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A Screening Procedure to Evaluate Air Pollution Effects in Region 1 Wilderness Areas, 1991

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Abstract

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Based on mandates contained in the 1977 and 1990 Clean Air Act amendments (Public Law 95-95) and the 1964 Wilderness Act (Public Law 88-557), 25 scientists and 15 managers discussed approaches for evaluating air pollution effects on aquatic, terrestrial, and visibility resources in wilderness areas administered by Region 1 of the Forest Service. Participants identified screening parameters that may predictably vary with changes in air quality. Criteria for those parameters were identified for assessing permit applications involving new emissions that may impact wilderness values. Region 1 participation in the multi-agency process for evaluating proposed emissions would require a monitoring program, effective analysis methodology, and proactive review and consultation.

Keywords: air pollution, wilderness, acid neutralizing capacity

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Cover photo: Mission Mountains Wilderness

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Acronyms

ABW	Absaroka-Beartooth Wilderness
ANC	Acid Neutralizing Capacity
AQRV	Air Quality Related Values
BMW	Bob Marshall Wilderness
CALK	Calculated Alkalinity
DOC	Dissolved Organic Carbon
EPA	Environmental Protection Agency
GIS	Geographic Information System
IMPROVE	Interagency Monitoring of Protected Visual Environments
LAC	Limits of Acceptable Change
MAGIC	Model of Acidification of Groundwater In Catchments
MDFWP	Montana Department of Fish, Wildlife and Parks
N	Nitrogen
NADP	National Atmospheric Deposition Program
NAPAP	National Acid Precipitation Assessment Program
NTN	National Trends Network
P	Phosphorus
PSD	Prevention of Significant Deterioration
SAA	Sum of Acid Anions
SBC	Sum of Base Cations
SBW	Selway-Bitterroot Wilderness
SIP	State Implementation Plan
SVR	Standard Visual Range
USGS	United States Geological Survey

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Introduction

The 1977 Clean Air Act amendments reinforced by the 1990 amendments gave the Forest Service the "affirmative responsibility" to protect air quality related values (AQRVs) of certain wilderness areas from adverse air pollution effects. The Forest Service must recommend to the appropriate air regulatory agencies, usually the state, whether a proposed emission source will have adverse impacts on wilderness resources. The air regulatory agency considers the recommendation before permitting the proposed source to discharge pollutants. The objective of the process, examined herein, is the prevention of significant deterioration of air quality within Class I and other wilderness areas of Region 1 as mandated by the Clean Air Act.

Air pollution sources from outside wilderness boundaries are pervasive and impacts are difficult to quantify. Little is known about how air pollutants may impact wilderness resources. What resources broadly characterize the wilderness setting in the context of air quality? How should they be monitored to detect effects of deteriorating air quality? Are impacts occurring now that complicate a state's assessment of permit applications for new emissions? We need answers to such questions to be an effective partner in judging emission permit applications.

Therefore, workshops were held in each Forest Service Region to help define resources or air quality related values that could be impacted by air pollution (e.g., Adams et al. 1991, Peterson et al. 1992). Workshops were patterned after a national workshop that brought together scientists and forest managers in round table discussions (Fox et al. 1989).

The Region 1 workshop was held at the Flathead Lake Biological Station from April 29 through May 2, 1991.[1] Three working groups (Appendix A) considered aquatic, terrestrial, and visibility resources in the context of permitting processes mandated by the federal Clean Air Act. Each working group attempted to determine the resources sensitive to air pollutants, thresholds, or criteria that would demonstrate adverse impacts. Each one also discussed monitoring and research needs. In compliance with the federal Advisory Committee Act, the groups did not strive for consensus but to provide options to managers that would move the Region toward meeting the goals of the Clean Air Act. This document integrates reports produced by these groups during and after the workshop.

Key Terms and Definitions

To clearly understand the permitting process and the results of the workshop, important terms that describe impacts of changing air quality on wilderness resources were defined. A list of acronyms appears after the Contents page.

Class I areas—all international parks, national parks greater than 6,000 acres, and national wilderness areas greater than 5,000 acres that existed on August 7, 1977 (when the Clean Air Act amendments were passed). This Class provides the most protection to pristine lands by severely limiting the amount of additional air pollution that can be added to these areas. The seven Class I areas administered by Region 1 (figure 1) are:

Wilderness	Forest(s)
Anaconda-Pintler	Bitterroot, Beaverhead, Deerlodge
Mission Mountains	Flathead
Selway-Bitterroot	Bitterroot, Clearwater, Nez Perce
Cabinet Mountains	Kootenai
Scapegoat	Helena, Lewis & Clark, Lolo
Gates of the Mountains	Helena
Bob Marshall	Flathead, Lewis & Clark

Class II areas—all Forest Service lands that are not designated Class I are referred to as Class II lands (figure 1). This includes the wilderness areas: Gospel Hump, Welcome Creek, Lee Metcalf, Great Bear, Absaroka-Beartooth, Rattlesnake, and Frank Church-River of No Return. A greater amount of additional air pollution may be allowed within Class II areas.

Prevention of significant deterioration (PSD)—a permitting process described under Part C, Section 160 of the Clean Air Act. Goals of the program include: preserving and protecting air quality in national parks and wilderness areas; assuring that emissions in a state will not interfere with the prevention of significant deterioration of air quality; and assuring that any decision to permit increased air pollution is made only after careful evaluation of all the consequences and after informed public participation.

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[1] *This document captures the conversations and conclusions of this 1991 workshop. With few exceptions, it does not incorporate changes in air quality regulations or science occurring since that time.*

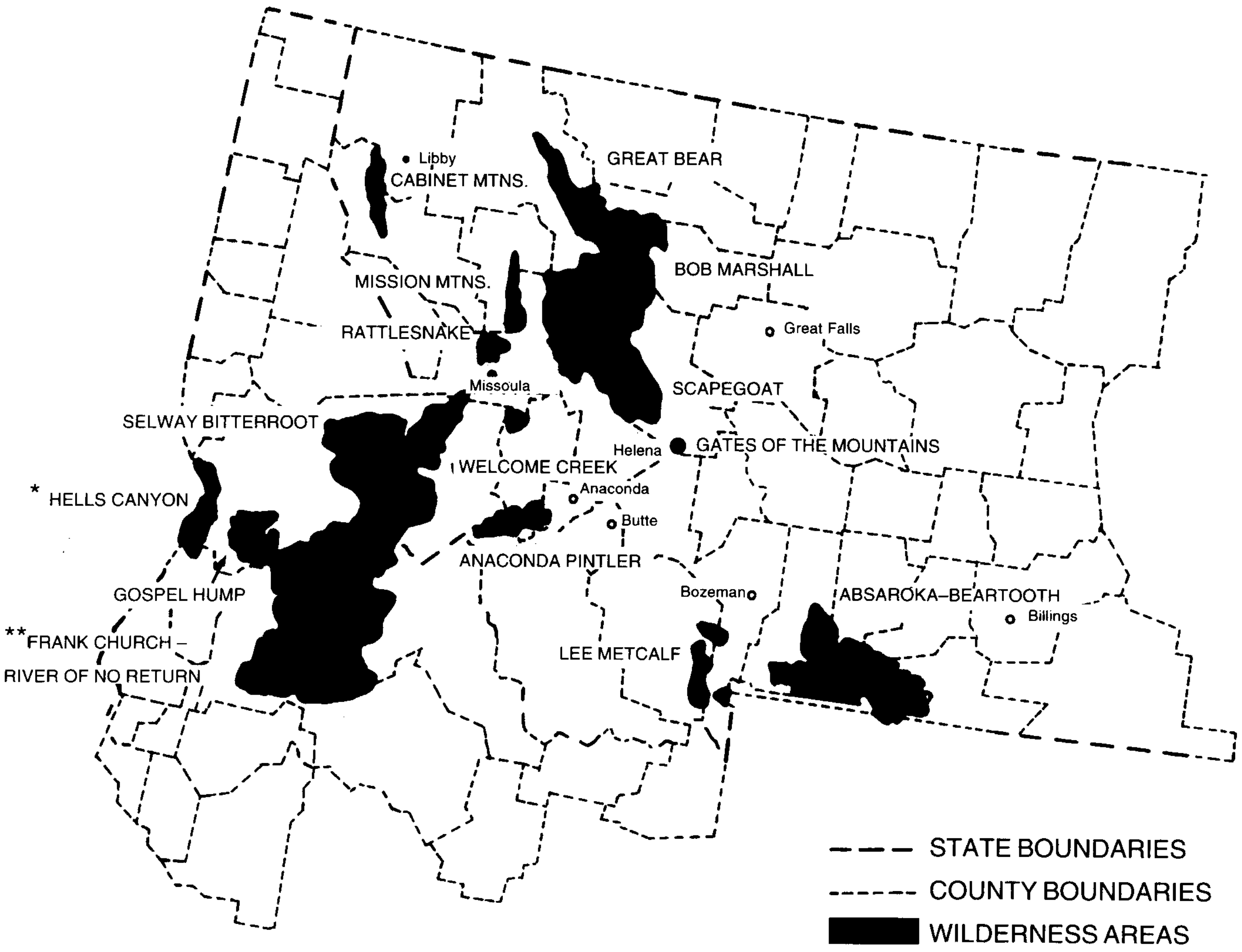

*Figure 1. Wilderness areas administered by the Forest Service in Region 1 (from Saunders, G. 1991). *Hells Canyon is administered by Region 6. **The Frank Church and portions of the River of No Return are administered by Region 4.*

Air quality related values (AQRVs)—the features or properties of a Class I wilderness that made the area worthy of designation as a wilderness area and that would or could be adversely affected by air pollution. Examples of adverse effects are degraded visibility or impaired biological populations. AQRVs generally relate to visibility, odor, flora, fauna, soil, water, climate, geological features, and cultural resources. AQRVs are specific and described differently, however, for each Region 1 wilderness (Appendix B).

Sensitive receptor—a wilderness component clearly related to an AQRV. For example, an individual lake or stream may serve as a sensitive receptor indicating the overall health of lakes or streams in the wilderness.

Baseline conditions—The chemical and biological status of an AQRV or receptor as determined on the date of first measurement or quantification. Baseline conditions are not necessarily pristine.

Screening parameters—variables used to compare conditions in different ecosystems. For example, acid neutralizing capacity or specific conductance are measures used to characterize the status of water bodies relative to pollution loads.

Screening criteria—measures of sensitivity to change or critical thresholds for screening parameters. For example, extremely low specific conductance in lake water could indicate potential sensitivity to acidification. Critical conditions could be indicated by very low or high pH. Quantification of criteria requires quality-assured methodology, often using experiments to determine dose-response relations.

Dose-response relations—the assumption that a subject's response to a new compound (chemical) will intensify in a predictable way as the dose or level of exposure increases.

Limits of acceptable change (LAC)—the amount of change that could occur without significantly changing an AQRV or receptor. For example, the aquatic working group identified a change in the sulfate load that could be tolerated in lakes without a deleterious effect on sensitive receptors.

The relationship between AQRVs, sensitive receptors, screening parameters, screening criteria, and limits of acceptable change are examined hierarchically, as shown below:

Wilderness Area: Bob Marshall

AQRV: aquatic ecosystems

  sensitive receptor: Lena Lake

    screening parameter: Acid Neutralizing Capacity

      screening criteria: ANC < 100 µeq/l

        LAC: cumulative change in ANC < 10%

The Regulatory Process

Prevention of Significant Deterioration

Class I Wilderness Areas

The current PSD process requires a permit application be submitted to the appropriate state air quality agency whenever a new source of air pollution is proposed or if modification of operations at an existing source are expected to emit a certain kind and amount of air pollution. In Region 1 the appropriate state air quality agency is expected to notify the Regional Forester of a permit application if the proposed new emissions may have an impact on a Class I wilderness area. A state generally has 30 days to inform the owner or operator of the source whether or not their application is complete. The Regional Forester submits comments to the state regarding the completeness of the application within this 30-day period.

Once an application is complete, an air quality agency has a specified number of days in which they must approve, modify, or deny the permit. This time frame varies between agencies but is generally 40 to 60 days. During this time the Forest Service evaluates the expected impacts to AQRVs and ecosystems from the added pollution identified in the permit application and recommends to the air quality agency appropriate action to protect AQRVs and ecosystems. Recommendations are based on information such as baseline air and water quality conditions, impacts of new emissions to the PSD increments, and modeling and discussion of potential emissions movement, deposition, and effects.

If the Forest Service determines that the impacts to AQRVs are not adverse, it recommends to the state that the permit be issued. If impacts are unclear, it recommends mitigation or requests more information from the applicant. The Forest Service recommends emission reduction alternatives or denial of the permit if the impacts are clearly adverse.

Class II Wilderness Areas

Class II wilderness areas in Region 1 contain many of the same features and properties as Class I areas. However, the Forest Service does not have the affirmative responsibility "tool" to protect resources from air pollution in Class II wilderness areas as it does in Class I. In this case, the state determines whether to require the PSD applicant to include analysis of effects on wilderness values. However, the Forest Service may provide information and review loading estimates for sulfur dioxide, nitrogen oxides, ozone particulates, best available control technology, and emissions compliance to National Ambient Air Quality Standards.

Non-PSD Permits

The states may require non-PSD permits for stationary emission sources greater than some specified emission level (e.g., 25 tons/year in Montana) but less than the emissions level that would require a PSD permit. The requirements for these permits are guided by the State Implementation Plan and involve some regulatory constraints such as New Source Performance Standards, other control technology, or emission limitations. Forest Service participation in evaluation of non-PSD permits is on a consultant basis and requires effective and proactive information sharing with the state.

Other Legal Requirements

In addition to the Clean Air Act, the Forest Service has other legal requirements that directly refer to air resource management of National Forests: the Forest and Rangeland Renewable Resources Act of 1974 (16 U.S.C. 1601), as amended by the National Forest Management Act (16 U.S.C. 1602), and the Federal Land Management Policy Act of 1976 (43 U.S.C. 1701). These acts and subsequent rules and regulations provide a mandate to protect and improve the quality of the air resource on National Forests and to manage public lands in a manner that protects air quality and atmospheric values. In addition, the 1964 Wilderness Act (and subsequent acts designating individual wilderness areas) was enacted to preserve wilderness resources and character. The Wilderness Act requires the Forest Service to minimize the effects of human use or influence on natural ecological processes and preserve "untrammeled" natural conditions within wildernesses. Therefore, the Forest Service should minimize the effects of air pollution on wilderness areas regardless of Class I or Class II designation.

Workshop Goals and Objectives

Region 1 developed two primary goals and a set of objectives before the workshop. The goals were: 1) to discuss facts and information as a basis for evaluating potential adverse effects of air pollution on wilderness resources and 2) to recommend actions for responding to future PSD permit applications. To achieve these goals, each working group identified and addressed a set of objectives:

1. Review and discuss outcomes of previous Regional screening workshops;
2. Identify screening parameters;
3. Develop screening criteria for the parameters identified in objective 2 and discuss limits of acceptable change;
4. Recommend models or modeling approaches for assessing air pollution impacts on screening parameters;
5. Identify research and monitoring needs to evaluate impacts of changing air quality on screening parameters; and
6. Propose alternative management actions to anticipate or detect adverse impacts to aquatic ecosystems resulting from air pollution.

Aquatic Resources

Background Information

The northern Rocky Mountains contain many important aquatic resources located within federally designated wilderness areas. Class I areas contain 773 lakes and Class II areas contain 976 lakes. These lakes are contained within a vast network of wetlands, streams, and rivers.

An important quantitative assessment of water quality within the western United States was developed from the Western Lakes Survey conducted by the U.S. EPA (Landers et al. 1987, Eilers et al. 1988). This survey was conducted in fall 1985 and it covered the major mountain ranges in the western United States, including the Sierra Nevada, the Cascade Range, and the Rocky Mountains. In the northern Rockies 143 lakes were sampled. An additional 18 lakes in Montana were sampled as part of the central Rockies subregion (Landers et al. 1987).

Many of the lakes sampled by the Western Lakes Survey were characterized as dilute (Eilers et al. 1988). Concentrations of most major ions, including base cations, were generally lower than in areas sampled in fall 1984 by the Eastern Lake Survey in the eastern United States (Linthurst et al. 1986). Comparisons of survey results from the eastern and western United States are given in Landers et al. (1987) and in Baker et al. (1990).

Compared with other areas in the western United States, the northern Rocky Mountains had the second lowest percentage of lakes (50.7%) with acid neutralizing capacity (ANC) < 200 µeq/l and few lakes had ANC < 50 µeq/l. There was a broad range of ANC values found in the northern Rockies. Explanations for these differences and an evaluation of the pattern of ANC concentrations in the western United States are given in Eilers et al. (1987a). Variance estimates for chemical variables were reported by Landers et al. (1987) and Eilers et al. (1987b).

Chemical assessments were made for lakes in specific geomorphic units within the various subregions of the Western Lakes Survey, including the northern and central Rockies (figure 2). Similar evaluations also were made for all lakes located in wilderness areas and for individual wilderness areas (Eilers et al. 1989). Two geomorphic units in the northern Rockies, the Idaho Batholith and the Bitterroot Range, had lakes with generally lower values of ANC and specific conductance than did the other areas within the northern Rockies (table 1). These areas are of particular interest in the evaluation of AQRVs in Region 1.

Because of the Western Lakes Survey design, relatively few lakes were sampled in some geomorphic units; for example, only 12 lakes were sampled in the Anaconda-Pintler Mountains. Similarly, within individual wilderness areas, the number of lakes sampled generally was not large. Consequently, estimates of chemical characteristics for specific wilderness areas yielded large confidence limits. Reasonable precision among the data was obtained only in the Selway-Bitterroot (31 lakes) and the Absaroka-Beartooth (15 lakes). The total number of lakes sampled in wilderness areas in northwestern Montana was particularly low: one in Great Bear and none in the Bob Marshall or the Scapegoat Wilderness Areas. However, few lakes exist within the Great Bear/Bob Marshall/Scapegoat wilderness complex. Stanford et al. (1990a and Ellis et al. 1992) studied the most dilute lakes in the areas.

Based on data from the Western Lakes Survey, the lowest ANC values in Region 1 were reported from the Selway-Bitterroot, Absaroka-Beartooth, Gospel Hump, and Frank Church-River of No Return Wilderness Areas. Values ranged from 11 to 324 µeq/l and specific conductance varied from 4.5 to 30.5 micro Siemans/centimeter (µS/cm) in the Selway-Bitterroot. The Bitterroot Range had the third lowest median ANC among geomorphic units in the Western Lakes Survey. Chemistry was relatively uniform for lakes located on the Boulder Batholith. Within the

Table 1. Minimum (and mean for selected areas) values of base cation, alkalinity, sulfate, and specific conductance (conductivity) for selected lakes in wilderness areas of Region 1 of the Forest Service[a]. Data are from the Western Lakes Survey (Eilers et al. 1987b, Landers et al. 1987). Units are in μeq/l, except specific conductance (μS cm^{-1}).

Wilderness	Lakes sampled	Number of cations	Base alkalinity	Sulfate	Specific conductance
Selway-Bitterroot	31	26(86)	19(70)	3(11)	3(9)
Absaroka-Beartooth	15	64(142)	37(107)	9(24)	7(14)
Anaconda-Pintler	2	149	123	17	14
Mission Mountains	2	387	360	8	36
Rattlesnake	2	78	72	8	8
Lee Metcalf	1	361	288	31	35
Cabinet Mountains	1	292	265	22	28
Great Bear	1	1393	1388	20	134

[a] *Data for lakes in Glacier National Park, which is managed by the National Park Service, are not presented here; however, lakes in the Park have comparable chemistry (Ellis et al. 1986, 1987, 1988, 1989, 1990, 1991).*

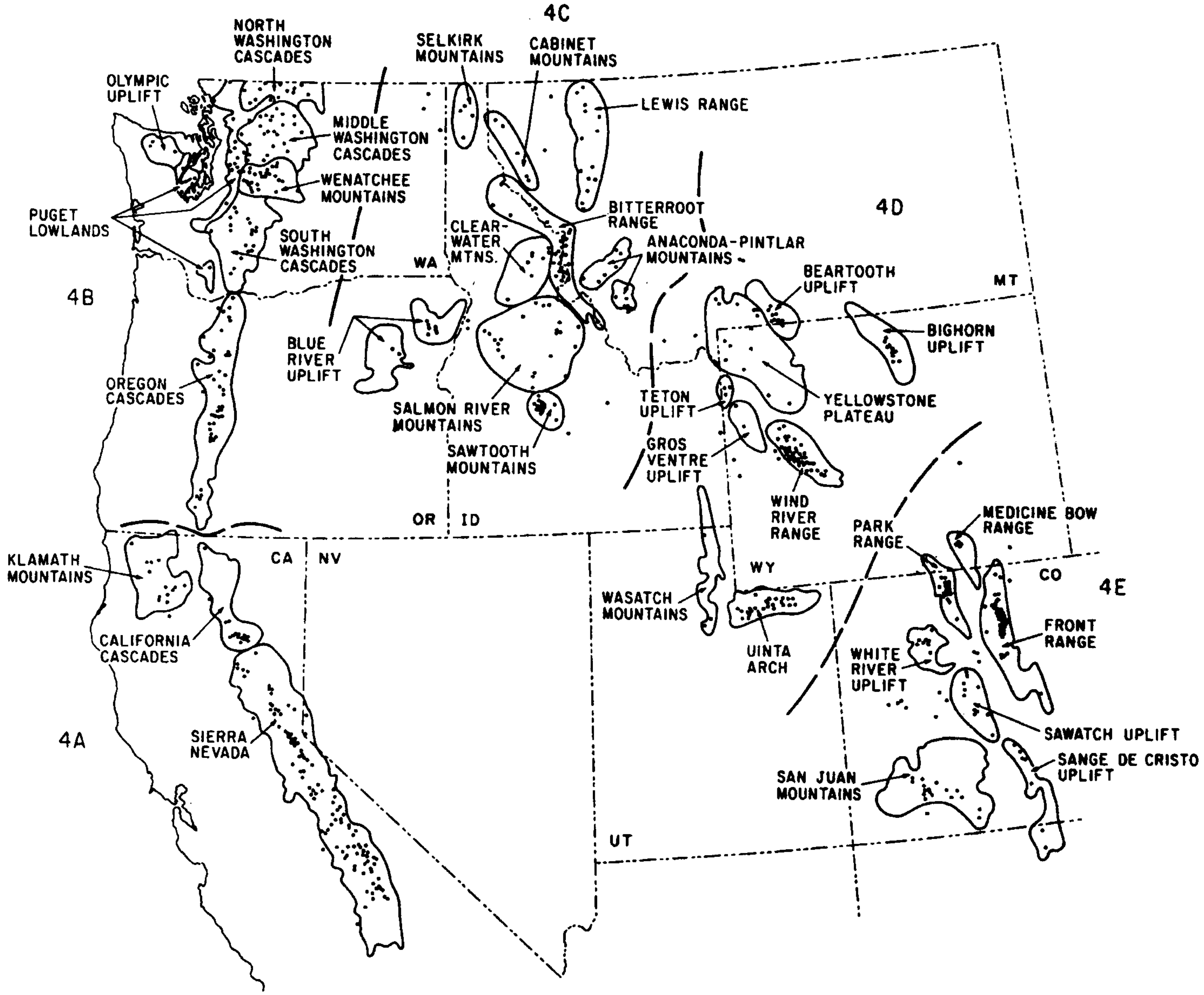

Figure 2. Geomorphic units and lakes sampled in the Western Lakes Survey (from Landers et al. 1987).

River of No Return, ANC ranged from 70 to 90 µeq/l, whereas in the Gospel Hump values ranged from 24 to 235 µeq/l. The Absaroka-Beartooth Wilderness Area is underlain by Precambrian granites and other hard crystalline rocks and contains the largest number of alpine lakes in Region 1. ANC values ranged from 31 to 170 µeq/l (Eilers et al. 1987b, Landers et al. 1987).

For each of the subregions in the Western Lakes Survey, wilderness lakes had lower concentrations of ANC and base cations than did non-wilderness lakes. Wilderness lakes also tended to have lower concentrations of sulfate and dissolved organic carbon (DOC) (Eilers et al. 1989). Additional information on lake chemistry has been collected by Montana State University (Pagenkopf 1982), and the Forest Service (Story 1993). Most of the information covers the period since the late 1970's.

Four wilderness areas contain lakes that had ANC generally 200 µeq/l. These areas include the Anaconda-Pintler, Cabinet Mountains, Hells Canyon, and Rattlesnake Wilderness. The Bob Marshall and the Great Bear generally had lakes with high ANC concentrations. The average ANC was 811 µeq/l for lakes in the Bob Marshall and 1376 µeq/l in the Great Bear.

Many lakes in the western United States are dilute and have low concentrations of base cations and most other variables. Increasing atmospheric deposition of pollutants can potentially degrade these systems (Cosby et al. 1985). The primary concern is for changes in surface water chemistry that would impact the biota that characterize the pristine nature of wilderness areas. The aquatics working group evaluated various scenarios that might change the nature and chemistry of atmospheric deposition in Region 1.

Working Group Approach

There is not enough data on aquatic biota in the northern Rockies to assess their potential response to changes in chemical conditions resulting from changes in air quality. Moreover, should protection of a water body be based on all or many species, or only key species such as sport fish or rare amphibians, or on a more integrative measure of ecosystem function? A variety of potentially interactive stresses may result from the cumulative impacts of different pollution sources. This is particularly problematic with respect to evaluation of PSD impacts.

Therefore, the aquatics working group decided that screening parameters should be

1. Measurable;
2. Detectable;
3. Precise;
4. Sensitive to change;
5. Related to a particular AQRV or pollutant;
6. Biologically relevant (whenever possible);
7. Widespread (that is, a variable that describes conditions and can be measured in all water bodies of interest) or, alternatively, be clearly unique to a particular water body (for example, an endemic or endangered population);
8. Monitored effectively in wilderness areas; and
9. Amenable to models or evaluation procedures of the PSD permitting process.

Selection of screening parameters that will be applicable to all wilderness areas in the Region is difficult because

1. Limited information exists for chemical conditions and status of aquatic biota other than sport fish;
2. Variability among and within wilderness areas is likely to be great; and
3. Dose-response data are available for few, if any, potentially useful screening parameters.

Screening Parameters

Recognizing these uncertainties, a list of priority screening parameters (table 2) was developed. ANC, pH and specific conductance, were considered to be essential screening parameters. If the full complement of anions and cations are measured, pH and ANC can be estimated. However, the group recommends that, at a minimum, all variables in table 2 be measured. These measures are particularly important when attempting to identify sensitive receptors. Other variables could be used as screening parameters for specific permit applications, depending upon potential pollutant discharge (e.g., toxic organics or metals).

Initial evaluations within a wilderness area should involve analyses of the chemical variables and water clarity (table 2) so that an understanding of the chemical buffering system may emerge along with some estimation of the nutrient status and potential productivity of the system. Information on the presence of important biological species should be collected when possible, but the working group cautions that extensive biological screening or monitoring is expensive when done accurately. Biological monitoring may be essential when unique biological populations are known to occur in the area.

In some cases it may not be logistically possible to collect information on all of the recommended screening parameters (table 2). However, Landers et al. (1987) showed a clear relationship between specific conductance and

Table 2. Screening parameters for aquatic resources recommended for the PSD permitting process in Region 1. Analytical methods are given in American Public Health Association (1989) and U.S. Environmental Protection Agency (1987).

Chemical variable
ANC
pH
specific conductance
predominant cations and anions
  (Ca^{+2}, Mg^{+2}, K^{+}, Na^{+}, SO_4^{-2}, Cl^{-}, NO_3^{-})
aluminum (Al^{+n})
phosphorus (soluble reactive- and total-P)
ammonium (NH_3^{+})
alkalinity as $CaCO_3$

Physical variables[a]
water clarity (e.g., secchi depth in lakes)

Biotic variables
the
- presence or absence, or
- numbers/unit volume, or
- area of a variable

are identified to species, if possible (e.g., number of *Ascaphus truei* m^{-2}.)

[a] *Waterbody morphometrics, catchment area, geology, and soils descriptions also are needed for modeling purposes.*

ANC in the western United States. Specific conductance is a simple, inexpensive, and easily controlled measure. Many water bodies could be evaluated at little cost while providing a means to either screen systems for potential sensitivity or select sites for more complete sampling and evaluation. Other variables should be added to long-term monitoring programs, if the survey data intend to be useful in relating the sensitivity of the water body to change.

Screening Criteria

Screening criteria (table 3) were developed for some of the screening parameters in table 2. These screening criteria are sensitivity thresholds for the screening parameters, based on anticipated chemical thresholds for biological populations. Rationale was based on the working group's collective understanding of data from eastern North America and Europe because of the paucity of information on western United States species. The validity of assuming similar relationships for plant and animal species in the western United States is unknown and the screening criteria should be evaluated and revised when new information specific to western species becomes available.

In general, these thresholds were developed with lakes in mind, although the criteria should apply to any stream or wetland. These screening criteria can be used to classify water bodies into representative groups:

1. Dilute systems, with low ANC and base cations that might be especially sensitive to acidic inputs;
2. Those that might be especially sensitive to nutrient inputs; or
3. Water bodies with moderate or high ANC that are of lesser concern with respect to acidic inputs.

Using this very general classification scheme, it should be possible to determine sensitive receptors of water bodies.

Table 3. Screening criteria (thresholds) for screening parameters recommended for lakes within Class I wilderness areas in Region 1.

Screening parameter	Criteria (potential sensitivity)
ANC or base cations:	>200 μeq/l, negligible; 100-200, low; <100, moderate; <25, high.
pH:	>7.0, negligible; 6.4-7.0, low; <6.0-6.3 moderate; <6.0, high.
Specific conductance:	>20 μS/cm, negligible; 10-20, low; <10, high.
Anions:	$SO_4^{2-} + NO_3^{-} >$ 10% total base cation concentrations (μeq/l) may indicate acidic input is occurring.
Water clarity (secci depth, m)[a]:	>5 m, moderate; >10 m, high.
Total P:	<10 μg/l, moderate; <5 μg/l, high.
Al^{+n}	no criteria developed.

[a] *Could be measured as light transmission (e.g., as determined with a submarine transmissometer), but criteria were not discussed.*

Limits of Acceptable Change (LAC)

After compilation and assessment of chemical and biological conditions in each wilderness area and identification of sensitive receptors, the next important step is to determine how screening parameters and receptors may respond to incremental changes in the mass of pollutants associated with atmospheric deposition. Responses to incremental change may be based on model projections or simple empirical relations. However, it is critical to establish limits of incremental change that can occur without causing chronic or episodic mortality to biotic receptors.

Due to the lack of dose-response information for most western aquatic species, the aquatics working group agreed upon interim LACs, based on empirical relationships between chemistry and biota in other areas of the United States.

The recommended LACs (table 4) include the amount of change that could occur without significantly changing an AQRV or sensitive receptor. These LACs were established to protect lake biota but should be re-evaluated and revised as monitoring and dose-response data for the Region becomes available.

LACs (table 4) were not developed for all the listed screening criteria (table 3) because of lack of information. For example specific conductance and total phosphorous are useful as screening criteria to indicate levels of lake sensitivity but insufficient information is available to develop reliable LACs for these parameters.

Monitoring Programs

From 1989 to 1994, the University of Montana's Flathead Lake Biological Station has been sampling two lakes in the Bob Marshall Wilderness (Stanford et al. 1990, Stanford et al. 1991, Ellis et al. 1992). These two lakes were selected from an initial survey of 13 pristine lakes because of their low ANC values (125 - 372 μeq/l) relative to the other lakes in the Bob Marshall/Great Bear/Scapegoat wilderness complex. However, neither lake is considered highly sensitive to acid deposition. Each lake was sampled three times per year to evaluate physical, chemical, and biological conditions.

The Forest Service sampled 108 lakes in the Selway-Bitterroot, Cabinet Mountains, and Anaconda-Pintler Wilderness Areas in 1992 and identified several lakes for long-term intensive monitoring (Story 1993). None were acidified, but ANC in several was < 25 μeq/l. Based on the criteria given earlier (table 4) the lakes were considered highly sensitive to anthropogenic acidic deposition. Story (1993) noted that lakes rated as highly sensitive using ANC criteria also had pH values that would lead to highly sensitive designations in the PSD process. However, that was not the case for specific conductance unless the criterion for "highly sensitive" was lowered from 10 to 5 μS/cm. Moreover, several of the very dilute lakes reported by Story exceeded the anion criteria given in table 4, which could be explained by geochemistry of bedrock in the lake catchments. Sulfate plus nitrate approached 50% of the total anions in some of the dilute lakes (ANC = 10 - 100

Table 4. Limits of Acceptable Change (LACs) for screening parameters for lakes within Class I wilderness areas in Region 1.

Screening parameter	Threshold or range	Description of LAC
ANC[a] (μeq/l)	>100	Not a sensitive indicator.
	100-10	Cumulative change should be <10% of baseline condition.
	<10	Any significant change from baseline will likely damage biota (pH ~6.0); no change allowed.
pH	>pH 7	Not a sensitive indicator.
	pH 7.0-6.0	Cumulative change should be <10% of baseline condition.
	pH 6.0	Any significant change from baseline will likely damage biota (pH ~6.0); no change allowed.
Specific Conductance		No LAC developed
Anions $\Sigma(SO_4^{2-}+NO_3^-)$ (μeq/l) should	ANC = 10-100	Cumulative change in anions should be < 10% of baseline concentration of total base cations; $(SO_4^{2-}+NO_3^-)$ not be elevated to >10% of total base cation[b].
Water clarity[c]		Cumulative change should be <10% of baseline condition.
Total P		No LAC developed
Al^{+n} (μg/l)		Should not be elevated to >50 μg/l

[a] *Minimal measurable ANC any time during the year.*

[b] *Some dilute lakes in Region 1 have natural anion:cation ratios as high as 0.46, hence this LAC applies to lakes with naturally low anion:cation ratios.*

[c] *Related to any changes in N:P that would produce such a response.*

μeq/l) in the Anaconda-Pintler Wilderness, owing to mineralization of sulfide in the parent materials in the lake catchments. This far exceeded the 10% criteria recommended herein. Story's data suggested that the criteria given herein are reasonable and should be used in the PSD process, but screening criteria probably should be reconsidered as additional data allows a better understanding of how to separate natural and anthropogenic variation in ionic constituents.

Modeling Responses to Atmospheric Deposition of Pollutants

Modeling Approach

Mathematical models can be used to evaluate the potential response of aquatic resources to changes in atmospheric emissions of nitrogen and sulfur. One of the prominent models developed to estimate acidification of lakes and streams is MAGIC (Model of Acidification of Groundwater in Catchments). MAGIC has been used extensively in Europe (Cosby et al. 1986, Neal et al. 1986, Whitehead et al. 1986) and was the principal model used by the National Acid Precipitation Assessment Program (NAPAP) scientists in assessment of potential future damage to lakes and streams in the eastern United States (Thornton et al. 1990). The general validity of the model has been verified by comparison with estimates of lake acidification inferred from paleolimnological evidence of lake change.

Before the workshop, MAGIC simulations of chemical change in response to increases in sulfate SO_4^{2-}deposition were done from measured chemistry in some of the most sensitive lakes in Region 1 wilderness areas (Eilers et al. 1991). The model provided estimates of long-term chemical change (chronic acidification). Estimates of short-term change during snowmelt, referred to as episodic acidification (Wigington et al. 1990), were not addressed.

The parameters used by MAGIC are estimated from specific field data including some that were not available for the lakes of interest (e.g., soil characteristics, precipitation). Missing data were extrapolated from outside wilderness boundaries. Consequently, the level of uncertainty may be greater than what has been estimated in many other applications of MAGIC.

Description of the MAGIC Model

MAGIC is a lumped-parameter model of intermediate complexity, developed to predict the long-term effects of acidic deposition on surface water chemistry. The model simulates soil solution chemistry and surface water chemistry to predict the annual average concentrations of water chemistry constituents.

MAGIC represents the catchment with two soil-layer compartments. These soil layers can be arranged vertically or horizontally to represent the vertical or horizontal movement of water through the soil. A horizontal configuration was used for the Region 1 lakes, and the soil compartments were assumed to be spatially homogeneous. One soil compartment was simulated as exposed bedrock and the second compartment was used to simulate a soil type representative of the soils in that wilderness. Precipitation was routed onto the bedrock and soil in proportion to their extent in the watershed as determined from examination of Forest Service aerial photographs. The meteorological and deposition input requirements for MAGIC include wet deposition concentrations, precipitation, and annual air temperature. The spatial/temporal scales in the model reflect the intended use for assessment and multiple scenario evaluations. MAGIC does not use an acid neutralizing capacity in simulating watershed response. Rather, it uses a calculated alkalinity (CALK) defined as:

$\mathrm{CALK} = \mathrm{SBC} + NH_4^+ - \mathrm{SSA}$, where,

$\mathrm{SBC} = Ca^{2+} + Mg^{2+} + Na^+ + K^+$ (in equivalent concentrations),

and

$\mathrm{SAA} = Cl^- + NO_3^- + SO_4^{2-}$ (also in equivalent concentrations)

where SBC = Sum of base cations and

SAA = Sum of acid anions.

MAGIC was calibrated using an optimization procedure that selected parameter values so that the difference between the observed and predicted measurements was minimized. The MAGIC calibration process is detailed in Cosby et al. (1986) and complete descriptions of calibration for Region 1 are given in Eilers et al. (1991).

Selection of Lakes for Modeling

Data used in the workshop modeling effort were selected from lakes for which major ion chemistry data were available. Candidate lakes included those sampled in the Western Lakes Survey (figure 2), by the University of Montana (Stanford et al. 1990a), and by Montana State University (Pagenkopf 1982). Primary criteria for lake selection were:

1. Low alkalinity waters within each wilderness area;
2. Availability of complete ion chemistry for the lakes; and
3. Availability of data about lake and catchment morphometry.

Fifteen lakes (figure 3) were selected for modeling; their chemical and physical characteristics represent the range of values for wilderness lakes in Region 1 (tables 5 and 6).

Lakes with lowest alkalinity are located in the Selway-Bitterroot Wilderness, whereas lakes in the Absaroka-Beartooth Wilderness have alkalinity values approximately double those in the Selway-Bitterroot Wilderness. Lakes in the Bob Marshall Wilderness have alkalinity values substantially greater than lakes in the other two groups and are more similar to values observed in limited sampling of lakes in other wilderness areas of Region 1.

Model Deposition Scenarios

The MAGIC model was used to estimate the acid-base chemistry of the 15 study lakes in response to atmospheric inputs of major ions. Unlike many other models, baseline conditions in MAGIC pre-date current measurements of lake chemistry. MAGIC is calibrated to fit best estimates of both historical and current chemistry before it is used to provide projections of future chemistry. Pre-industrial conditions were established as per those of the year 1845. Historical deposition for sulfate, nitrate, and ammonium in the northern Rocky Mountains increased from virtually zero in 1845 to a maximum in the 1950's and 1960's and then decreased to current levels (figure 4). In the last two decades, deposition of SO_4^{2-} in the western United States apparently decreased 70% (Office of Technology Assessment 1984). However, ion-specific reconstructions

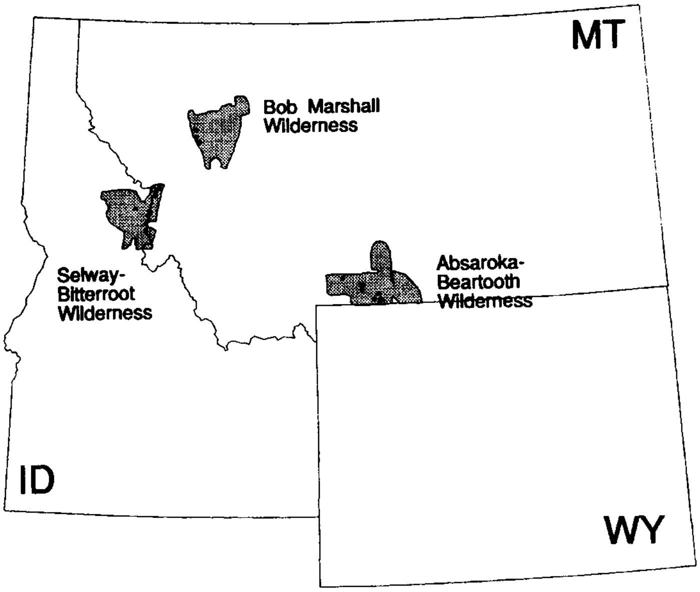

Figure 3. Locations of lakes selected for MAGIC modeling in three wilderness areas of Region 1 (from Eilers et al. 1991.)

Table 5. Major ion chemistry of the study lakes for applications of the MAGIC model in wilderness areas of Idaho and Montana (all units in µeq/l except for pH, standard units, and SiO_2, mg/L.)

Wilderness/ lake	Lake ID	Ca^{2+}	Mg^{2+}	Na^+	K^+	NH_4^+	SO_4^{2-}	Cl^-	NO_3^-	F^-	HCO_3	pH	SiO_2
Selway-Bitterroot[a]													
Holloway	4C1-010	34.0	10.8	12.3	6.2	0.0	36.0	1.6	0.3	0.5	29.6	6.79	1.9
Middle Fork	4C1-012	31.2	5.9	10.2	3.4	0.0	14.0	3.2	2.4	0.5	25.9	6.36	2.4
Heinrich	4C1-016	22.3	3.9	8.3	14.3	0.0	3.0	2.8	0.9	0.4	29.8	6.59	1.4
Blodgett	4C1-017	13.6	2.9	8.1	1.6	0.0	5.0	1.6	0.8	0.4	20.7	6.49	1.4
Milepost	4C1-022	25.4	8.0	11.4	6.3	0.0	7.0	1.6	0.3	0.5	38.4	6.62	2.2
Kidney	4C1-032	27.9	5.9	18.4	2.7	0.0	5.0	1.6	0.0	0.5	38.3	6.72	2.5
Average		25.7	6.2	11.4	5.8	0.0	11.7	2.1	0.8	0.5	30.4	6.60	2.0
Absaroka-Beartooth[a]													
Wand	4D1-001	41.4	14.4	5.7	3.1	3.5	14.0	2.3	0.1	0.6	38.7	6.90	0.8
Red Rock	4D2-006	80.8	37.0	8.6	5.4	0.0	32.0	4.6	13.0	0.5	88.4	7.23	1.8
Z	4D2-007	65.2	26.3	8.2	5.0	0.4	29.0	5.5	4.9	0.6	77.2	7.18	1.7
Unnamed	4D2-050	35.1	20.9	16.3	2.9	0.1	8.0	5.4	0.3	0.6	59.3	6.98	3.0
Fire	4D3-002	54.7	15.1	9.6	9.1	0.0	28.0	4.7	5.0	0.5	57.1	6.84	0.9
Rainbow	4D3-056	32.2	11.9	19.7	2.9	0.1	11.0	4.3	0.3	0.6	45.1	6.89	2.6
Average		51.5	20.9	11.4	4.7	0.7	20.3	4.5	3.9	0.6	61.0	7.00	1.8
Bob Marshall[b]													
Pendant	4X1-001	189.6	24.7	22.6	1.3	0.4	13.3	2.8	0.0	1.0	263.7	6.15	-
Lena	4X1-002	79.8	74.0	14.4	3.8	0.5	9.6	2.8	0.0	1.0	153.8	5.86	-
George	4X1-003	563.9	255.0	13.1	2.3	0.1	17.5	5.9	0.2	1.9	835.2	7.59	-
Average		277.8	117.9	16.7	2.5	0.3	13.5	3.8	0.1	1.0	417.6	6.53	-

[a] *Source of data: Eilers et al. 1987*

[b] *Source of data: Stanford et al. 1990a (except for fluoride, which was estimated at 1.0)*

Table 6. Deposition scenario, sulfate concentrations, and approximate precipitation pH used in MAGIC simulations of lake responses to sulfate loading. The pH of precipitation in areas receiving deposition similar to modeled scenarios is shown for comparison.

Scenario[a]	**SO_4^{2-} multiplier**	**SO_4^{2-} concentration**[b] **(µeq/l)**	**SO_4^{2-} deposition ABW**[c]	**Wet (kg/ha/yr) SBW**[c]	**Precipitation pH**	**pH of precipitation in reference areas**
Historical (1845)	0.1	1	0.6	0.7	5.8	"Background"
Historical (1970)	1.7	18.0	9.8	11.6	4.9	Minnesota
Current (1985)	1.0	10.6	5.8	6.8	5.4	Oregon
Future (2035)	3.0	31.8	17.0	20.0	4.6	S. Norway
	5.0	53.0	29.0	34.0	4.3	Michigan
	7.0	74.0	40.0	48.0	4.2	Adirondacks
	10.0	106.0	58.0	68.0	4.0	Ohio Valley
	15.0	159.0	86.0	102.0	3.8	Eastern Europe
	50.0	530.0	288.0	341.0	3.3	Sudbury, United Kingdom (1970s)

[a] *nitrogen species (NH_4^+ and NO_3^-) and base cations in the historical deposition estimates coincided with changes in SO_4^{2-} deposition; nitrogen and base cations were held at current levels for all future scenarios.*

[b] *current data for wet deposition of sulfate observed at nearby NADP/NTN sites; no adjustments were made for possible changes in SO_4^{2-} concentrations as a function of elevation.*

[c] *SO_4^{2-} concentration in wet deposition multiplied by average annual precipitation of 134 cm.*

Table 7. Physical characteristics of the study lakes and their watersheds.

Wilderness/ lake	**Lake ID**	**Lake elevation (m)**	**Lake area (ha)**	**Watershed area (ha)**	**Maximum watershed/ lake area**	**Residence depth (m)**	**Hydraulic annual time** [c] **(yr)**	**Exposed runoff** [d] **(cm)**	**Bedrock (%)**
Selway-Bitterroot[a]									
Holloway	4C1-010	2379	7	104	13.9	20.4	0.55	152	80
Middle Fork	4C1-012	1824	7	218	30.1	9.0	0.15	117	75
Heinrich	4C1-016	2212	3	34	10.3	7.6	0.18	145	85
Blodgett	4C1-017	2068	10	142	13.2	18.3	0.36	137	70
Milepost	4C1-022	2123	6	241	39.2	20.4	0.33	140	80
Kidney	4C1-032	2063	5	44	7.8	4.5	0.18	110	80
Average		2112	6.3	130	19.1	13.4	0.29	134	78
Absaroka-Beartooth[a]									
Wand	4D1-001	2842	3	1160	385.7	5.5	0.38	99	80
Red Rock	4D2-006	3233	8	228	27.5	9.8	0.16	137	95[e]
Z	4D2-007	3013	7	422	59.3	3.7	0.08	123	95[e]
Unnamed	4D2-050	2920	2	65	31.5	4.5	0.15	107	40
Fire	4D3-002	2916	3	80	25.7	26.5	0.72	107	95[e]
Rainbow	4D3-056	2935	4	179	43.8	3.3	0.08	107	40
Average		2976	4.5	356	95.6	8.9	0.26	113	74
Bob Marshall[b]									
Pendant	4X1-001	1977	89.6	144	0.6	1.7	0.35	118	50
Lena	4X1-002	2052	29.9	221	6.4	23.0	1.23	121	30
George	4X1-003	2169	46.1	467	9.1	60.0	1.86	145	70
Average		2066	55.2	277	5.4	28.2	1.15	128	50

[a] *Source: Eilers et al. 1987*

[b] *Source: Stanford et al. 1990a*

[c] *t_w as calculated from the inputs to MAGIC*

[d] *Estimates provided by Forest Service hydrologists*

[e] *There was no soil observed in the aerial photographs; 5% of the watershed was designated as soil to allow use of a two-compartment configuration of MAGIC*

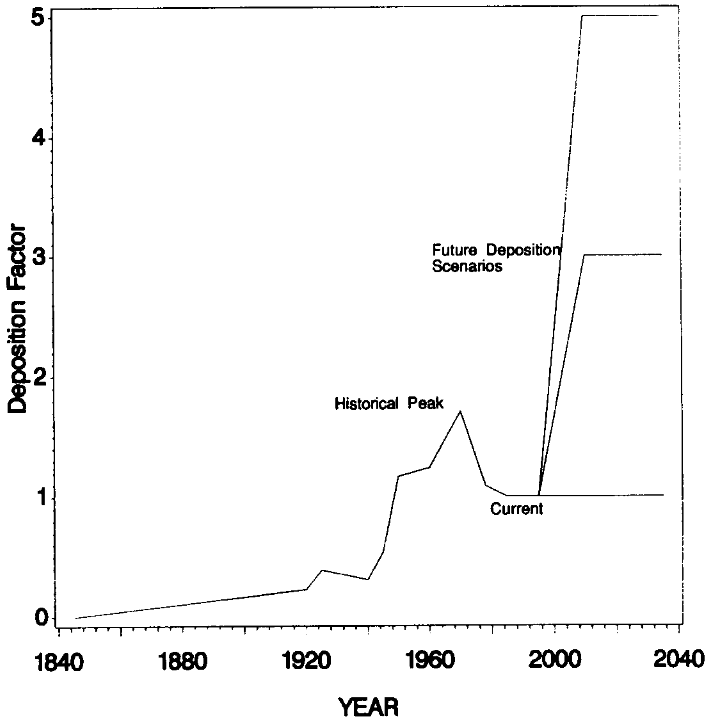

Figure 4. Historical emission values and future scenarios used as inputs for modeling lake response to increases in deposition. The deposition factor is the multiplier of the current sulfate deposition (1.0X) (data from Office of Technology Assessment 1984). For example, a deposition factor of 0.2 represents sulfate deposition 20% of the current value, whereas a factor of 3 represents a threefold increase over current sulfate deposition (from Eilers et al. 1991.)

Table 8. Calibrated and projected average lakewater pH and alkalinity output from MAGIC as a function of changes in sulfate deposition.

		Calibrated						Projected							
		1845		1970		1985		2035							
		0.1X		1.7X		1X		3X		5X		10X		Other	
Wilderness/lake	**Lake ID**	**pH**	**alk**	**pH**	**alk**	**pH**	**alk**	**pH**	**alk**	**pH**	**alk**	**pH**	**alk**	**pH**	**alk**
Selway-Bitterroot															
Holloway	4C1-010	6.4	31	6.21	21	6.3	25	6.00	13	5.47	0				
Middle Fork	4C1-012	6.5	40	6.40	33	6.4	34	6.29	26	6.16	19				
Heinrich	4C1-016	6.5	42	6.38	31	6.4	35	6.22	21	5.87	8	4.8	-23	5.2[a]	-5[a]
Blodgett	4C1-017	6.2	19	5.97	11	6.0	13	5.60	3	5.14	8				
Milepost	4C1-022	6.5	42	6.44	36	6.5	39	6.13	20	5.98	14				
Kidney	4C1-032	6.6	47	6.49	40	6.5	42	6.39	32	6.27	24				
Average		6.4	37	6.32	29	6.4	31	6.11	19	5.82	10				
Absaroka-Beartooth															
Wand	4D1-001	6.6	52	6.50	41	6.5	45	6.27	24	5.65	4				
Red Rock	4D2-006	6.9	97	6.67	62	6.7	74	6.59	52	6.36	30				
Z	4D2-007	6.8	79	6.61	54	6.7	64	6.50	42	6.18	20				
Unnamed	4D2-050	6.7	68	6.61	53	6.6	55	6.52	44	6.41	34				
Fire	4D3-002	6.7	64	6.46	38	6.6	48	6.27	25						
Rainbow	4D3-056	6.6	53	6.54	46	6.5	46	6.43	36	6.30	26				
Average		6.7	68	6.56	49	6.6	55	6.43	37	6.18	23				
Bob Marshall															
Pendant	4X1-001	7.2	223	7.2	208	7.2	212	7.2	192	6.9	120				
Lena	4X1-002	7.1	153	7.0	144	7.0	144	7.0	129	6.8	80			6.5[b]	46[b]
George	4X1-003	7.8	814	7.8	803	7.8	804	7.8	788	7.7	734			7.5[c]	438[c]
Average		7.4	397	7.3	385	7.3	387	7.3	370	7.1	311				

[a] *Other = 7X*

[b] *Other = 15X*

[c] *Other = 50X*

of historical emissions for the northern Rocky Mountains were not available for this analysis. So, emissions data for 1978 (Office of Technology Assessment 1984) were used as current values and defined in the model runs as conditions for 1985, the year in which the Western Lakes Survey data were obtained. Base cations in the historical and future deposition scenarios were held constant; thus H^+ was the only cation allowed to change in response to dynamics of SO_4^{2-} and NO_3^- deposition.

The model was run for the Selway-Bitterroot Wilderness and Absaroka-Beartooth Wilderness lakes using deposition scenarios that increased SO_4^{2-} by 3 and 5 times greater than present; several other scenarios were run for selected lakes to observe the lake response to extreme loadings of SO_4^{2-} (table 8). Loading increases of 3 and 10 times the baseline condition were selected for the Bob Marshall Wilderness lakes.

Results and Inferences From Simulations

Model output suggested that the wilderness lakes selected for study have a moderate capacity to neutralize acidic inputs (table 8). None were projected to become acidic (alkalinity < 0 µeq/l) at a SO_4^{2-} loading factor 3 times the current level, although the projected pH of 5.6 for Blodgett Lake in the Selway-Bitterroot Wilderness would be of concern.

The most sensitive lake modeled, Blodgett, was projected to become acidic at a deposition of 3.5 times the present loadings. Holloway Lake was not projected to acidify at more than 5 times present loadings (figure 5). The other lakes required even higher deposition for them to become acidic.

The ability of a lake to neutralize acidic inputs is determined not only by its current alkalinity, but also by the types and extent of soil, the parent bedrock material, hydrologic routing in the catchment, and the volume of the lake water relative to runoff volume. Consequently, lakes with similar initial alkalinity values may acidify at different rates in response to future changes in deposition. Moreover, a number of uncertainties exist with respect to the accuracy of MAGIC predictions. While the model is a state-of-the-art simulator, it is only a formalization of existing information, and output is only as good as input and the reality of model construction. Data for wilderness lakes are limited, and the model results should be used as guideposts, not end points, for a decision process.

Indeed, Stoddard (1987) and Stauffer (1990) showed that weathering rates in western alpine catchments were determined by the relative acidity of precipitation. Therefore, watersheds in the Absaroka-Beartooth Wilderness and Bob Marshall Wilderness may be expected to respond rapidly to increased acidic inputs by concomitant increases in weathering of base cations. Future modeling applications need to adjust model formulations to account for weathering from bare rock surfaces and also allow consideration of effects other than changing lake acidity (e.g., eutrophication associated with nitrate and phosphate loading that may occur with increased weathering of substrata).

Data that would be very useful to improve model projections are summarized by variable in table 9.

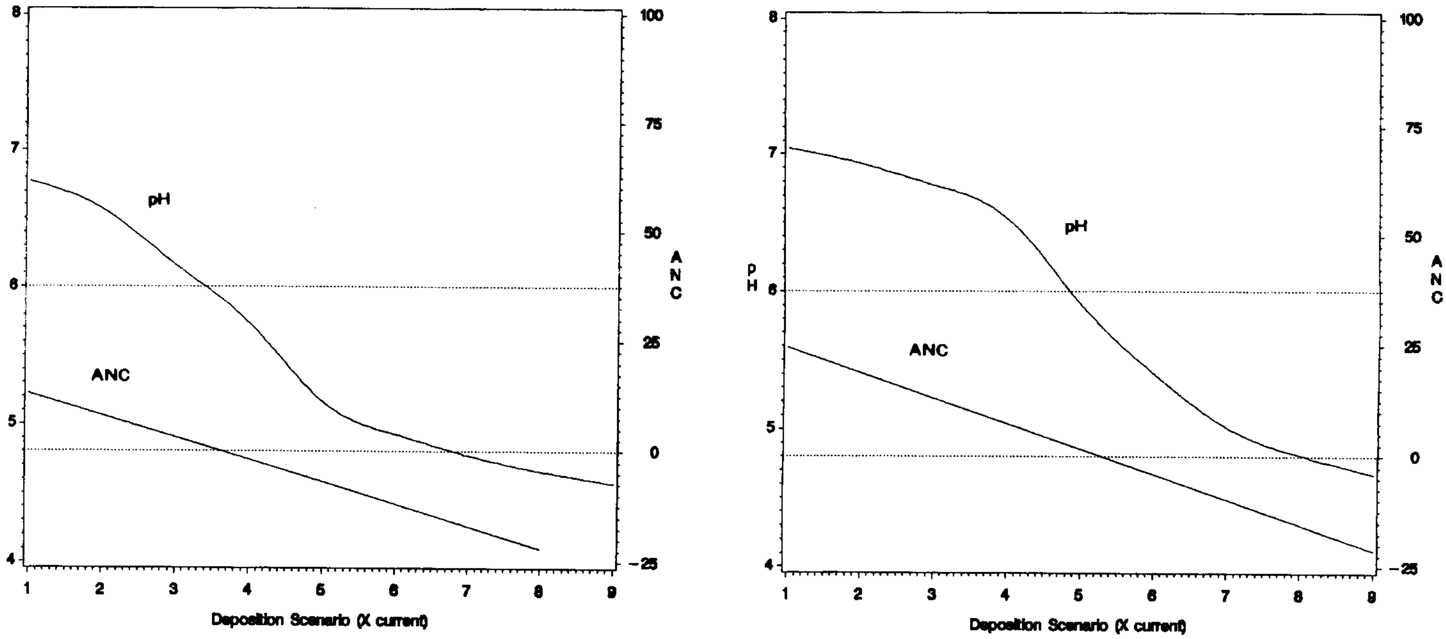

Figure 5. Simulations (MAGIC) of change in pH and alkalinity (CALK + ANC) as a function of increasing sulfate deposition in the catchments of Blodgett (left) and Holloway (right) Lakes. Broken lines at pH = 6.0 and ANC = 0 are provided for reference (from Eilers et al. 1991.)

Table 9. Suggested monitoring needs for reducing uncertainty in characterizing lake response to acidic deposition in Region 1.

Variable	Parameters	Description/rationale
Soils	Extent, depth, texture, SO_4^{2-} adsorption, exchangeable base cations	Knowledge of the soils, particularly those surrounding the lake or located in flowpaths to the lake are essential to mass balance calculations and modeling of change. Among the least known, yet important, properties of the soils that needs to be characterized is sulfate adsorption. The soils data are needed most for lakes in the SBW.
Hydrology	Discharge to/from lake, precipitation, lake mixing, snowmelt runoff	Information on hydrology is critical, particularly in documenting lake response to episodic acidification. Need to determine amount of snowmelt flowing under ice prior to lake mixing.
Water chemistry	Major ion chemistry of precipitation, inlet streams, and lakes	Ion chemistry of the major components of the catchment (precipitation, runoff, lake) would be extremely useful in characterizing lake responses. More frequent chemical measurements during the snowmelt period are required to characterize episodic acidification. Judging from the nitrate concentration in some of the ABW lakes, assessment of nitrogen deposition in this area may be warranted.
Deposition	Precipitation, volume, snow chemistry, dry deposition, summer thunderstorms	Deposition is one of the major forcing functions of MAGIC (and most acidification models), yet large uncertainties in deposition rates remain in remote areas of the Rocky Mountains.

Future Monitoring of Wilderness Lakes

The most fundamental problem facing current efforts to review PSD applications concerns the lack of data describing normal seasonal and annual variation in baseline conditions. Moreover, some areas may already be impacted by emissions, and partitioning variation becomes even more problematic with limited data. Therefore, a primary need exists to monitor key parameters (table 2) over long time periods (5 - 10 years) in order to improve predictions of lake responses to air pollution.

Selection of lakes for monitoring within wilderness areas should include a number of important considerations:

- Is the lake representative of the suite of lakes within a particular wilderness area?
- Is it a sensitive receptor (i.e., characterized by low solute concentrations)?
- Is it located in an area where air quality degradation may occur in the future?
- Are biota present that may be sensitive to changes caused by increasing deposition?
- Is the lake easily accessed by foot or pack animals?
- Are long-term chemical and/or biophysical records available?

Lake surveys and preliminary modeling presented above may be used to segregate sensitive lakes. Survey data may also suggest areas where other sensitive lakes likely are located. For example, given patterns in water chemistry observed in one area, we might expect similar values in unsampled lakes in the same area. Lakes with similar chemistry are generally found in regions of similar bedrock, topography, and other physical characteristics. Consequently, reasonably complete data (e.g., table 2) for one area may provide useful insight as to what to expect in other areas.

Lakes selected for routine monitoring should be as accessible as possible while still representing the range of conditions found in the wilderness area. Locations along a trail or near a wilderness boundary should be considered, although most lakes of interest are located in inaccessible places. The need to sample in winter adds to the difficulties of access. Very few data are available on snowmelt effects on lake chemistry. The tendency to study higher alkalinity lakes with easier access should be resisted because processes controlling stoichiometry are likely to be very different in very dilute lakes.

In areas where lakes are limited in number, wetlands and streams should be screened for use as monitoring sites. In general, lakes are more useful study sites because the hydraulic turnover time is longer. However, particularly sensitive biota may be restricted to non-lacustrine environments, obviating the need to examine streams and wetlands in addition to lakes.

The logistics and cost of establishing representative baseline conditions at enough sites to characterize wilderness areas must be balanced with the need to conduct long-term monitoring at a few sites. However, long-term records are required to unequivocally demonstrate change (Magnuson 1990). Within-site sampling design may also be critical for statistical resolution of site-specific variables.

The working group recommended that Region 1 design and implement long-term monitoring of lakes and wet deposition for key parameters (table 2) within wilderness areas and encourage interagency cooperation in the effort.

Research Needs

Only a limited and very preliminary understanding of the sensitivity of wilderness water bodies and biota exists for wilderness areas. Simulation and other evaluations leading to PSD decisions are conducted with a great deal of uncertainty, owing to lack of dose-response data. For example, predicted changes in alkalinity cannot generally be linked to likely impacts on biota. Inventories, monitoring, and process-oriented research is required to produce an effective and realistic PSD permitting process that is responsive to aquatic systems.

Some of the main areas where critical information is lacking include:

- Significance of episodic changes in chemistry due to snowmelt runoff;
- Dose-response information for sensitive, native biota in wilderness lakes and streams (for example: cutthroat trout [*Oncorynchus clarki clarki; O. c. lewisi*], bull charr [*Salvelinus confluentus*], zooplankters [e.g., *Daphnia thorata; Diaptomus shoshoni*], zoobenthos [e.g., easily identified insects such as *Amphcosmoecus* sp. and *Doranueria theodora*], and amphibians such as tailed frog [*Ascaphus truei*]);
- Long-term data bases allowing trend analyses for deposition chemistry in remote catchments and resultant water chemistry in representative water bodies;
- New modeling techniques, including evaluation of empirical models from similar montane environments (for example, Norway) and more mechanistic models;
- Evaluation of satellite or aircraft mounted sensors for correlatively detecting changes in water chemistry within wilderness areas;
- Ramifications of cumulative effects from multiple pollution sources, including analysis of lake cores for inferences about historical changes in chemistry and biota that may be attributed to air pollutants; and
- Use of stable isotopes and other new technologies to assess the impacts of pollutants within trophic guilds or keystone species that characterize wilderness lakes.

Terrestrial Resources

Background Information

Most of the existing information on dose-response relations for terrestrial biota concerns effects on vegetation. The working group considered reports from other screening workshops and identified sensitive plants found in Region 1 that may be useful in the PSD screening process.

Sulfur Dioxide

Davis and Wilhour (1976) compiled lists of species sensitive to sulfur dioxide at a dosage of 0.02-0.04 ppm for 8 hours. They included *Alnus incana* and *A. viridis* (alders), *Populus tremuloides* (aspen), *Prunus emarginata* (bitter cherry), *Acer negundo* (box elder), and *Amelanchier alnifolia* and *A. utahensis* (serviceberry), which commonly occur in Region 1 wilderness areas. Less sensitive species were *Pseudotsuga menziesii* (Douglas-fir), *Pinus ponderosa* (ponderosa pine), *Abies lasiocarpa* (subalpine fir), and *Pinus contorta* (lodgepole pine). Hill established that three other species, *Symphoricarpos oreophilus* (mountain snowberry), *Bouteloua gracilis* (blue grama), and *Oryzopsis hymenoides* (Indian ricegrass) are relatively sensitive to sulfur dioxide, with symptoms at 1 ppm in two hours.

Sensitivity of lichens to sulfur dioxide has been repeatedly documented, but few of the species studied to date occur in the Rocky Mountains (Bunin 1990). Closely related species that may be sensitive indicators are fructose species that attach to trees: *Alectoria sarmentosa*, *Bryoria fremontii*, *Usnea hirta*, *U. laricina*, *Ramalina* sp., and *Evernia* spp. Genera in the "reindeer lichen" groups, *Cladonia* and *Cladina*, have also been shown to be sensitive, as has *Lobaria pulmonaria*. Foliose, or leafy, lichens on tree bark and rock that might be pollution-sensitive are *Platismatia glauca*, *Umbilicaria hyperborea*, *U. kraschenninikovii*, *Xanthoparmelia plittii*, *X. lineola*, and *X. novomexicana* (Wetmore and Bennett 1991).

Ozone

The most phytotoxic air pollutant is ozone, which has been shown to produce visible foliar mottling in the following species at less than 200 ppb in 2 hours of field fumigation: *Populus tremuloides* (aspen), *Aster engelmannii* (Engelmann's aster), *Bromus tectorum* (cheatgrass), *Gentiana amarella* (northern gentian), *Geranium fremontii* (Fremont's geranium), and *Senecio serra* (tall butterweed) (Treshow and Stewart 1973, Harward and Treshow 1975). At fumigation for 3 hours per day for a week with 50 to 150 ppb ozone, foliar effects were evident in *Achillea millefolium* (yarrow), *Chenopodium album* (lamb's quarters), *C. fremontii*

(Fremont's goosefoot), *Descurainea californica* (tansy mustard), *D. pinnata* (western tansy mustard), *Geranium fremontii* (Fremont's geranium), *Isatis tinctoria* (Dyer's Woad), *Lepidium virginicum* (Virginia pepper grass), *Ligusticum porterii* (Porter's lovage), *Madia glomerata* (clustered tarweed), *Phacelia heterophylla* (Virgate phacelia), *Polygonum aviculare* (doorweed), *P. douglasii* (Douglas knotweed), *Senecio serra* (tall butterweed), and *Viola nuttallii* (Nuttall's violet.)

The Montana state ozone standard is 100 ppb in 1 hour; the federal standard is 120 ppb in 1 hour. Fumigation studies with ozone at 180-200 ppb have resulted in visible cell damage to the algae in the lichens, reduced chlorophyll fluorescence, and reduced photosynthesis in species of *Anaptychia, Collema, Evernia, Flavoparmelia, Hypogymnia, Lobaria, Pseudevernia*, and *Umbilicaria* (Eversman and Sigal 1987). Species of these genera are present in this region. About 122 ppb has been recorded at Fortress Mountain in southern Alberta (Bohm 1989), suggesting that ozone contamination can be serious in the Rocky Mountains.

Nitrogen Compounds

Nitrogen compounds apparently cause few direct adverse effects on vegetation, except at high concentrations. However, nitrogen deposition may produce a fertilizer effect and prevent trees from properly acclimatizing to winter conditions. Fertilization also may change plant community structure, owing to differences in growth and reproduction responses to nitrogen subsidies. Nitrogen gases may interact with sulfate ions in wet and dry deposition and increase soil acidity. Increased acidity may mobilize metals in toxic concentrations. Nitrogen gases are also a precursor, with hydrocarbons, in complex reactions that form ozone.

Particulates

Toxic effects of particulates on plants and animals have not been studied in sufficient detail to draw inferences about wilderness biota in Region 1. However, gas and solid phases of wood smoke, which is produced throughout the region by slash burning and wildfires, are mutagenic to the bacteria *Salmonella typimurium*, especially in the presence of NO$_x$ (Kleindienst et al. 1986). The inference is that key microbial components of forest soil systems may be directly impacted by particulate deposition.

Working Group Approach

This working group focused considerations of the PSD process on soils, vegetation, and land animals. Unfortunately, as noted earlier for aquatic resources, determinations of dose-response relationships are very limited for wilderness resources. This group, like terrestrial groups in screening workshops in other Regions, discussed major pollutants, such as sulfur dioxide, ozone, nitrogen, heavy metals, and particulates. It emphasized that new information on other compounds, particularly hydrocarbons, is especially needed in the context of the PSD permitting process (Legge and Krupa 1989).

Screening Parameters

Screening parameters were defined broadly as specific terrestrial components of wilderness ecosystems that should be surveyed and monitored for stress by air pollution. Screening parameters must provide maximum information about the complex and highly linked attributes of terrestrial ecosystems (table 10).

The working group recommended five priority screening parameters that should be monitored and studied in the context of dose-response relationships within terrestrial components of wilderness areas (table 10) as well as other screening parameters that should be considered because they are affected by air pollution (table 11).

The biotic parameters in table 10 may also be regarded as sensitive receptors. Conifers and lichens are easily recognized, are long-lived, and accumulate toxins, thereby

Table 10. Priority screening parameters and measures for terrestrial resources recommended for the PSD permitting process in Region 1.

Air and precipitation chemistry

Wet and dry deposition of total and ionic forms of sulfur, phosphorus, and nitrogen; ambient ozone concentration; total particulate mass; and metals concentrations.

Dominant conifer species

Sulfur, nitrogen, and metals (e.g., Pb, As, Cu, Al) concentration in needles, and measures of stress (e.g., needle browning or blotching, photosynthetic efficiency of needles, growth rates determined from ring analyses).

Lichens and mosses

Sulfur, nitrogen, and metals (e.g., Pb, As, Cu, Al) concentration in tissues, and measures of stress (e.g., P/R ratio, tissue elaboration).

Soil chemistry

Acid/base saturation, pH, cation exchange capacity (CEC), metals, and nutrient (C, N, P) storage pools (measures should complement those listed in Table 2 under Aquatic Resources).

Soil micro-organisms

Descriptions of community types, respiration rate, biomass measures.

Table 11. Other screening parameters of terrestrial ecosystems that should be considered in the context of air pollution impacts on terrestrial biotopes within Region 1 wilderness areas.

Abiotic components

- Meteorological characteristics of local airsheds
- Geomorphic features of catchments (elevation, slope, chemistry and permeability of bedrock, unique formations, such as karst caves)
- Soil classifications and chemistry

Biotic components

- Producers: vascular and non-vascular plants
- Consumers: vertebrate and invertebrate animals
- Decomposers: fungi and bacteria
- Nitrogen-fixers: free-living bacteria, cyanobacteria, some lichens
- Symbiotic associations: pathogens, mycorrhizae, root-nodules with N-fixing bacteria, actinomycetes
- Interactions between components: nutrient cycling, food webs, pollinators
- Physiological processes: photosynthesis, nitrogen fixation, respiration

providing capability for direct assessment of the degree of impact from changing air quality. Soil microorganisms (biomass and productivity per unit soil volume) provide critical information about important relationships between vegetation and storage and recycling of organic matter and nutrients that control forest productivity. No specific parameters or sensitive receptors for wildlife were developed because of the lack of dose response information. This should be adjusted as more information becomes available.

Screening Criteria

None were determined by the terrestrial working group, owing to unavailability of dose-response and monitoring data at the workshop.

However, Saunders (1991) summarized deposition values recorded at National Atmospheric Deposition Program (NADP) sites in Region 1 from 1986-1989. Wet deposition rates per variable are listed in table 12. The lower values generally correspond to lower elevations and lower precipitation; higher values generally reflect higher elevations and more precipitation. Dry deposition rates were not included. These data may be used as very general baselines or screening criteria in the absence of other data. Any predictions forthcoming from PSD permit applications that exceed these values may be considered problematic for terrestrial resources and require extensive analysis by the applicant to demonstrate efficacy of alternative criteria. However, caution is warranted because the deposition values reported by Saunders (1991) may be causing changes in wilderness areas that have not yet been detected due to lack of monitoring.

Other data describing screening parameters (table 10) for terrestrial resources likely are available from diffuse sources and should be compiled and archived in a single location. Information on other wilderness resources (e.g., species lists, plant community types, animal population dynamics) may be useful as reference data in the PSD screening process. The Regional Office is the logical location for a data center and information clearinghouse. Information sources include the NADP/NTN network, National Park Service, Bureau of Land Management, state air quality agencies, fish and game departments, Natural Resource Conservation Service (formerly Soil Conservation Service), Fish and Wildlife Service, Natural Heritage Program, private enterprises, Environmental Protection Agency, Department of Energy, institutions (colleges and universities), Canadian agencies, and data systems such as the GIS. Centralization and synthesis of available data from these sources will provide an initial basis for development of screening criteria in addition to providing a baseline for other wilderness management objectives.

Table 12. Screening criteria for precipitation chemistry. These values are to be used in the absence of other data to assess air pollution impacts to terrestrial resources within Region 1 wilderness.

Kg/ha/year[1] Variable	**low elev.**	**to**	**high elev.**
SO_4^{2-}	.40	to	4.73
NO_3^-	.27	to	2.89
NH_4	.22	to	1.90
Total N	.49	to	4.79

[1] Region 1 should be concerned if modeling demonstrates that these values are exceeded.

Limits of Acceptable Change

High elevation communities in wilderness areas are likely to be especially fragile in the context of anthropogenic pollutants. Alpine and subalpine zones have thin, delicate soils, and generalized assumptions about movement of water and solutes derived for deeper soils probably cannot be used to assess impacts accurately. Thus, establishing numerical values for allowable increases in deposition and uptake of air pollutants is inappropriate right now. Quantitative inferences from empirically based models that predict long-term effects (decades to centuries) are prerequisite.

Limits of acceptable change (LAC) in Class I wilderness areas should be 0% change for all biological measures until more information is available. This means no extirpation of species or change in community composition, soil chemistry, or other screening parameters due to air quality changes.

However, LAC of 0% does not mean zero emissions with regard to current PSD applications; it does mean that no emissions, current or proposed, will be allowed to produce measurable changes in screening parameters. If research and monitoring indicates that standards are too stringent, then standards will be relaxed.

Models for Assessing Air Pollution Impacts

The MAGIC model for predicting impacts on aquatic resources will provide useful inferences for impacts on terrestrial screening parameters listed above. Other models may also be useful.

Future Monitoring

Time-series trends for variables describing screening parameters (table 10) will be indicative of ecosystem vitality relative to changing conditions of pollutant deposition. However, responses to air pollution may not always be specific and stresses such as drought or winter damage can mimic pollution symptoms. Thus, it is extremely critical to monitor air pollutants over long time periods (> 5 years) so that anthropogenic and natural sources of variation can be distinguished. By the same token, air and precipitation chemistry data alone do not allow prediction or correlation of biological impacts. Both types of data are required for a successful screening process. Moreover, collection of data should be consistent between Rocky Mountain wilderness areas (that is, not specific to Region 1) and cooperative with other monitoring and evaluation efforts (for example, EPA Environmental Monitoring and Assessment Program, Natural Resource Conservation Service snowpack monitoring program, USGS stream flow and chemistry monitoring programs).

Site location is a critical consideration because data obtained on ridgetops dividing catchment basins will differ from data obtained in valley bottoms. Sites should be distributed in a manner that will provide an array of data that accurately characterizes the entire wilderness setting in the context of altitudinal and aspect gradients. Quality assurance, time frames, plot size, and replications are important considerations along with global positioning and geographical information systems. Presence of rare plants or unique communities determined from baseline surveys may influence location of monitoring sites as well.

Consideration should be given to establishing plots in which no collecting occurs, but in which periodic quantitative observations, such as photographs and quantitative sampling of plant communities, are made. Ideally, some such sites would be used cooperatively with visibility and aquatic sampling.

Collections of bone marrow samples of game animals at check stations should be considered for monitoring chemical contaminants of mammals.

Research Needs

The primary need is for a better understanding of dose-response relationships.

Laboratory Studies

Biota, including microbes, thought to be sensitive indicators should be subjected to various levels of pollutants, singly or in combinations, in fumigation chambers to determine their responses to known levels of pollutants under controlled conditions. Detectable internal damage and changes in spectral characteristics generally precede visible external damage.

Dose-response data can be coupled with other information, such as presence or absence of a cuticle, stomatal characteristics, internal microscopic damage, or characteristic external signals, to produce alternative modeling approaches for assessing direct impacts of pollutants.

Preliminary choices of species for experiments should be those cited in the literature as sensitive, such as conifers, lichens, mosses, and understory plants listed earlier in this section. Exposed perennial alpine species such as *Geum rossii* (Ross's avens), *Silene acaulis* (moss campion), *Eritrichium nanum* (alpine forget-me-not), *Polygonum bistortoides* (American bistort), and *Deschampsia cespitosa* (tufted hairgrass) might be good choices.

Field Studies

In some instances it is possible to apply known amounts of a potential pollutant to a plant community and record cumulative responses, such as changing proportions of species through time, movement of the pollutant through soil, possible fertilizer effects of nitrogen, and some interactions between organisms and between organisms and soil. Field testing is important in giving more realistic observations of effects than lab testing, but variables are difficult to control.

Plots representative of wilderness areas could be selected in areas outside wilderness boundaries for large-scale dose-response studies. Study of impacts and flux of pollutants through the land-water interface should be done in cooperation with aquatic research objectives.

Pollutants probably affect soil crust organisms followed by soil penetration. Nitrogen and sulfur entering a system are mobile and excess amounts may enter aquatic systems. Heavy metals are not as mobile and generally accumulate such that direct assessments of pollutant loads at different trophic levels can be assessed (e.g., metals in game animals).

New technologies, such as spectral data from remote sensors, may provide direct or correlative inferences with regard to baseline forest conditions. Remotely sensed time-series data may be particularly useful in the PSD permit context. In some cases broad scale changes in spectral imagery may be evident before changes are quantified on the ground. However, ground truth data derived from ongoing monitoring efforts is ultimately required.

Useful inferences about historical or cumulative changes wrought by air pollutants may also be obtained from innovative analyses of cores of wetlands or lake sediments (Spencer 1991).

Visibility

Background Information

The 1977 CAA amendments strengthened by the 1990 Amendments defined visibility as an AQRV in all but two of 88 Forest Service Class I wilderness areas including the seven Class I areas in Region 1. Congress also declared the national goal of remedying and preventing any existing visibility impairment in Class I areas due to humanmade pollution (Sec. 169A.(a)(1)). The 1990 CAA amendments reaffirmed the importance of visibility protection in Class I areas. At the state level, visibility is the only AQRV for which Montana has a standard.

Working Group Approach

Region 1 has a responsibility to help meet the national goal and the state standard. The visibility working group identified screening parameters, criteria, and LAC's for visibility; examined alternative predictive models; identified monitoring needs; and proposed alternative management actions with regard to the PSD permitting process.

Screening Parameters

Visibility measures are related to how well and how far one can see. A variety of visibility screening parameter indices exist or are under development, but only those that could also be related to current, practical measurement techniques were considered. The results of other Regional workshops on the PSD permitting process also were used to develop visibility screening parameters for Region 1. Four parameters were identified:

1. Extinction coefficient and its components (scattering and absorption coefficients) represented as standard visual range (SVR);
2. Particulate concentration and composition;
3. Scene contrast; and
4. Feature contrast.

Estimates of the ***extinction coefficient*** or its components (represented as SVR) were selected as the primary optical screening parameter. Current monitoring techniques and instruments that can be applied to estimate the extinction coefficient (or SVR) include directly measuring the extinction coefficient of a site path using a transmissometer, measuring the contrast of a scene using photographs, measuring the scattering coefficient using a nephelometer, and measuring the absorption coefficient using a particle filter.

Particulate concentration and composition is quantified by retention on filter media under controlled sampling conditions. Concentration of particulate matter by source can be estimated if the elemental composition (or signatures, determined by use of a mass spectrometer or other elemental analysis technique) of contributing sources are known.

Scene contrast (a dimensionless number) is measured from photographs and can be used directly as a screening parameter.

Feature contrast also is determined from photographs. A series of features on a specific scene are measured and compared to produce a dimensionless rating of contrast. Selecting the scene and specific features can be subjectively related to the elements of a scene that are important to a visitor. Feature contrast is an example of a variety of visibility indices that are related to specific views.

Screening Criteria

Existing visibility conditions must be input into visibility models to predict changes in contrast between a plume and the background visibility. The 90th percentile (or "cleanest" days) for standard visual range during the snowfree period (generally June through November) should be used as a visibility screening criteria to model the effects of plumes.

Ability to further define criteria for the other visibility parameters is limited by the paucity of SVR and particulate data in Region 1 and the northern Rockies. Data for at least a five-year period are needed, including continuous measurements throughout the year at some sites, to establish variability in SVR conditions. Visibility in Region 1 has been documented at only a few sites during summer 1989 and 1990. Screening criteria should be established in the context of the cleanest year from existing monitoring sites to ensure visibility protection. However, current conditions may already be substantially impaired relative to pristine conditions or conditions that are acceptable to the public.

Modeling Visibility Changes

Three EPA models, VISCREEN, PLUVUE, and PLUVUE II, address impairment in terms of plume visibility impacts (Latimer and Ireson 1988, Johnson et al. 1980). Models to predict regional haze impacts are being developed but are not currently available. As haze modeling capabilities develop, a perceptible change in uniform or layered haze probably would be signified by a 5% change in measured extinction.

The Forest Service should work closely with other federal land management agencies, the EPA, and the state air quality agencies to develop and refine diagnostic and deterministic models that formalize an empirical understanding of uniform and layered haze dynamics. Transport, dispersion, and chemical transformation of emissions in response to differing meteorological conditions are key issues if spatial and temporal distributions of aerosol and gas concentrations within wilderness areas are to be assessed and predicted accurately. The effect that light-scattering and absorbing aerosols have on the visual appearance of a scene and the simulation of these effects is another critical area that modelers should consider (Latimer 1991).

Limits of Acceptable Change

A stepwise procedure was recommended to meet the Forest Service's Clean Air Act responsibilities in unimpaired wilderness areas (figure 6). This is an interim procedure meant to help focus time and budgets that will be improved as additional screening criteria are derived from monitoring data and improvements in visibility models.

The Region must first decide, on the basis of information in the PSD permit application, if the proposed emissions will cause a change in visibility from the current condition. Visibility models (e.g., VISCREEN) may be used to predict if the plume from a proposed pollution source likely will be perceptible. An LAC of > .05 change in sky/terrain contrast was selected as a threshold of perceptible change in visibility. Background visibility was determined to be the 90% cumulative frequency of SVR during summer and fall (June - November) from the site or nearest site to be impacted and for the "cleanest" year for which monitoring data exist. Model output showing violation of this criterion would trigger further visibility analysis. If change is not predicted, the Forest Service may recommend to the appropriate air regulatory authority that a permit be granted. If perceptible change in visibility is predicted, determination of adverse impact. An adverse impact depends on the geographical extent of the visibility impairment, intensity, duration, frequency, and time of year. Adverse impact assessment must also consider the frequency and timing of visitor use relative to occurrence of conditions that naturally reduce visibility (for example, lightning-caused fires). This recommended method should fulfill and help focus Region 1 visibility responsibilities under 40 CFR 52.21 (29) of the Clean Air Act.

Table 13 summarizes visibility screening parameters, criteria, and limits of acceptable change.

Future Monitoring of Visibility

Although visibility is an important issue in both Class I and Class II wilderness areas, the first priority should be documenting the resource in Class I areas. The airsheds between Glacier National Park and the Yellowstone area need to be inventoried and characterized in a scientifically

Table 13. Visibility screening parameters, criteria, and limits of acceptable change for use in the PSD permitting process in Region 1.

Screening parameter	Screening criteria	Limits of acceptable change
Extinction coefficient represented as SVR	impact of plume to June-November 90th percentile SVR obtained during "cleanest" monitoring year	>.05 change in modeled plume contrast
Particulate concentration and composition	none developed	none developed
Scene contrast	none developed	none developed
Feature contrast	none developed	none developed

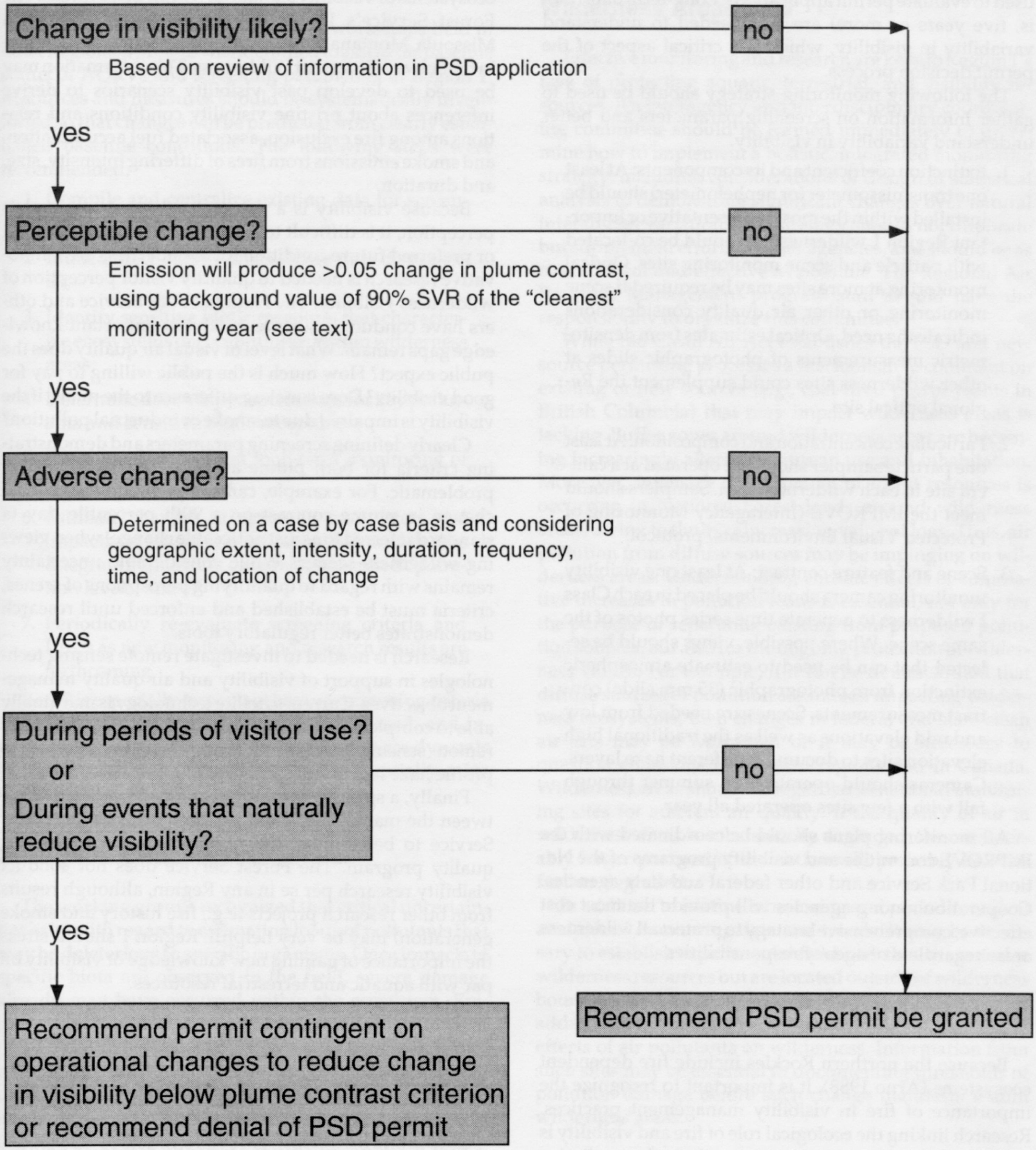

Figure 6. Process for evaluating visibility impairment as a result of anthropogenic emissions related to PSD permit applications in wilderness areas administered by the USFS.

sound and reproducible method. The information can be used to evaluate permit applications. Long-term data (that is, five years or more) are also needed to understand variability in visibility, which is a critical aspect of the permit decision process.

The following monitoring strategy should be used to gather information on screening parameters and better understand variability in visibility.

1. Extinction coefficient and its components: At least one transmissometer (or nephelometer) should be installed within the most representative or important Region 1 wilderness. It should be co-located with particle and scene monitoring sites. Optical monitoring at more sites may be required if scene monitoring or other air quality considerations indicate the need. Optical estimates from densitometric measurements of photographic slides at other wilderness sites could supplement the Regional optical site.
2. Particulate concentration and composition: At least one particle sampler should be operated at a camera site in each wilderness area. Samplers should meet the IMPROVE (Interagency Monitoring of Protected Visual Environments) protocol.
3. Scene and feature contrast: At least one visibility monitoring camera should be placed in each Class I wilderness to generate time series photos of the same scene. Where possible, views should be selected that can be used to estimate atmospheric extinction from photographic (35 mm slide) contrast measurements. Scenes are needed from low and mid elevations as well as the traditional high elevation sites to document different haze layers. Cameras should operate from summer through fall with a few sites operated all year.

All monitoring plans should be coordinated with the IMPROVE committee and visibility programs of the National Park Service and other federal and state agencies. Cooperation among agencies will provide the most cost effective, comprehensive strategy to protect all wilderness areas regardless of agency responsibilities.

Research Needs

Because the northern Rockies include fire dependent ecosystems (Arno 1988), it is important to recognize the importance of fire in visibility management practices. Research linking the ecological role of fire and visibility is needed along with a better understanding of quantitative relationships between visibility, fuel loading, and fire management scenarios. Careful consideration should be given to the short-term and long-term impacts of fire management strategies occurring inside and outside of wilderness boundaries that may be incompatible with ecosystems or visibility standards within Class I areas. The Forest Service's Intermountain Research Station in Missoula, Montana, is researching the historical role of fire in the Selway-Bitterroot Wilderness. This information may be used to develop past visibility scenarios to derive inferences about pristine visibility conditions and relations among fire exclusion, associated fuel accumulation, and smoke emissions from fires of differing intensity, size, and duration.

Because visibility is a value closely tied to people's perception, it is difficult to quantify in terms of a desired or preferred future condition for a wilderness area. Innovative research is needed to quantify visitor perception of wilderness visibility. The National Park Service and others have conducted such research but important knowledge gaps remain. What level of visual air quality does the public expect? How much is the public willing to pay for good visibility? Does it make a difference to the public if the visibility is impaired due to smoke or industrial pollution?

Clearly defining screening parameters and demonstrating criteria for both plume and haze impacts remains problematic. For example, can the public perceive a .05 change in plume contrast on a 90th percentile day (a standard referred to as just noticeable change) when viewing wilderness scenes? While considerable uncertainty remains with regard to quantifying perceptions of scenes, criteria must be established and enforced until research demonstrates better regulatory tools.

Research is needed to investigate remote sensing technologies in support of visibility and air quality management objectives. Current satellite technology is marginally able to complement existing surface networks. The use of remote sensing and laser systems offer the potential to profile haze layers and plumes impacting Class I areas.

Finally, a stronger working relationship is needed between the management and research arms of the Forest Service to better meet the needs of an expanding air quality program. The Forest Service does not conduct visibility research per se in any Region, although results from other research projects (e.g., fire history and smoke generation) may be very helpful. Region 1 should stress the importance of gaining new knowledge of visibility on par with aquatic and terrestrial resources.

Alternative Management Actions

Each working group independently discussed how the Region should implement an effective screening process to routinely and promptly evaluate PSD permit applications. Recommendations from each working group were similar and are synthesized here.

Document Baseline Conditions

Based on a review of the results of workshops held in other Regions, a process was identified to assess the baseline status of AQRVs and screening parameters in Region 1. Resources and measures should be systematically inventoried so that changes can be predicted from clearly established baseline conditions. The following steps were recommended:

1. Compile and centralize existing data for screening parameters;
2. Immediately survey areas where data do not exist;
3. Identify sensitive biotic receptors that characterize ecosystems or communities within wilderness areas;
4. Determine dose-response relations for key pollutants and sensitive biotic receptors;
5. Design and implement long-term monitoring of screening parameters;
6. Estimate changes in screening parameters and impacts on sensitive receptors using models that integrate monitoring data and atmospheric pollution levels; and
7. Periodically re-evaluate screening criteria and LACs as new monitoring and research results are forthcoming.

Item 7 is especially important because screening criteria must be legally defensible, scientifically based, and include public perception and desire. Criteria are dynamic in an adaptive management sense and essentially drive the other steps in the process.

Recognize Critical Uncertainties

The working groups recognized that critical uncertainties exist with regard to estimating loads of pollutants that may be deleterious to specific organisms. Once impacts to specific biota are observed in the field, severe damage already may have occurred within the ecosystem. Episodic and cumulative effects from multiple sources of pollutants further complicate the analysis process. Moreover, the "value" of ecosystem components is not well understood. Existence of uncertainties underscores the need to ensure that truly integrative screening parameters and sensitive receptors have been identified and are being carefully monitored.

Implement Monitoring Within Wilderness Areas Now

Effective monitoring and research are keys to Region 1's task of protecting aquatic, terrestrial, and visibility resources. An interagency and interdisciplinary coordinating committee should be formed immediately to determine how to implement a holistic, integrated monitoring strategy, including considerations of design of statistical analysis to demonstrate significant changes over natural interannual variation. This strategy should not duplicate but supplement efforts of other agencies, and should be as cost efficient and effective as possible. The Regional Air Resource Management program staff should have the responsibility to organize this committee.

While the Clean Air Act establishes the PSD and new source permitting processes a mechanism to comment on existing or new sources (e.g., coal-fired power plants in British Columbia) that may impact wilderness areas is lacking. Buffer zones around wilderness areas are becoming increasingly altered by human use and inhabitation. Moreover, intensive development of forest resources is occurring in National Forest lands around wilderness areas, owing to the ever increasing value of logs. Thus, air pollution from diffuse sources may be impinging on wilderness areas. Understanding chronic effects of cumulative increases in pollution loads is essential, not only for the purpose of separating existing from proposed pollution sources, but also for the ongoing protection of wilderness values. For example, if it can be demonstrated that diffuse sources of pollution are indeed impacting wilderness ecosystems, then changes in federal and state clean air acts may be warranted or it may be necessary to question emissions in adjacent regions and in Canada. Wilderness areas should be regarded as national monitoring sites for ambient air quality. If the quality of air in wilderness areas is substantially degraded, the considerably larger portions of the nation will probably be even further degraded.

In addition to routine monitoring and periodic, critical analysis of monitoring data and trends, it may be necessary to establish experimental field sites that characterize wilderness resources but are located outside of wilderness boundaries. At these sites, low levels of pollutants may be added under controlled conditions to assess cumulative effects of air pollutants on wilderness. Information from such sites may be essential in documenting thresholds of pollution damage before such change manifests within wilderness areas.

Use Better Modeling Approaches

Each working group tried to address the issue of appropriate modeling technologies in the context of predicting deposition rates and responses. Modeling capabilities in the workshop environment were limited to use of MAGIC by the aquatics group. Nonetheless, the need is clear for diagnostic screening models to illustrate transport, dispersion, and chemical transformation of industrial pollutants under differing meteorological conditions and in complex terrains. Refined deterministic receptor models, like MAGIC, are needed to predict the effects of specific sources and/or variations in emission strategies on all screening parameters and to reconstruct historical patterns and cumulative effects. Computer-generated images and dynamic graphics illustrating predicted responses to various emission scenarios are now possible and can greatly assist the decision process.

However, models only formalize current understanding of the problem. They should be used to study pollution problems, not to definitively predict consequences. Empirical determinations ultimately are required to demonstrate cause and effect.

Refine the PSD Screening Process

A step by step process for screening PSD permit applications could be developed from the procedure produced by the visibility working group (figure 6). Monitoring data pertaining to screening parameters should be examined systematically in relation to proposed emission levels and according to law. This workshop and the other regional air workshops did not determine a specific management action for dealing effectively with air pollution problems that are outside the PSD process. The Forest Service must continue to foster strong working relationships with the local and state air quality agencies, EPA, and interagency programs such as IMPROVE. This will help protect resources from both local and distant sources. Clearly, interagency cooperation is needed to force emission offsets or retrofit of existing sources with new technologies to reduce contaminants. Air quality should be a key issue in all Region 1 environmental assessments and environmental impact statements. Internally, the Region 1 air program needs to work closely with Forest Service research and the wilderness council in the Regional Office. Effective information transfer between the Regional, Forest, and District levels is needed, especially with regard to monitoring.

Smoke from slash burning and prescribed fires on Forest Service lands and adjacent private forest lands will be an increasingly important air pollution issue. Recent research has shown that smoke from these sources may also abnormally increase carbon, nitrogen, and phosphorus loads in wilderness catchments, resulting in a fertilization effect (Spencer and Hauer 1991, Stanford et al. 1990b). Fugitive dust from high density roads near wilderness boundaries may also contribute to diffuse sources of particulates entering wilderness airsheds. These considerations underscore the need for the Forest Service to examine its own management actions with regard to air quality issues.

Involve University Scientists in Basic Research

Each working group was partially composed of university scientists who routinely conduct basic ecological research that is germane to the PSD process. University scientists should work cooperatively with Forest Service managers to meet basic research needs such as dose-response data for screening parameters, sensitive receptors, pollutants, and new modeling approaches. Universities also have tools and expertise in monitoring, data archiving, and trends analysis.

Involve the Public

Finally, public involvement and understanding in all phases of the air program is essential. The Regional coordinating committee, recommended earlier in regard to monitoring, should develop approaches for public involvement and education so that all parties have a common understanding of air quality issues in Region 1.

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Appendix B. Air Quality Related Values (AQRVs) in Class I Wilderness Areas of the USDA Forest Service, Region 1

Bob Marshall Wilderness

The material presented here on the Bob Marshall Wilderness was taken from the following source: Acheson, A.L. 1989. Bob Marshall Wilderness air quality related values management plan. Master's thesis. Colorado State University. 132 p.

Aquatic Ecosystems

Aquatic ecosystems are the biotic community of a lake or stream plus the community's abiotic environment. Protecting aquatic ecosystems in the Bob Marshall Wilderness, therefore, will protect fish, Big Salmon Lake, and wilderness watersheds.

Aquatic ecosystems support a variety of vertebrates and invertebrates including several fish species designated by the Montana Department of Fish, Wildlife and Parks species of "special concern" (bull trout, westslope cutthroat trout, and mountain whitefish.)

The threatened grizzly bear and the endangered bald eagle depend on aquatic ecosystems, especially during certain seasons. The grizzly bear uses riparian areas (which border aquatic ecosystems) in the spring; the bald eagle uses the South Fork of the Flathead River as a feeding ground in the fall.

Many forms of recreation depend on the quality of aquatic ecosystems including fishing, birding, photography, and swimming. Fishing is important to Bob Marshall Wilderness visitors as documented in surveys conducted in 1970 and 1982 by R.C. Lucas. In 1970, visitors cited fishing as the number one appeal of wilderness. In 1982, fishing dropped to sixth, ranked below such values as relaxing, solitude and escaping civilization.

Aquatic ecosystems are also important because they supply water for human consumption within and beyond the wilderness.

Aquatic ecosystems, especially those with low alkalinities, are known to be sensitive to acid deposition. Acid deposition can lower the pH of surface waters, which adversely affects aquatic species.

Visibility

This is the only AQRV specifically mentioned in the Prevention of Significant Deterioration portions of the Clean Air Act and for which there is a Montana state standard. The Clean Air Act set as a national goal "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution" (Sec. 169A. (a)(1)).

Montana adopted a state visibility standard to prevent visibility degradation in Class I areas. The maintenance of this standard contributes to the national visibility goal as well as Montana's quality of life and overall economy.

Visitor surveys conducted in 1970 and 1982 in the Bob Marshall Wilderness determined that visitors considered enjoyment of scenic beauty a high priority. In 1970, they ranked it as the second most appealing attribute of wilderness. In 1982, it was ranked first by a wide margin.

Visibility impairment is one of the most obvious effects of air pollution to wilderness visitors. Even a small amount of additional pollution in pristine areas can greatly degrade visibility.

Wildlife

Elk have historically been important in the Bob Marshall Wilderness but are just one of a variety of species that are presently found there. The Bob Marshall Wilderness is unique because every major wildlife species that was present when Europeans first entered the area is still present, although the grizzly bear and wolf are on the threatened and endangered list. All of the Bob Marshall Wilderness is considered essential habitat for the recovery of grizzly bear populations as identified by the U.S. Fish and Wildlife Service in the Grizzly Bear Habitat Recovery Program. Other species found in the wilderness that are listed as endangered include the bald eagle and peregrine falcon.

Any damage from air pollution to forest ecosystems interferes with relationships between forest plant communities and the wildlife communities associated with these ecosystem. Recent research indicates that terrestrial wildlife may be indirectly impacted by air pollution through a and talus slopes are present. Elevations generally range from 4500 feet to 9000 feet, with the average about 7000 feet. From within the area one may view the Bob Marshall Wilderness, Great Bear Wilderness, Scapegoat Wilderness, Glacier National Park, and the Swan Front and Valley to the northeast, southeast, and east. To the west the Mission Tribal Wilderness Area may be viewed as well as the Mission Valley from certain vantage points.

Vegetation

The Mission Mountains Wilderness contains a wide diversity of plant communities. No inventories of endangered, rare, or sensitive plants have been completed. Common tree species include western larch, alpine larch, western red cedar, Engelmann spruce, Douglas-fir, western white pine, lodgepole pine, whitebark pine, limber pine, alpine fir, grand fir, and quaking aspen.

Wildlife

An abundance of wildlife inhabits the Mission Mountains Wilderness, including listed endangered species, large game animals, nongame animals, and approximately 50 identified bird species. Endangered species that frequent the area include the grizzly bear, gray wolf, and bald eagle. Large game animals include elk, white-tailed deer, mule deer, moose, black bear, and mountain goat. Nongame species include pine marten, wolverine, fisher, coyotes, golden eagles, osprey, and pileated woodpeckers. A host of smaller mammals also exist including squirrels, rabbits, etc.

Aquatic Ecosystems

Well over 100 lakes are located in the Mission Mountains Wilderness in addition to numerous potholes, bogs, and so on. Many lakes contain populations of fish species including western cutthroat trout, rainbow trout, golden trout, Dolly Varden, and mountain whitefish. Most lakes are crystal clear. Some lakes are easily accessible while many others offer a challenge to the experienced backcountry traveler.

Selway-Bitterroot Wilderness

Scenery and Visibility

Visibility is an extremely important wilderness characteristic and value within the Selway-Bitterroot Wilderness. The ability to clearly view panoramic vistas both within and outside the wilderness has direct relevance to the quality of a wilderness experience.

Historically, the primary source of human-caused pollution in the airshed has been generated by wildfire and planned prescribed fire. Current policy does not allow for planned ignition inside wilderness except when used to suppress wildfire. Therefore, planned ignition smoke sources will be from fires outside the wilderness. This is manifested in the "blue haze" commonly noticed during the summer. Temperature inversions that are common in the late summer and during the fall also tend to trap smoke in the major drainages, reducing visibility.

Smoke from both artificial and naturally ignited forest fires has perhaps the most significant implications on air quality, visibility, and odor of any pollutant in the Selway-Bitterroot Wilderness. Accepting the premise that forest fires are a natural part of the wilderness environment lends support to the acceptance of a temporary reduction in visibility, decrease in air quality, and the smell of smoke as an integral part of wilderness. An opposite argument can be made for human-caused fires, both wild and prescribed.

Soil and Geology

Soil and its underlying geology are resource values affected by acid deposition associated with increased levels of nitrogen and sulfur oxides in the atmosphere, especially in the Selway-Bitterroot Wilderness. As is typical of the Idaho Batholith, the decomposed granitic soils are shallow, are acidic, are susceptible to leaching of metals and nutrients, and have little buffering capacity to neutralize acid deposition. There is abundant rock outcrop that further limits the availability of soils to buffer acid precipitation. Changes in soil acidity, caused by air pollution, can adversely affect both terrestrial and aquatic ecosystems.

Aquatic Ecosystems

Rivers and streams in the Selway-Bitterroot Wilderness are integral to the ecosystem, have national and international significance, and could be adversely affected by air pollution. The Lochsa River is designated a "Recreation" river, and the Selway River is designated "Wild" under the wild and scenic river system. Outstandingly remarkable qualities of the Selway and its tributaries include critical wild runs of anadromous steelhead trout and naturally spawning chinook salmon, primitive recreation opportunities, spectacular natural features, wildlife, and cultural resources. The eastslope of the Selway-Bitterroot Wilderness drains into the Bitterroot River.

Six streams within the Selway-Bitterroot Wilderness have been determined eligible for "Wild" river designation but have not been nominated. These drainages, which include additional tributary streams, are Bear, Moose, Three Links, West Fork of Gedney, Running, and Blodgett Creeks.

There are about 315 lakes within the Selway-Bitterroot Wilderness. These mountain lakes are particularly sensitive to the effects of acid deposition. Some of the lowest buffering capacities for lakes in the northern Rockies have been measured in the Selway-Bitterroot.

The westslope cutthroat trout, found in lakes and streams in the Selway-Bitterroot, may be more sensitive than other species to changes in water chemistry caused by air pollution. The bull trout may also be sensitive. Effects on amphibians such as the Coeur d'Alene salamander and invertebrates are unknown at this time but may be significant.

Terrestrial Ecosystems

Any damage from air pollution to forest ecosystems interferes with relationships between forest plant communities and the wildlife communities associated with these ecosystems. Recent research indicates that terrestrial wildlife may be indirectly impacted by air pollution through a loss or change in food resources or habitat. Bioaccumulation of metals mobilized by acidification can also occur in certain wildlife species. Impacts are usually tied to some aspect of an animal's life history that depends on the aquatic ecosystem.

Many plant and animal communities exist in the Selway-Bitterroot Wilderness and may be affected by air pollution. In particular, moose, bald eagles, peregrine falcons, gray wolves, grizzly bears, and harlequin ducks also warrant special attention to discover the effects of air pollution.

Some wilderness plant communities are extremely sensitive to soil and other microenvironmental conditions and could be affected by air pollution. Little research is currently available on sensitive plants in the Selway-Bitterroot and even less on their potential susceptibility to air pollution. Old growth cedar ecosystems, alpine larch stands, and aspen at Moose Creek are special in the Selway-Bitterroot and may require monitoring to determine possible effects of air pollution.

Odor

Odors and fragrance contribute to the quality of a wilderness experience. Air pollution could mask natural fragrances with foreign, humanmade odors not characteristic of the Selway-Bitterroot Wilderness. Odor and fragrance also ties in with the discussion of smoke management in the visibility section.

Cabinet Mountains Wilderness

Scenery and Visibility

The Cabinet Mountains Wilderness is composed of a series of prominent peaks surrounded by more gentle, timbered ridges and valleys. Their stunning scenery provides inspiration, instills awe, and yet serves as an escape to peaceful seclusion and rest.

The Cabinet Mountains contain some of the finest examples of glaciated geology in the West. Spectacular scenery relative to geology is one of several primary attractants to this area. Glaciation is responsible for features like amphitheater basins, razorback ridges, cliffs, and craggy peaks. Other scenic characteristics include snow-clad peaks, glaciated lakes, several small alpine glaciers, cold and clear streams, and cascading waterfalls. The ability to view and photograph these same features at all times of the day is key to accomplishing the intent of preserving the Cabinets in their natural state for the enjoyment of humankind.

Other than a small number of cross-country skiers, few visitors physically enter the Cabinets during winter. However, summer use is intense. Because the Cabinet peaks are long and narrow and nearly surrounded by federal and state highways, they are viewed and prized by the traveling and recreating public.

Recreational pursuits that depend on the quality of the viewing activity include cross-country skiing, hiking, photography, driving, and snowmobiling (from outside the wilderness).

Aquatic Ecosystems

The quality of water in streams and lakes of the Cabinets is considered to be significantly greater than the minimum standards set by the State of Montana. The community of Libby derives much of its municipal water supply from the Flower Creek watershed, which originates in the Sky Lakes and Hanging Valley of the Cabinet Mountains Wilderness.

Nearly all recreational activities depend on aquatic ecosystems for a quality experience. Activities include fishing, bird watching, photography, cross-country skiing, hunting, hiking, and camping. Water is needed for drinking, cooking, and bathing.

Genetically pure native trout species (westslope cutthroat and bull trout) exist in several of the streams and lakes of the Cabinets. Maintaining the purity of native fish is a concern to the Montana Department of Fish, Wildlife and Parks and the Forest Service.

Glaciated lakes of the high cirque basins are generally low in buffering capacity and are largely unvegetated. Thus, this area is particularly sensitive to changes (reduced alkalinity) in natural pH. Acid deposition over winter snowpacks could adversely affect pH in both streams and lakes and could elevate levels of naturally occurring heavy metals in area streams. Aquatic fish, insects, amphibians, phytoplankton, and macrophytes would, in turn, also be adversely affected in varying degrees.

Vegetation

The vegetation of the Cabinets is primarily subalpine in nature. Large representatives of western white pine and western red cedar exist in many drainages. The other coniferous species located in the general area are also found in the Cabinets including white bark pine and alpine larch, both high elevation trees.

Confirmed as a resident within the Cabinets, the fringed onion (*Allium fibrillum*) is considered a sensitive plant species requiring protective measures to assure its continued existence. Though not confirmed as residents, the small yellow lady's slipper (*Cypripedium calceolus* L. var. parviflorum) and the northern bastard toad-flax (*Geocaulon lividum*) are also sensitive plants that probably occur within the Cabinet Mountains Wilderness.

The grizzly bear, whose survival in the Cabinet-Yaak Ecosystem is considered to be threatened, is heavily dependent on mesic ecosystems in the wilderness. In the spring the grizzly frequents habitat adjacent to streams in search of food. Huckleberries are plentiful and, while in season, are a key staple in the diet of the grizzly.

Recreational huckleberry picking is directly dependent on natural vegetation stability. Indirectly, viewing, hiking, camping, and photography are also dependent on the naturally occurring vegetative communities of the Cabinets.

Subtle changes in soil pH can have significant adverse effects on the vegetation. Acid rain and other particulate depositions on the soil may lower soil pH. Direct deposition of acid rain and particulates on plant surfaces can also have detrimental effects on their general vigor.

Wildlife

The Cabinets encompass many wildlife types including fisher, wolverine, deer, elk, moose, grizzly and black bears, mountain goat, and bighorn sheep. Nearly the entire wilderness is considered prime grizzly bear habitat and is included as a key part of the Cabinet-Yaak Ecosystem. Here the bear is considered a threatened species whose population will require assistance through augmentation in order to recover.

Hunting, viewing, and photography are directly affected by the quality of the wildlife resource supported by the Cabinets. Indirectly, hiking and camping depend on the availability of wildlife within the wilderness.

Scapegoat Wilderness

Scenery and Visibility

Red Mountain is the highest peak in the Bob Marshall Complex. The vista is far reaching and landmarks from 100 miles away are easily seen. From Bugle Mountain the view toward Scapegoat Mountain is very clear for 20 miles. From Bugle Mountain and Crow Peak, vistas into the Avon Valley and beyond are relatively clear. The Scapegoat Wilderness is largely formed by the Dearborn River, Blackfoot River, and Copper Creek. Views from the lower elevations and valleys are limited to only a few miles because of the adjacent ridges.

Water Quality

The high mountain streams in the Scapegoat Wilderness produce unpolluted clear water. At least 8 lakes are found within the wilderness including Heart Lake, which is regarded as one of the deepest and largest in the wilderness. Heart Lake is a one-day hike from the Indian Meadows trailhead.

Wildlife

The Scapegoat Wilderness has the usual array of Montana wildlife. In addition, it is considered prime grizzly habitat and provides seasonal habitat for gray wolf. Not surprisingly, the area is occupied by elk, black bears, moose, mule and whitetail deer, mountain lions, and so on.

Vegetation

Vegetation is mixed conifer interspersed with mountain bunchgrasses and riparian areas. Many sites along the Continental Divide have a harsh subalpine influence devoid of trees and grasses. Included is the possibility of threatened, rare, or endangered species. Klauses bladderpod (*Lesquerella klaussi*) is found along the Continental Divide just south of the wilderness boundary. Other threatened and endangered species are undoubtedly present.

Odor

There is the strong effervescence of high mountain air, crisp and breathtaking in the early morning. There is no scent of civilization and the hint of wildflowers and blowing pollen from the green boughs is a value of the wild landscape that cannot be described.

Climate

A general easterly airflow across the Continental Divide is influenced by a combination of the jetstream and high/low pressure cells that occur far to the east and west. As a result, strong air movement across the Scapegoat Wilderness is fairly typical. These strong airflows created a virtual fire storm that expanded the 1988 Canyon Creek fire to 250,000 acres that included a large portion of the Scapegoat. Due to the mixing effect of these westerly winds, local sources of air pollution are largely obscured.

Gates of the Mountains Wilderness

Visibility

Perhaps the most spectacular vista from the Gates of the Mountains Wilderness is the view of the Big Missouri River as it passes through a narrow gorge that forms the western boundary of the wilderness itself. The Lewis and Clark journals described the rock cliffs in the narrow gorge as parting like a gate as the explorers travelled upriver. From Moores Mountain, Candle Mountain, and Willow Mountain the vistas are largely of lower foothills and rolling plains that extend for great distances onto grasslands and agriculture.

Under almost all cloudless days all points within the wilderness are clearly visible and landmarks up to 60 miles are easily recognized. There are no snowcapped peaks or lakes or large streams that would attract visitors.

Water Quality

The Gates of the Mountains Wilderness is comprised of a high rocky outcrop of Madison limestone and paleozoic shales, which have eroded into spectacular scenery. Due to the geology of the area, free groundwater is mostly absent. The Missouri River that flows adjacent to the western boundary and Beaver Creek to the east has formed natural and obvious boundaries. A multitude of springs have formed small wetlands adjacent to Moores Mountain that lead to small ephemeral streams. It appears water quality would be largely independent of air quality.

Wildlife

This area supports one of the best herds of bighorn sheep around Helena. Due to the lack of flowing water, the area supports modest herds of elk, deer, and bear; but with reduced populations of big game and their predators, populations of birds are better than normal. The high cliffs along the river support populations of eagles, osprey, and peregrine falcons.

Flora

Due to the dry character of the area, there is an apparent lack of diverse vegetation. The canyon walls support a prolific growth of lichen and simple moss. Removal of these plants by early Americans provided a method for drawing petroglyphs. The cliffs are made from a yellow/white limestone that has become crusted with a gray/green lichen that was chipped away to form images and messages.

General Information

Recreational use of the Gates is limited to day trips from one trailhead to another because of the absence of water and lack of diversity. Early season use is probably the more favored time for this kind of recreation.

The climate east of the Continental Divide forms a rain shadow that may extend eastward for many miles and influences much of the Gates of the Mountains Wilderness. As expected the Continental Divide gives rise to an easterly flow of air known as "chinook." Chinooks and the general strong easterly flow of air during much of the year give rise to these stronger than average winds. This strong flow of air was the main force that swept the North Hills Fire from a spark near Interstate 15 to a 29,000 acre fire that burned over much of the southern boundary in 1986. Airflow over the Gates wilderness is strong enough during much of the year to offset the effects of local air pollution.

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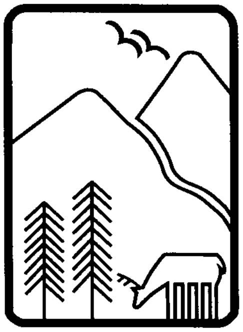
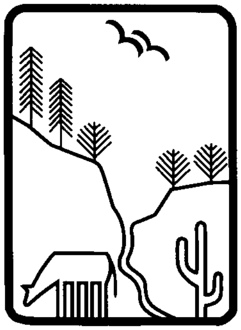
U.S. Department of Agriculture
Forest Service

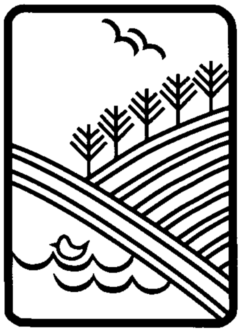
Rocky Mountain Forest and Range Experiment Station



Rocky Mountains



Southwest



Great Plains

The Rocky Mountain Station is one of seven regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526