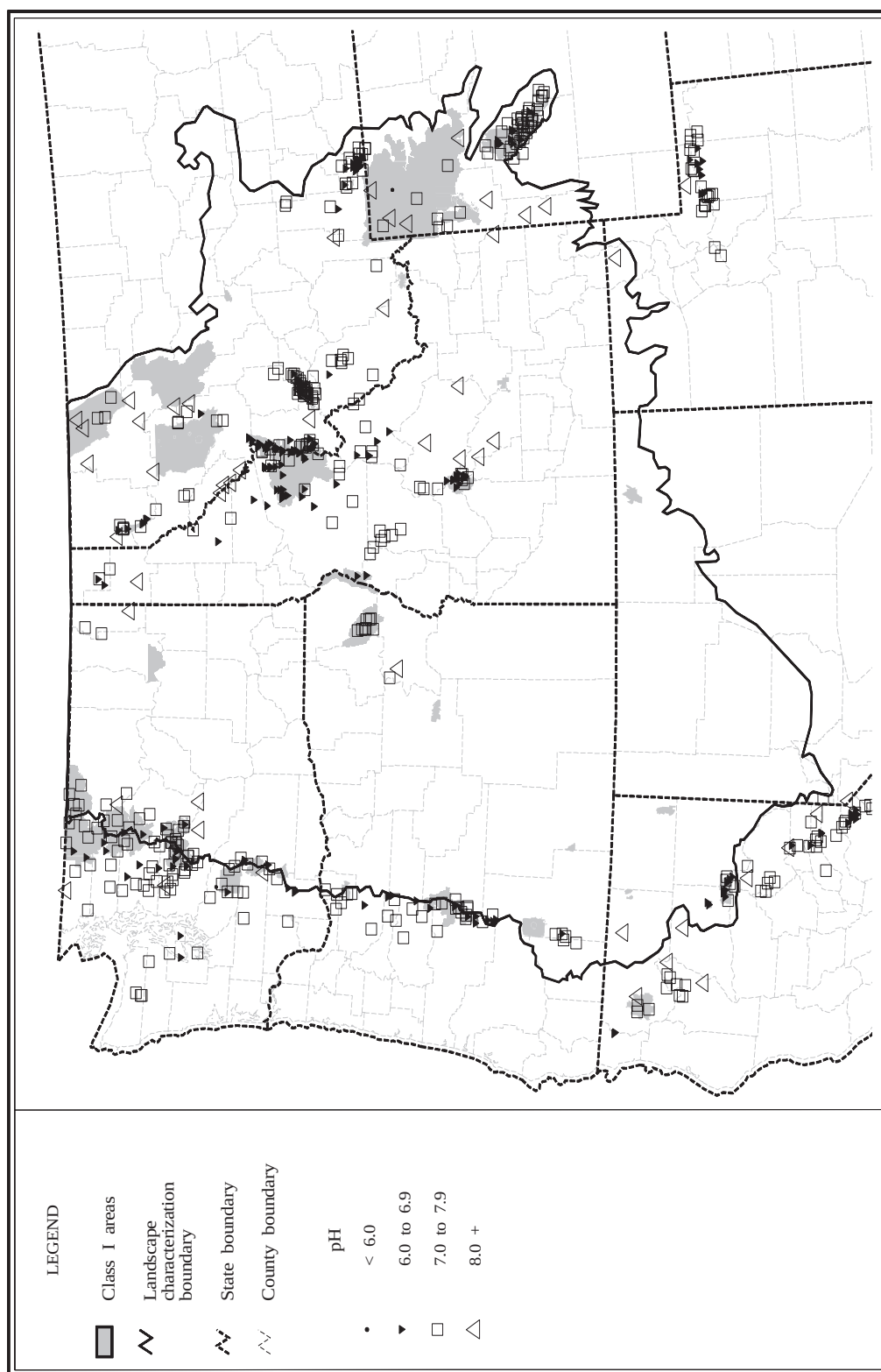


Figure 17—Lake pH values from sites within or near the interior Columbia River basin (from Eilers and others 1987).

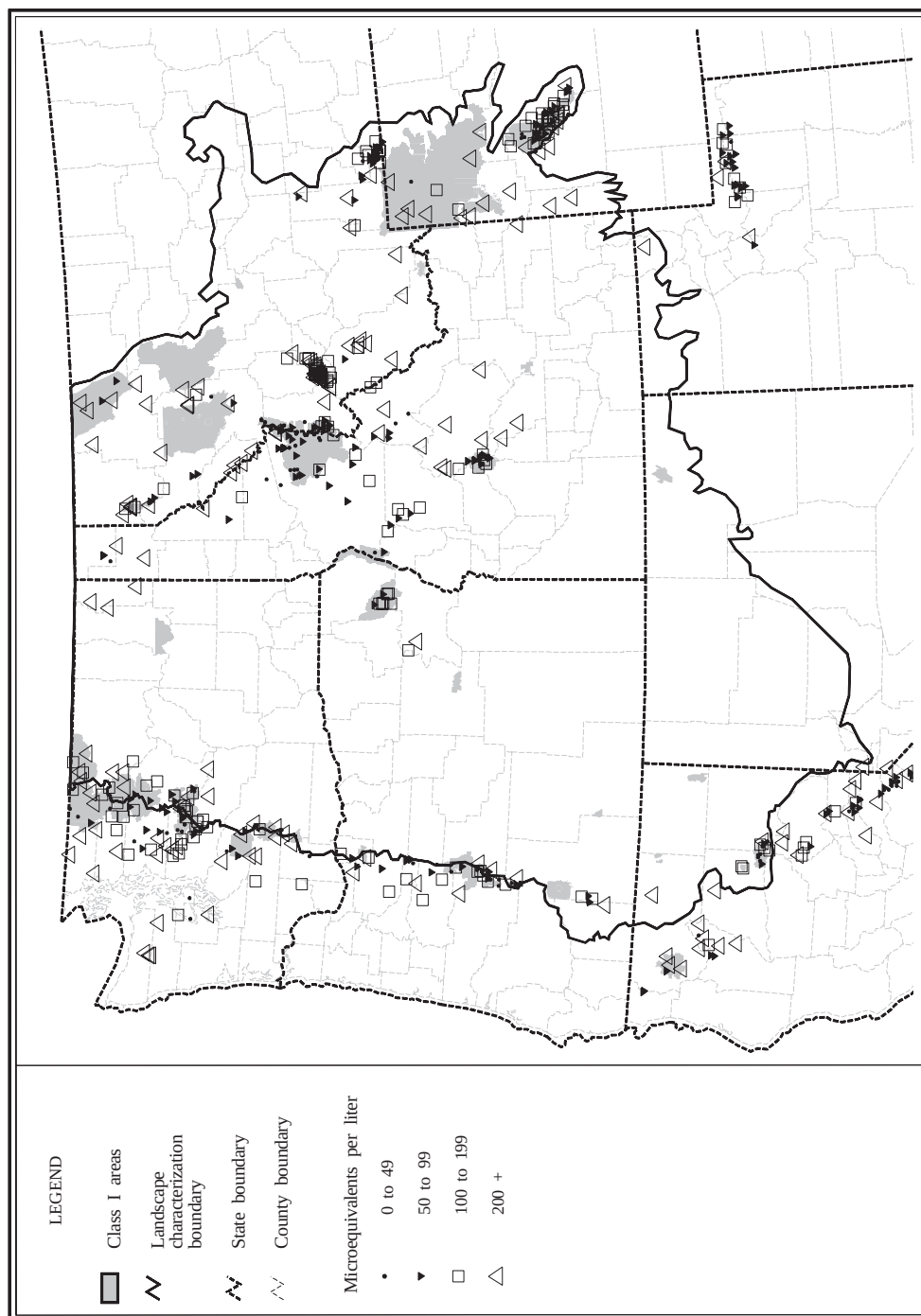


Figure 18—Lake acid neutralizing capacity values from sites within or near the interior Columbia River basin (from Eilers and others 1987).

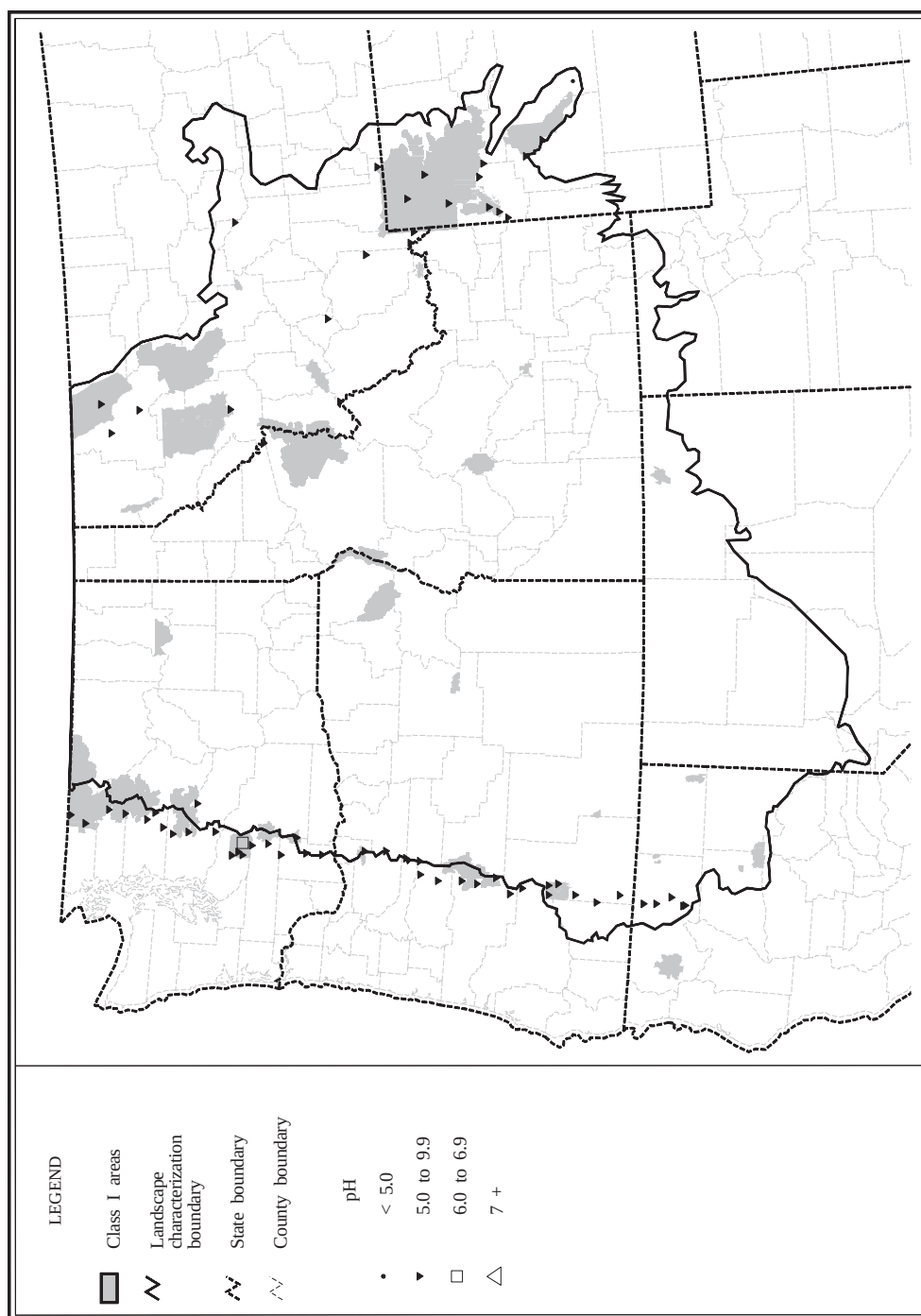


Figure 19—Snowpack pH values from sampling sites within or near the interior Columbia River basin (from Laird and others 1986, Turk 1995).

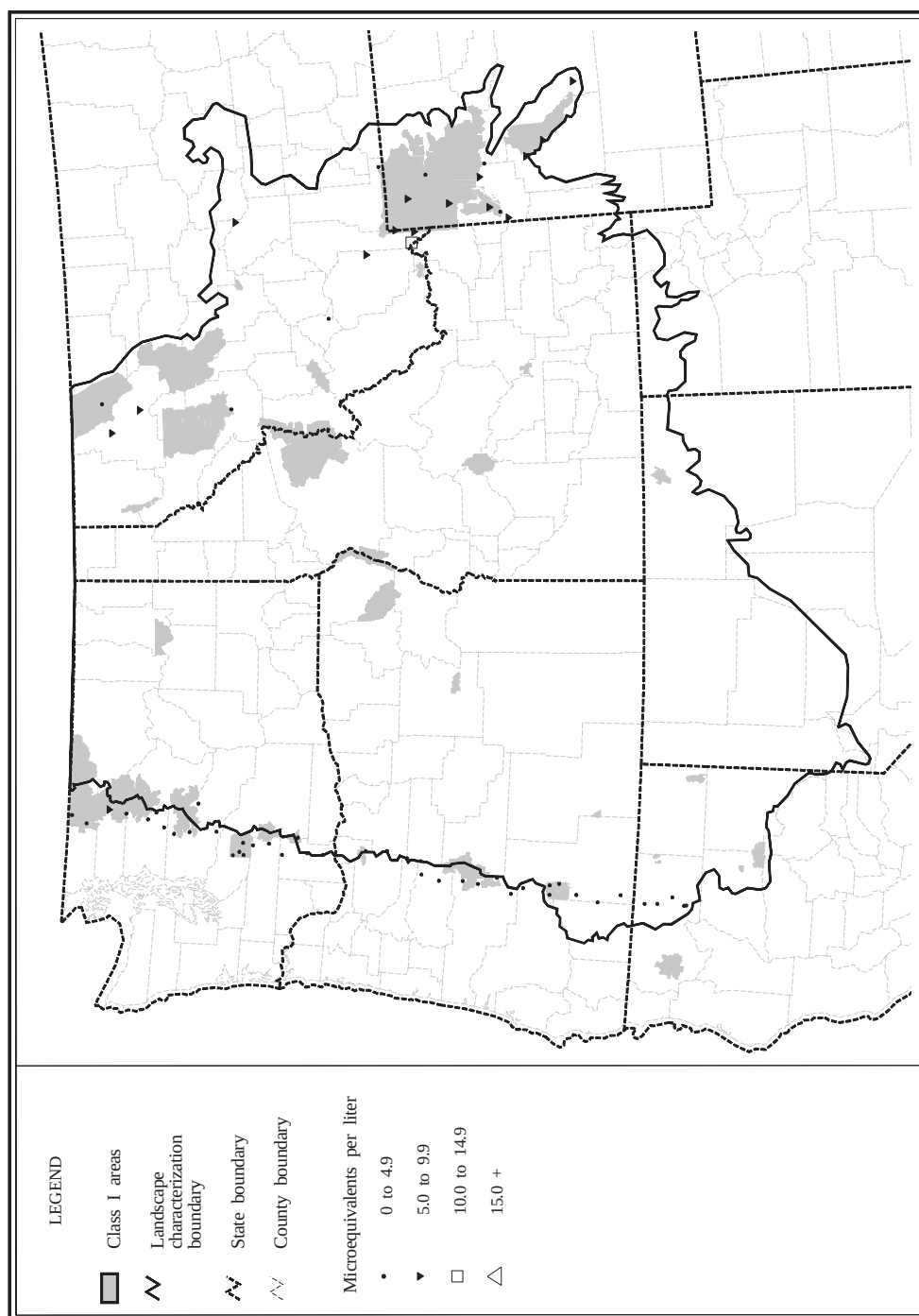


Figure 20—Nitrate (NO_3^-) values from snow sampling sites within or near the interior Columbia River basin (from Laird and others 1986, Turk 1995).

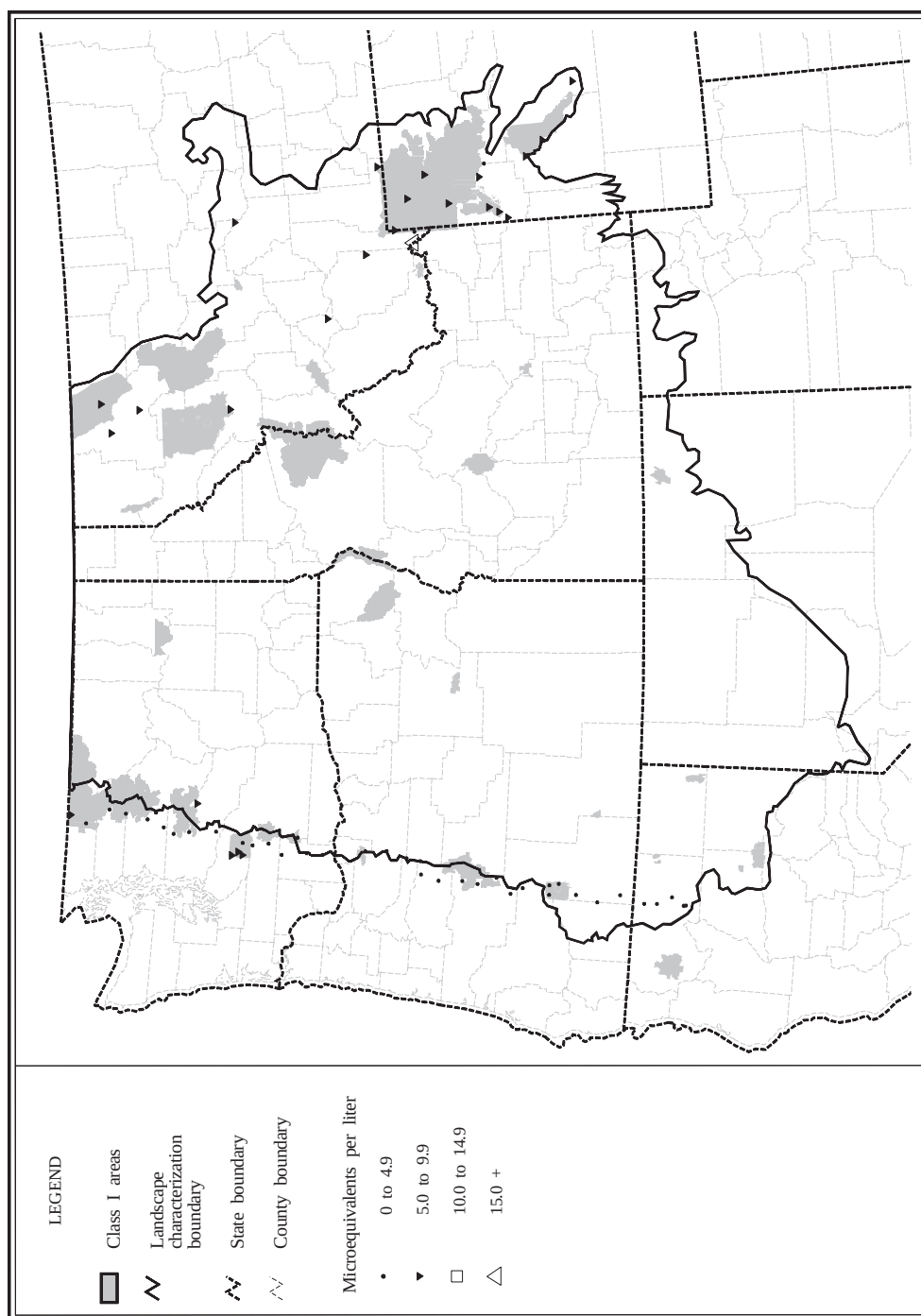


Figure 21—Sulfate (SO_4) values from snow sampling sites within or near the interior Columbia River basin (from Laird and others 1986, Turk 1995).

Location of Aquatic Ecosystems Affected by or Sensitive to Air Pollutants

Because of differences in bedrock geology, soil development, and hydrology, those Rocky Mountain lakes having the smallest acid neutralizing capacity are clustered in specific mountain ranges, such as the Bitterroot Range (Montana) and the Wind River Range (Wyoming). Lakes in the Cascade Range and the Sierra Nevada with small acid neutralizing capacity tend to be more evenly distributed. Many of these clusters of lakes with low acid neutralizing capacity occur within class I areas (fig. 18). The greatest risk of damage from atmospheric deposition is likely in these clusters of lakes with very low acid neutralizing capacity and nearby, but unsampled, lakes, streams, and ephemeral pools.

Routine chemical analyses of the snowpack and wetfall as well as of the lakes, streams, ponds, and ephemeral pools would be most effective in protecting critical aquatic ecosystems if focused on systems having low acid neutralizing capacity.

Information Needed for Assessing Future Risks to Aquatic Ecosystems

Lakes and streams in the interior Columbia River basin showed little evidence of acidification; however, many are likely to respond rapidly to changes in atmospheric deposition. Given the number of lakes and streams in the region, and the number of important watershed characteristics that may affect watershed response to acidity, few index systems are monitored routinely. Thus, preparation of any watershed model appropriate for the evaluation of regional acidification is hampered. Such models need to be calibrated to include the variability of geology, soil, vegetation, climate, atmospheric deposition, and hydrologic characteristics common to the region. Presently (1995), data do not exist to calibrate and verify such models, except for a few individual watersheds.

At present, monitoring networks have few sites at appropriate elevations to determine adequately whether watersheds are adversely affected by atmospheric deposition. Instruments that work at high elevations are difficult to use or are unreliable: thus, data on the quantity and quality of wet-

fall at high elevations generally are unavailable. Direct measurements of dry deposition, fog, and rime ice are needed at high elevations.

Because of access problems at high elevations, measurements of aquatic chemistry during periods of snowmelt or intense rainfall are hindered. Most data collections of lake and stream chemistry are restricted to sampling during midsummer through early fall. This period is not as likely to indicate early stages of acidification as is the period of snowmelt.

Only a few watersheds in the Rocky Mountain region have been studied with respect to watershed processes important to acidification. Regional data about soil-exchange chemistry, weathering reactions, ground water chemistry, in-lake processes, and hydrologic flow paths are almost nonexistent. These same data are even less common in watersheds typical of those sensitive to acidification. No catchment-size areas exist in sensitive watersheds in which experimental manipulation has been done.

To evaluate or predict acidification of sensitive watersheds, it will be necessary to determine how much effect a given change in emissions from a particular source (or sources) will have on atmospheric deposition. The comparative effects of local, regional, or extraregional human or natural sources in controlling the chemistry of atmospheric deposition need to be determined.

In summary, watershed studies need to represent the variety of geographic and geologic conditions and the full seasonal range of hydrologic conditions common to watersheds sensitive to acidification. Information is needed on the effects of changes in emissions to atmospheric deposition and how those changes affect watersheds. Watershed and in-lake processes need to be incorporated into realistic models to simulate existing conditions and responses to pollution sources, to predict effects from potential sources, and to guide data collection and monitoring.

Terrestrial Ecosystems

To assess present impacts of air pollutants on vegetation in the interior Columbia River basin, we chose to concentrate on four major air pollutants: sulfur dioxide (SO₂), nitrogen oxides (NO_x), ozone (O₃), and fluoride (F) (table 1). Less

emphasis is placed on F because it is now important only locally. Ozone will increase with increases in NO_x emissions; thus, its potential effects on vegetation in the basin are emphasized.

Sulfur Dioxide Effects on Terrestrial Ecosystems

Vascular plant and cryptogam sensitivity to sulfur dioxide—Sulfur dioxide enters the leaves through open stomata where it is oxidized to highly toxic sulfite (SO₃) and then to less toxic sulfate (SO₄). Prolonged exposure to SO₂ can result in the accumulation of high levels of sulfate in the leaf tissue which causes chronic sulfate toxicity. In conifers, this causes a yellow-green to red-brown coloration of the needle; in broad-leaved plants this can be a general chlorosis of the leaf. Because SO₂ is assimilated through the stomata, sensitivity of well-watered plants would be expected to be greater than water-stressed plants. Damage therefore may be more likely during wet years or in wet-moist habitats (riparian areas).

Of all vascular plant species tested, alfalfa is the most sensitive species (Davis and Wilhour 1976). From limited data on tree seedlings, Hogsett and others (1989) found that SO₂ concentrations below 20 ppb (24-hour mean) do not produce visible symptoms, yet slight injury is found in ponderosa pine and lodgepole pine above 40 ppb and moderate injury can be expected above 65 ppb.⁴ Slight injury also was observed for Douglas-fir exposed to above 65 ppb SO₂. To protect all vascular plant species, maximum SO₂ concentrations should not exceed 40 to 50 ppb (24-hour mean), and annual average SO₂ should not exceed 8 to 12 ppb (Peterson and others 1992a, 1992b).

Generally, lichens and mosses are more sensitive to SO₂ than are vascular species (Peterson and others 1992b) and may be the most important species to investigate for SO₂ impacts. To protect lichens from impact, the concentration of SO₂ for prolonged periods should not exceed 3 to 5 ppb. Sensitive species are likely to be impacted if concentrations are between 5 to 15 ppb; species with intermediate levels of sensitivity may be impacted when exposed to 10 to 35 ppb SO₂; tolerant spe-

cies may not show symptoms until they experience prolonged exposure to concentrations greater than 30 ppb (Peterson and others 1992a, 1992b).

Sulfur within the basin—Damage to vegetation from SO₂ emitted during late 1920s to mid 1930s smelting operations in Stevens County, WA, and in Montana was observed by Sheffer and Hedgecock 1955. The sensitivity listings from these field observations and some field fumigations are as follows, listed in descending order of sensitivity:

Conifers	Broadleaf trees	Forest shrubs
Grand fir	Thinleaf alder	Pacific ninebark
Subalpine fir	Western paper birch	Western poisonivy
Western redcedar	Sitka mountain-ash	Lewis mockorange
Western hemlock	Water birch	Wild rose
Douglas-fir	Douglas maple	Saskatoon serviceberry
Western white pine	Bitter cherry	California hazel
Ponderosa pine	Common chokecherry	Shinyleaf spirea
Lodgepole pine	Elderberry	Sticky currant
Western larch	Willow	Columbia snowberry
Engelmann spruce	Columbia hawthorn	Redstem ceanothus
Western juniper	Black cottonwood	Snowbrush ceanothus
Pacific yew	Black hawthorn	Redosier dogwood
	Quaking aspen	Smooth sumac

The approximate order of SO₂ sensitivity, as determined from field observations, of trees growing near a smelter in Montana is given in descending order of sensitivity (adapted from Sheffer and Hedgecock 1955): subalpine fir, Douglas-fir, lodgepole pine, Engelman spruce, ponderosa pine, limber pine, Rocky mountain juniper, common juniper.

⁴ Scientific names for all plant species are given in appendix 3.

Rankings determined from field observations and exposures for other western conifers are presented below (Davis and Wilhour 1976). No air chemistry measurements accompanied these field data, so they cannot be used to establish specific exposure thresholds. Species are given in descending order of sensitivity to SO₂: western larch, Douglas-fir, Engelman spruce, western white pine, western hemlock, lodgepole pine, Pacific silver fir, white fir, western redcedar.

Rankings determined from field observations and exposures for other western broad leafed trees and western woody shrubs are presented below (Davis and Wilhour 1976). No air chemistry measurements accompanied these field data, so they cannot be used to establish specific exposure thresholds. Species are listed in descending order of sensitivity to SO₂:

Broadleaf trees	Woody shrubs
Very sensitive	
Bitter cherry	Ninebark
Quaking aspen	Ocean spray
Western paper birch	Serviceberry
Sensitive to intermediate	
Apple (cultivated)	Current
Black cottonwood	Gooseberry
Locust	Grape
Mountain alder	Hazel
Red hawthorn	Mountain laurel
Rocky mountain maple	
Sitka mountain ash	
Willow	
Intermediate	
Apricot (cultivated)	Elderberry
Cherry (cultivated)	Mock orange
Common chokecherry	Snowberry
Elderberry	Thimbleberry
Peach (cultivated)	
Pear (cultivated)	
Plum (cultivated)	
Tolerant	
Elm	Buck brush
Horse chestnut	Buffalo berry
	Dogwood
	Kinnikinnick
	Oregongrape
	Spiraea
	Sumac

In the past several decades, stack heights have increased considerably, thus diluting the emissions before the SO₂ contacts the vegetation. The increase in stack height has reduced vegetation damage near the source yet has caused the emissions to be deposited over a greater area downwind or to be transformed to sulfates and then deposited.

Currently, there are sulfur dioxide monitoring sites to the west and east of the assessment area (table 2), yet only three within the assessment area. These are National Dry Deposition Network sites. The annual average SO₂ concentration at sites in Port Angeles, Seattle, Tacoma, and Clallum County, WA; and East Helena, MT, are within or exceed the suggested maximum concentration (8 to 12 ppb) for the protection of vascular vegetation. In addition to the sites listed above, the annual average SO₂ concentration at sites in Cosmopolis, Hoquiam, March Point, Bellingham, Everett, Calas, and Clallum County, WA; Portland, OR; and Jefferson County, MT, are within or exceed the suggested maximum (3 to 5 ppb) for the protection of lichens. These high values include all monitoring sites in the area except Broadwater County, MT (Continental Lime; 1 ppb annual average), Lewis County, WA (Mount Rainier National Park; <1 ppb annual average), and the three National Dry Deposition Network sites within the basin.

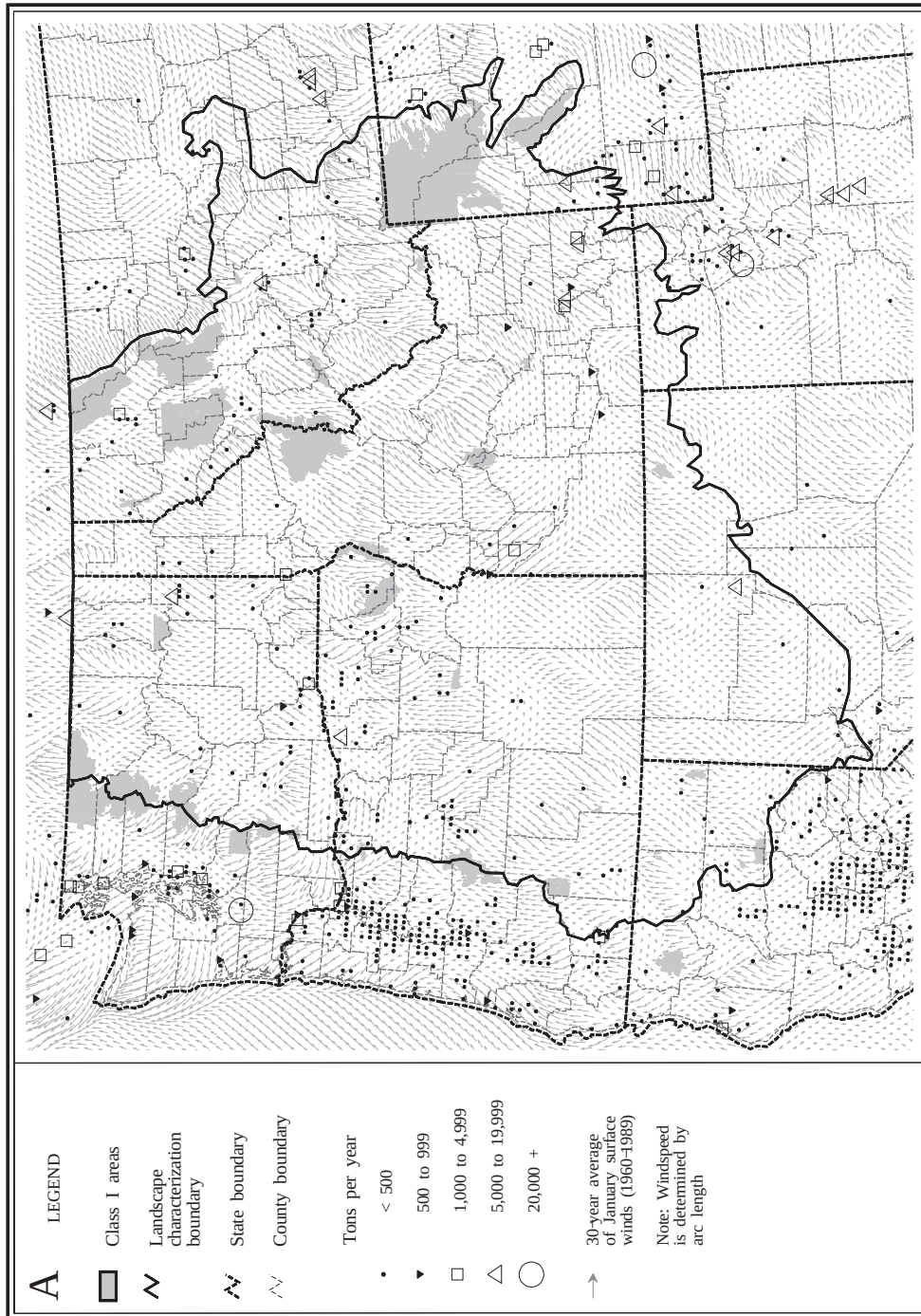
The three National Dry Deposition Network sites within the assessment area are in Nevada, Idaho, and Glacier National Park, MT (fig. 15). All three stations report very low annual mean concentrations. The highest concentrations were at Glacier National Park with an annual mean of only 0.25 ppb SO₂, well below the threshold for damage for vascular plants and lichens. This location also had a greater proximity to emissions of sulfur from point sources than any other class I area within the basin (table 1). Figure 22, displays the proximity of class I areas to SO_x point sources overlaid with 30-year mean surface winds for January and July. Without more monitoring data, it is not possible to assess the current condition of vegetation or cryptogams for SO₂ within the assessment

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Table 2—Summary of Federal, state, and local ambient SO₂ monitoring data for the interior Columbia River basin assessment area

State	City	Station name	Type ^a	Station location		Year of data	SO ₂		
				W. longitude	N. latitude		3-hour	24-hour	Annual
							--- Parts per million ---		
OR	Portland	Standard Oil	SLAMS	122.7416	45.5623	1992	0.048	0.03	0.007
WA	Port Angeles	1st & Chamber	SLAMS	123.4144	48.1114	1991	0.117	0.035	0.008
WA	Port Angeles	Roosevelt	SPMS	123.3887	48.1027	1991	0.129	0.03	0.004
WA	Port Angeles	3d & Chestnut	SLAMS	123.3991	48.1134	1991	0.183	0.055	0.011
WA	Cosmopolis	School Bus Garage	SLAMS	122.457	46.9304	1991	0.128	0.059	0.005
WA	Hoquiam	Poseys	SLAMS	123.8654	46.9716	1991	0.36	0.055	0.006
WA	Anacortes	Texaco South	SLAMS	122.5585	48.4667	1991	0.191	0.041	0.004
WA	March Point	Kiesser	SLAMS	122.5494	48.486	1991	0.14	0.043	0.006
WA	Bellingham	Chestnut Street	SLAMS	122.4828	48.7502	1992	0.073	0.023	0.007
WA	Seattle	Duwamish	NAMS	122.337	47.5585	1992	0.069	0.027	0.01
WA	Tacoma	Lyle	SLAMS	122.4074	47.2667	1991	0.08	0.075	0.004
WA	Tacoma	54th Avenue NE	NAMS	122.3742	47.2808	1992	0.083	0.042	0.01
WA	Tacoma	Alexander Avenue	SLAMS	122.3832	47.2658	1992	0.074	0.026	0.009
WA	Everett	Hoyt Avenue	SLAMS	122.2227	47.9408	1992	0.041	0.017	0.006
WA	Camas	Armory Building	SPMS	122.4295	45.5873	1991	0.08	0.031	0.007
WA	Clallum Co.	Olympic NP	NPS	123.4256	48.0975	1993	0.015	0.048	0.065
WA	Lewis Co.	Mount Rainier NP	IMPROVE	122.1217	46.7614	1993		0.001	
MT	Broadwater Co.	Continental Lime	SLAMS	111.6092	46.3314	1993	0.001		0.001
MT	Jefferson Co.	Microwave Site	SLAMS	111.9172	46.5578	1993	0.96	0.39	0.007
MT	Jefferson Co.	Asarco-Ash Grove	SLAMS	111.9325	46.5389	1993	0.086	0.025	0.006
MT	E. Helena	Asarco-Kleffner	SLAMS	111.9103	46.5731	1993	0.097	0.041	0.007
MT	E. Helena	Asarco-Water Tank	SLAMS	111.9344	46.5833	1993	0.14	0.042	0.012
MT	E. Helena	Asarco-Kennedy	SLAMS	111.92	46.5939	1993	0.09	0.049	0.012

^a SLAMS= state and local air monitoring site; SPMS= special purpose monitoring site; NAMS= National air monitoring site; NPS= national Park Service operated monitoring site; IMPROVE= interagency monitoring of protected visual environments monitoring site.



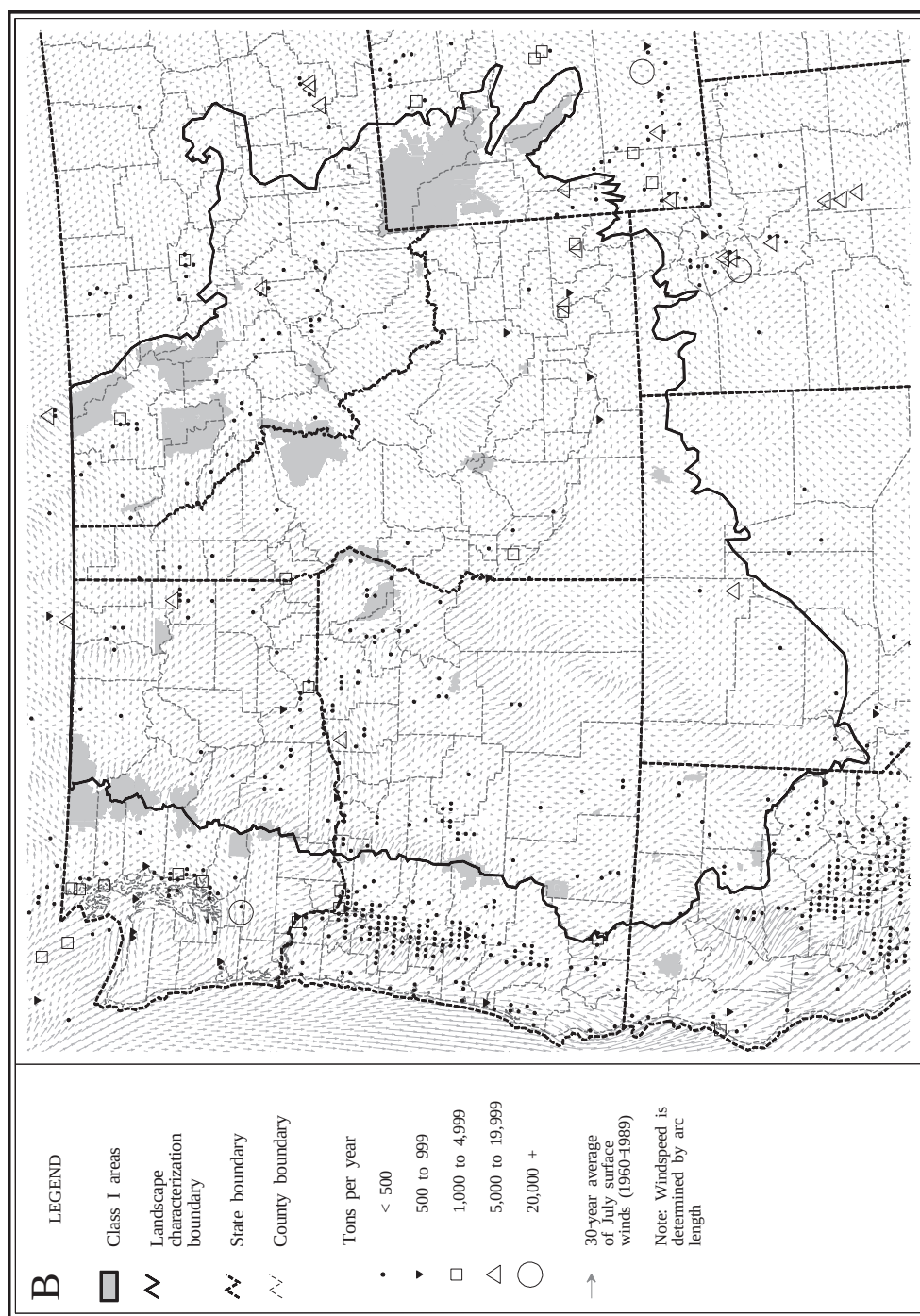


Figure 22—Proximity of class I areas to sulfur oxide (SO_x) point source emissions within or around the interior Columbia River basin and 30-year mean surface winds for (A) January and (B) July.

area. The chemical analyses of lichen tissues can provide a surrogate monitor of SO₂ exposure, because lichens bioaccumulate S and heavy metals, yet the exposure dynamics cannot be known without direct continuous monitoring (Stolte and others 1993).

No current vascular plant surveys that looked for SO₂ injury within the assessment area were found. Gates of the Mountain Wilderness and Glacier National Park in Montana have the closest proximity to SO₂ point source emissions; Gates of the Mountain is also near an SO₂ nonattainment area (fig. 1).

The ecosystems within the interior Columbia River basin assessment area may be becoming more sensitive to SO₂ exposure as a result of forest management practices. The exclusion of fire is increasing the land area supporting grand fir (Filip 1994), the most air-pollution-sensitive conifer species in the area. Alder also is sensitive to SO₂. The expansion of coverage by this species within the basin is making the landscape increasingly susceptible to impact by ambient SO₂ pollution.

Summary of SO₂ information—For SO₂ and the condition of terrestrial resources in the basin:

1. Ambient SO₂ within the basin is contributed by sources within the area and is transported to the basin from sources outside of the area.
2. To protect vascular plants and lichens from direct damage caused by sulfur dioxide, annual mean SO₂ should not exceed 8 to 12 ppb for vascular plants and 3 to 5 ppb for lichens.
3. There are only three SO₂ monitoring stations within the basin (fig. 15). They report mean annual concentrations of SO₂ below the thresholds suggested to protect vegetation.
4. It is not possible to say conclusively that SO₂ is not a threat to vegetation within the assessment area without additional ambient air monitoring and field surveys of vegetation and lichens.

Nitrogen Oxide Effects on Terrestrial Ecosystems

The EPA (1993) provides the most recent and thorough review of the effects of oxides of nitrogen on plant biochemistry, growth, and yield. The impacts of NO_x on plant growth and metabolism are not addressed here. Instead, areas of research that address potential effects of NO_x on plant communities and ecosystems within the interior Columbia River basin are emphasized.

Point source estimates of NO_x by EPA are relatively accurate because they are calculated from fossil fuel consumption and can be monitored (fig. 23). Area sources, such as emissions from biological activity, are not currently used in the emission estimates (fig. 5) because they are much more difficult to estimate owing to temporal and spatial variability in rates. Chameides and others (1994) suggest that biogenic emissions of NO_x significantly contribute to elevated ozone concentrations in the three largest agricultural production areas of the world, and that ozone concentrations in these areas may severely impact crop productivity in the future. Because few monitoring data for ambient levels of NO_x or ozone are available for large regions within the interior Columbia River basin, possible sources of nitrogen oxides that were not used when estimating area emissions (EPA 1994b) and have potential to significantly impact vegetation either directly or indirectly will be discussed.

Emissions of NO_x unaccounted for in the basin—The emissions data used for this assessment did not include emissions of nitrogen oxides derived from soil microbial activity because of large uncertainties in their estimation (Davidson 1991). Nitrous oxide emissions of biogenic origin are of interest because they act as precursors to ozone and could potentially account for a significant amount of NO emissions in the basin. The global budget of NO emissions by source was estimated by Logan (1982) as follows: fossil fuel combustion (21 teragrams NO-N per year); biomass burning (12 teragrams NO-N per year); lightning (8 teragrams NO-N per year); and microbial activity in soils (8 teragrams NO-N per year). Globally, microbial activity is estimated to provide about 16 percent of the NO emitted to the atmosphere (Logan 1982).

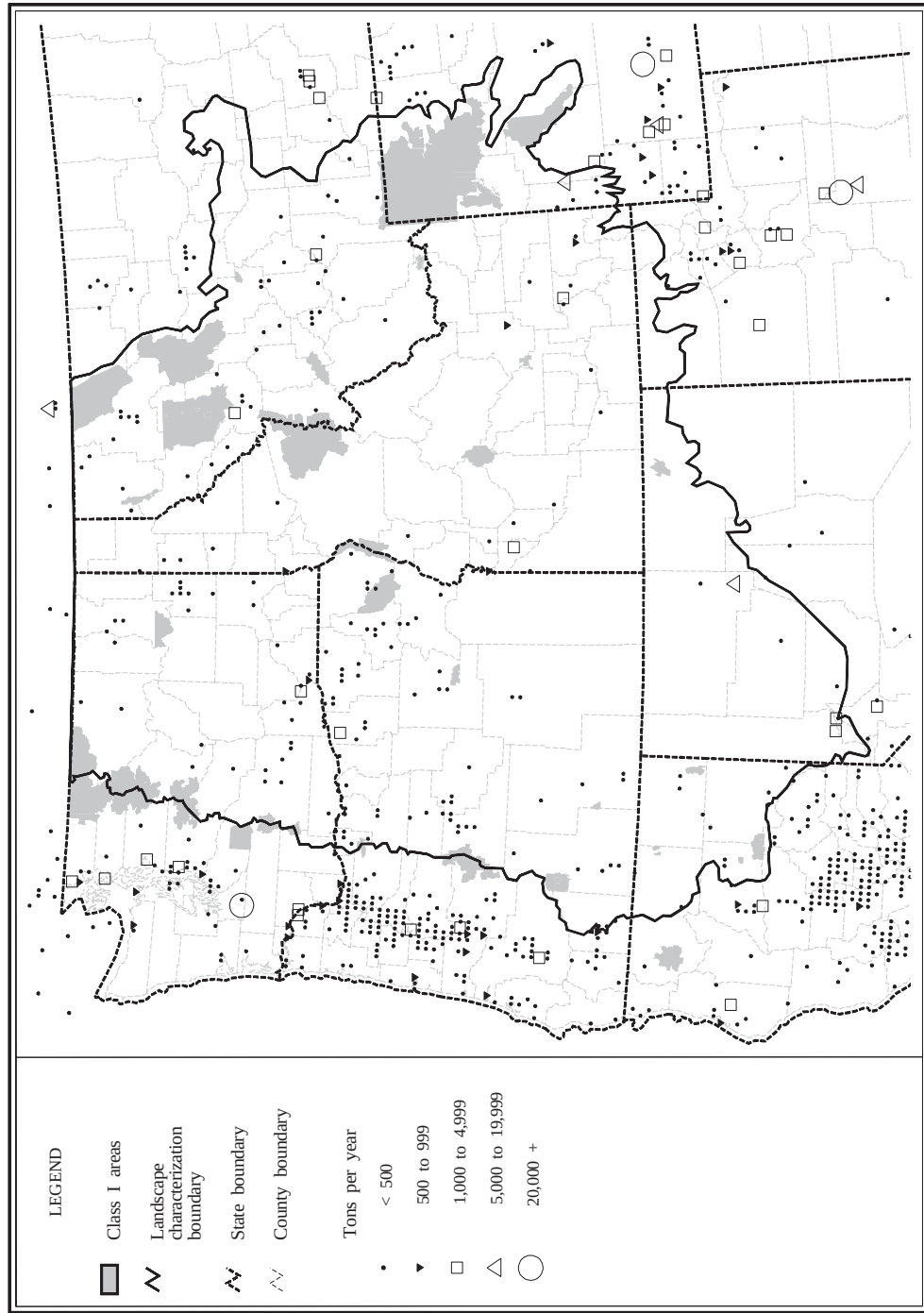


Figure 23—Proximity of class I areas to nitrogen oxide (NO_x) point source emissions within or around the interior Columbia River basin.

Anderson and Poth (1989) report that the major source of biologically derived NO is from fertilized agricultural land. Because of the large amounts of N-fertilizer used in the basin (Oregon Department of Agriculture 1994, Washington Department of Agriculture 1994), microbial activity may be a substantial but unaccounted for source of NO_x in the basin. In addition, shrub-steppe and forested ecosystems also could be seasonal sources of NO_x emissions.

Potential for biologically derived NO_x from agriculture—Hundreds of thousands of tons of N-fertilizer are applied to agricultural ecosystems in the basin annually (Oregon Department of Agriculture 1994, Washington Department of Agriculture 1994). In a long-term study of N-fertility in an agricultural ecosystem near Pendleton, OR, Rasmussen (1991) estimated that about 15 percent of N added as fertilizer cannot be accounted for in crops, soils, or ground water. This suggests that N has been lost to the atmosphere. Excess N in soil can be released through the process of denitrification as gaseous ammonia, inert N₂, NO (precursor of ozone), or N₂O (Davidson 1991), which contributes to global warming. Gaseous N₂ is normally released under anaerobic conditions that occur in water-saturated soils, an unlikely situation in dryland or irrigated agricultural systems of the basin.

Release of N-gases from agricultural lands has the potential to provide a substantial percentage of NO_x emissions within the basin, which may subsequently impact N-limited ecosystems. Eilers and others (1994) suggest that the high concentrations of both nitrate and ammonium in precipitation at Craters of the Moon National Monument in Idaho are derived regionally from fertilized fields or feedlots. For these reasons, additional studies on N-emissions from agricultural activities and their impact to downwind ecosystems are warranted.

Potential for biologically derived NO_x from shrub-steppe ecosystems—No measurements of oxides of nitrogen emissions from shrub-steppe or juniper ecosystems of the basin were found. Both of these seasonably dry ecosystems may function similarly to the seasonably dry chaparral ecosystems in California, which have been measured for NO_x emissions (Anderson and Poth 1989). Anderson and Poth (1989) state that any ecosys-

tem accumulating a soil N-source, either ammonium (NH₄⁺) or nitrate (NO₃⁻), due to burning or to slowly alternating wet-dry or freeze-thaw cycles, may be an important source of nitrogen oxides entering the atmosphere.

Potential for biologically derived NO_x from forest ecosystems—Any activity, such as clear-cutting, fire, or other forest disturbances, that results in mobilization of N (Bowden and Bormann 1986, Klopateck 1987, Matson and others 1987) will result in losses of both NO and N₂O. The largest potential source of nitrogen oxide losses from forested ecosystems is from fire.

Disturbances that reduce site growth potential and increase decay of organic matter and subsequent release of ammonia or nitrate to soil can result in increases in NO_x emissions (Davidson 1991). Rapid, high mortality of forest trees due to fire, clearcutting, pests and pathogens, or catastrophic wind results in high gaseous losses of N because there is relatively little vegetation to take up the excess N released to the soil after the disturbance. Forested ecosystems of the interior Columbia River basin are most likely net sinks for NO_x because they are normally N-limited (Aber and others 1989), have high surface areas to intercept and take up gaseous N as wet or dry deposition, and except for periods of disturbance, effectively recycle N (Bormann and others 1977).

Direct effects of NO_x on vegetation—The lowest concentrations of NO and NO₂ are normally found in nonurban, maritime regions and highest concentrations are associated with urban areas (EPA 1993, 1994b; Chameides and others 1994). We are not aware of monitoring data for oxides of nitrogen within the basin other than for urban areas, but given the relatively low estimated emissions of NO_x in the region, it is doubtful that NO_x concentrations are ever high enough to produce visible injury to vegetation (EPA 1993, Heck and Tingey 1979). Concentrations above 0.1 ppm for over 100 days of exposure are needed to reduce metabolism and growth (EPA 1993).

The time-concentration exposure relation for NO₂ also suggests that visible injury would occur only at concentrations above 2 to 3 ppm for a 1-hour exposure period or above 1 ppm for an exposure period of 10 hours. Because these concentrations and exposure intervals are at least an order of magnitude higher than what would be reasonable

for urban areas within the basin (EPA 1994b), it can be assumed that ambient concentrations of NO_x do not produce visible injury to vegetation within the basin. Concentrations of NO_x causing negative effects on photosynthesis are at least an order of magnitude higher than those found in the basin, thus the probability of direct negative effects of NO_x on photosynthesis and growth of individual species within the basin is extremely low.

Indirect effects of NO_x on vegetation—The highest potential for effects of NO_x on vegetation in the basin seems to be indirect effects of (1) N-deposition on species composition within unmanaged, N-limited ecosystems (Ellenberg 1988, EPA 1993); and (2) the contribution of elevated NO_x concentrations to ozone formation, which is toxic to vegetation (see following section).

An initial step in determining whether N-deposition is influencing plant community composition within the basin is to determine the levels of N-deposition currently occurring on soils having the lowest cation exchange capacities. The limited data on N-deposition within the basin (Eilers and others 1994) indicate it is occurring at low rates. Even though measured N-deposition is low, Eilers and others (1994) suggest the N-deposition is from human activities and thus outside the normal range for that system. Therefore, in seasonally dry, slow-growing, N-limited systems, enhanced N-deposition may influence species composition (Ellenberg 1988) and may threaten several class I areas within the basin (table 1).

Summary of NO_x effects—For NO_x and the condition of terrestrial resources in the basin:

1. Vegetation can be impacted directly by increased inputs of N via wet or dry deposition or indirectly through fertilization effects and NO_x-mediated increases in ozone.
2. Area source estimates are inaccurate. NO_x emissions from fertilized agricultural land may be substantial in the interior Columbia River basin yet are not accounted for in the NO_x inventory.
3. For direct impacts to occur, a concentration of 0.1 ppm NO_x for over 100 days of exposure is

likely to be needed to affect plant metabolism and growth. It is unlikely that this level of sustained exposure is occurring within the basin.

4. There is potential for vegetation to be affected by NO_x in the basin via indirect effects of N-deposition on species composition within unmanaged, N-limited ecosystems.

5. NO_x emissions will have a significant affect on O₃ formation within the basin that may affect plant growth (see following section).

Ozone Effects on Terrestrial Ecosystems

In general, plant response to ozone is negatively related to the increasing dosage to which the plant is exposed (Reich 1987). At equal exposure dosages, exposures with higher concentrations and shorter durations may be more damaging than exposures with lower concentrations and longer durations (Hogsett and others 1988). The diversity of responses to ozone exposure within and between species, as well as interactions with other stresses, complicate development of highly reliable dose-response functions. The EPA currently is attempting to establish a secondary ozone standard to protect vegetation from ozone impacts; the process was not complete at the time of this writing.

Little ozone monitoring has been done in remote wildernesses and parks because of logistical difficulties and cost. There are only two nonurban monitoring sites currently operating within the interior Columbia River basin: Yellowstone National Park, WY, and Lassen Volcanic National Park, CA (Joseph and Flores 1993). The highest daily maximum concentrations recorded from 1988 to 1991 ranged from 80 to 98 ppb in Lassen and from 61 to 98 ppb in Yellowstone.

Species most at risk from ozone exposure—

Eilers and others (1994) compiled lists of species found in the national parks and monuments of the Pacific Northwest that have potential for sensitivity to ozone. The tree species found highly sensitive to ozone exposure are balsam poplar, quaking aspen, and ponderosa pine. Eilers and others (1994) also indicated that trees ranked as “sensitive” would be negatively impacted by a 7-hour

growing-season mean of 60 to 90 ppb for conifers and 70 to 120 ppb for hardwoods. It is reasonable to assume that current mean seasonal ozone concentrations in the basin are significantly below these levels (Böhm and others 1995).

Only one tree species, quaking aspen, was reported by Treshow and Stewart (1973) as sensitive to ozone out of 15 tree and shrub species tested. Five forbs were injured by one 2-hour exposure to 150 ppb ozone. Harward and Treshow (1975) studied 15 understory species from the aspen zone of the Western United States to determine the long-term effects of ozone exposures. Foliar injury was found in all 15 species tested after exposure for 1 to 5 weeks to 150 ppb ozone. Eleven species had visible ozone injury at ambient ozone concentrations.

Hogsett and others (1989) exposed ponderosa pine, western hemlock, western redcedar, Douglas-fir, and lodgepole pine to ozone and acid fog for one growing season and assessed effects on growth in the second season. First-year results suggested that ponderosa pine was the most sensitive tree species to ozone, whereas western hemlock and Douglas-fir were intermediate. Western redcedar and lodgepole pine were the least susceptible to ozone. These rankings are consistent with field studies showing that ponderosa pine is sensitive to elevated ambient ozone concentrations in California (Miller and others 1989). Studies by Hogsett and others (1989) also indicate that no economically important tree species in the Northwestern United States is more sensitive to ozone than ponderosa pine.

Other than the species listed above, there is little information on the sensitivity of natural high-elevation plant species to ozone. Seven native western herbaceous and shrub plant species were tested for their sensitivity to ozone fumigation in a study by Mavity and others.⁵ Several of these species developed visible leaf injury after short exposures to the low ozone concentrations typical of Yellowstone National Park. Further research is needed to refine the use of these species as

bioindicator species for field monitoring for ozone impacts. Ozone concentrations and exposures tend to increase with increasing elevation (Lefohn 1992), putting high-elevation ecosystems at risk. Most of the class I areas also contain high-elevation ecosystems and may be at risk (table 1). Because of the lack of air-quality monitoring in these systems, we were unable to assess whether impacts are likely to be occurring.

Winter wheat and potatoes are two economically important crops in the interior Columbia River basin that are sensitive to ozone (Heck and others 1983, Kohut and others 1987, Kress and others 1987, Pell and others 1988). Ambient ozone concentrations (7-hour seasonal mean of 44 ppb) reduced the yield of winter wheat in Ithaca, NY, compared to yields from charcoal-filtered controls (seasonal mean 7-hour = 22 ppb) (Kohut and others 1987). Ozone concentrations higher than ambient were needed to reduce yields in potatoes grown in State College, PA (Pell and others 1988).

Physiological sensitivity and variation in response—Ozone effects on vegetation have been studied extensively. Recent reviews provide the latest hypotheses on plant responses to ozone (tree response, Reich 1987; allocation, Laurence and others 1994; compensation, Pell and others 1994; forest ecosystems, Taylor and others 1994).

The most common and apparent response of ponderosa pine to chronic ozone exposure is accelerated senescence of foliage. Surveys of foliar injury and needle retention in ponderosa pine should be useful in identifying whether ozone is a problem within the basin. Ozone-induced stress also can have secondary effects beyond reduced growth and vigor of trees, as was shown for pine in the Los Angeles area in the 1950s (Miller 1973). Ponderosa pines weakened by air pollution also are more susceptible to root rot (*Fomes annosus*) and pine beetles (*Dendroctonus brevicomis*) (Cobb and Stark 1970), and these additional stresses greatly increased mortality.

Variation in susceptibility to ozone within populations and its implications to plant communities and ecosystems is comprehensively presented by Taylor and others (1991). Although changes in the genetics of annual populations have been documented near point sources of pollution (Taylor

⁵ Mavity, E.; Stratton, D.; Berrang, P. 1995. Effects of ozone on several species of plants which are native to the Western United States. Internal report. [Place of preparation unknown]: [preparer unknown]. 61 p. On file with: U.S. Department of Agriculture, Forest Service, Center for Forest Environmental Studies, Dry Branch, GA.

1978), pollution-induced changes to tree populations are not likely at this time (Taylor and others 1994) because of the short period of stress (ozone) relative to the length of the life cycle for trees. Genetic selection has not had the opportunity to be manifested within native populations. It is possible, however, that tree plantations in some areas have been inadvertently selected for increased tolerance to ozone through collection of seeds from asymptomatic individuals.

Dose-response functions over a range of tree ages and sizes—Stolte and others (1992) attempted to quantify a relation among foliar retention, chlorotic mottle of foliage, and ambient ozone concentrations in a study of ponderosa pine in California. They found that a sum06⁶ ranging from 112 to 164 ppm-hours annually caused moderate injury to ponderosa pine examined in 1986. Andersen and others (1991) found that coarse and fine root carbohydrates are significantly reduced by exposure to elevated ozone. New root growth just before budbreak also is significantly reduced in ozone exposed seedlings. Furthermore, reductions in ozone-induced root growth potential may be related to the increased incidence of root rot in ozone-stressed ponderosa pine in California (Cobb and Stark 1970).

The National Crop Loss Assessment Network developed a series of dose-response functions for the major economic crops in the United States (Heck and others 1983). All models indicated slight to significant reductions in yield under ambient ozone concentrations near Ithaca, NY, and Chicago. Pell and others (1988) present a linear model for effects of ozone on potato, but they found significant reductions in yield only at ozone concentrations above ambient. It is doubtful that present ozone concentrations in the basin affect potato yields; however, it is possible that sensitive winter wheat cultivars such as Vona (Kohut and others 1987) may have reduced yields due to ambient ozone concentrations in the basin.

Analyses of ambient ozone data for the Western United States (Böhm and others 1995) indicate that concentrations are substantially lower region-wide in the basin than in California and the East-

ern United States. It is possible that downwind of urban and industrial areas in or outside the basin, ozone concentrations may increase sufficiently to negatively affect sensitive native and agricultural species. Increased monitoring, in conjunction with better pollution modeling capacities, is needed to accurately predict ambient ozone concentrations in the basin.

Summary of O₃ effects—For O₃ and the condition of terrestrial resources in the interior Columbia River basin:

1. Ozone has the greatest potential of any air pollutant to directly reduce growth and vigor of vegetation in the basin because it is highly phytotoxic and is found globally in elevated concentrations. In addition, the levels of its precursors (NO_x and hydrocarbons) is increasing within and upwind of the basin.
2. Ozone and its precursors can be transported hundreds of miles and therefore can threaten resources in remote areas.
3. Ambient air quality data for ozone in the basin is less well characterized than for the rest of the United States.
4. The most sensitive tested species within the basin may be impacted by a 7-hour growing-season mean of 60 to 90 ppb of ozone for conifers and 70 to 120 ppb for hardwoods.
5. Recent analyses of ozone monitoring data in the Western United States suggest that the seasonal mean ozone concentrations are significantly below the suggested threshold levels. These levels may be exceeded however, near urban areas or downwind from sources of ozone precursors.
6. Ozone-induced stress may have secondary effects beyond reduced growth, such as increased susceptibility to root rot and insect infestation.

Fluoride

Injury to forest tree species by airborne fluoride (F) has occurred worldwide (Bunce 1979), and information is available from several studies conducted in the interior Columbia River basin (Adams and others 1952, Carlson and Dewey 1971, EPA 1973, Treshow and others 1967). The principal industrial sources of airborne F are aluminum smelting, steel manufacture, conversion of fluorapatite to phosphate and phosphorus in

⁶ Sum06 is the seasonal sum of all hourly ozone concentrations that are 0.06 ppm or higher.

fertilizer production, and glass, ceramic, and brick production. Natural sources of airborne F are principally from soil particles, fumaroles, and volcanoes. The ash from the eruption of Mount St. Helens contained 8 ppm soluble F (Stoiber and others 1980) and 400 ppm total F, but this did not result in F-related injury to forested ecosystems in the basin.

Several indigenous plant species are sensitive to atmospheric F, including goatweed, common barberry, Oregongrape, blueberry, and young needles of many conifers. One general conclusion can be made: field observations of plants can be a good qualitative but usually a poor quantitative indicator of effects. There has been severe depletion of lichen populations in many cases of F-pollution (reviewed by Gilbert 1973).

The advent and implementation of new technologies for control of F-emissions within the aluminum industry has greatly reduced F-emissions within the basin. Emission monitoring and field surveys still are conducted by aluminum industry personnel, but we are not aware of ongoing research programs to determine F-induced effects on forested ecosystems within the basin. The potential impact of F-emissions to vegetation presently seems low because the emissions are limited to a few point sources associated with aluminum reduction plants within the basin.

In summary, for fluoride and the condition of terrestrial resources in the basin:

1. The implementation of new technologies for control of F-emissions within the aluminum industry has greatly reduced F-emissions within the basin.
2. Current impacts due to F are likely to be limited to proximity to the few point sources within the basin.

Visibility in the Basin

Visibility is an important air resource. Congress recognized this and included visibility protection as part of the 1977 Clean Air Act amendments (U.S. Laws, Statutes 1977). In section 169A, Congress declared, as a national goal, "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution."

Visibility degradation can manifest itself in various ways, including discoloration, a change in the sharpness or clarity of a view, or as a decrease in the distance one can see. Human-caused air pollution phenomena affecting visibility are generally categorized as plumes, layered hazes, or uniform hazes. Plumes are generally coherent masses of pollutant that either discolor parts of a scene or affect the sharpness of objects viewed. Distinct plumes are generally observed within a few kilometers of a pollutant source. Layered hazes are similar to plumes, in that they are a distinct mass of pollutant observed in the atmosphere, but their spatial extent is greater and they may not be visually linked to a nearby source. Uniform hazes are more ubiquitous masses of visibility-affecting pollutant; they generally cover a large geographic area and are well mixed vertically. Uniform hazes usually are formed by a number of contributing sources, although, individual large sources can dominate under the right atmospheric conditions. Uniform hazes can be formed by pollutants traveling over a few to several hundred kilometers. For characterizing visibility over an area such as the interior Columbia River basin, measurements of uniform haze are generally used. Localized visibility problems within the region can be caused by plumes and layered hazes, but the available measurements are more appropriate for characterizing uniform hazes.

The available data for characterizing visibility conditions in the basin come from the IMPROVE (Interagency Monitoring of Protected Visual Environments) monitoring network. IMPROVE sites generally include aerosol and optical measurements. The aerosol sampling is accomplished by particle collection and sample analysis. View monitoring is also performed. Three color slides are taken each day, via automatic camera, to document the appearance of a selected scene.

The aerosol scattering efficiencies differ for different aerosol components. The efficiencies for hygroscopic aerosols, such as sulfate, nitrate, and some organic aerosols, differ as functions of relative humidity. The effect of humidity on scattering from hygroscopic aerosols is especially pronounced at high relative humidities; the effect can be greater than an order of magnitude than if the same aerosol was dry. For more information on IMPROVE, see Sisler and others (1993).

Available Data

The IMPROVE monitoring stations within the basin are all near the perimeter of the area: Columbia River Gorge, Snoqualmie Pass, Crater Lake National Park, Lassen Volcanic National Park, Jarbidge Wilderness Area, Yellowstone National Park, and Glacier National Park. There also is an IMPROVE site at Mount Rainier, which is just outside of the basin boundary; the actual monitoring site is at low elevation on the west side of Mount Rainier National Park. The interior of the basin is not well characterized, and conditions there may be different from those measured on the periphery.

Figure 24 shows the contribution of aerosols to light extinction at the IMPROVE sites around the basin. Figure 25 displays the same information, expressed as a percentage. At all sites, organic aerosol is a major component of the aerosol extinction budget, and at most of the sites sulfate is also a major contributor. With the exception of the Columbia River Gorge and Snoqualmie Pass sites, the contribution of nitrate is slight. The component identified as soot, sometimes referred to as light-absorbing carbon, is the third largest component everywhere except the Columbia River Gorge site, where it is the largest component. At Jarbidge, coarse aerosols contribute slightly more to extinction than sulfate, and at Columbia River Gorge, nitrate is comparable to sulfate.

Visibility at the sites is quite variable as seen in figure 26, where visibility is expressed in terms of standard visual range. The more northerly sites, Columbia River Gorge, Glacier National Park, Mount Rainier, and Snoqualmie Pass, have much lower average visual ranges than the more southerly sites. The southerly sites all have average standard visual ranges in excess of 130 km, and all the northerly sites are less than 80 km. The Jarbidge site exhibits some of the best visibility conditions of any site in the IMPROVE network, with an annual average standard visual range of 168 km.

Discussion

To better understand why the northern sites have poorer average visibility conditions than the southerly sites, the relative influence of various fine particles must be examined. All northern sites have higher concentrations of organic aerosols and higher levels of sulfate. The annual average organic concentration is highest at the Glacier National Park site, and the highest sulfate concentration occurs at the Columbia River Gorge site. Although the concentrations of organics and sulfate are higher at Glacier National Park and Columbia River Gorge, the highest extinction due to those elements is at the Mount Rainier site. As noted earlier, the light scattering efficiency of sulfate, nitrate, and some organics is enhanced at higher relative humidities. Humidity at the Mount Rainier site is much higher on average than generally occurs at east-side sites. Therefore the importance of those components to light extinction also is enhanced, relative to the total mass of those aerosols. This can be seen by comparing figure 27 with figure 24. In figure 27, the mass of sulfate and organics at Mount Rainier is similar to other sites, but figure 24 shows that the effect on extinction is much greater.

One of the differences of the three sites along the northern Cascade Range (Snoqualmie Pass, Mount Rainier, and Columbia River Gorge), relative to the other sites in the region, is their proximity to the upwind pollution source areas of western Washington and Portland, OR. This leads to elevated sulfate and, at Columbia River Gorge and Snoqualmie Pass, nitrate concentrations. The Mount Rainier IMPROVE site is located slightly west of Mount Rainier National Park and at relatively low elevation. The Mount Rainier IMPROVE is likely to be more affected by sources in the Puget Sound region and the western Washington lowlands than sites actually located in the basin. Even though the Snoqualmie Pass and Columbia River Gorge sites are both within the basin area, they are each near the boundary and are at low points in the Cascade Range where pollutants are channeled from Seattle and Portland. Major interstate highway routes run through Snoqualmie Pass and along the Columbia River. The Columbia River Gorge site also may be affected by various industrial facilities along the Columbia River.

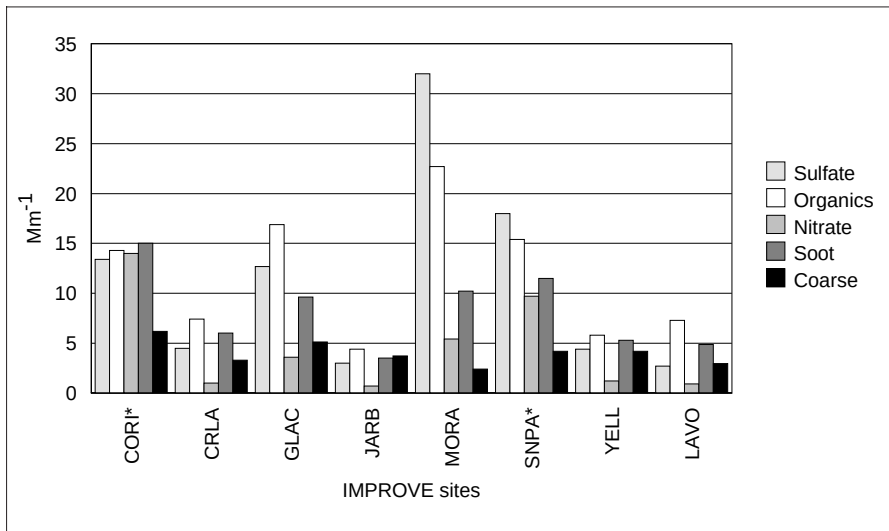


Figure 24—Light extinction due to aerosol components for the interior Columbia River basin IMPROVE sites. Columbia River Gorge Scenic Area = CORI, Crater Lake National Park = CRLA, Glacier National Park = GLAC, Jarbidge Wilderness = JARB, Mount Rainier National Park = MORA, Snoqualmie Pass = SNPA, Yellowstone National Park = YELL, Lassen Volcanic National Park = LAVO. * = the period of record for Columbia River Gorge and Snoqualmie Pass from June 1993 to August 1994.

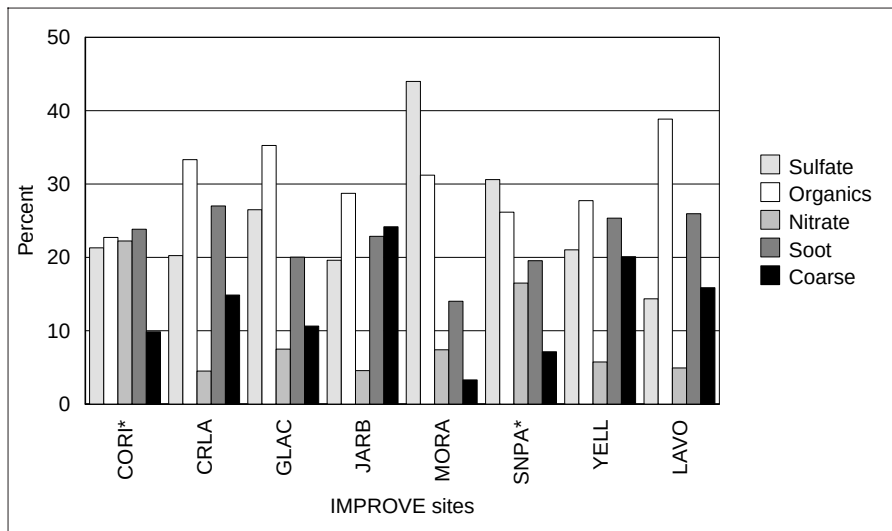


Figure 25—Percentage of light extinction due to aerosol components for the interior Columbia River basin IMPROVE sites. Columbia River Gorge Scenic Area = CORI, Crater Lake National Park = CRLA, Glacier National Park = GLAC, Jarbidge Wilderness = JARB, Mount Rainier National Park = MORA, Snoqualmie Pass = SNPA, Yellowstone National Park = YELL, Lassen Volcanic National Park = LAVO. * = the period of record for Columbia River Gorge and Snoqualmie Pass from June 1993 to August 1994.

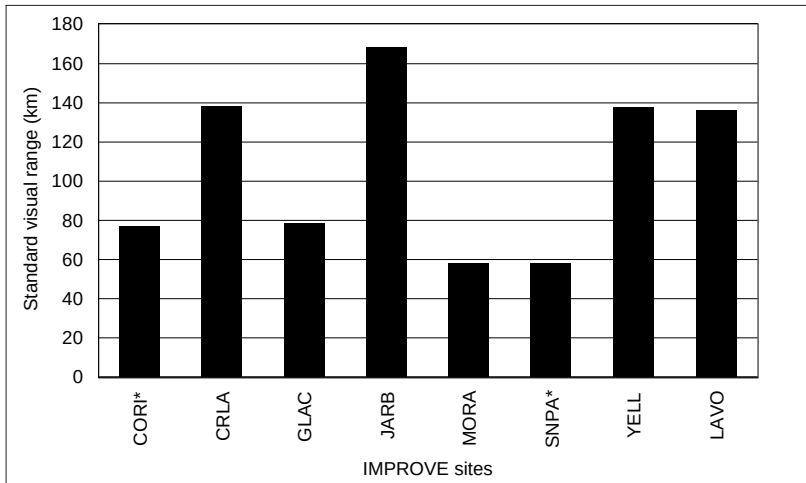


Figure 26—Standard visual range, expressed as an annual average, in kilometers, for the interior Columbia River basin IMPROVE sites. Columbia River Gorge Scenic Area = CORI, Crater Lake National Park = CRLA, Glacier National Park = GLAC, Jarbidge Wilderness = JARB, Mount Rainier National Park = MORA, Snoqualmie Pass = SNPA, Yellowstone National Park = YELL, Lassen Volcanic National Park = LAVO. * = the period of record for Columbia River Gorge and Snoqualmie Pass from June 1993 to August 1994.

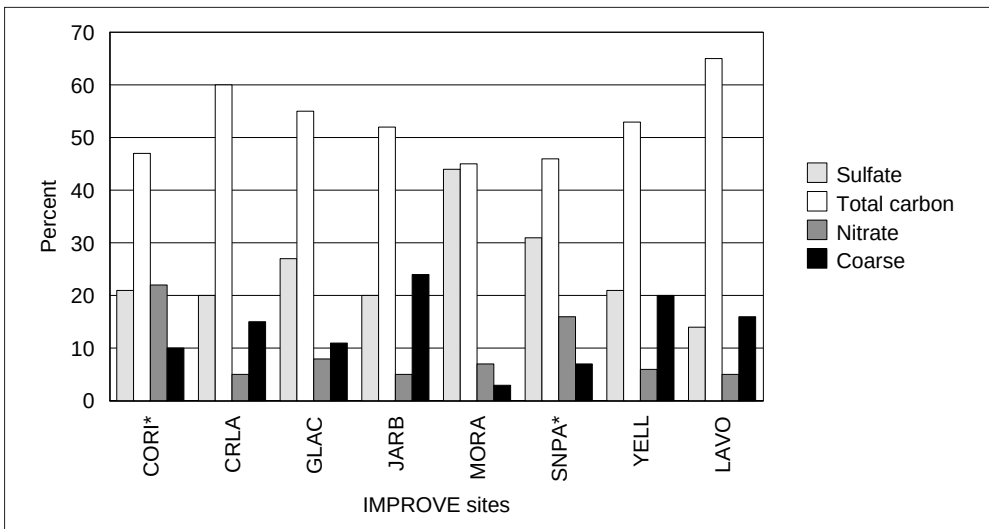


Figure 27—Aerosol extinction budget with organics and soot combined into total carbon for the interior Columbia River basin IMPROVE sites. Columbia River Gorge Scenic Area = CORI, Crater Lake National Park = CRLA, Glacier National Park = GLAC, Jarbidge Wilderness = JARB, Mount Rainier National Park = MORA, Snoqualmie Pass = SNPA, Yellowstone National Park = YELL, Lassen Volcanic National Park = LAVO. * = the period of record for Columbia River Gorge and Snoqualmie Pass from June 1993 to August 1994.

Although there are elevated nitrate concentrations at Columbia River Gorge and Snoqualmie Pass, the nitrate aerosol may not be transported very far into the interior of the interior Columbia River basin. Ammonium nitrate aerosol is in equilibrium with its gas phase components and can revert back to those components. Generally, cool, moist conditions are more favorable for the formation of ammonium nitrate aerosol, and warmer dryer conditions are more favorable for the gaseous components. Ammonium nitrate therefore can be somewhat transient in the atmosphere and usually is not measured in high concentrations at sites distant from source areas.

At all the sites in and around the basin, carbon in its various forms dominates the extinction budget. Figure 27 displays the same information as figure 25 but combines the organics and soot categories into "total carbon." With the exception of the sites along the northern portion of the Cascade Range, total carbon accounts for more than 50 percent of the total aerosol extinction. This has certain implications for forest management practices in the basin. Carbonaceous aerosols are emitted by forest burning. Dramatic increases in burning are likely to degrade visibility in the protected areas of the region. Burning practices will have to be considered for improvements to be made in visibility conditions.

The data discussed here have been presented as annual average conditions for comparison among sites. Depending on the use of the data, other statistical groupings may be more appropriate. For example, the distribution of aerosols on the worst visibility days would be worth examining if the management objective were to remedy some existing visibility impairment on those days. Conversely, the relative distribution of aerosols on the best visibility days would be more appropriate if the management objective were protection of the cleanest days. Similarly, the visibility conditions also differ by season. If management options being examined are seasonal in nature, seasonal visibility values should be determined.

Ecosystems and Resources at Risk From Air Pollution

Forests

Much of the interior Columbia River basin includes pine, fir, and spruce species (fig. 28). These forests are exposed to ozone and deposition of sulfur and nitrogen compounds. Ponderosa pine within the basin is likely to be especially sensitive to ozone and is at high risk of injury if ozone levels continue to rise. The forests are also at risk for alteration of growth rates and patterns, soil acidification, shifts in species composition, and modification of the effect of natural stresses such as drought and insect infestation in response to N- and S- deposition. One of the biggest unknowns relative to the effects of air pollution on these forests is the status of forest soils and the effects of N-deposition on nutrient cycling, particularly in forest stands disturbed by fire, pests, and disease outbreaks.

High-Elevation Lakes and Streams

The EPA is required to prepare an assessment of the information available to set a standard to protect sensitive ecosystems from damage due to deposition of acidity, sulfur, and nitrogen compounds. In the 1995 report (EPA 1995), sensitive aquatic resources were identified in (1) the Cascade Range in Washington, Oregon, and California; (2) the Idaho Batholith in Idaho and Montana; (3) the mountain ranges of northwestern Wyoming; and (4) the Rocky Mountains in Colorado.

At present there are no chronically acidified lakes due to deposition inputs in the basin; however, many of the sensitive, low-acid neutralizing capacity systems found at high elevations are susceptible to episodic acidification associated with intense rains or spring snowmelt. There is evidence that N-deposition in rain, snow, and dry fall have caused small, chronic losses of acid neutralizing capacity in high-elevation lakes in the West. The

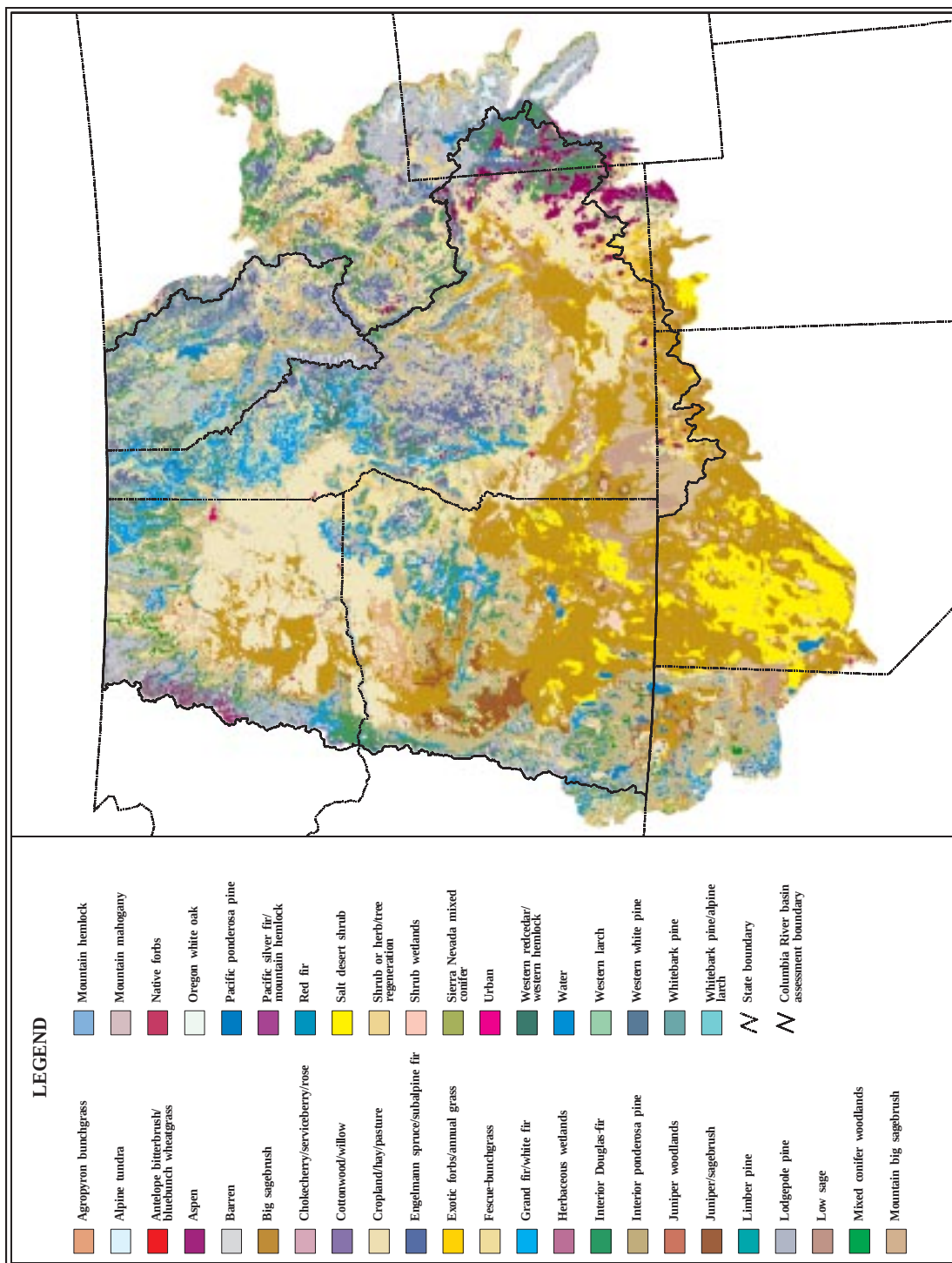


Figure 28—Current cover types within the interior Columbia River basin assessment area.

EPA's Western Lake Survey (Eilers and others 1987, Landers and others 1987) detected measurable amounts of nitrate in lakes of northwestern Wyoming and the Colorado Rocky Mountains (especially in Front Range locations). These concentrations were sufficiently high to indicate that these high-elevation watersheds have little remaining capacity to absorb nitrogen in deposition (EPA 1995).

Arid Lands

Mangis and others (1991) review the possible effects of air pollution and deposition on resources found in arid lands. Areas of eastern Oregon and Washington and south-central Idaho can be considered part of the Great Basin and Intermountain desert and semidesert ecoregions, where little research or monitoring has been done to determine levels of air pollutants and their effects. These parts of the basin include salt desert shrub and sagebrush-dominated landscapes (see the southwest section of fig. 28) and depend on the integrity of cryptogamic crusts for soil stabilization. Additional information on exposure of these ecosystems to air pollutants and deposition is needed with special attention to the cryptogams.

Class I Areas

Federal land managers of class I wildernesses and parks (fig. 1) have an "affirmative responsibility to protect the air quality related values;" e.g., visibility, vegetation, water, soil, fauna, and ecosystem processes, from adverse effects of air pollution (40 CFR 52.21(p)(2)). High-elevation vegetation may be particularly at risk from ozone because ozone concentrations are often highest at these elevations. For a more detailed discussion of class I areas managed by the National Park Service in the Pacific Northwest, refer to Eilers and others (1994); a compilation of information on U.S. Department of Agriculture Forest Service class I areas can be found in Peterson and others (1992a, 1992b) and Stanford and others (1997).

Research, Development, and Assessment

Future air quality assessments for the interior Columbia River basin would benefit from:

1. Integration of criteria air pollutants and deposition information with information on other pollutants of interest (for example, organics and particles from wildfires, pesticides and herbicide transport, and toxic air contaminants identified in the 1990 Clean Air Act amendments [U.S. Laws, Statutes 1990]).
2. Continued and augmented monitoring of pollutants important to ecosystem function in the basin, including (1) high-elevation monitoring of rain and snow with emphasis on quantification of nitrogen species, (2) dry deposition monitoring, (3) ozone monitoring in remote areas using both continuous and integrated methods, (4) preliminary assessment of levels of persistent organic pollutants and mercury, and (5) improved estimates of nonpoint source NO_x emissions.
3. Creation of an air quality related value inventory for each of the class I areas and other sensitive ecosystems and watersheds within the basin. Once this inventory is compiled, Federal and state agency personnel could devise an air quality related value monitoring program to detect changes in response variables in the sensitive ecosystems. Before this monitoring program is implemented, more studies would be needed to determine levels of pollutants that might affect sensitive end points (for example, fumigation experiments on representative vascular and nonvascular plant species, nitrogen additions to determine thresholds to prevent changes in terrestrial community structure, and acidification and nitrogen addition experiments to determine degree of change in surface water chemistry and biota).

4. Discussion of population growth, planned development activities, and the projection of future emissions, transport, transformation, and deposition and the effects of these increases in emissions on human health and resource degradation. Ecosystem level effects and impact on air quality related values in wilderness areas and national parks may need special attention.

5. Extensive information about sensitive processes, populations, and ecosystems found in the basin that are at risk from air pollutants and deposition is lacking. These include forests, high-elevation lakes and streams, and arid lands. More

information on the potential impacts of air pollutants and deposition on ecological and biological resources including forests, high-elevation lakes and streams, and arid lands would benefit this assessment. This can be accomplished only with the collection of ecosystemwide data on current status and the prediction of future condition under different air quality scenarios. This type of prediction will be furthered through the use of models and experimental manipulations in the field. This level of research and monitoring will require a commitment of funds and the cooperation and coordination among agencies with interest in air quality and ecosystem integrity.

Definition of Terms Used

Acid neutralizing capacity: A quantitative measure of the ability of water to neutralize acid. In the basin, acid neutralizing capacity is almost entirely due to the bicarbonate ion (HCO_3^-). Units commonly used are $\mu\text{eq L}^{-1}$ (microequivalents per liter) and $\text{mg L}^{-1} \text{CaCO}_3$ (milligrams per liter calcium carbonate). $1 \text{ mg L}^{-1} \text{CaCO}_3 = 20 \mu\text{eq L}^{-1}$.

Acidification: The loss of some or all acid neutralizing capacity due to reaction with acid.

Acidic lake: One with acid neutralizing capacity of zero or less (negative acid neutralizing capacity corresponds to acidity).

Aerosol: Microscopic solid or liquid particles in a gaseous medium.

Area source: Any small source of nonnatural air pollution that is released over a relatively small area but which cannot be classified as a point source.

Class I areas: All international parks, national parks greater than 2430 ha (6,000 acres), and national wilderness areas greater than 2025 ha (5,000 acres) that existed on August 7, 1977, when the 1977 Clean Air Act amendments (U.S. Laws, Statutes 1977) were passed. This class provides the most protection to pristine lands by severely limiting the amount of air pollution that can be added to an area.

Criteria pollutant: The 1977 Clean Air Act amendments (U.S. Laws, Statutes 1977) requires EPA to set standards for certain pollutants known to be hazardous to human health. The EPA has identified and set standards for six pollutants: ozone, carbon monoxide, particulate matter, sulfur dioxide, lead, and nitrogen oxides.

Cryptogam: A plant (such as a fern, moss, alga, or fungus) reproducing by spores and not producing flowers or seed.

Dry deposition: Removal of gaseous and particulate species from the atmosphere to terrestrial and aquatic ecosystems.

IMPROVE: Interagency Monitoring of Protected Visual Environments was initiated to fulfill the national goal of preventing any future and remediating existing visibility impairment in national parks and wilderness areas. The National Park Service, Forest Service, Fish and Wildlife Service, Bureau of Land Management, and Environmental Protection Agency coordinate to meet this goal.

National Atmospheric Deposition Program (NADP) network: This network monitors geographical and temporal trends in the chemical composition of rain and snow, in support of research on effects, particularly on aquatic and terrestrial ecosystems.

National Dry Deposition Network (NDDN): This network monitors the magnitude, spatial variability, and trends in dry deposition of ozone and acidic particles and gases.

Nitrate: A compound containing nitrogen that can exist in the atmosphere or as a dissolved gas in water and that can have harmful effects on humans and animals.

Nitrogen oxides (NO_x): Product of combustion from transportation and stationary sources and a major contributor to acid deposition and the formation of ground level ozone in the troposphere.

Nonattainment area: An area deemed by EPA or a State air regulatory agency as not meeting the ambient air quality standard for a specific pollutant.

Occult deposition: Deposition not easily identified or measured, such as fog.

Particulates: Any material, except water or gas in a chemically uncombined form, that is or has been airborne and exists as a liquid or solid at standard temperature and pressure conditions. Minute particles of dust, fly ash, fumes, and oxides of various metals are examples of particulates.

pH: A measure of the acidity or alkalinity of a liquid or solid material measured as the negative log of the hydrogen ion; $-\text{Log}_{10}[\text{H}^+]$. Typical rainwater measures about 5.5 pH, lemon juice about 2 pH, and ammonia about 11 pH. Common pH conversions:

pH of 4 = 100 $\mu\text{eq L}^{-1}$ of acidity

pH of 5 = 10 $\mu\text{eq L}^{-1}$ of acidity

pH of 6 = 1 $\mu\text{eq L}^{-1}$ of acidity

Point source: A stationary location or fixed facility from which pollutants are discharged or emitted.

Pphm: Parts per hundred million.

Radionuclide: Radioactive element characterized by its atomic mass and atomic number; can be human-made or naturally occurring.

Sensitivity: A subjectively defined measure of whether a lake or stream has enough acid neutralizing capacity to neutralize additional acid. If the acid neutralizing capacity is large relative to the anticipated amount of acid, the lake or stream is said to not be sensitive to acidification. If, however, acid neutralizing capacity is lower than the specified amount of acid, the lake or stream is said to be very sensitive. This measure is useful in broadly characterizing whether populations of lakes or streams are at risk.

Standard visual range (SVR): The distance at which a large black object just disappears on the horizon.

Stomata: Small pores in the epidermis of the leaf, to provide for the entry of carbon dioxide and the discharge of oxygen and water vapor.

Sulfates: Aerosols that have origins in the gas-to-aerosol conversion of sulfur dioxide; e.g., sulfuric acid and ammonium sulfate.

Sulfur dioxide (SO₂): A heavy, pungent, colorless, gaseous air pollutant formed primarily by industrial fossil fuel combustion processes.

Volatile organic compounds (VOC): Organic compounds that participate in atmospheric photochemical reactions.

Conversion Table

When you know:	Multiply by:	To find:
Millimeters (mm)	0.039	Inches
Centimeters (cm)	0.394	Inches
Meters (m)	3.281	Feet
Kilometers (km)	0.621	Miles
Kilograms (kg)	2.205	Pounds
Hectares (ha)	2.471	Acres
Kilograms/hectare (kg/ha)	0.893	Pounds per acre
Liters (L)	0.265	Gallons
Milligrams (mg)	35.27	Ounces
Milligrams/liter (mg/l)	1.0	Parts/million (ppm)
Tons (U.S.)	0.907	Tonnes
Tons (U.S.) per acre	2.24	Megagrams per hectare

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Appendix 1

Class I Areas Within the Interior Columbia River Basin¹

Class I area	State	Managing agency	Area	
			<i>Ha</i>	<i>Acres</i>
Caribou Wilderness	CA	Forest Service	7 727	19,080
Lava Beds Wilderness	CA	National Park Service	11 599	28,640
South Warner Wilderness	CA	Forest Service	27 745	68,507
Thousand Lakes Wilderness	CA	Forest Service	6 356	15,695
Marble Mountain Wilderness	CA	Forest Service	86 566	213,743
Lassen Volcanic National Park	CA	National Park Service	42 849	105,800
Hell's Canyon Wilderness ²	ID	Forest Service	33 939	83,800
Sawtooth Wilderness	ID	Forest Service	87 635	216,383
Selway-Bitterroot Wilderness ³	ID	Forest Service	400 127	988,700
Craters of the Moon National Monument	ID	National Park Service	17 513	43,243
Yellowstone National Park ⁴	ID	National Park Service	12 753	31,488
Flathead Reservation	MT	Tribal	505 440	1,248,000
Anaconda Pintler Wilderness	MT	Forest Service	63 910	157,803
Bob Marshall Wilderness	MT	Forest Service	384 750	950,000
Cabinet Mountains Wilderness	MT	Forest Service	38 780	94,272
Gates of the Mountains Wilderness	MT	Forest Service	11 568	28,562
Scapegoat Wilderness	MT	Forest Service	96 914	239,295
Selway-Bitterroot Wilderness ³	MT	Forest Service	101 956	251,930
Yellowstone National Park ⁴	MT	National Park Service	67 888	167,624
Glacier National Park	MT	National Park Service	410 103	1,012,599

¹ From 40 CFR 81.400, revised July 1, 1994 and tribal sources.

² Hells Canyon Wilderness, 78 043 ha (192,700 acres) overall, of which 44 105 ha (108,900 acres) are in Oregon and 33 939 ha (83,800 acres) are in Idaho.

³ Selway-Bitterroot Wilderness, 502 083 ha (1,240,630 acres) overall, of which 400 127 ha (988,700 acres) are in Idaho and 101 930 ha (251,930 acres) are in Montana.

⁴ Yellowstone National Park, 898 993 ha (2,219,737 overall, of which 818 353 ha (2,020,625 acres) are in Wyoming, 67 888 ha (167,624 acres) are in Montana, and 12 753 ha (31,488 acres) are in Idaho.

Red Rock Lakes Wilderness	MT	Fish and Wildlife Service	13 102	32,350
Jarbridge Wilderness	NV	Forest Service	26 190	64,667
Eagle Cap Wilderness	OR	Forest Service	118 858	293,476
Gearhart Mountain Wilderness	OR	Forest Service	7 577	18,709
Hell's Canyon Wilderness ³	OR	Forest Service	44 105	108,900
Mount Hood Wilderness	OR	Forest Service	5 735	14,160
Mount Washington Wilderness	OR	Forest Service	19 487	48,116
Strawberry Wilderness	OR	Forest Service	13 366	33,003
Three Sisters Wilderness	OR	Forest Service	80 960	199,902
Crater Lake National Park	OR	National Park Service	64 918	160,290
Alpine Lakes Wilderness	WA	Forest Service	122 921	303,508
Glacier Peak Wilderness	WA	Forest Service	188 024	464,258
Goat Rocks Wilderness	WA	Forest Service	33 485	82,680
Mount Adams Wilderness	WA	Forest Service	13 104	32,356
Mount Rainier National Park	WA	National Park Service	95 272	235,239
North Cascades National Park	WA	National Park Service	203 827	503,277
Pasayten Wilderness	WA	Forest Service	204 737	505,524
Spokane Reservation	WA	Tribal	54 004	133,344
Bridger Wilderness	WY	Forest Service	158 825	392,160
Fitzpatrick Wilderness	WY	Forest Service	77 397	191,103
Grand Teton National Park	WY	National Park Service	123 729	305,504
North Absaroka Wilderness	WY	Forest Service	142 197	351,104
Teton Wilderness	WY	Forest Service	225 711	557,311
Washikie Wilderness	WY	Forest Service	278 067	686,584
Yellowstone National Park ⁴	WY	National Park Service	818 353	2,020,625

Appendix 2

Nonattainment Areas Within or Near the Interior Columbia River Basin¹

State	Nonattainment Area	Pollutant
California	Lake Tahoe North Shore area: Placer County (part)	Carbon monoxide
	Lake Tahoe South Shore area: El Dorado County (part)	Carbon monoxide
	Idaho	Carbon monoxide
Idaho	Boise, Northern Ada County area	Carbon monoxide
	Boise, Ada County	PM-10
	Shoshone County (part)	PM-10
	City of Pinehurst	PM-10
	Pocatello area	PM-10
	Sandpoint area, Bonner County	PM-10
	Montana	Carbon monoxide
Montana	Missoula County (part)	Carbon monoxide
	Flathead County (part)	PM-10
	Columbia Falls and vicinity	PM-10
	City of Whitefish and vicinity	PM-10
	Libby and vicinity	PM-10
	Ronan	PM-10
	Polson	PM-10
	Missoula and vicinity	PM-10
	Thompson Falls and vicinity	PM-10
	Helena	Sulfur dioxide
Nevada	Lake Tahoe area:	
	Carson City County (part)	Carbon monoxide
	Douglas County (part)	Carbon monoxide
	Washoe County (part)	Carbon monoxide
	Reno area:	
	Washoe County (part)	Carbon monoxide
	Washoe County	Ozone
Oregon	Reno planning area	PM-10
	Lakeview (urban growth boundary area)	PM-10
	La Grande (area within the urban growth boundary area)	PM-10

¹ From 40 CFR 81.300 revised July 1, 1994.

Utah

Ogden

Provo

Salt Lake City

Davis County

Salt Lake County

Salt Lake County

Utah County

Salt Lake County

Toole County (part)

Carbon monoxide

Carbon monoxide

Carbon monoxide

Ozone

Ozone

PM-10

PM-10

Sulfur dioxide

Sulfur dioxide

Appendix 3

Species List¹

Common name	Scientific name
Alder, mountain	<i>Alnus incana</i> (L.) Moench
Alder, thinleaf	<i>Alnus incana</i> ssp. <i>tenuifolia</i> (Nutt.) Breitung
Apple	<i>Malus</i> Mill.
Apricot	<i>Prunus</i> L.
Aspen, quaking	<i>Populus tremuloides</i> Michx.
Barberry, common	<i>Berberis vulgaris</i> L.
Birch, water	<i>Betula occidentalis</i> var. <i>fecunda</i> Fern.
Birch, western paper	<i>Betula papyrifera</i> var. <i>commutata</i> (Regel) Fern.
Buckbrush	<i>Ceanothus cuneatus</i> (Hook.) Nutt.
Buffaloberry, russet	<i>Shepherdia canadensis</i> (L.) Nutt.
Ceanothus, redstem	<i>Ceanothus sanguineus</i> Pursh
Ceanothus, snowbrush	<i>Ceanothus velutinus</i> Dougl. ex Hook.
Cedar, western red	<i>Thuja plicata</i> Donn. ex D. Don
Cherry	<i>Prunus</i> L.
Cherry, bitter	<i>Prunus emarginata</i> Dougl. ex Eaton
Chokecherry, common	<i>Prunus virginiana</i> L.
Cottonwood, black	<i>Populus trichocarpa</i> Torr. & Gray
Currant	<i>Ribes</i> L.
Currant, sticky	<i>Ribes viscosissimum</i> Pursh
Dogwood	<i>Cornus</i> L.
Dogwood, redosier	<i>Cornus sericea</i> ssp. <i>sericea</i> L.
Douglas-fir	<i>Pseudotsuga menziesii</i> (Mirb.) Franco
Elderberry	<i>Sambucus</i> L.
Elderberry, blue	<i>Sambucus cerulea</i> var. <i>cerulea</i> Raf.
Fir, grand	<i>Abies grandis</i> (Dougl. ex D. Don) Lindl.
Fir, Pacific silver	<i>Abies amabilis</i> Dougl. ex Forbes
Fir, subalpine	<i>Abies lasiocarpa</i> (Hook.) Nutt.
Fir, white	<i>Abies concolor</i> (Gord. & Glend.) Lindl. ex Hildebr.
Goatweed	<i>Hypericum perforatum</i> L.
Gooseberry	<i>Ribes</i> L.
Hawthorn, black	<i>Crataegus douglasii</i> Lindl.
Hawthorn, Columbia	<i>Crataegus columbiana</i> Howell
Hawthorn, red	<i>Crataegus erythrocarpa</i> Ashe
Hazel	<i>Corylus</i> L.
Hazel, California	<i>Corylus cornuta</i> var. <i>californica</i> (A. DC.) Sharp

¹ According to Little (1979) and USDA-NRCS (1998).

Hemlock, western	<i>Tsuga heterophylla</i> (Raf.) Sarg.
Horsechestnut	<i>Aesculus</i> spp. L.
Juniper, common	<i>Juniperus communis</i> L.
Juniper, Rocky Mountain	<i>Juniperus scopulorum</i> Sarg.
Juniper, western	<i>Juniperus occidentalis</i> Hook.
Kinnikinnick	<i>Arctostaphylos uva-ursi</i> (L.) Spreng.
Locust	<i>Robinia</i> L.
Larch, western	<i>Larix occidentalis</i> Nutt.
Laurel	<i>Kalmia</i> L.
Maple, Douglas	<i>Acer glabrum</i> spp. <i>douglasii</i> (Hook.) Wesmael
Maple, Rocky Mountain	<i>Acer glabrum</i> Torr.
Mockorange	<i>Philadelphus</i> L.
Mockorange, Lewis	<i>Philadelphus lewisii</i> Pursh
Mountain-ash, Sitka	<i>Sorbus sitchensis</i> Roem.
Ninebark	<i>Physocarpus</i> Maxim.
Ninebark, Pacific	<i>Physocarpus capitatus</i> (Pursh) Kuntze
Oceanspray	<i>Holodiscus discolor</i> (Pursh) Maxim.
Oregongrape	<i>Mahonia</i> Nutt.
Peach	<i>Prunus</i> L.
Pine, limber	<i>Pinus flexilis</i> James
Pine, lodgepole	<i>Pinus contorta</i> Dougl. ex Loud.
Pine, ponderosa	<i>Pinus ponderosa</i> Dougl. ex Laws.
Pine, western white	<i>Pinus monticola</i> Dougl. ex D. Don
Plum	<i>Prunus</i> L.
Poisonivy, western	<i>Toxicodendron rydbergii</i> (Small ex Rydb.) Greene
Pear	<i>Pyrus</i> L.
Rose, wild	<i>Rosa</i> L.
Serviceberry	<i>Amelanchier</i> Medic.
Serviceberry, Saskatoon	<i>Amelanchier alnifolia</i> var. <i>humptulipensis</i> (Jones) Hitchc.
Snowberry	<i>Symphoricarpos</i> Duham.
Snowberry, Columbia	<i>Symphoricarpos albus</i> var. <i>laevigatus</i> (Fern.) Blake
Spiraea	<i>Spiraea</i> L.
Spiraea, shinyleaf	<i>Spiraea betulifolia</i> ssp. <i>lucida</i> (Dougl. ex Greene) Hitchc.
Spruce, Engelmann	<i>Picea engelmannii</i> Parry ex Engelm.
Sumac	<i>Rhus</i> L.
Sumac, smooth	<i>Rhus glabra</i> L.
Thimbleberry	<i>Rubus parvifolia</i> Nutt.
Willow	<i>Salix</i> L.
Yew, Pacific	<i>Taxus brevifolia</i> Nutt.

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Schoettle, Anna W.; Tonnessen, Kathy; Turk, John; Vimont, John; Amundson, Robert, authors; Acheson, Ann; Peterson, Janice, tech. eds. 1999. An assessment the effects of human-caused air pollution on resources within the interior Columbia River basin. Gen. Tech. Rep. PNW-GTR-447. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 66 p. (Quigley, Thomas M., ed.; Interior Columbia Ecosystem Management Project: scientific assessment).

An assessment of existing and potential impacts to vegetation, aquatics, and visibility within the Columbia River basin due to air pollution was conducted as part of the Interior Columbia Basin Ecosystem Management Project. This assessment examined the current situation and potential trends due to pollutants such as ammonium, nitrogen oxides, sulfur oxides, particulates, carbon, and ozone. Ecosystems and resources at risk are identified, including certain forests, lichens, cryptogamic crusts, high-elevation lakes and streams, arid lands, and class I areas. Current monitoring data are summarized and air pollution sources identified. The assessment also includes a summary of data gaps and suggestions for future research and monitoring related to air pollution and its effects on resources in the interior Columbia River basin.

Keywords: Atmospheric deposition, acid rain, air pollution, aquatic effects, class I areas, terrestrial effects, sensitive species, visibility.

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