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Guidelines for Evaluating Air Pollution Impacts on Class I Wilderness Areas in California

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The 1977 Clean Air Act legally mandated the prevention of significant deterioration (PSD) of air quality related values (AQRVs) on wilderness lands. Federal land managers are assigned the task of protecting these wilderness values. This report contains guidelines for determining the potential effects of incremental increases in air pollutants on natural resources in wilderness areas of the National Forests of California. These guidelines are based on current information about the effects of ozone, sulfur, and nitrogen on AQRVs. Knowledge-based methods were used to elicit these guidelines from scientists and resource managers in a workshop setting. Linkages were made between air pollutant deposition and level of deterioration of specific features (sensitive receptors) of AQRVs known to be sensitive to pollutants. Terrestrial AQRVs include a wide number of ecosystem types as well as geological and cultural values. Ozone is already high enough to injure conifers in large areas of California and is a major threat to terrestrial AQRVs. Aquatic AQRVs include lakes and streams, mostly in high elevation locations. Current sulfur and nitrogen deposition is probably too low to warrant immediate concern in most areas (with the exception of nitrogen deposition at some locations in southern California), although the low buffer capacity of many aquatic systems in California makes them sensitive to potential future increases in acidity. Visibility is considered as a discrete AQRV. Guidelines are presented for determining degradation of visibility based on sensitive views in wilderness areas. Estimates of current deposition of ozone, sulfur, and nitrogen are compiled for all California wilderness areas. Recommendations are included for resource monitoring, data collection, and decision criteria with respect to the disposition of permit applications.

Retrieval Terms: acidic deposition, air pollution, air quality related values, ozone, wilderness, visibility

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Wilderness areas within National Forests are some of the last remaining lands in the United States with minimal disturbance by humans. Legislative mandates provide special protection for wilderness in order to preserve ecosystems in perpetuity. Although wilderness lands are often thought of as pristine, they are subject to potential impacts from various types of air pollutants. The 1977 Clean Air Act (CAA) is a critical piece of legislation that ensures the prevention of significant deterioration (PSD) of air quality related values (AQRVs) in wilderness. Although federal land managers (FLMs) are responsible for protecting wilderness from damage caused by air pollution and other threats, they have few tools for evaluating potential or actual air pollution effects.

This report contains guidelines to assist FLMs in determining the potential effects of future increases in air pollutants on terrestrial resources, aquatic resources, and visibility in wilderness areas of National Forests in California. The guidelines are based on current information on the effects of ozone, sulfur, and nitrogen on AQRVs. Guidelines were developed during a three-day workshop in South Lake Tahoe, California conducted by the Pacific Southwest Region of the USDA Forest Service. The workshop was an interdisciplinary effort between scientists and resource managers, who worked cooperatively to develop guidelines that are technically rigorous and address management concerns.

Linkages were made between air pollutant deposition levels and the amount of deterioration of AQRV features with known sensitivity to pollutants (sensitive receptors). AQRVs for terrestrial resources include a broad range of ecosystem types as well as certain types of geological and cultural features. There is particular concern about the potential impact of ambient ozone on terrestrial resources. Ozone concentrations are already high enough in some parts of California to cause reduced vigor in sensitive conifer species. Increasing human population and use of fossil fuels could exacerbate this problem. Sulfur and nitrogen deposition is too low in most of the state (with the exception of nitrogen in parts of southern California) to cause much concern about effects on terrestrial resources. Aquatic resources are probably not endangered by current levels of sulfur and nitrogen deposition, although the low buffer capacity of some lakes and streams makes them potentially sensitive to future increases in acidic deposition. Visibility is an AQRV that is highly valued by most visitors to wilderness. Guidelines are presented for determining how visibility might be degraded for vistas in each wilderness.

There are many other topics relevant to determining pollution impacts in wilderness. An important first step is simply knowing current deposition levels. These data are summarized for each wilderness area in California. In some cases, additional information must be obtained in order to make a decision on whether an additional increment of air pollution will cause a significant effect on a resource. Recommendations are therefore included for resource monitoring and data collection that will assist in quantifying the relationship between pollutants and potential impacts. Guidelines and associated information in this document will assist Forest Service managers in reviewing applications for permits that would increase pollution levels.

Glossary of Acronyms

ANC:	Acid neutralizing capacity (alkalinity)
AQRV:	Air quality related value
CAA:	Clean Air Act
DOC:	Dissolved organic carbon
EPA:	Environmental Protection Agency
FLM:	Federal land manager
ILWAS:	Integrated Lake and Watershed Acidification Study
IMPROVE:	Integrated Monitoring of Protected Visual Environments
JND:	Just noticeable difference
LAC:	Limits of acceptable change
MAGIC:	Model of Acidification of Groundwater in Catchments
NADP:	National Atmospheric Deposition Program
NAPAP:	National Acid Precipitation Assessment Program
NESCAUM:	Northeast States for Coordinated Air Use Management
NFS:	National Forest System
NPS:	National Park Service
NTN:	National Trends Network
PM:	Particle mass
PSD:	Prevention of significant deterioration
QA:	Quality assurance
QC:	Quality control
TSP:	Total suspended particulates
UTM:	Universal Transverse Mercator
VIT:	Visibility impairment table
WLS:	Western Lake Survey

Introduction

The development of guidelines to evaluate the effects of air pollution on wilderness resources is an ambitious task. It requires the assessment of a wide range of physical, chemical, and biological data, as well as knowledge about individual wilderness areas. It requires information on technical scientific issues as well as input from resource managers. Furthermore, guidelines must be developed in the absence of all the data that would be desirable for decision-making (Sigal and Suter 1987).

In order to develop a screening procedure in an efficient and cost-effective manner, a workshop was convened by the Pacific Southwest Region (California and Hawaii) of the Forest Service in South Lake Tahoe, California, May 1–4, 1990. This forum was used to collect information, elicit expert knowledge from participants, and summarize recommendations for wilderness protection (Schmoldt and Peterson 1991).

There were approximately 50 workshop participants, including both scientists and resource managers (*table 1*). Participants were organized into working groups to review and discuss air quality related values (AQRVs), sensitive receptors, pollutant loadings, and resource impacts. Each of the working groups specialized in one of the following areas:

- Terrestrial effects (northern California wilderness: Caribou, Marble Mountain, South Warner, Thousand Lakes, Yolla Bolly-Middle Eel)
- Terrestrial effects (Sierra Nevada wilderness: Ansel Adams, Desolation, Domeland, Emigrant, Hoover, John Muir, Mokelumne, Kaiser)
- Terrestrial effects (southern California wilderness: Agua Tibia, Cucamonga, San Gabriel, San Gorgonio, San Jacinto, San Rafael, Ventana)
- Aquatic effects (water quality)
- Aquatic effects (biota)
- Visibility

Forest Service land managers were responsible for: (1) identifying and describing AQRVs in each class I wilderness, and (2) defining the limits of acceptable change (LAC) in the AQRVs that were identified as sensitive receptors. Scientists helped to: (1) identify sensitive receptors among the AQRVs listed for class I wilderness areas, (2) describe their relative susceptibility to air pollutant impacts, and (3) determine the quantity of various pollutants expected to cause LAC to be exceeded. Information was gathered on the sensitivity of AQRVs to the effects of sulfur (S) and nitrogen (N) deposition, ozone exposure, and particulates (with respect to visibility impairment). This report summarizes the results of the workshop. Details on the workshop procedures and knowledge elicitation techniques used to compile information were reported by Schmoldt and Peterson (1991).

Table 1—*Participants in the workshop are listed by subgroup.*

VEGETATION EFFECTS (Northern California Forests)

Suraj Ahuja
Tom Cahill
Cal Conklin
Beth Corbin
Don Haskins
Bill Hogsett
Bob Musselman

VEGETATION EFFECTS (Sierra Nevada Forests)

Mike Arbaugh
Diane Ewell
Earl Franks
Luci McKee
John Pronos
Jim Shiro
Geroge Taylor
Susan Ustin

VEGETATION EFFECTS (Southern California Forests)

Andrzej Bytnerowicz
Carl Fox
Kathy Jordan
Craig Mahaffey
Paul Miller
Tom Nash
Linda Riddle
Judy Rocchio

AQUATIC EFFECTS (Water Quality)

Aaron Brown
Jim Frazier
Bob Goldstein
Bob Harris
Andrea Holland
George Ice
Dale Johnson
Mike McCorrison

AQUATIC EFFECTS (Biota)

Scott Conroy
Malcolm Gordon
Maryanne Hackett
Rick Jameson
Matt Lechner
Bruce McGurk
Deborah Potter
John Stoddard

VISIBILITY

Bob Bachman
Cliff Benoit
Alan Ewert
Rich Fisher
Francis Fujioka
Ron Henry
Dennis Inman
John O'Gara
Joan Reynolds
Will Richards
Tony Van Curen

Legal Background of Managing Air Quality in Class I Wilderness

Class I wilderness areas[1] managed by the USDA Forest Service contain ecosystems and esthetic values that have the potential to be degraded by existing or future air pollutant emissions. The Clean Air Act (CAA) as amended in 1977 (Public Law 95-95)[2] gives Federal land managers (FLMs), including the Forest Service, "... an affirmative responsibility to protect the air quality related values . . . within a class I area." Forest Service land managers need information to help prevent unacceptable changes from new or increased pollutant sources to AQRVs[3] within lands they are mandated to protect (*table 2*). Information required by the Forest Service to protect AQRVs in class I areas includes:

- Components, or sensitive receptors (*table 2*), of the AQRVs within class I areas most vulnerable to degradation from air pollution.
- Acceptable limits of air pollution-caused changes (LAC) for these sensitive receptors.
- The amount of various pollutants that could be expected to cause more than the acceptable change in sensitive receptors.
- Legal mechanisms that empower Forest Service managers in air resource management decision-making.

Wilderness Act

The Wilderness Act (Public Law 88-557) gives the Forest Service the responsibility to manage designated wilderness to preserve and protect wilderness integrity. The Wilderness Act defines wilderness as "an area untrammeled by man" and "an area of undeveloped Federal land retaining its primeval character and influence." It is to be "protected and managed so as to preserve its natural conditions." "Untrammeled" means not subject to human controls or manipulations that hamper the free operation of natural forces. The regulations for managing wilderness and primitive areas state, "National Forest Wilderness resources shall be managed to promote, perpetuate, and where necessary, restore the wilderness character of the land." The National Forest Management Act (Public Law 94-558) gives the Forest Service the authority to determine the management goals and objectives for wilderness, including the protection of wilderness from external threats.

Table 2—*Examples of AQRVs, sensitive receptors, and factors potentially changed by air pollution.*

AQRV	Sensitive receptors	Factors changed by air pollution
Flora	Ponderosa pine, lichens	Growth, mortality, reproduction, visible injury
Water	Alpine lakes	Total alkalinity, pH, metal concentration, dissolved oxygen
Soil	Alpine soils	pH, cation exchange capacity, base saturation
Visibility	High usage vista	Contrast, visual range, coloration
Cultural/archaeological values	Pictographs	Decomposition rate
Odor	Popular hiking trail	Ozone odor

The Wilderness Act and regulations developed to implement it do not directly address air quality or air pollution impacts to wilderness. However, they do provide guidance to the Forest Service in determining what should be protected in wilderness and to what degree. Although it may not be possible to manage every wilderness in a natural state, each wilderness should be maintained in as pristine a condition as possible within legal and political constraints.

The Clean Air Act and the PSD Program

The CAA Amendments of 1977 include a program for prevention of significant deterioration (PSD) of air quality. The basic objective of the PSD program is to prevent substantial degradation of air quality in areas that comply with national ambient air quality standards, while maintaining a margin for future industrial growth. Certain new or modified air pollution sources must apply for a PSD permit from the appropriate air regulatory agency before construction. In California, some air pollution control districts and counties have the authority to manage the PSD permitting program; U.S. Environmental Protection Agency has authority for others.

A permit applicant is required to demonstrate that the proposed polluting facility will: (1) not violate national or state ambient air quality standards, (2) use the best available control technology to limit emissions, (3) not violate either class I or class II PSD increments for sulfur dioxide, nitrogen dioxide, and particulates, and (4) not cause or contribute to adverse impacts to AQRVs in any class I area.

The PSD increments are allowable pollutant concentrations that can be added to existing concentrations over a given time period. The values chosen as PSD increments by Congress were

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[1] Class I wildernesses are those wilderness areas more than 5000 acres (2041 ha) that were in existence as of August 7, 1977, or any later expansions made to these wildernesses. All other National Forest lands are class II, including new wilderness.

[2] Legislation was passed by the US Congress in 1990 amending the Clean Air Act. Protection is extended to land areas that are extensions of existing wilderness, although other implications on the discussion presented here are not clear at the present time.

[3] 42 U.S.C. 7475 (d)(2)(C)(ii) and (iii).

not selected on the basis of any existing information on concentration limits relative to specific resource values. Therefore, it may be possible to exceed the legal class I increments without causing any damage to a class I wilderness. It is also possible that a class I wilderness could be impacted without exceeding the increments. The role of the Forest Service manager is to determine whether there is potential for additional air pollution to cause more than the LAC in a sensitive receptor whether or not the PSD increments have been exceeded. If a proposed facility will not violate any class I increments, the Forest Service can still recommend denial of a permit by demonstrating that there will be adverse impacts in an AQRV in a wilderness. Provisions for mitigation can be recommended by the Forest Service or the agency that regulates permits.

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

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

The first two are land management questions that should be answered on the basis of management goals and objectives for wilderness areas. The third is a technical question that must be answered on the basis of modeled analysis of emissions from the proposed facility and available scientific data.

The permit application decision is the responsibility of the air regulatory agency if PSD increments are not exceeded. The Forest Service may determine that the proposed facility will result in a change in a sensitive receptor within a wilderness beyond an identified LAC, but the regulatory agency has the authority to make the final decision.

If the proposed facility will cause a violation of the class I increments, the PSD permit can still be issued if the applicant demonstrates to the satisfaction of the Forest Service and air regulatory agency that the facility will not create an adverse impact on a class I area. The permit can be issued even if the proposed facility will cause a violation of a class I increment and the applicant cannot demonstrate that the facility will not create an adverse impact. In this case, the governor of the state containing the proposed facility must recommend approval and transmit this recommendation to the President of the United States. The President is able to approve or deny the permit application after reviewing the recommendations.

The exceedance or non-exceedance of class I increments determines which party has the burden of proof in demonstrating whether a particular new pollutant source would compromise identified wilderness management goals and objectives. The burden of proof is with the applicant if the PSD increments are predicted to be exceeded. The burden of proof rests with the Forest Service air resource manager if the increments are predicted to not be exceeded.

Coordination between the Forest Service and the air regulatory agency is required in decisions on PSD permits. In nearly all cases, the air regulatory agency makes the final determination to grant or deny a PSD permit. However, the Forest Service, not the air regulatory agency, is authorized to define LAC to sensitive receptors of AQRVs in class I wilderness. The Forest Service must be able to provide timely, credible, and effective recommendations to state air regulatory agencies in order to protect wilderness from potential air pollution effects.

Forest Service air resource managers clearly have legal mechanisms available to help them protect class I wilderness from air pollution impacts. The CAA is a tool that can be implemented to meet the management goals and objectives of the Wilderness Act and the National Forest Management Act. Forest Service managers facilitate the PSD process by: (1) making management decisions on which components of the wilderness should be protected from air pollution impacts, (2) providing high-quality information on the existing condition of AQRVs, atmospheric deposition, and air chemistry in wilderness, and (3) understanding the state PSD permitting process. The development and implementation of air resource monitoring programs by the Forest Service can help to ensure the protection of wilderness resources from the impacts of air pollution and other human activities.

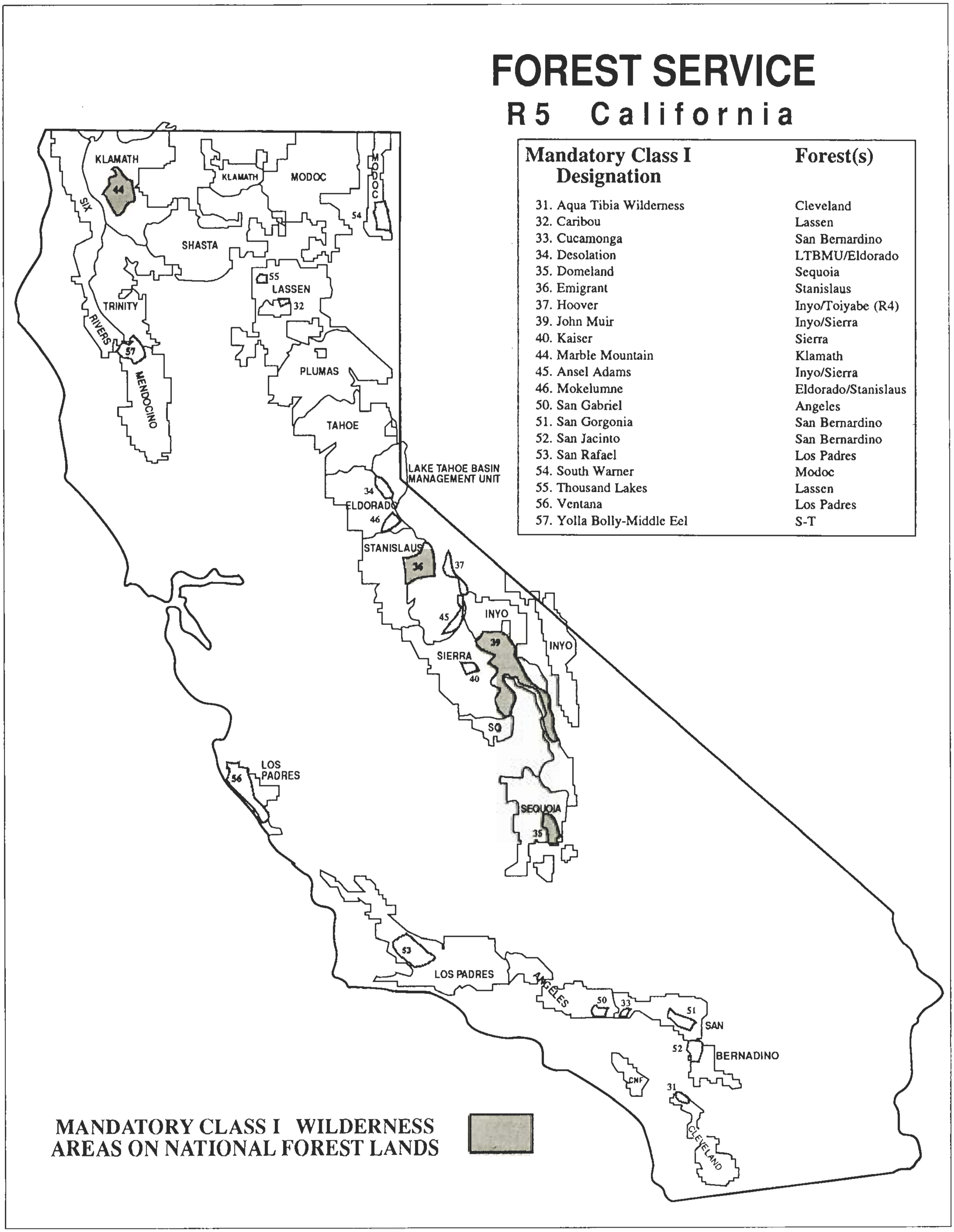
Atmospheric Deposition in California Class I Wilderness

California covers a large land area that ranges from coastal environments along the Pacific Ocean to high peaks in the Sierra Nevada and other mountain ranges. Class I wilderness areas are located throughout the state (*fig. 1*). Climate and atmospheric circulation patterns vary considerably, although the state generally has a mediterranean climate regime, with most of the annual precipitation falling between October and March.

The pollution climate of an area is influenced by: (1) regional and local emissions of air pollutants and (2) regional and local meteorology. The physical and chemical states of the atmosphere determine the dispersion, transport, chemical transformation, and deposition of air pollutants. In many cases, meteorology is more important than atmospheric chemistry in determining the place at which, and the form in which, pollutants are deposited (e.g., Cape and Unsworth 1987).

Atmospheric conditions in California tend to be relatively stable with dominant high pressure systems and strong inversions in valley locations. These conditions are conducive to the accumulation of pollutants (nitrogen [N] and sulfur [S] compounds, hydrocarbons). Nitrogen oxides and hydrocarbons from fossil fuel combustion are photochemically oxidized and transported from metropolitan and industrial areas to adjacent mountain locations (Carroll and Baskett 1979, Ewell and others 1989, Seinfeld 1989). Ozone, a product of this oxidation, is generally considered the most phytotoxic component of air pollution in California.

Estimates of pollutant loadings to an area usually require a detailed analysis of (1) emissions, (2) transport, dispersion, and



Mandatory Class I Designation	Forest(s)
31. Aqua Tibia Wilderness	Cleveland
32. Caribou	Lassen
33. Cucamonga	San Bernardino
34. Desolation	LTBMU/Eldorado
35. Domeland	Sequoia
36. Emigrant	Stanislaus
37. Hoover	Inyo/Toiyabe (R4)
39. John Muir	Inyo/Sierra
40. Kaiser	Sierra
44. Marble Mountain	Klamath
45. Ansel Adams	Inyo/Sierra
46. Mokelumne	Eldorado/Stanislaus
50. San Gabriel	Angeles
51. San Gorgonia	San Bernardino
52. San Jacinto	San Bernardino
53. San Rafael	Los Padres
54. South Warner	Modoc
55. Thousand Lakes	Lassen
56. Ventana	Los Padres
57. Yolla Bolly-Middle Eel	S-T

Figure 1—Location of class I wilderness on Forest Service lands in California. (LTBMU=Lake Tahoe Basin Management Unit; R4=Region 4; S-T=Shasta-Trinity)

chemical transformation of the pollutants in the atmosphere, and (3) deposition processes and the relative roles played by each process in the total deposition of pollutants. Such an analysis can be based on statistical techniques of extrapolation or on atmospheric modeling.

The California Air Resources Board maintains a network of air pollution monitoring stations in metropolitan and valley locations that can be used to infer air pollution exposure in adjacent wildland areas. These data are summarized in the annual publication *California Air Quality Data* (California Air Resources Board 1989). A limited amount of air quality data collected by the USDA Forest Service and National Park Service from mountain locations can be used to verify these inferences. Pollutant exposure is generally considered severe in the Los Angeles Basin area of southern California, where high emissions are confined topographically, and ozone concentrations and N deposition are especially high. Pollutant concentrations are moderate in the southern Sierra Nevada, where ozone is the major problem. The northern half of the state has relatively low pollutant levels because of lower emissions, less restrictive topography, and more active atmospheric mixing.

There are few data on air pollution exposure from montane locations or class I wilderness in California. There are large differences in climate and deposition processes (e.g., snow vs. rain, cloud frequency) between monitoring sites and wilderness areas, because of differences in elevation. Air quality data from one site or a large region are therefore not necessarily representative of specific sites in wilderness. Statistical extrapolation of monitoring data is compromised by lack of information on pollutant concentrations at high elevations and little information on the different mechanisms influencing deposition at high rather than low elevations.

Even with these constraints, it is necessary to have some estimate of current deposition levels in class I areas in order to evaluate the current and future condition of natural resources. Pollution loadings in class I areas of California were estimated by a workshop subgroup (Bob Bachman, Tom Cahill, Diane Ewell, Paul Miller, Tony Van Curen) that used the best existing data to infer exposure to ozone, N, and S. The analysis integrated monitoring data and information from local experience and the literature. The following sources were used to compile air pollution loadings: Ashbaugh and others (1989), Böhm (1989, in press), Böhm and Vandetta (1990), Cahill (1989), Cahill and others (1990), California Air Resources Board (1989), Fenn and Bytnerowicz (1991).

Annual N deposition is based on ammonium and nitrate concentrations, including both wet and dry deposition. Annual S deposition is based on sulfate concentrations, including both wet and dry deposition. Ozone data are given as a 24-hour average concentration for the period May through October. Air pollutant loadings are summarized in *table 3*. Most values in *table 3* are not direct measurements, but inferences from various data sources, most of which are from lower elevation locations. Interpolation of isopleths of pollutant concentrations was used in many cases, in addition to professional judgment and knowledge about specific areas. Dry deposition for high-elevation class I areas is estimated as 50 percent of low-elevation measurements, because of a known reduction in particle transport of approximately this magnitude. Dry deposition of N for class I areas in the Los Angeles Basin is much higher than for other areas in California because of high nitric acid inputs (as high as 80 percent of total N input). Nitrogen deposition for the San Gabriel, San Gorgonio, and San Jacinto Wildernesses are estimates based primarily on data in Fenn and Bytnerowicz (1991), adjusted for the location of each wilderness. Values in *table 3* are appropriately listed as ranges; they should be considered estimates only, not exact measurements.

Effects on Terrestrial Resources

The effects of air pollutants on natural resources have been studied for at least 50 years. The sensitivity of plant species to abnormally high exposures of ozone, N, S, and other pollutants has been the focus of many of these studies. Sulfur concentrations are relatively low in California compared to the eastern United States, and N deposition is high only at some locations adjacent to the Los Angeles Basin. However, ozone concentrations are high enough to cause plant injury over large areas of the state.

Table 3—*Estimates of pollutant deposition for each class I wilderness in California are listed for total annual nitrogen (N), total annual sulfur (S), and mean ozone concentration (24-hour mean, May through October)*[1]

Wilderness	N	S	Ozone
	kg/ha/yr	*kg/ha/yr*	*ppb*
Agua Tibia	2.9 - 4.8	0.9 - 1.1	40 - 70
Ansel Adams	2.0 - 2.7	0.6 - 0.9	22 - 50
Caribou	1.3 - 1.7	0.4 - 1.2	9 - 36
Cucamonga	3.8 - 5.2	1.0 - 1.2	70 - 100
Desolation	2.0 - 2.7	0.6 - 1.4	22 - 50
Domeland	2.4 - 2.9	0.8 - 0.9	50 - 60
Emigrant	2.0 - 2.7	0.6 - 0.9	22 - 50
Hoover	2.0 - 2.7	0.6 - 0.9	22 - 50
John Muir	2.4 - 2.9	0.8 - 0.9	22 - 50
Kaiser	2.4 - 2.9	0.8 - 0.9	20 - 60
Marble Mountain	0.3 - 0.9	0.1 - 0.4	9 - 36
Mokelumne	2.0 - 2.7	0.6 - 0.9	22 - 50
San Gabriel	20 - 30	1.0 - 1.2	70 - 100
San Gorgonio	20 - 30	1.0 - 1.2	70 - 100
San Jacinto	5 - 15	1.0 - 1.2	60 - 90
San Rafael	1.4 - 2.1	0.5 - 1.1	40 - 60
South Warner Mountain	0.5 - 1.1	0.2 - 1.0	22 - 50
Thousand Lakes	1.3 - 1.7	0.1 - 0.4	22 - 50
Ventana	1.4 - 2.0	0.6 - 0.9	20 - 40
Yolla Bolly-Middle Eel	0.9 - 1.4	0.5 - 0.7	22 - 50

[1] Ranges are used to quantify estimates, because data are generally not based on measurements in specific wilderness areas. See section on atmospheric deposition for methods used to calculate deposition.

During the 1980's there was a major research effort in North America and Europe to evaluate forest health and vigor. The motivation for this research effort was increased awareness of the concept of "forest decline," and of how stress in forest ecosystems might be affected by atmospheric deposition, including acidic precipitation and ozone (Smith 1984). Much of this work focused on documenting the physiological and growth status of forest stands, and on establishing dose-response relationships under experimental conditions for economically important tree species. There has been less emphasis on the effect of pollutants on organisms such as lichens and mosses. Relatively few taxa of higher plants were evaluated in these studies, and the difficulty of identifying physiological stress in the field has made it difficult to quantify the relationship between pollutants and specific organisms or processes.

The terrestrial subgroup of the workshop initially determined that they would address two different classes of AQRVs. One class consists of vegetation; the other class consists of all other terrestrial resources, including geological and cultural features. These classes were evaluated separately with respect to pollutant effects and guidelines. Generic guidelines were developed that apply to all class I areas in California, because there is insufficient information to justify guidelines for specific wilderness areas.

Vegetation

Ecosystems, AQRVs, and Sensitive Receptors

It was determined that ecosystems are the most appropriate representative of AQRVs in California wilderness. A limited number of systems are identified across different wilderness locations, despite minor differences in structure and species composition. Some of the "ecosystem" designations more closely approximate plant "communities" or "associations," but these distinctions are not critical for this application. The main objective is to use a designation that can be readily used to identify discrete AQRVs.

Fifteen ecosystem types are used to represent specific AQRVs in California. These types are intended to encompass the range of terrestrial communities that might be found at any location, including areas such as intermittent riparian zones. These ecosystem types are:

Alpine	AL
Bigcone Douglas-fir	BD
Buckwheat / lichen / grass	BL
Chaparral	CH
Desert	DE
Digger pine / oak	DP
Juniper shrubland	JS
Mixed conifer	MC
Montane forest	MF
Oak woodland	OW
Pinyon pine / juniper	PJ
Redwood	RE
Riparian	RI
Sagebrush	SA
Subalpine forest	SF

These ecosystems are distributed among the class I wilderness areas as shown in *table 4*. The higher elevation systems such as alpine, subalpine forest, and mixed conifer forest are the most common types, and most others have relatively low representation.

Sensitive receptors identified within each of the AQRV ecosystems (*table 5*) represent species or groups of species. Only those species for which some information was available on sensitivity to pollutants, or whose sensitivity could be inferred from studies of related species, were identified. Some of the groups, such as lichens and herbaceous species, include a large number of species. They are included as sensitive receptors, because at least some species within these general categories are known to be sensitive to pollutants.

Trees and Herbaceous Plants

More information is available on ozone effects on plants than on N and S effects. In fact, much of the research on ozone effects has been conducted in the mixed conifer forest and other vegetation types of California, and studies have tended to focus on dominant species in those areas (e.g., Miller and others 1989; D.L. Peterson and others 1987, 1991). There are few data that relate pollutant exposure to growth or other characteristics of mature trees, and almost no data for herbaceous species. As a result, guidelines were established to be general enough to apply to all species with respect to potential stress from air pollutants.

Ozone

Exposure of plants to elevated levels of ozone can produce several quantifiable effects, including visible injury, reduced photosynthetic capacity, increased respiration, premature leaf senescence, and reduced growth (Miller and others 1989; Patterson and Rundel 1989; D.L. Peterson and others 1987, 1991; Pronos and Vogler 1981; Reich and Amundson 1985). The severity of effects depends on pollutant concentration, duration of exposure, and other environmental factors. Sensitivity to ozone and other stresses varies within and among species because of differences in uptake (Reich 1987) and genetic factors (Karnosky and Steiner 1981).

The immediate effects of elevated ozone levels in wilderness areas are expected to be one or more of the following: foliar injury, decreased leaf longevity, reduced carbon gain of foliage, and reduced plant growth. Other effects could include alteration of carbon allocation, greater susceptibility to environmental stress (such as low soil moisture, insects, and fungi), changes in plant community composition, and loss of sensitive genotypes from a population (Fox and others 1989, Treshow 1984).

Although a change in histological and physiological processes (for example, photosynthesis) is probably the earliest detectable evidence of pollutant stress, visible signs of damage (for example, chlorosis, leaf senescence) are easier and more practical to detect in class I areas. Much of the existing data on ozone stress in conifers has been compiled for ponderosa pine and Jeffrey pine, which are sensitive to elevated ozone concentrations. Injury levels have been established for these species with respect to chlorotic injury and needle longevity based on

Table 4—*Air quality related values (AQRVs) for vegetation are listed by ecosystem type for each class I wilderness in California.*

Wilderness	AQRV ecosystem[1]														
	AL	BD	BL	CH	DE	DP	JS	MC	MF	OW	PJ	RE	RI	SA	SF
Agua Tibia		X		X				X		X			X		
Ansel Adams	X							X							X
Caribou	X			X					X						X
Cucamonga		X		X				X							
Desolation	X								X				X		X
Domeland						X	X	X					X		X
Emigrant	X							X					X		X
Hoover	X								X		X		X	X	
John Muir	X							X			X		X		X
Kaiser	X							X					X		X
Marble Mountain	X			X				X					X		X
Mokelumne								X							X
San Gabriel		X		X						X					
San Gorgonio	X			X				X							X
San Jacinto					X			X							X
San Rafael		X		X				X							
South Warner Mountain	X		X				X	X					X		X
Thousand Lakes	X			X				X	X						X
Ventana										X		X			
Yolla Bolly-Middle Eel	X			X				X		X			X		X

[1] AL, alpine; BD, bigcone Douglas-fir; BL, buckwheat/lichen/grass; CH, chaparral; DE, desert; DP, digger pine; JS, juniper shrubland; MC, mixed conifer; MF, montane forest; OW, oak woodland; PJ, pinyon pine/juniper; RE, redwood; RI, riparian; SA, sagebrush; SF, subalpine forest.

studies conducted in the Sierra Nevada and San Bernardino Mountains of California (Duriscoe and Stolte 1989, Miller and others 1989, Pronos and others 1978). These and other data collected by these authors are the best information available on field level analysis of pollutant stress. Additional experimental data on the effects of ozone on seedlings are available for some conifers found in California (Hogsett and others 1989).[4] These data sources were used to develop condition classes for all conifers considered sensitive receptors, even though data are not available for all species. Limited experimental data for conifer seedlings indicate differences in sensitivity among species (*table 6*). For example, ponderosa pine is more sensitive to ozone than is incense-cedar.

Four condition classes were established with respect to ozone effects on trees: **no injury, slight injury, moderate injury**, and **severe injury**. These condition classes are based on a per tree evaluation. A given stand can have trees in multiple condition classes, so overall stand condition can be stated as percentages of each condition class. Acceptable distributions of condition classes can be set; or, alternatively, the condition of a stand can be defined conservatively as being synonymous with the tree with the most severe condition class. The same condition classes are used for different species because (1) there is insufficient information to confidently infer sensitivity in mature trees, and (2) generic condition classes based on sensitive species are conservative enough to provide maximum protection for all species. Condition classes and ozone concentrations associated with those classes (Miller and others 1983)[4] are as follows:

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[4] Unpublished data from P.R. Miller, Pacific Southwest Research Station, Riverside, California.

***Table 5**—Sensitive receptors are indicated for each of the air quality related value (AQRV) ecosystems.*

Sensitive receptor	AQRV ecosystem[1]														
	AL	BD	BL	CH	DE	DP	JS	MC	MF	OW	PJ	RE	RI	SA	SF
Lichens	X	X	X		X		X	X	X	X		X			X
Herbaceous plants	X	X	X		X			X	X	X				X	X
Ponderosa pine								X							
Jeffrey pine								X							
White fir								X							X
Sugar pine								X							
Incense cedar								X							
Calif. black oak						X		X		X					
Douglas-fir								X							
Bigcone Douglas-fir		X													
W. white pine								X							
Lodgepole pine									X						X
Whitebark pine															X
Foxtail pine															X
Pacific silver fir									X						
Limber pine															X
Mountain hemlock															X
Red fir									X						X
Digger pine						X									
Aspen									X				X		
Alders													X		
Cottonwoods													X		
Junipers							X				X				
Coast redwood												X			
Pinyon pine											X				
Santa Lucia fir								X							
Huckleberry oak				X			X								
Sagebrush											X			X	
Sedges	X								X				X		X

[1] AL, alpine; BD, bigcone Douglas-fir; BL, buckwheat/lichen/grass; CH, chaparral; DE, desert; DP, digger pine; JS, juniper shrubland; MC, mixed conifer; MF, montane forest; OW, oak woodland; PJ, pinyon pine/juniper; RE, redwood; RI, riparian; SA, sagebrush; SF, subalpine forest.

Table 6—Sensitivity of tree species to ozone, S, and N pollution[1].

Sensitive receptor	Sensitivity		
	Ozone	Sulfur	Nitrogen
Ponderosa pine	H	H	H
Jeffrey pine	H	H	H
White fir	M	H	H
Incense cedar	L		
Calif. black oak	M		
Douglas-fir	M	H	H
Bigcone Douglas-fir	L		
W. white pine	L-M		
Lodgepole pine	M	H	H
Limber pine	M		
Huckleberry oak	L		
Aspen	H		
Alders	M		
Sugar pine			
Whitebark pine			
Foxtail pine			
Pacific silver fir			
Mountain hemlock			
Red fir			
Digger pine			
Cottonwoods			
Junipers			
Coast redwood			
Pinyon pine			
Santa Lucia fir			

[1] Ratings are based on Davis and Wilhour (1976), Miller and others (1983), Hogsett and others (1989)[2], and personal knowledge of workshop participants. Sensitivity to S and N are based primarily on experimental exposures to acidic fog, SO_2 and NO_2. Sensitivity ratings are: high (H), moderate (M), and low (L). Blanks indicate that there is insufficient information to rate sensitivity.

[2] Unpublished data from P.R. Miller, Pacific Southwest Research Station, Riverside, California.

Condition class	Needle age class with chlorotic mottle	Needle retention as percent of normal	Ozone concentration (7-hr growing season mean)
	years	*pct*	*ppb*
No injury	None	>80	<60
Slight injury	≥5	71-80	61-70
Moderate injury	3-4	41-70	71-90
Severe injury	1-2	<40	>90

This table has been developed with data from pine species and is therefore more accurate for pines than for other species. The table can be applied cautiously to other conifers as well. However, the needle age class should not be used because some species retain many years of needles (up to 18 years in white fir).

The condition classes listed above are based on visible injury characteristics that can be observed in the field. The relationship of these condition classes to tree growth is unknown, although it has been shown for Jeffrey pine that photosynthesis is reduced 50 percent when 30 percent of needles show chlorotic mottle (Patterson and Rundel 1989). Only detailed long-term monitoring of many mature trees would establish the relationship between growth and ozone exposure (Peterson and Arbaugh 1988; D.L. Peterson and others 1987, 1991).

Some areas of the Sierra Nevada and southern California are subject to episodes of high ozone concentration during periods of atmospheric stability. The effect of these occasional pulses of pollutants on conifers is poorly quantified, but may produce substantial stress and affect the condition class of trees (Hogsett and others 1989). No guidelines are offered here with respect to these ozone episodes because there are no data on which to base them. The potential effects of these episodes on plants should be considered, however, when considering the impacts of ozone exposure on wilderness. Probability of effects will likely be greater downwind from large metropolitan areas.

Hardwood tree species have different leaf injury symptoms than conifers, and there are few data available on the effects of ozone on hardwoods (Jensen and Masters 1975). The condition classes for hardwoods are similar to those for conifers, and an additional class has been added:

Condition class	Percent of leaf area with chlorotic mottle	Ozone concentration (7-hr growing season mean)
	pct	*ppb*
No injury	0	< 45
Very slight injury	1-20	45-70
Slight injury	21-40	71-90
Moderate injury	41-60	91-120
Severe injury	60-100	>120

Because there are few data on which to base ozone effects on hardwoods, the condition classes and associated ozone levels are less reliable than for conifers. The higher ozone concentrations for hardwood condition classes reflect somewhat less sensitivity than in conifers, although injury should be considered on a species-by-species basis if data are available.

There are so few data on the effects of ozone on herbaceous and grass species in California that it is difficult to define condition classes. Native species for which there is some information about ozone sensitivity include sweet-cicely (*Osmorhiza brachypoda*) (high sensitivity), squawbush (*Rhus trilobata*) (high), and perennial ryegrass (*Lolium perenne*) (moderate).[4] Cultivated grasses with known sensitivity include timothy (*Phleum pratense*) (high), orchardgrass (*Dactylis glomerata*) (high), and fescue (*Festuca* sp.) (low).[5] These data are insufficient to make generalizations about all herbaceous species and grasses. The condition classes for hardwood species can be applied cautiously to herbaceous species until additional data are available.

Sulfur

There are very few data on the effects of S compounds on mature trees or other native plants, and there is a wide range of sensitivities to ambient S compounds (Davis and Wilhour 1976, Westman and others 1985). Limited data on tree seedlings (Hogsett and others 1989)[5] indicate that SO_2 concentrations below 20 ppb (24-hour mean) do not produce visible injury symptoms. Slight injury is found in ponderosa pine and lodgepole pine above 40 ppb and moderate injury above 65 ppb. Slight injury is found for Douglas-fir above 65 ppb. It is difficult to set condition classes for California plant species on the basis of these data, so only general guidelines are suggested. In order to maximize protection of all plant species, maximum SO_2 concentrations should

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[5] Unpublished data from W. Hogsett, U.S. Environmental Protection Agency, Corvallis, Oregon.

not exceed 40-50 ppb, and annual average SO_2 concentrations should not exceed 8-12 ppb.

Despite the lack of good quantitative information, the relative sensitivity of some California tree species to SO_2 can be ranked (Davis and Wilhour 1976). This list can be referred to if a greater level of resolution is needed. Sensitivity to SO_2 is as follows, listed from most to least sensitive: Douglas-fir, lodgepole pine, ponderosa pine, Western white pine, Pacific silver fir, white fir, juniper (several species), limber pine, pinyon pine.

Total S loadings are relatively low in most of California, although there are some areas adjacent to smelters and power plants where total S deposition is locally high. The effects of S deposition, especially sulfates, are often mediated through soil processes such as cation exchange. Deposition must be high to produce potentially toxic effects. Fox and others (1989) determined that 20 kg S/ha/yr is the maximum long-term deposition that can be tolerated without impacts in most terrestrial ecosystems, on the basis of several assumptions about cation exchange capacity and mineral weathering rates. Effects are very unlikely below 5 kg/ha/yr. In the absence of additional data, these general guidelines can be used for California as a first approximation. However, soil properties vary among locations, and it is important to consider soil effects with respect to specific wilderness areas.

Nitrogen

There are few data on the effects of nitrogen dioxide (NO_2) on plant species in California; however, scattered data from scientific studies in the United States and Europe can be used to establish some general guidelines for injury and exposure (Davis and Wilhour 1976, J. Peterson and others 1992, Smith 1990, Treshow 1984):

Condition class	NO_2 concentration (24-hr annual mean)
	ppb
No injury	<15
Potential injury	15-50
Severe injury	>50

These values were defined for all plant species in California and should be used only as general guidelines. Individual plant species have a wide range of sensitivities.

Nitrogen is a critical nutrient for many plant metabolic processes. Nitrogen deposition in the form of nitrate or ammonium can increase plant growth in some cases. Long-term deposition of elevated levels of nitrogen compounds may affect soil microbiological processes, resistance to insect and pathogens, winter injury in conifers, and foliar leaching. Perhaps more important are the potential effects of long-term N deposition on ecosystem structure and diversity. Nitrogen is a potential fertilizer that can be assimilated preferentially by some plant species. For example, plant species in a N-poor system such as a bog may be replaced by species with higher N requirements. Based on limited data on ecosystem effects (Fox and others 1989), generic condition classes can be set for different vegetation types as follows:

Vegetation type	Total N deposition (kg/ha/yr)		
	No injury	Potential injury	Severe injury
Coniferous forest	<3	3-15	>15
Hardwood forest	<5	5-20	>20
Shrubs	<3	3-5	>5
Herbaceous plants	<3	3-10	>10

These general guidelines do not account for variation in plant sensitivity. It is also known that acidic fog, which contains S and N compounds, has the potential to alter the growth of seedlings of some California tree species (Hogsett and others 1989, P.R. Miller unpublished data[4]). These effects do not generally occur under experimental conditions unless pH is below 3.5. Fog acidity less than 3.5 has been measured in the San Gabriel Mountains of southern California (Hoffman and others 1989). Unfortunately there are too few data on cloud chemistry and the effects of acidic fog on plants to set guidelines for acidity at this time.

Lichens[6]

Lichens are known to be sensitive receptors for air pollution, as determined by a variety of studies (Ferry and others 1973, Galun and Rohnen 1988, Nash and Wirth 1988, Ross 1982, Ryan and Rhoades 1991, Sigal and Nash 1983). Water and gas exchange proceed uninhibited over the entire surface of a lichen because there are no stomata or cuticles to exclude gases. Lichens grow slowly and can live for centuries, and are therefore exposed to pollution for a long period of time. In addition, lichens tend to concentrate heavy metals and other elements, and are not capable of shedding parts of the thallus injured by toxic gases. Lichens reflect the cumulative effects of air pollution over time, not just the acute effect of a given concentration.

Lichens are often the most sensitive component of the vegetation within a given ecosystem, and can have predictive value in assessing future effects on vascular plants. Reduced vigor of lichens may have direct impacts on an ecosystem, because of their importance for N-fixation, soil stabilization, rock weathering, and food for animals.

There is a wide range of sensitivity of lichens to various types of air pollutants, although sensitivity is poorly quantified with respect to dose-response relationships. There is more information on sensitivity to SO_2 and ozone than sensitivity to nitrogen oxides (NOx) or fluoride. Four classes of lichen sensitivity to air pollution can be defined: very sensitive, sensitive, tolerant, and very tolerant. These classes can be associated with pollutant exposure as follows:

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[6] The information in this section was compiled with the assistance of Tom Nash, professor, Arizona State University, Tempe, Arizona.

Pollutant	Sensitivity class			
	Very sensitive	Sensitive	Tolerant	Very tolerant
Ozone (ppb)[1]	≤20	21-40	41-70	>70
Sulfur (kg/ha/yr)	≤1.5	1.5-2.5	2.6-3.5	>3.5
Nitrogen (kg/ha/yr)	≤2.5	2.6-5.0	5.1-7.0	>7.0

[1] Ozone concentration is the 7-hour mean for May-October.

These sensitivity classes are based on pollutant effects on *Hypogymnia enteromorpha*, which commonly grows on trees in the mixed conifer forest of California. Morphological and reproductive changes have been measured in this species under field and experimental conditions (Nash 1988, Nash and Sigal 1979, Nash and Sigal 1980, Sigal and Nash 1983). The classes with respect to ozone exposure can be characterized in some detail for *H. enteromorpha* and for other species in somewhat less detail (*table 7*). Ozone exposures at the highest level (> 70 ppb) have caused the loss of up to 50 percent of all lichen species present in some areas of mixed conifer forest in southern California (Sigal and Nash 1983). It is assumed that morphological changes observed in the field in southern California are, in fact, caused by ozone rather than by N or S pollution.

A comprehensive list of lichens in California wilderness is beyond the scope of this document. However, the more common species, their sensitivity class with respect to ozone sensitivity, and location are summarized here in order to aid assessments of potential impacts (*tables 8-10*). Morphological criteria associated with condition classes for ozone exposure can also be applied cautiously to effects of exposure to S and N in the absence of other criteria, although the species' sensitivities may be completely different. Limited experimental and field data on the effects of S pollution on lichens indicate a range of sensitivities for the following species found in California (from most to least sensitive): *Evernia prunastri*, *Hypogymnia* sp., *Usnea* sp., *Bryoria* sp., *Parmelia* sp.) (Nash 1988). There is considerable variation among studies with respect to species' sensitivities. More experimental work is necessary to clearly differentiate the effects of small amounts of S pollution. There are insufficient data on the effects of N pollution to compile even a relative ranking of sensitivity.

Interactions

The potential for interactions between pollutants should be considered when evaluating effects of pollutants on natural resources. Three general types of interactions are (1) pollutant-pollutant, (2) pollutant-natural stress, (3) and pollutant-genotype. An interaction occurs when the presence of one stress modifies the response to a second stress such that the effect is not additive. The interaction can be antagonistic (less than additive) or synergistic (greater than additive). This can occur as the interactive effects of two gases, such as ozone and SO_2, on photosynthesis and growth. It can also occur as the interaction of a pollutant and natural factors, such as ozone stress, drought, and bark beetles; this interaction has been documented for conifers in southern California. It is probably beyond the scope of the PSD process to identify pollutant-genotype interactions, but it is important to recognize that there is differential sensitivity within and between populations. There are very few data on stress interactions for pollutants and plant species in California. Limited data on lichens suggest that there are likely synergistic interactions for ozone/SO_2 (DeWit 1976) and ozone/NOx (Sigal and Nash 1983). Although it is difficult to make generalizations, situations can be identified for which interactions are likely (*table 11*).

Table 7—*Sensitivity classes for lichens with respect to ozone exposure are defined in terms of (1) morphological changes in* Hypogymnia enteromorpha, *and (2) relative presence of other species.*

Sensitivity class	Ozone conc.[1]	Description	
		Hypogymnia	Other species
	ppb		
Very sensitive	< 20	- Generally not bleached or convoluted - Fertility > 75 pct	- Very sensitive species common
Sensitive	21-40	- Majority not bleached, but large percentage bleached - Most thalli slightly convoluted - Fertility 65-85 pct	- A few very sensitive species absent - Sensitive species common
Tolerant	41-70	- Majority slightly bleached - Unconvoluted to moderately convoluted - Fertility 40-65 pct	-Some very sensitive species absent - A few sensitive species present (*Usnea* sp.) - Tolerant and sensitive species more common
Very tolerant	> 70	- Moderately to highly bleached - Moderately to highly convoluted - Fertility < 40 pct	- A few very tolerant species common (*Parmelia subolivacea*, *P. multispora*) - 50 pct of all species absent

[1] Ozone concentration is the 7-hour mean for May-October.

Table 8—*Sensitivity classes for lichen species found in mixed conifer forest in southern California wilderness.*

Sensitivity class	Lichen species
Conifers	
Very sensitive[1]	*Alectoria sarmentosa* *Bryoria abbreviata* *Bryoria fremontii* *Bryoria oregana* *Calcium virile* *Cetraria canadensis* *Evernia prunastri* *Platismatia glauca*
Sensitive[2]	*Cetraria merrillii* *Cladonia* sp. *Parmelia quercina* *Ramalina farinacea* *Usnea* sp.
Tolerant	*Hypogymnia enteromorpha*
Very tolerant	*Letharia vulpina*
Oaks (primarily California black oak)	
Very sensitive[1]	*Evernia prunastri* *Pseudocyphellaria anthraspis*
Sensitive[2]	*Collema nigrescens* *Parmelia sulcata* *Parmelia quercina* *Phaeophyscia ciliata* *Usnea* sp.
Tolerant	*Parmelia (Melanelia) glabra* *Parmelia (Melanelia) subolivacea* *Parmelia (Melanelia) multispora* *Parmelia (Melanelia) elegantula*
Very tolerant	*Physconia grisea* *Xanthoria fallax*

[1] Species in the very sensitive class are no longer found in the mountains adjacent to the Los Angeles Basin.

[2] Species in the sensitive class are found only in small amounts in the mountains adjacent to the Los Angeles Basin.

Monitoring, Data Collection, and Criteria for Decisions on PSD Applications

As indicated above, there are few data on which to base current guidelines for evaluating PSD applications. More data are needed to improve the quantitative rigor of these guidelines. Constraints on time and money will always limit scientific efforts in this area, so it is important to set priorities for data needs with respect to estimating pollution impacts and evaluating PSD applications.

It is extremely difficult and costly to determine the effects of air pollutants on entire AQRVs or ecosystems. It is therefore appropriate to focus on specific components, such as sensitive receptors, that have the greatest potential sensitivity to air pollution. For example, an applicant whose pollution source may contribute to elevated levels of ozone should survey the existing and future condition of ponderosa pine, which is known to be sensitive to this gas. Several lichen species are known to be sensitive to elevated concentrations of ozone, so lichens may be another sensitive indicator of pollutant effects.

Table 9— *Sensitivity classes for lichen species found on oaks in oak woodland in southern California wilderness.*

Sensitivity class	Lichen species
Very sensitive[1]	*Evernia prunastri* *Peltigera collina* *Pseudocyphellaria anthraspis* *Ramalina farinacea* *Ramalina menziesii*
Sensitive[2]	*Collema nigrescens* *Leptogium californicum* *Parmelia quercina* *Parmelia sulcata*
Tolerant	*Parmelia (Melanelia) glabra* *Xanthoria polycarpa*
Very tolerant	*Physcia biziana* *Physcia tenella* *Physconia grisea* *Xanthroia fallax*

[1] Species in the very sensitive class are no longer found in the mountains adjacent to the Los Angeles Basin.

[2] Species in the sensitive class are found only in small amounts in the mountains adjacent to the Los Angeles Basin.

The recent effort by scientists and policy makers to understand effects of acidic deposition on ecosystems has produced several models of plant and ecosystem response (for example, Gay 1989). In the future, these or other models may be appropriate for predicting ecosystem-specific effects of new sources. One of the goals of protecting wilderness should be to apply appropriate models to identify the sensitivity of various features of AQRVs to air pollutants. This could greatly expedite decisions about potential effects if large amounts of data from a specific wilderness are not available.

In general, there are few air quality monitoring data for wilderness areas in California. The monitoring network is located mostly in and near metropolitan areas, with few measurements in mountain locations near class I areas. Improving this network in wildland areas would have a large immediate impact on our knowledge of atmospheric deposition in class I areas in California. For example, the few data that exist on cloud chemistry suggest that cloudwater at high elevations can be highly acidic in some cases, although the level of exposure and potential for biological impacts are unknown. A research and monitoring effort in this area would be an important contribution. The placement of additional monitors should be optimized to provide data that will be applicable over relatively broad geographic areas. Protocols should be established for data collection and analysis to ensure high-quality data.

It is necessary to know natural rates of change in the absence of pollutant stress, in order to detect changes that might be associated with increased levels of air pollution. It is also important to recognize that for long-lived organisms such as trees, community organization may reflect stochastic events related to disturbances, rather than a common tolerance to environmental conditions. In any case, a better understanding of basic ecological relationships is needed at the population, community, and ecosystem level. A carefully designed inventory and monitoring program can determine the current condition of natural resources

Table 10—*Sensitivity classes for lichen species found in mixed conifer forest / oak woodland and subalpine forest in Sierra Nevada and northern California wilderness.*

Sensitivity class	Lichen species
Mixed conifer forest/ oak woodland: conifers and oaks	
Very sensitive	*Alectoria sarmentosa* *Bryoria* sp. *Evernia prunastri* *Peltigera canina* *Peltigera collina* *Pseudocyphellaria anthraspis*
Sensitive	*Collema nigrescens* *Parmelia sulcata* *Parmelia quercina* *Usnea* sp.
Tolerant	*Melanelia glabra* *Melanelia subolivacea* *Xanthoria polycarpa*
Very tolerant	*Letharia columbiana* *Letharia vulpina* *Xanthoria fallax*
Subalpine forest: conifers	
Very sensitive	*Bryoria* sp. *Pseudephebe minuscula* *Pseudephebe pubescens*
Sensitive	*Cladonia* sp. *Tuckermannopsis merrillii* *Usnea* sp.
Tolerant	*Hypogymnia enteromorpha* (may not be found at higher elevations)
Very tolerant	*Letharia columbiana* *Letharia vulpina*

as well as potential future changes (Silsbee and Peterson 1991). Simply conducting an inventory of lichen species is an important first step in describing resource condition. Monitoring programs must maintain strict protocols for sampling and measurement in order to detect subtle changes in resource condition (for example, Fox and others 1987). Standardized guides would greatly assist monitoring efforts in wilderness. For example, a pictorial atlas with examples of foliar injury in conifers and evaluation criteria would assist in measuring potential ozone effects. Managers and permit applicants should be made aware of plant species that are valued because of their sensitivity to air pollution (sensitive receptors) or scarcity (threatened or endangered species).

There are currently few experimental data on plant species found in California wilderness, and very few field data. Research on basic ecological relationships is clearly needed to quantify air pollution effects that can be observed in the field. Typical symptoms of air pollutant injury and sensitivities to air pollutants are unknown for most plant species in California wilderness. Additional data on dose-response relationships for pollutants and various plant species will help make the critical link between pollutant exposure and plant effects.

Several subjects must be addressed as part of the decision-making process for PSD permit applications. At the least, class I areas should have a complete inventory of sensitive receptors within each AQRV. These inventories can be updated as new information becomes available (for example, scientific data may indicate that a sensitive receptor should be added that was not previously thought to be sensitive to a pollutant). In addition, sensitive receptors should be monitored for a minimum of three consecutive years in order to evaluate natural temporal changes in the condition of natural resources. Scientific literature and unpublished data relevant to pollutant effects in each AQRV should be compiled and updated as necessary; site- and species-level information should be obtained whenever possible. Monitoring requirements, data needs, and decision criteria for PSD applications should be summarized and made available, so that

Table 11—*Summary of probable interactions among pollutants and other environmental factors with respect to effects on plants*[1].

	Ozone	Sulfur dioxide (SO_2)	Cloud acidity	Total nitrogen (N)	Total sulfur (S)	Drought	Cold	Insects/ pathogens
Ozone		X		X		-	+	X
SO_2				X				X
Cloud acidity							+	
Total N						X	X	X
Total S								

[1] Interactions are: greater than additive (+), less than additive (-), or likely but of unknown direction or magnitude (X); blanks indicate that there is no known or suspected interaction.

potential applicants and regulatory agencies will be aware of Forest Service concerns for wilderness protection.

Maintenance of the vigor and health of wilderness ecosystems and values (AQRVs) is a primary management objective in protecting class I areas from degradation by air pollution. The condition of sensitive receptors within AQRVs is used to measure potential changes. Deterioration of sensitive receptor condition beyond the current condition class exceeds the LAC in class I areas. The challenge for resource managers and permit applicants is to identify these potential changes and to distinguish the effects of pollutants from other environmental factors.

Other Terrestrial Resources

Many other terrestrial resources could be potential AQRVs in California wilderness. Defining and describing some of these resources was a difficult component of the workshop, despite general agreement that they were important AQRVs. The workgroup responsible for this topic concluded that six AQRVs could be defined generically across all wilderness: prehistoric rock art, geological features, threatened and endangered animals, human response relative to wilderness perceptions, natural odors, and pollutant odors.

Prehistoric Rock Art

Various forms of rock art by Native Americans, including pictographs and petroglyphs, are found in some of the wilderness areas of California. Rock art is considered an important resource and AQRV in the Agua Tibia, San Rafael, and Ventana Wildernesses. Air pollutants can degrade these features through degradation of pigments and dissolution of rock. Oxidants are known to degrade some organic compounds, and the effect of acidic deposition on statues, buildings, and other mineral-based structures is well known. Although there are no methods of monitoring the condition of rock art over time, it may be possible to draw some inferences from the literature on the effects of acidic compounds on structural materials. Because cultural artifacts are irreplaceable, it was determined that no degradation beyond baseline ("normal") deterioration would be acceptable in wilderness. A monitoring program to evaluate the condition of prehistoric art features over time should be established in order to evaluate potential degradation of the resource.

Geological Features

This AQRV includes prominent geological features and deposits that are unique because of their beauty or scientific value. For example, cliff marble formations are an important AQRV in the Marble Mountain Wilderness. Other wildernesses have large deposits of fossils that contain information on prehistoric plants and animals. The minerals that comprise these features are subject to degradation from acidic deposition. It is difficult to establish condition classes for these AQRVs because there are few data on deterioration of natural geological features. The deterioration of massive features would no doubt be less observable than that of prehistoric art. It may again be possible to draw some inferences from the literature on the effects of acidic deposition on structural materials. A monitoring program to evaluate the condition of geologic materials over time could include photographic and spectroscopic techniques. Such a monitoring program would require relatively infrequent sampling, and could be augmented by the use of standard reference materials.

Threatened and Endangered Animals

Many animals found in California wilderness are rare because that is their natural condition or because their populations have been affected by humans. Some of these species have federal or state protection or both by having been designated as threatened or endangered. This status makes protection of a species from all threats, including air pollution, a high priority. Unfortunately, almost nothing is known about the effects of air pollutants on animals. Clinical data on humans and laboratory animals might be used to draw inferences about the response of other animals to exposure to ozone, S, and N pollutants. Perhaps the most well-known effect of pollutants on animals is impaired respiratory capacity in humans and other mammals, which is caused by elevated ozone exposure. An indirect effect of air pollutants on animals is alteration of habitat as a result of pathological effects on plants or aquatic systems. It was determined that no reduction in population viability due to air pollution should be allowed in wilderness, although this may be difficult to quantify. The condition of populations can be monitored over time, but caution must be used to differentiate the effects of air pollutants from those of other environmental factors.

Human Response Relative to Wilderness Perceptions

People often use wilderness in order to enjoy a relatively pristine environment. Clean air is clearly one component of that experience. Humans have different sensitivities to air pollutants with respect to both physiological and psychological effects. Ozone can affect respiratory capacity in relatively small concentrations, reduce overall physiological well-being, and restrict hiking or other strenuous activity at high elevations. A range of condition classes defines the possible effects:

Condition class	Class description
No effect	No human-perceived discomfort or physiological impairment
Slight effect	Slight discomfort or short-term physiological impairment
Moderate effect	Moderate discomfort or moderately long-term physiological impairment
Severe effect	Severe discomfort or long-term physiological impairment

These categories are quite general in order to reflect the subjectivity of human response as well as the variation in human sensitivity. It may be possible to quantify these descriptions through inferences from the medical literature on human respiratory function and vision with respect to pollutants. It may also be possible to conduct a survey of National Forest users to determine levels of discomfort and physiological impacts. In any case, it was determined that any deleterious effect of air pollutants on humans (respiratory impairment, eye irritation, etc.) is unacceptable in wilderness.

Natural Odors

Air pollutants such as ozone and SO_2 can mask the wide variety of natural fragrances perceived by humans and other animals. Masking of volatile organic chemicals, secondary plant compounds, and pheromones can reduce enjoyment of wilderness by humans and block important chemical cues sensed by animals. Disruption of normal odor detection can therefore affect human perceptions as well as ecosystem function. The following condition classes are defined for natural odors:

Condition class	Class description
No effect	No interference with natural odors
Moderate deterioration	Masking of natural odors observed by 10-30 percent of observers
Severe deterioration	Masking of natural odors observed by >30 percent of observers

It may be possible to monitor the effect of air pollutants on natural odors by comparing exposure data with the concentration of volatile organic compounds.

Pollutant Odors

Some pollutants are readily identified by smell. Ozone has a distinctive metallic odor; SO_2, an acrid odor; and hydrogen sulfide (H_2S), a "rotten egg" odor. These odors, as well as the masking of natural odors, are generally perceived as negative impacts by wilderness users. The following condition classes were defined for pollutant odors:

Condition class	Class description
No effect	No chemical or sensory interference with human smell
Moderate deterioration	Air pollutant odor is detectable
Severe deterioration	Air pollutant odor is the only detectable odor

Effects on Aquatic Resources

Lakes, streams, and their associated biota represent important AQRVs in most class I wilderness areas and national parks in California *(table 12)*. The aquatic resources can be conveniently divided into three primary subpopulations, located in the Klamath Mountains, Southern Cascade Mountains, and Sierra Nevada/southern California (*table 13*). Of these, the Sierra Nevada contains the greatest number of wilderness areas and the most intensively studied aquatic resources.

The most extensive study to date of the aquatic resources in this region is the Western Lake Survey (WLS) conducted by the U.S. Environmental Protection Agency (EPA) in 1985 (Landers and others 1987). The purpose of the survey was to quantify, with known uncertainty, the chemical status of lakes in areas of the western United States that contain the majority of lakes having acid neutralizing capacity (ANC) less than 400 µeq/L. Although the western United States currently receives a small fraction of the atmospheric acid loading received in the East (Young and others 1988), an acceptable atmospheric deposition loading to prevent acidification of western aquatic resources is unknown. Of particular concern is the degree of protection necessary to maintain the chemical and biological integrity of lakes and streams in the designated USDA Forest Service wilderness areas and national parks.

The WLS sampled a statistically representative group of lakes in California, including 13 lakes in each of the Klamath Mountains and Southern Cascades and 71 lakes in wilderness areas (not all class I) of the Sierra Nevada. Although no lakes were sampled in southern California wilderness areas, watersheds in this region are similar to those of the Sierra Nevada with predominantly granitic geology and thin, poorly developed soils. Potential effects of pollutants on aquatic resources in southern California wilderness can be estimated reasonably well from data collected at Sierra Nevada lakes, until additional data are available.

Table 12—*Aquatic air quality related values (AQRVs) for California wilderness.*

	AQRV	
Wilderness	Lake	Stream
Agua Tibia		
Ansel Adams	X	X
Caribou	X	X
Cucamonga		X
Desolation	X	X
Domeland		X
Emigrant	X	X
Hoover	X	X
John Muir	X	X
Kaiser	X	X
Marble Mountain	X	X
Mokelumne	X	X
San Gabriel		X
San Gorgonio	X	X
San Jacinto		X
San Rafael		X
South Warner Mountain	X	X
Thousand Lakes	X	X
Ventana		X
Yolla Bolly-Middle Eel	X	X

Table 13—*USDA Forest Service wilderness areas (not all class I) and national parks in California containing lakes sampled during the Western Lake Survey by the U.S. Environmental Protection Agency (Landers and others 1987).*

Subpopulation	Number of lakes sampled
Klamath Mountains	13
Siskiyou Wilderness	2
Marble Mountain Wilderness	4
Trinity Alps Wilderness	7
Southern Cascades	13
Thousand Lakes Wilderness	2
Lassen Volcanic National Park	7
Caribou Wilderness	3
Bucks Lake Wilderness	1
Sierra Nevada	71
Desolation Wilderness	11
Mokelumne Wilderness	3
Hoover Wilderness	1
Emigrant Wilderness	4
Yosemite National Park	9
Minarets Wilderness	5
John Muir Wilderness	16
Kaiser Wilderness	1
Dinkey Lakes Wilderness	1
Kings Canyon National Park	11
Sequoia National Park	9

Aquatic resources in this region are vulnerable to potential effects from acidic deposition because of the predominance of slowly weatherable igneous rocks, thin acidic soils, and generally large volumes of winter precipitation (Melack and others 1985, Melack and Stoddard 1991). These aquatic resources provide water for agriculture, and for municipal and industrial use in metropolitan areas such as Los Angeles and San Francisco. They also provide the focus for many wilderness recreational activities in the region. Although important aquatic resources include rivers and streams, as well as lakes, few of the former have been chemically or biologically characterized in a systematic fashion. Consequently, this section on aquatic resources focuses primarily on lakes.

Climate in the mountainous areas of California is characterized by warm, dry summers and cool, wet winters. Altitude and topography strongly influence climatic factors in the region. Meteorological stations and data are scarce at the higher elevations. Available data, however, suggest the following climatological conditions (Melack and Stoddard 1991). Mean annual precipitation on the western side of the crest of the mountains increases from less than 40 cm below 250 m elevation in the foothills to about 140 cm above 2000 m elevation. The eastern side receives about two-thirds as much precipitation as the western side. Most precipitation falls as snow at the higher elevations, especially above about 3000 m. Runoff from mid- to high-elevations comes predominantly during snowmelt from April through July. Prevailing winds are from the west. On a local scale, winds are channeled by valleys, with generally up-valley flow during warm months and down-valley flow during cool months.

The initial concern regarding potential impacts to the aquatic resources in this region has focused on potential acidification from anthropogenic emissions of S and N (Eilers and others 1989; Landers and others 1987; Melack and others 1983, 1985; Melack and Stoddard 1991; Stoddard 1986). Sulfate, nitrate, and ammonium all have the potential to acidify surface waters (Stumm and Morgan 1981). Increased sulfate is typically associated with chronic acidification of surface waters (L.A. Baker and others 1990), although nitrate (NO_3^-) (Henriksen and others 1988) and ammonium (NH_4^+) (Schuurekes and others 1988) are important in some cases. Episodic acidification, however, is typically associated with rapid release of accumulated NO_3^- during snowmelt runoff (Eshleman 1988, Schnoor and Nikolaidis 1989, Wigington and others 1990). Episodic acidification may be of particular concern in California because of the relative importance of N, as compared with S, deposition in the West. Many of the workshop participants believed that aquatic resources in the Sierra Nevada are not likely to experience chronic acidification in the near future. This belief was based on various model applications in the literature and on empirical studies suggesting that increased acidic inputs to the Sierra Nevada would likely increase weathering rates rather than cause chronic acidification. For this reason, empirical modeling efforts that employ F-factor calculations (for example, Henriksen 1984) were not considered appropriate for AQRV guidelines in this region. Rather, most workshop participants favored an approach based on episodic chemistry, and this preference is reflected in the condition classes selected during the workshop.

Acidification of soils and surface waters contributes to increased mobilization and availability of aluminum (Al), which can be highly toxic to aquatic life, especially if the Al is in the inorganic monomeric form (J.P. Baker and others 1990). The toxic effects of surface water acidification have been attributed to the combined increases in hydrogen ion and Al (J.P. Baker and others 1990). Calcium (Ca) concentration is also important; biota generally tolerate lower pH and higher Al concentrations in the presence of higher calcium ion (Ca^{2+}) concentration.

Organic acids can also play an important role in affecting the acid-base status of surface waters and their sensitivity to acidification. However, only waters low in concentrations of both base cations and organic acids are highly susceptible to acidification (Sullivan 1990). Waters high in base cations (and therefore alkalinity) receive substantial neutralization potential from their watersheds, and therefore typically have the capacity to completely neutralize acidic deposition inputs, largely through increased weathering and exchange of base cations (Brakke and others 1990, Henriksen 1984). Similarly, waters high in organic acids have a strong buffering capability that resists further acidification (Kramer and Davies 1988). Nearly all surface waters in this region have low dissolved organic carbon (an indication of organic acid concentrations); consequently, the issue of sensitivity in these systems is determined primarily by their base cation concentrations.

Other potential consequences of atmospheric pollutants in the deposition include eutrophication[7] of N-limited lakes and damage associated with trace contaminants such as metals (for example, mercury, cadmium) and organic compounds (polynuclear aromatic hydrocarbons, pesticides). Cases of N limitation in oligotrophic Western lakes are becoming more widely documented (Axler and others 1981, Goldman 1981, Larson 1988, Morris and Lewis 1988), suggesting that increases in N deposition could be a concern with respect to both episodic acidification and increases in lake productivity. Trace contaminants are typically not addressed in the PSD process and will not be discussed here.

Although concern for damage associated with atmospheric deposition of pollutants is primarily associated with the possible loss of sensitive biota, most studies of atmospheric impacts on aquatic ecosystems have focused on measuring changes in surface water chemistry. Therefore, most of the criteria for evaluating sensitive waters are based on water chemistry, reflecting the relative ease and precision of collecting and measuring water chemistry as compared to quantitative sampling of aquatic organisms. The need to base the criteria on water chemistry also reflects the poor state of knowledge of aquatic communities.

The only statistical sampling of aquatic resources in the region is the WLS. Other limited data sets have also been collected in the Sierra Nevada and provide more detailed information, especially regarding seasonality, for a nonstatistical subset of lakes. Wilson and Wood (1984) sampled 85 lakes in northern California, including 22 lakes sampled during both summer and fall. Melack and others (1985) sampled 73 lakes along the Sierra Nevada crest. Stoddard (1986) and Holmes (1986) sampled 29 lakes to relate lakewater pH to diatom distributions, including mostly lakes previously sampled by Melack and others (1985). Melack and Setaro (1986) sampled 17 lakes during the ice-free seasons and during ice cover. McCleneghan and others (1985, 1987) sampled 34 lakes as part of a statewide survey of lakes vulnerable to acidic deposition. Data collected in these studies have been summarized by Melack and Stoddard (1991). Characteristics exhibited by lakes included in these surveys are presented in *table 14*, from Melack and Stoddard (1991).

The majority of the lakes in the Sierra Nevada are small and shallow, and drain relatively large watersheds. About 70 percent of the lakes are less than 10 ha in area and 10 m deep. Most have pH between 6.5 and 7.5 and ANC < 100 µeq/L. Sulfate concentrations tend to be extremely low (< 7 µeq/L), as are concentrations of dissolved organic carbon (DOC) (< 160 µmol/L). As a whole, the region is characterized by a large number of small, extremely dilute lakes (Melack and Stoddard 1991). They constitute the most dilute group of lakes sampled in the United States (Landers and others 1987). Thus, although no acidic lakes were sampled, they are undoubtedly among the most sensitive aquatic resources to acidic deposition effects in the country. The median ANC of lakes in the Sierra Nevada is 60 µeq/L (*table 14*). Perhaps of greater interest with respect to the PSD process is the large number of lakes in this region with alkalinity values less than 25 µeq/L. Local variations in geology and hydrologic flow paths can greatly modify lake alkalinity expected on the basis of generalized geology. Assessment of lake alkalinity in relatively small areas such as wilderness areas may require more detailed information than is available from surveys such as Landers and others (1987). Fortunately, the lakes in California are primarily bicarbonate systems (Landers and others 1987),[8] and one can estimate surface water alkalinity simply by measuring conductivity. Regressions of base cation sum and alkalinity versus conductivity for low-conductivity (≤ 15 µSiemens/cm) lakes in the Sierra Nevada yield the following (*fig. 2*):

$$\text{Basic cation sum } (\mu\text{eq/L}) = 9.52\,C + 0.09$$
$$n = 34,\ r^2 = 0.96,\ SE = 0.36$$

$$\text{Alkalinity } (\mu\text{eq/L}) = 9.42\,C - 8.59$$
$$n = 34,\ r^2 = 0.93,\ SE = 0.45$$

where C is conductivity (µS/cm). Both base cation sum and alkalinity have been used widely to estimate surface water sensitivity to acidification, and conductivity is a suitable surrogate for quickly estimating either of these parameters to identify low-conductivity lakes. The high percent variance in alkalinity explained by conductivity shows that this inexpensive measurement can be used to conduct rapid assessments of surface water alkalinity throughout the region. This regression equation will have poor predictive capability for lakes receiving substantial marine aerosols or those with watershed sources of sulfate, but for most lakes conductivity can be used to accurately estimate alkalinity. With the additional measurements of SO_4^{2-} and pH, the process can be further refined to screen for acidic waters from either watershed or atmospheric sources of S. Although conductivity screening would not provide direct information on the prevalence or likelihood of episodic acidification, it is the low alkalinity/conductivity systems that are most sensitive to episodic acidification. A conductivity screening provides a rapid and inexpensive procedure for identifying waters of highest interest.

Low-alkalinity lakes are found throughout the region. Weathering of base cations is extremely low in many of these watersheds. Background SO_4^{2-} values are also extremely low; sea-salt-corrected SO_4^{2-} values are typically near 0. This is in general agreement with estimates of background sulfate concentrations for areas not receiving acidic deposition (Brakke and others 1988). It is generally accepted that surface waters with chemical

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[7] The process of increasing lake productivity is usually associated with increasing nutrient loads ot the lake. Increasing nutrient loads stimulate growth of algae and aquatic plants. This usually results in decreased lake transparency.

[8] A small number of lakes in the West have substantial sulfate concentrations (Landers and others 1987) that have been attributed to watershed sources of sulfur (Loranger and Brakke 1988, Stauffer 1990). When the sulfate concentrations are sufficiently great, the lakes can be acidic. For example, West Twin Lake in the Oregon Cascades has an alkalinity of -5 µeq/L and a sulfate concentration of 307 µeq/L (Eilers and Bernert 1990). There are two known acidic lakes from watershed sources of sulfate in the Sierra Nevada, located in Kings Canyon National Park and the John Muir Wilderness Area (J. Stoddard personal communication).

Table 14—*Median values, with first and third quartiles in parentheses, for elevation and major ion chemistry in five Sierra Nevada lake chemistry data sets*[1] *(from Melack and Stoddard 1991)*

Data set	n	pH	ANC	SO_4^{2-}	DOC	NO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	SBC	Elevation
			µeq/L	*µeq/L*	*µmol/L*	*µeq/L*	*µeq/L*	*µeq/L*	*µeq/L*	*µeq/L*	*µeq/L*	*m*
Western Lake Survey (population)	2119	6.93 (6.65-7.30)	60 (37-130)	7 (4-7)	67 (42-158)	0.4 (0.1-1.7)	2 (1-3)	43 (29-104)	6 (3-9)	19 (11-21)	76 (51-120)	3008 (2150-3140)
Western Lake Survey (sample)	114	6.95 (6.71-7.29)	71 (45-137)	6 (4-11)	106 (58-183)	0.3 (0.1-1.2)	3 (2-6)	45 (29-91)	10 (4-20)	23 (14-40)	86 (58-164)	2626 (2131-3159)
Melack and others (1985)	82	6.95 (6.51-7.26)	48 (25-98)	15 (9-31)	———	0.4 (0.1-1.5)	6 (4-10)	37 (24-83)	5 (3-10)	19 (11-31)	73 (44-137)	3255 (2999-3424)
Holmes (1986)	29	6.93 (6.44-7.42)	67 (27-258)	12 (5-83)	———	0.7 (0-3.3)	2 (2-4)	58 (42-345)	9 (4-18)	12 (9-29)	88 (60-413)	3194 (2999-3365)
Melack and Setaro (1986)	17	6.64 (6.50-6.72)	57 (53-101)	10 (8-14)	———	2.6 (1.3-3.9)	3 (2-4)	46 (40-92)	6 (4-9)	17 (10-19)	74 (64-113)	3170 (2899-3365)
McCleneghan and others (1985, 1987)	34	6.56 (6.19-6.73)	66 (30-97)	22 (16-39)	———	0.4 (0.1-1.2)	3 (2-4)	47 (22-79)	11 (6-19)	12 (18-26)	88 (52-121)	2664 (2195-3146)

[1] ANC = acid neutralizing capacity, DOC = dissolved organic carbon, SBC = sum of base cations. Western Lake Survey pH values are closed system; others are partially air-equilibrated.

characteristics typical of this region are extremely sensitive, but the lakes do not currently exhibit any signs of acidification from atmospheric deposition (L.A. Baker and others 1990, Sullivan 1990). The WLS provided a quantitative assessment of the chemical status of lakes in the region, although the sampling intensity was generally insufficient to adequately characterize the lake populations within individual wilderness areas. Furthermore, the samples for each lake were taken on a single day and all sampling was done in the autumn. The number of WLS sample lakes is not sufficient to develop an acceptable characterization of the lakes within individual wilderness areas, with the possible exception of the John Muir Wilderness (*table 13*).

The primary concern for maintaining high water quality in wilderness areas is the desire to prevent the loss of indigenous (and intentionally stocked) aquatic organisms. Other nonbiotic concerns, however, such as water clarity, are also thought to be important to the wilderness experience. There are two problems with the use of aquatic organisms to serve as indicators of air pollution stress. First, very little is known about the species of aquatic organisms present in these wilderness areas. Only isolated studies of a small number of aquatic habitats have been conducted. Second, little is known about the potential response of these species to changes in water quality. Most studies of species response to acidification have been conducted outside California.

Although the workshop participants favored including organisms in a monitoring strategy, the paucity of high-quality, biological data precludes their effective use at this time. Chemical criteria are easier to implement as indicators of atmospheric degradation. It is hoped that subsequent research will provide support for use of specific values linking the changes in water chemistry with undesirable biological impacts. Suggested water quality parameters that can be used to indicate air quality related impacts in wilderness areas are shown in *table 15*. Most of these parameters can be applied to both lakes and streams, with the exceptions of Secchi disk transparency and dissolved oxygen concentrations. The latter two parameters reflect potential changes in lake trophic status caused by either increased deposition of nutrients, or by effects on the watershed that might affect nutrient export to aquatic systems.

Aquatic organisms were also recognized as potentially valuable indicators of air pollution effects on wilderness areas. Selected taxonomic groups are thought to include sensitive species (*table 16*), based on use of these taxa in studies on biological impacts of acidic deposition in North America and Europe (see J.P. Baker and others 1990).

Several concerns were identified in the use of biota to monitor effects in California. The faunistic diversity of wilderness lakes in the region is low; therefore, locating enough organisms for effective biological monitoring might be a problem. For example, molluscs and other benthic invertebrates were used to measure biological damage in Norwegian lakes (Økland and Økland 1986), but the low Ca^{2+} concentrations in many Western lakes may restrict the distribution of these organisms to lower elevations.

Table 17 is a preliminary list of sensitive receptors for the aquatic resources in California. Although uncertainties and ambiguities are substantial in the use of these sensitive receptors for assessing the onset of AQRV deterioration, they represent a first step in the process of identifying AQRV monitoring needs. The proposed preliminary sensitive receptors for lakes are pH, ANC, water clarity, and fish populations. For streams they are pH, ANC, fish populations, and macroinvertebrates.

Once the sensitive receptors have been defined, it is necessary to determine which changes in the sensitive receptors warrant management response. All measures of water quality

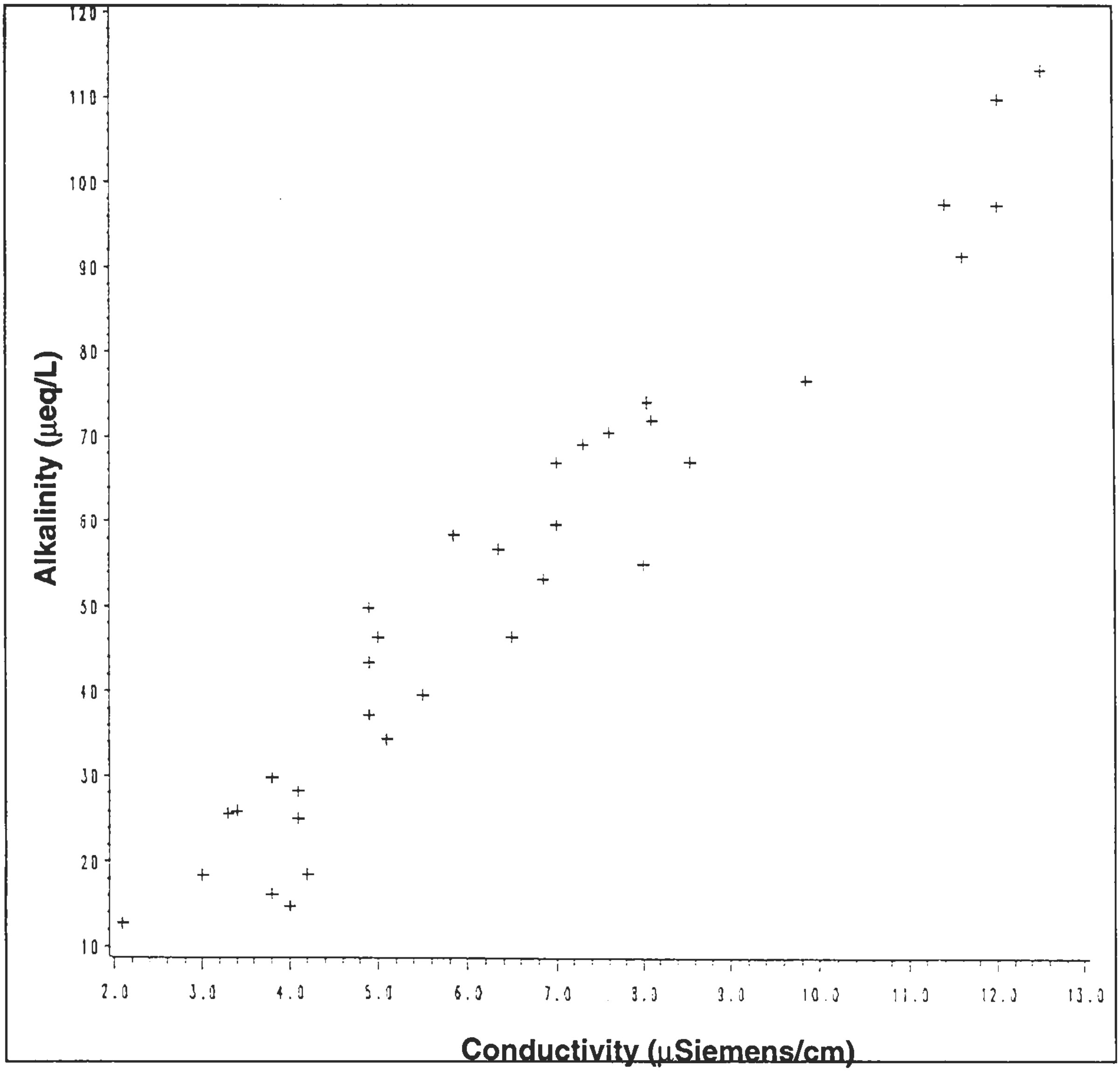

Figure 2—Alkalinity versus conductivity for low-conductivity (≤ 15 µSiemens/cm) Western Lake Survey lakes in California (from Landers and others 1987).

and biota are associated with uncertainty. Measurement uncertainty arises from sampling error, analytical error, and natural variability associated with hydrologic processes. Selection of LAC requires incorporation of some element of uncertainty. However, if the level of uncertainty is too great, then it would be possible for the resource to be degraded yet still within the LAC. Thus, in developing some initial LAC, the aquatics group followed the guidance of the Forest Service legal mandate, which is to err on the side of protecting the resource (as stated in the Wilderness Act 1964).

Three condition classes were defined for each water quality indicator to reflect classes of impacts associated with changes in the indicator values: (1) no significant deterioration, (2) significant deterioration, and (3) severe deterioration. The values assigned to each of these classes are intended to reflect realistic changes based on mechanisms of acidifying (or eutrophying) processes, observations in areas already acidified (or eutrophied), and the reliability of data on aquatic resources in these wildernesses (*table 17*). These values represent changes in addition to those imposed by natural processes such as dilution, and should be used only as an interim guide until subsequent monitoring and research results are available to revise them. The rationale for selecting each receptor is briefly summarized below:

ANC: Acid neutralizing capacity (alkalinity) is the most direct measure of surface water sensitivity to acidification for surface waters that have not been previously affected by acid deposition. Reductions in ANC to values near 0, as observed during some hydrologic events (summer thunderstorms, snowmelt), can reduce the quality of aquatic habitat. California lakes have the lowest average ANC values of any region in the United States (Landers and others

***Table 15**—Potential water quality parameters and their descriptions identified for surface water chemistry.*

Parameter	Description	Indicates
Acid neutralizing capacity	Alkalinity (µeq/L)	Decrease is a direct measure of acidification
Conductivity	Specific conductance (µSiemens/cm)	Can be related to alkalinity; use as a screening tool
pH	Hydrogen ion (-log [H$^+$])	Decrease is a direct measure of acidification
Al$_i$	Inorganic monomeric aluminum (µg/L)	Present in measurable amounts only in acidified waters
SO_4^{2-}	Sulfate (µeq/L)	Acid anion most often associated with chronic acidification
NO_3^-	Nitrate (µeq/L)	Acid anion most often associated with episodic acidification
NH_4^+	Ammonium (µeq/L)	Seldom present in wilderness lakes; increase suggests elevated nitrogen deposition
Total P	Total phosphorus (µg/L)	Often a limiting nutrient; changes affect trophic status
DO	Dissolved oxygen (mg/L)	Reduction in winter or increased diurnal fluctuations may represent increased productivity of waters
Secchi disk transparency	Water clarity (m)	Decrease indicates loss of transparency, possibly from increase in phytoplankton or organic acids. Increased transparency may indicate acidification.

1987). Condition classes are set to reflect both chronic and episodic reductions in ANC. Overlapping class descriptions for the first two condition classes reflect a range of values, because of the uncertainty in specifying deterioration thresholds.

pH: Organisms respond to changes in H$^+$ ion, not ANC. Although it is often difficult to obtain reliable measures of pH in dilute waters, it is important that every effort be made to do so. It is difficult to detect any negative biological response associated with H$^+$ concentration above pH 6.0 (J. P. Baker and others 1990, Eilers and others 1984, Schindler 1988). Ninety-nine percent of the lakes in the WLS Western region had pH > 6.0 (Landers and others 1987). There can be changes in community composition for sensitive taxonomic groups below pH 6.0. ANC is typically near or ≤ 0 at pH values < 5.3, and detrimental biological impacts become quite apparent. The impacts become increasingly severe at pH < 5.0 as inorganic monomeric aluminum (Al$_i$) is mobilized into solution. Lake pH can vary considerably during the year because of normal variation in chemical parameters, such as the concentration of dissolved gases. Changes can be relatively large at times, particularly in small bodies of water. The dynamic nature of lake pH dictates periodic sampling to establish temporal trends, rather than annual sampling. Reductions in pH < 5.5 during hydrologic events (storms, snowmelt) were considered by the workshop participants to be an indication of severe deterioration with respect to habitat quality for aquatic organisms. However, natural processes of dilution and organic enrichment can in some cases lower episodic surface water pH < 5.5 in the absence of acidic deposition (Wigington and others 1990). Chronic reductions of 0.3 to 0.5 pH units can also cause significant deterioration of aquatic habitat. Overlapping class descriptions for the first two pH condition classes (*table 17*) reflect a range of values because of the uncertainty in specifying deterioration thresholds. Monitoring of pH should be done at least three times a year at standard seasonal times in order to characterize temporal variation.

Water Clarity: Measurement of transparency (for example, by lowering a Secchi disk into a lake or measuring optical density) provides an inexpensive indication of phytoplankton production. Transparency in some cases may increase in acidified lakes. If nutrient deposition (NO_3^-, NH_4^+, total phosphorus [P]) to the lakes increases, it is conceivable that the lakes would become less oligotrophic and therefore less transparent. Workshop participants noted that although measurement of transparency with a Secchi disk is easily measured, the majority of the lakes in the Sierra Nevada are too shallow and too clear to allow sufficient Secchi disk depth to provide any useful information. The recommended condition classes were therefore based on optical density rather than Secchi disk transparency.

***Table 16**—Suggested taxonomic groups of aquatic organisms that could be investigated for sensitivity to stress from atmospheric pollutants.*

Taxonomic group	Primary habitat	Notes
Macroinvertebrates		
Mollusca (snails, clams)	Lakes, streams	Check for loss of species; may be limited by availability of calcium
Ephemeroptera (mayflies)	Lakes, streams	Check for loss of species; larval (aquatic) forms are the sensitive life stage
Plecoptera (stoneflies)	Lakes, streams	Check for loss of species; larval (aquatic) forms are the sensitive life stage
Trichoptera (caddisflies)	Lakes, streams, ponds	Check for loss of species; larval (aquatic) forms are the sensitive life stage
Plankton		
Phytoplankton	Lakes	Check for changes in species composition, especially loss of diatoms and increase in blue-greens
Zooplankton	Lakes	Check for changes in species composition, including a change to larger species associated with a reduction in predators (fish)
Amphibians	Lakes, streams, ponds, wetlands	Possible confounding effects from fish stocking
Fish	Lakes, streams	Also can be sampled for accumulation of trace contaminants; check for loss of year classes
Bryophytes (mosses)	Wetlands, lakes, streams	Accumulators of some trace metals
Macrophytes (aquatic plants)	Wetlands, lakes	Leaf chlorosis on emergent species

The clarity of water in mountain lakes is a valuable resource for many wilderness users. It can also serve as a sensitive receptor for air pollutants, especially elevated levels of N deposition. Most Sierra Nevada lakes have low to moderate productivity levels. Additional N deposition could act as a fertilizer, increasing the productivity of algae and other organisms, although some Sierra Nevada lakes may be P-limited (or quickly become P-limited with increased N inputs). An increase in plankton biomass generally reduces the clarity of surface water.

Fish Populations: Fish develop more slowly in acidified water and are generally less physiologically resistant to environmental stress. Detecting significant changes in fish populations is difficult because of the high natural variability in most lakes. Fish populations vary in response to changes in food supply, climate, removal by humans, and other factors. Because of this variation, it is suggested that young-of-the-year (0-age class) fish be examined to detect deterioration in habitat quality of lakes. The condition class for "significant deterioration" was not defined because it was thought that it would not be possible to distinguish interannual variation in fish populations from changes due to pollutants. The nonfunctional category indicates an extremely severe situation in which acidity is so great that it contributes to adult fish mortality. The species monitored in lakes will vary among locations; in the absence of knowledge about species sensitivity to acidity, a common species should probably be monitored in order to better characterize variation. Difficulties in the use of fish populations as sensitive receptors include the absence of fish from many waters (especially at high elevation) and the confounding influence of stocking practices.

Macroinvertebrates: Some species of macroinvertebrates commonly found in streams are known to be sensitive to increases in acidity. In fact, changes in their populations may precede and be detected earlier than those in fish populations. Natural population variations can obscure changes that might be related to increased acidity, so condition classes for macroinvertebrates are quite general.

Pollutant Interactions

Because of the acidifying impact of N and S deposition on aquatic systems, the addition of N or S to a sensitive system may result in an additive impact due to an increase in acidity. In addition, some interaction effects between ozone, SO_2, and N deposition may occur (see section on terrestrial resources above) in riparian/wetland areas where terrestrial flora are sensitive receptors (for example, mosses, lichens). It is currently unclear whether interaction effects among these three pollutants will be

Table 17—Sensitive receptors and associated condition classes for aquatic resources proposed at the workshop.

Sensitive receptor	Condition class	Class Description
Lake/stream pH	No change	— Long-term reduction of pH < 0.5 pH units
	Significant deterioration	— Long-term reduction of pH > 0.3 pH units
	Severe deterioration[1]	— pH < 5.5 during and immediately following hydrologic events
Lake/stream ANC[2]	No change	— Long-term reduction of ANC < 10 μeq/L
	Significant deterioration	— Long-term reduction of ANC between 5 and 10 μeq/L
	Severe deterioration	— Reduction of ANC ≤ 0 during and immediately following hydrologic events
Lake clarity	No change	— Reduction in optical density of < 0.003 optical density units (ODU)
	Significant deterioration	— Reduction in optical density of 0.003 to 0.01 ODU
	Severe deterioration	— Reduction in optical density of > 0.01 ODU
Lake/stream fish populations	No change	— Young-of-the-year present each year in which reproducing populations and suitable habitat exist
	Significant deterioration	— Not specified
	Severe deterioration	— Long-term loss in reproductive capacity—ranging from 3 years to no reproduction
	Non-functional	— Abnormal adult mortality observed
Stream macroinvertebrates	No change	— No loss of sensitive species
	Significant deterioration	— Loss of some sensitive species
	Severe deterioration	— Loss of all sensitive species

[1] There was some concern expressed subsequent to the workshop that episodic reductions in pH and/or ANC contribute the first warning signals of acidification damage, rather than "severe deterioration." This discrepancy illustrates the generally poor knowledge base regarding episodic acidification in these systems.

[2] ANC = acid neutralizing capacity.

synergistic or antagonistic. Nevertheless, Federal Land Managers should be aware of potential interactions and be prepared to monitor their effects.

Monitoring, Data Collection, and Criteria for Decisions on PSD Applications

Although survey data for lakes in California are available to qualitatively document the high sensitivity of these systems to possible effects of acidic deposition, major uncertainties regarding the quantitative aspects of this sensitivity for lakes, streams, and wetlands hamper the FLM's ability to assess impacts associated with the PSD process. The major research/monitoring needs to reduce these uncertainties include the following:

Lakes: The major ion chemistry of lakes in the region was characterized in the WLS and other local surveys. However, data areas are generally insufficient to characterize these resources for individual wilderness (see *table 13*). Research and monitoring needs for lakes include: (1) characterization of lake chemistry in individual wilderness areas, (2) establishment of long-term monitoring of one to several lakes/watersheds in selected wilderness areas for the purpose of detecting trends, and (3) improving our understanding of the processes controlling chronic, and especially episodic, lake chemistry.

Streams: Little research has been conducted on streams in California. There is a need to investigate stream chemistry, especially in the higher mountain sites. No stream chemistry in the region has been compiled to provide an overall assessment of the sensitivity of streams to acidification. There is a need for both baseline (for example, current export of N from undisturbed watersheds) and episodic stream chemistry data.

Wetlands/Ponds: No data were available to evaluate the potential sensitivity of wetlands, riparian corridors, or vernal pools (spring ponds) to damage from acidic deposition.

Deposition: Estimates of wet deposition in the region are based on National Atmospheric Deposition Program/National Trends Network (NADP/NTN) sites that are generally located at much lower elevations than the aquatic resources of interest. Deposition data from high elevation sites dominated by snow inputs are needed. Snow cores could be considered as an alternative to establishing additional NADP sites (Laird and others 1986).

Biota: No species-specific biological data were available to make assessments of either the distribution of sensitive species in the region or their dose-response to pollutant exposure. A plan should be developed to begin collecting this basic information.

Snowmelt: Most of the data on aquatic resources in California have been collected in summer and autumn. Collecting hydrologic and chemical data for lakes, streams, and ponds needs greater emphasis during the snowmelt period. Dilution of base cations will greatly increase the sensitivity of those systems to acidic deposition.

The condition of sensitive receptors should be monitored at specific times: (1) in summer, when primary productivity is highest in lakes and streams, (2) in autumn, when lake turnover and mixing within the water column occurs, and (3) during hydrologic event conditions, when there is dynamic change in physical and chemical parameters. It may be logistically difficult to collect data for short-term events, but some effort is necessary in this area because of its importance in determining the condition of surface water.

Although the areas listed above identify some of the major research/monitoring needs for aquatic resources in California, there are several important related issues. First, the FLM needs to anticipate data requirements for quantitatively evaluating lake and stream response to atmospheric deposition via process-based model projections. In addition to the information described above, ancillary information on watershed characteristics for selected sensitive resources is needed. The two models used extensively in forecasting lake and stream response to acidification in the National Acid Precipitation Assessment Program (NAPAP) program were MAGIC (Model of Acidification of Groundwater in Catchments) and ILWAS (Integrated Lake and Watershed Acidification Study). MAGIC model requirements include detailed information on soil properties (for example, depth, bulk density, cation exchange capacity, S-absorption, base cations, extent of soil cover), vegetative cover, exposed bedrock (extent and composition), deposition, and hydrologic flowpaths (Cosby and others 1985a,b,c). More intensive data collection is required to fully calibrate the ILWAS watershed simulation model (Chen and others 1983, 1984), and it is therefore not as generally applicable as is MAGIC.

One of the difficulties in obtaining the needed input data for modeling efforts has been the problem of conducting research in wilderness areas. The difficulty of gathering data in mountainous areas is compounded by administrative restrictions of the 1964 Wilderness Act. Relaxing management guidelines that impede data collection may be appropriate in some cases, because one of the purposes of establishing wilderness areas was for their scientific use (Sec 2(c)(4) of the 1964 Wilderness Act).

Relatively little is known about the effects of long-term acidic deposition on aquatic systems. Loadings of S and N in California are currently low (except for high N deposition in parts of southern California) and well below previously cited levels associated with damage. However, the potential sensitivity of California watersheds to small changes in acidity dictates a conservative approach to resource protection. Dramatic changes in chemical parameters are observed during hydrologic events in some aquatic systems, even with low deposition values. Monitoring episodic changes in the most sensitive lakes and streams will provide the earliest signal of potential changes caused by air pollutants. Research that can link S and N inputs to changes in aquatic systems in California should be a high priority. Studies are also needed that can determine the effect of episodic changes in chemical parameters on the biotic communities of lakes and streams.

Effects on Visibility

The CAA, as amended in 1977, 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 in which impairment results from man-made air pollution." The CAA further states that visibility will be an AQRV for class I areas. Visibility is equal in importance to other AQRVs, such as ecosystems and lakes, although it is usually not homogeneously affected by air pollution throughout a given area. It is a site-specific value affected by meteorology, topography, the position of the viewer and the sun, and a number of other variables. Assessments of visibility rely heavily on human perceptions of resource condition.

The majority of the visibility workgroup agreed to the premise that visibility *within* class I areas (not "integral vistas," that is, not including views from or to targets outside the class I area) is the AQRV, because of the administrative problems associated with managing air quality over lands outside federal jurisdiction. This premise was not a unanimous viewpoint because workshop participants felt that the value of views from class I areas reached well beyond their boundaries.

The visibility workgroup further concluded that specific vistas or views are the sensitive receptors. Although good visibility is an important resource throughout class I areas in California, sensitive receptor vistas selected and monitored by FLMs are a practical way to determine the effects of air pollution on the visibility resource.

The workgroup concluded that the protection of visibility should not depend on the number of visitors, and that one visitor is as important as many visitors.

A Process to Manage Visibility in Class I Areas

Visibility is a site-dependent value for which guidelines can be assigned only on a case-by-case basis. That is, each view or vista holds values of coloration, texture, and pattern, as well as potential to see distant targets that must be viewed and rated individually. No procedures have been established to accomplish this task in a standard way. Consequently, the workgroup developed a process to identify sensitive views, as well as to characterize, evaluate, and eventually manage those views. The following process was the result:

Step 1 - Select sensitive vistas.
Step 2 - Describe elements of the vistas that are of interest.
Step 3 - Discuss the sensitivity of the vista to air pollution.
Step 4 - Monitor to establish baseline levels, trends, and changes.
Step 5 - Predict the effect of projected additional loadings.

In order to implement this process, the workgroup suggested developing a notebook for the FLM that contains two pages for each identified vista. The first page will summarize the reasoning behind selection of the view and provide information necessary for modeling visibility impacts. It will include a photograph of the vista, a description of the vista's features, current visibility condition (if available), and a brief discussion of how the feature would be affected by air pollution. The second page will be a visibility impairment table (VIT) computed specifically for that vista. The table will give an estimated conservative (larger than actual) contrast change for a range of increased particle loadings, expressed as a percentage of the PSD class I increment. Guidance in the form of a photo and a table will be provided to help the FLM interpret projected contrast changes in terms of human perception of the vista.

Step 1–Select Sensitive Vistas.

Sensitive vistas are indicators that will be used to define impairment in class I areas. There are three main target areas for consideration, including:

1. *Unique physical features* important to the class I area (fossil bed, limestone layer, natural arch, high pinnacle, glacial feature).
2. *Visually dominant features* acting as focal points in a view. Features so physically dominant that the eye is drawn to them immediately (a set of arêtes, a waterfall, a high-contrast feature).
3. *Frequency and duration* of a person's exposure to a view. The higher the exposure time, the more important the visual quality.

The Visual Quality Index (in the Forest Service landscape architect or land management planning handbooks) may be helpful in evaluating vistas.

Step 2–Describe Elements of Interest in the Vistas.

The distances and objects of interest in each vista determine its sensitivity to a given input of additional aerosols. In order to apply appropriate criteria to judge potential impairment, the views in each class I area need to be described in terms of the following sensitivity-enhancing properties:

Distance: Greater viewing distances require cleaner air. List all the important or representative views in the class I area, including their viewer-to-target distance and direction.

Coloration: If color of features, such as rock formations, unusual vegetation, etc., is an important element of a vista, it is more sensitive than a view of undifferentiated forest or other "monochromatic" scenes. Describe colorful elements of the vista.

Contrast: Vistas with low internal contrast between scenic elements, or which have light-colored materials with low contrast to the sky are more sensitive than a "typical" forest scene. Describe both internal scene contrast and contrast with the bright sky.

Texture: Texture or fine detail in a scene is lost before the grand features are rendered invisible. If the interest of a vista depends on detail, describe it.

Dominant Forms: The shape of objects in a scene can influence how the human eye perceives them. Note unusual shapes, such as long straight lines, multiple ridge lines, etc.

The purpose of collecting this descriptive information is to address the relative sensitivity of different views. It should be presented in quantitative terms as much as possible. It may be useful to employ existing "systems," such as those developed by landscape architects, to describe some elements. Relate visual elements to significant wilderness resources, and note their sensitivity to visibility degradation.

Step 3–Discuss the Sensitivity of the Vista to Air Pollution.

The sensitivity of each identified physical feature of a vista to air pollution effects varies in relation to its attributes. These impairments can be quantified through monitoring and baseline data analysis. They are characterized as the obscuring of distant targets, color, texture, contrast, and form. The most sensitive of these (with distance as a constant) is texture, closely followed by color. The least sensitive indicator is form.

Step 4–Monitor to Establish Baseline Levels, Trends, and Changes.

The following step-by-step procedure can be used:

A. *Identify threats to visibility:* Monitoring visibility in class I areas can be directed by first considering the actual or perceived threat. This can be judged by using the following initial information.

1. *Location* of the class I area with regard to known sources of air pollution. If the area is in the vicinity of, or a few hundred kilometers downwind from, existing or proposed large point or area sources, the area could be threatened. If the area is relatively remote, the threat could be low.
2. *Nearby data* and data that can be interpolated for the site from existing National Park Service (NPS) and Integrated Monitoring of Protected Visual Environments (IMPROVE), Forest Service, or other data.
3. *Observations* from Forest Service staff and records located at fire lookouts, wilderness ranger stations, and other visits. These data might include notes on layered hazes, plumes, sources of pollutants, duration of impact, time of year, coloration, and frequency of occurrence.
4. *Visitor comments* about their experiences within the wilderness, with comments put in terms similar to those in A.3. above. In addition, expectations and desired conditions can be recorded.

5. *Comparing historical photos* with current conditions. This is largely anecdotal information.
6. *Proposed new sources of pollution.*

B. *Establish baseline:* If no existing or perceived threat exists, monitoring should be directed at establishing current (background) condition. Such monitoring should be sufficient to confirm lack of degradation while establishing a baseline for future threats.

1. *Establish a monitoring site* near the class I area at a similar elevation and predominant wind direction comparable to that in the class I area. The need for line power is not essential but desirable. Data should be collected over at least a 3-year period and be continuous for at least 1 year. Decisions to extend the monitoring period beyond 3 years or into more winter periods should be based on logistics, cost, and the potential threat to visibility.
    a. Photographic analysis should be performed on at least two photos per day at 9 a.m. and 3 p.m. These data should be densitized and qualitatively evaluated as is currently done in the Forest Service Visibility Monitoring Program. An additional photograph at noon is desirable. Only one photograph per day is not recommended because of the known changes in visibility during a day; significant events may well be missed. Multiple pictures per day offer the opportunity to record diurnal changes that occur in many locations.
    b. Personnel who work in the wilderness (such as wilderness rangers and fire lookouts) and provide "airways" type observations (as is done by the National Weather Service and Federal Aviation Administration) should be trained to make visibility observations in order to provide information about visibility and causes of any impairment to visibility outside the camera's field of view, and at times other than the moment the picture is taken.
2. *During the third year*, or sooner if a threat to visibility is observed, a 1- to 3-month intensive effort to collect data should be designed similar to the following configuration.
    a. Continuous optical measurements should be made with either a transmissometer or nephelometer.
    b. Aerosol measurements should be made with a sampler capable of providing haze-causing as well as source-attributing constituents. (The University of California, Davis SMART sampler is recommended, pending the outcome of a current evaluation of this instrument).
    c. Meteorology at the monitoring site at 1-hour intervals to include wind speed and direction, temperature, relative humidity, and precipitation. The length and time of year of the intensive study are site-dependent based on the prior record.

C. *Identify imminent threats:* If the initial assessment of visibility reveals a current or imminent threat, then the following protocol should be followed. It is aimed at identifying the kinds of sources contributing to establishing a baseline condition, as well as aerosol loading. This monitoring scheme should be in place long enough to take mitigating action. Establish a monitoring site at a location that, on the basis of topographical and meteorological analysis, is most likely to capture both views of impairment and also be within the area most affected. Monitoring should be conducted as follows:

1. Analysis of three photos per day plus human observation, as described above.
2. Additional optical measurements as described above.
3. Aerosol sampling should be performed, but the type will depend on the availability of line power and funding.

D. *Aerosol sampling methods (table 18)*: Particle sampling should be designed to allow resolution of the observed visibility degradation to causal factors, and trace aerosols to gas/particulate sources. The period of validation would be based on the prior record and reflect FLMs' concerns. Extension of the monitoring beyond 3 years, or into winter periods, should be evaluated on the basis of logistics, costs, and level of threats. Monitoring degraded and/or threatened sites should be adequate to allow separation of anthropogenic from natural sources.

E. *Validate data:* Aerosol sampling focuses on identifying species most responsible for scattering and absorbing light. Intensive aerosol and optical studies of limited duration should be scheduled every two years to: (1) extend the data set unless it is very complete, and (2) satisfy quality assurance requirements.

F. *Optical monitoring methods:* Inventory and trend analysis should include human, qualitative, semi-quantitative, and quantitative techniques. These include: (1) photographs (two or three times per day), (2) human observer (events not in camera range, clouds, etc.), and (3) battery- or solar- powered transmissometer (first choice), or nephelometer (second choice).

G. *Other considerations:* A number of other factors should be considered, including the following points:

1. *Quality assurance (QA) and control (QC).* The Forest Service should utilize EPA-reviewed QA/QC procedures. QC procedures have been prepared for camera monitoring; no QA procedures are known to exist.
2. *Nighttime visibility* is recognized as a valuable wilderness experience to be protected in some class I areas. Recommendations for monitoring at night do not include photography. A photometer and lens may be used at the camera site for vertical measurements of the darkness of the sky. Further investigation of this issue is warranted.
3. *Permanent storage.* It is recommended that selected baseline photographs be digitized. The data will probably be least perishable on optical discs. Such data should represent a range of the baseline condition.

Table 18—*Potential aerosol sampling systems (annual operating costs are based on 102 samples).*[1]

System	Features	Capital cost / operating cost	Power source
SMART	2 size ranges (0.3-2.5 µm, 2.5-10 µm); continuous sampling of S, trace elements and soot; 1-4 weeks unattended	$4500 / $65 for 24-hr sample	B/S
IMPROVE (full)	2 size ranges (<2.5 µm, <10 µm); flexible sampling period; sulfate, nitrate, organic C, trace elements; 4 channels	$16,000 / $12,000 annually	LP
IMPROVE (fines only)	Same as full IMPROVE except no PM10; 3 channels	$11,000 / $8500 annually	LP
IMPROVE (NESCAUM)	Same as full IMPROVE except no PM10, nitrate or C; only fine mass, including trace elements	$2000 / $3500 annually	LP
PM10	Mass < 10 µm; elemental analysis (influenced by soil)	$1500 / $3500 annually	LP

[1] LP = line power
B/S = battery / solar
S = sulfur
C = carbon
IMPROVE = Integrated Monitoring of Protected Visual Environments
NESCAUM = Northeast States for Coordinated Air Use Management
PM10 = Particle mass < 10 µm

4. *A nephelometer* capable of operating without line power and in a remote setting unattended for days at a time is now available. The workshop participants recommended that the Forest Service evaluate the usefulness of this device. Nephelometers are lower cost, continuous sampling instruments that avoid some of the problems of transmissometers and cameras. For example, clouds do not obscure the data, although techniques for accounting for moisture and internal instrument heating are necessary. Alignment on targets is also not an issue, although some operator experience is helpful.

H. *Individual site characteristics*: Finally, although substitute techniques for camera monitoring have been addressed here, a monitoring program should be tailored for each site to account for differing topography, resource and logistic issues, and real or perceived threats. Visibility measurements should be designed for their usefulness in addressing management problems at the class I area in question rather than to fit in spatially or temporally with a network of monitoring sites.

Step 5–Predict the Effect of Projected Additional Loadings.

This step provides a process for the manager to quickly screen the potential visibility impacts of an increase in suspended particle levels, expressed as a percentage of the allowable PSD increment. Given the detailed, vista-specific information developed as described above, a series of calculations are performed for each vista and line-of-sight that gives the estimated contrast change for several levels of increased particulate pollution. These calculations are performed beforehand and are summarized in a visibility impairment table (VIT) (see *figure 4*). An explanation of the use of the VIT and an outline of calculation procedures are provided in the example below.

A. *Visibility impairment table (VIT):* When confronted with a PSD permit, the FLM will consult a notebook that contains the description of the vistas and views and a VIT for each one. The PSD permit will usually include an estimate of the increment in total suspended particulates (TSP) in the class I area. Expressing TSP as a fraction of the total PSD increment, the FLM will look up the expected contrast change for each vista. Guidance is provided below on how to interpret these numbers in terms of changes perceptible to humans. The manager will then use personal judgment and knowledge of the area to determine whether the reduction in contrast is significant. The next section describes how the VIT calculations are made.

B. *Estimating visibility "loading":* The PSD "increments" address particles as TSP. Unfortunately, TSP is a very poor index of visual air quality. Correlations between TSP and visibility are inherently weak because the larger particles dominate TSP mass measurements, and the smaller particles dominate the optical effects. In addition, the small mass increments of fine particles needed to degrade visibility in "clean" wilderness locations are not likely to be noticed within the inherently large variability of TSP measurements. The following analysis addresses primarily the particles less than 2.5 µm in diameter (PM 2.5).

1. *Estimating baseline light extinction.*
   a. Use direct optical measurements if they are available. If photographic records are available, use cal-

culated extinction derived from contrast measurements, but be cautious that these calculations do not violate the assumptions on which they are based.

b. Use particle data, if no optical data are available. These will generally need to be interpolated from the regional data from the IMPROVE network. Calculate the extinction from the PM 2.5 estimated mass by applying either known values for each chemical component or the generic extinction efficiency (ε_E) value of 3 m^2/g. Total extinction is the particle value plus the light scattering due to air at the altitude of the class I area. If baseline aerosol composition is likely to include an unusually large amount of coarse particles, apply the extinction efficiency of 0.7 m^2/g to correct for the effect of coarse particles.

2. *Light extinction due to the predicted pollutant increment.* This should be calculated either by using known properties of its constituent chemicals, or by applying the generic urban industrial fine aerosol extinction efficiency of 5 m^2/g. Total extinction under the predicted increment is the sum of the total baseline plus the increment extinction.

3. *Atmospherical optical calculations of the VIT* (Henry 1977).

Given the extinction efficiency ε_E (see above) and an ambient concentration of particulate χ (mg/m^3), the extinction coefficient β (m^{-1}) can be calculated as:

$$\beta = \varepsilon_E \chi .$$

Assuming that absorption is the principal cause of signal attenuation (visibility reduction), the contrast of details in a vista (C_d) can be calculated as:

$$C_d = C_h e^{\beta R}$$

where C_h is the measured contrast of a dark target against the background sky, and R is the distance from the viewer to the target.

C. *Interpretation of the VIT:* The contrast changes from the VIT must be understood in terms of human perception of changes in the vista. Depending on the vista and the feature of interest, there are two ways of interpreting the contrast change numbers from the VIT. In the one case, an FLM may wish to know whether there is a noticeable change in the scene. In the other case, one would wish to know whether a feature will be visible or not. Each of these cases is discussed below.

1. *Just noticeable differences (JNDs).* As particles are added to the atmosphere, at some point the observer will notice a change in the clarity of the scene. This level is one JND (Carlson and Cohen 1978). As particles continue to be added, a level will be reached at which another change is just noticeable. This is two JNDs, and so on. *Figure 3* is the result of applying a rather complex model of the human visual system, and presents a relationship between contrast change and the number of JNDs in the scene (Henry 1979). Also included in the figure is a suggested interpretation of the meaning of the JNDs. The three different lines in *fig. 3* are the result of using three different values for a technical parameter in the model which is not easily estimated at this time. This figure will be updated as research into human perception of visibility degradation progresses.

2. *Visibility of landscape features. Table 19* gives the threshold contrast of various sizes of features. The VIT can be used to estimate whether the contrast threshold has been reached. The contrast change is subtracted from the baseline contrast. The FLM then refers to the table to estimate the contrast threshold for the particular feature of interest.

Example Application: Visibility AQRV for Desolation Wilderness

The five-step process described above is illustrated in *fig. 4* with an example for Desolation Wilderness.

Nighttime Visibility as an AQRV

The process for managing visibility in class I areas (*fig. 4*) deals implicitly with daytime visibility. The visibility workgroup reasoned, however, that nighttime visibility is sufficiently different and valuable that it should be treated as a separate AQRV. Views for nighttime visibility are defined as vertical and panoramic sights of the night sky. Several potential impacts of air pollutants are: (1) loss of light or extinction that would reduce the number of, or obscure, visible stars and planets, (2) source light diffusion that would decrease the intensity of light visible from stars and planets, (3) increased night sky brightness due to increased light sources in and around the viewing area, and (4) increased diffusion of light through the air mass that would reduce both light intensity and number of stars and planets visible in the dark night sky.

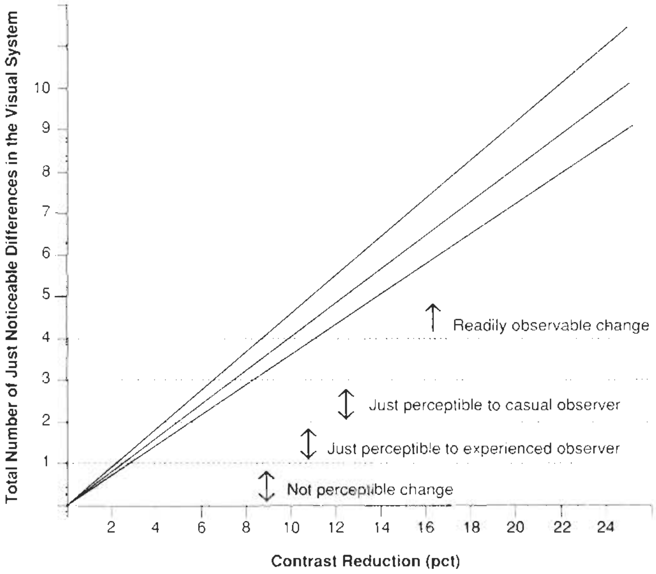

Figure 3—Predicted number of just noticeable differences vs. contrast reduction for three values of the equivalent sine-wave contrast of visual detail in a scenic vista (from Henry 1979).

Table 19—*Visual range of contrast detail, indicating threshold contrast for various sizes of landscape features (from Carlson and Cohen 1978).*

Detail of level	Characteristics size at 10 km	Examples for a hillside at 10 km	Visual range West (V_R=100 km)[1]	Visual range East (V_R=20 km)[1]	Contrast threshold
	m		*km*	*km*	
Very coarse (form)	> 100 (>0.57° arc)	Hills, valleys, ridgelines	79	16	-0.046
Coarse (line)	50-100 (0.29°-0.57° arc)	Cliff faces, smaller valleys	76	15	-0.052
Medium (texture)	25-50 (0.14°-0.29° arc)	Clumps of large vegetation, clearings on forested slopes	62	12	-0.089
Fine (texture)	< 25 (<0.14° arc)	Individual large trees, clumps of small vegetation	22	4	-0.424

[1] V_R is the assumed background visual range.

Principal viewers include professional astronomers at observatories, amateur astronomers, campers and hikers, professional and amateur photographers, and personnel at military installations. Viewers' objectives for nighttime observations differ, and perceptions of night visibility may vary.

The first three steps of the five-step process described above for day visibility can also be applied to night visibility. Steps 4 and 5, monitoring and prediction, need to be handled differently because of inherent differences in nighttime viewing.

Establishing Baseline Conditions

Collection of primary data to determine existing conditions should include viewer observations and photographs. These are necessary to establish extent and value of the dark sky view. Still or video photographs of horizontal and vertical views of the night sky should also be collected. Light scattering can be estimated from the photographs.

Viewer observations can be acquired by oral interviews or from written observations of personnel who work in the wilderness. Documentation can include interview sheets, visibility logs, and photographs. The visibility log should include date, time, location of viewer, and subjective observations of the visibility conditions of the night sky. Some viewing areas will be less sensitive because of differences in elevation, slope, or accessibility. Photographs should be correlated with oral interview results.

Observation of selected stars that can be recognized in the field can be repeated to track visibility over time. This information should be recorded on visibility log sheets. Extinction of visible stars in the Milky Way should be evaluated by observers and recorded in the visibility log. At least one calendar year of observations is needed to establish baseline nighttime visibility of the Milky Way because of the rotation of the earth and variation in weather conditions. Observers need adequate training to assure consistency in observations. Photographs can track both visibility of the stars and increases in light diffusion in the night sky. Stars that are part of or near constellations are more desirable for field observations. Local astronomers can be consulted to assess photographs and verify observations.

In areas where sensitivity and concern for existing conditions are high, correlation of systematic particle sampling, optical characterization, and paired horizontal-vertical photographs from established monitoring sites can be used to establish the existing condition and to provide sufficient data for modeling pristine and baseline night-sky conditions. After baseline conditions are established, periodic monitoring should be continued and data stored for long-term comparison.

Determining Source Impacts

Stars are the most distinguishing feature of the night sky, and their visibility extinction can be used to measure impacts on visibility from air pollutants. A decrease in star magnitude from 6 to 7 should be evaluated both by observation of selected magnitude 6 stars and by photographic record. Magnitude 6 stars are a sensitive receptor because they are barely visible with the naked eye, and source light diffusion could cause them to be invisible in the night sky. The following guidelines can be used to verify impacts:

(1) A decrease in star magnitude from 6 to 7 as the indicator of source light diffusion effects.

(2) Visibility extinction of 50 percent of the visible stars in the Milky Way as the indicator of loss of light in a dark night sky.

(3) Inability to capture magnitude 6 stars on photographs with enough clarity to identify the star with the naked eye as the indicator of increased night sky brightness.

Figure 4—Application of the five-step visibility process is illustrated with an example for Desolation Wilderness.

STEP 1 SENSITIVE VISTAS

Include a photo of receptor from the proposed monitoring site (with date on back).

Date: 06/19/92
Time: 10:05 a.m.
Photographer / observer: Jane Sharpeyes
Location of photo site (by Universal Transverse Mercator [UTM] coordinates, elevation [m]): 4314500 m North, 738800 m East; 2767 m
Location of receptor (by UTM coordinates, elevation [m]): 4314500 m North, 728700 m East; 2757 m
Line of sight distance: 10.1 km
Weather: wind speed 7 m/sec, temperature 15 °C, relative humidity 30 percent, high cirrus clouds, no haze

PHOTO

***RECEPTOR ATTRIBUTES**:* Give a brief description.

Unique Feature
A Focal Point
Long Exposure Time

continues

***Figure 4**, continued*

STEP 2 ELEMENTS OF INTEREST IN THE SCENE

Color:	Describe hues by color chart against background color. (For example, "top portion dark gray with red bands 100 m wide, low portion uniform light gray").
Contrast:	Select either a bright area or a dark area. (For example, "contrast of dark metamorphic rocks over light granitic rocks").
Texture:	Select fine, medium, or coarse.
Form:	Select conical, pyramid, dome, or jagged ridge. (For example, "rough, jagged upper surface and smooth, rounded lower surface").

STEP 3 HOW THE VISTA CAN BE AFFECTED BY AIR POLLUTION

Give a brief description of the effect of air pollution on the scene. For example:

1. Additional path radiance will remove the vividness of the red bands on the side of Mt. McConnell, making them more gray.
2. Additional particulate pollutant loading will reduce the contrast within the scene as presented in the visual impairment table (Step 5).

STEP 4 ESTABLISH A MONITORING STRATEGY

No new-source applications are pending, but there is concern about the effect of the Sacramento Valley area source of pollution. In addition, growth in the Tahoe Basin poses a threat because Basin aerometric samplers show high ambient concentrations of ozone. Particulate loadings will also probably increase.

Vista A is a point outside the Wilderness looking across much of the Wilderness that is at the average elevation and downwind. There is power at a site about 1 km away and 150 m lower. The site is readily accessible 9 months out of the year. Budget = $10,000/yr. The following strategy is therefore suggested:

Year 1 (1) Purchase one camera and take three photos per day for the 9-month accessible period and one photo per day at noon during the remaining period. Hire a temporary employee to change film and filter in years 2 and 3. Capital cost = $ 2500. Operating Cost = $4500. Labor cost = $1000.

(2) Train Wilderness Rangers to record one routine observation per day from a prominent or frequently visited part of the Wilderness and to make

a "special" observation if they notice a visibility impairment. Camera site operators should also be trained to make such an observation at the time the film is changed. Training cost = \$100.

(3) Purchase and begin operating, but do not analyze data from, one SMART particle sampler. Capital cost = \$2000.

Year 2, 3 (1) Continue with camera schedule. Operating cost = \$4500. Labor cost = \$1000.

(2) Continue observation by trained personnel. No extra cost.

(3) Continue to operate particle sampler. Analyze data for 1.5 years. Analysis cost = \$3000 x 1.5 yr = \$4500.

(4) At end of year 3, analyze data to determine actual impacts (compared to those predicted at project start). Based on results, assess strategy for future monitoring and mitigation.

STEP 5 EFFECT OF PROJECTED ADDITIONAL LOADINGS

The Forest Supervisor has determined from reviewing the data collected in Step 4 that a 2 percent change in the baseline contrast measurement (one JND from *fig. 3*) is unacceptable. The contrast threshold for coarse features (-0.052 from *table 19*) is exceeded by a substantial amount at all percentages of this increment (*see visual impairment table below*), so the target should be easily visible to the viewer. A new source is predicted to contribute 25 percent of the TSP class I annual increment (5 $\mu g/m^3$) to both sensitive views. McConnell Peak would experience a 5 percent contrast change against the background sky, while "Red Bands" along the escarpment would experience a 1.7 percent contrast change (*see visual impairment table below*). Thus, the criterion value of 2 percent is exceeded for one case. With no additional information, the FLM would probably recommend denial of the application.

A sample visual impairment table for McConnell Peak (Desolation Wilderness), showing the effect of additional particulate loading on contrast reduction.

	McConnell Peak		McConnell Peak (Red Bands)	
Percent of PSD increment[1]	Contrast	Contrast change	Contrast	Contrast change
0	-0.444	0.000	-0.148	0.000
10	-0.423	0.022	-0.141	0.007
25	-0.392	0.052	-0.131	0.017
50	-0.346	0.098	-0.115	0.033
75	-0.307	0.137	-0.102	0.046
100	-0.267	0.175	-0.090	0.058

[1] PSD = prevention of significant deterioration.

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