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Screening Procedure to Evaluate Effects of Air Pollution on Eastern Region Wildernesses Cited as Class I Air Quality Areas

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Abstract

The USDA Forest Service's Eastern Region manages eight wilderness areas that have been designated as Class I air quality areas by the Federal Clean Air Act. As part of this legislation, Federal land managers are required to consult with air pollution regulators on the potential impacts of proposed air pollution emissions—including phytotoxic gases and acidic materials—on the air quality-related values (AQRVs) of these wildernesses. Applications for Prevention of Significant Deterioration (PSD) permits must be reviewed and commented on by the Federal land manager. This publication provides the manager with a procedure to rapidly screen these applications to determine which should have detailed review. The screening approach is a regional modification of a national model developed by the Forest Service in 1988. In 1990, the Eastern Region, Northeastern and North Central Forest Experiment Stations, and the Northeastern Area, State and Private Forestry sponsored a workshop of scientists and land managers to obtain advice on regionalizing this screening procedure. Two loading levels for various pollutants were established. The "red line" is the loading level above which AQRVs are expected to be adversely affected. The "green line" is the loading level below which no adverse impacts are expected. Within the intermediate "yellow zone" effects are uncertain. The publication describes the criteria used to establish red and green line values, the AQRVs for each wilderness, and the relation between the two.

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Introduction

Forest Service land managers need information about the effects of air pollution on wilderness areas that have been designated as Class I by the Clean Air Act (Public Law 95-95). Regulations pursuant to that Act require that the U.S. Environmental Protection Agency and State air pollution emission regulators consult with "federal land managers" (FLMs) on potential impacts to the "air quality-related values" (AQRVs) of Class I areas. In turn, managers of Class I areas are required to review preconstruction applications for air pollution emission permits. Called Prevention of Significant Deterioration (PSD) permits, these are required for "major" new air pollution emission sources and major modifications of existing sources. Major is defined here as certain catagories of sources (for example, coal-fired power plants) emitting more than 100 ton/yr of any pollutant, or any other source emitting more than 250 ton/yr (42 U.S.C. 74779 (1)).

There are eight National Forest Class I air quality areas in the USDA Forest Service's Eastern Region (Region 9) (Fig. 1). Each area, designated as wilderness before the 1977 amendments to the Clean Air Act, is a mandatory Class I area because it is larger than 5,000 acres (Clean Air Act Sect. 162).

The workshop upon which this report is based was preceded by a meeting of National Forest managers and scientists in 1988 at the Institute of Ecosystem Studies, Millbrook, New York. At that workshop, attendees developed a green-yellow-red (G-Y-R) screening model (Fox et al. 1989) that suggests three alternative conclusions:

- Adverse impacts are unlikely: pollutant loadings less than green line.
- Uncertain impact: pollutant loadings in yellow zone.
- Predicted adverse impact: pollutant loadings will exceed red line.

The purpose of this report is to describe adaptation of a G-Y-R model for Eastern Region Class I areas, and to describe inventory and monitoring information needs and research needs identified by workshop attendees.

Wilderness Act

The Wilderness Act of 1964 (Public Law 88-557) established the National Wilderness Preservation System "to secure for the American people an enduring resource of wilderness." The Act describes wilderness as:

> ...undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which generally appears to have been affected primarily by the forces of nature, where the influence of people is substantially unnoticeable.

The Forest Service is responsible for ensuring the preservation of the wilderness character of congressionally designated National Forest wildernesses. Lightning-caused fires are allowed to burn under prescribed conditions, but roads, motorized equipment and mechanical transport, landing of aircraft, most commercial enterprises, and permanent structures and installations are prohibited. Special exceptions in some wilderness legislation allow for mineral exploration and development, access to private land, maintenance and use of airstrips, and, in Alaska, native use for subsistence.

Clean Air Act

The Clean Air Act (CAA) amendments of 1977 established a program for the prevention of significant deterioration of air quality. Certain wildernesses and National Parks established before August 1977 were designated by the CAA as mandatory Class I areas. A Class I designation allows small increments of additional air pollution above baseline levels within the area so long as the national ambient air quality standards are complied with and the AQRVs of the Class I area are not adversely affected. The baseline levels are those existing at the time of the first PSD application for an area (42 U.S.C. 7479(4)). The allowable increments are given in 42 U.S.C. 7473. Wildernesses established after August 7, 1977, are Class II areas, as is most of the country. Class II areas may receive a larger increment of air pollution. States may redesignate these Class II areas to Class I, but redesignation to Class I has not occurred for any Eastern Region National Forest Class II area.

The CAA charges the FLM with responsibility for protecting the AQRVs of Class I areas. Addresses of Forest Service officials with responsibility for the Class I areas of the Eastern Region are included in Appendix II. AQRVs are features or properties that are important for preserving wilderness character and that could be adversely affected by air pollution. An adverse impact to AQRVs is defined as an impact of magnitude such that the purpose for which the area was established as wilderness will not be met.

New source and major modification permit applicants submit plans to the air pollution emission regulatory authorities (EPA or State with EPA oversight). When a proposed source's emissions may have an impact on a Class I area, regulators are required to notify the FLM. The FLM then evaluates potential AQRV impacts and consults with the regulators on whether effects on the Class I area are adverse. A permit shall not be issued "in any case where the Federal Land Manager demonstrates to the satisfaction of the State that the emissions from such a facility will have an adverse impact on the air quality-related values (including visibility) of such lands..." (CAA Section 165 (d)). A permit may be issued even if Class I increments will be exceeded, but Class II increments will be complied with "in any case where the owner or operator of such a facility demonstrates to the satisfaction of the Federal Land Manager, and the Federal Land Manager so certifies, that the emission increases will have no adverse impact to the air quality-related values of such lands (including visibility)..." (CAA Section 165 (d)). The FLM might have as few as 30 days to evaluate impacts to AQRVs and respond to the regulatory authority after a permit application is determined to be complete.

Figure 1.—Class I areas in USDA Forest Service's Eastern Region.

Regional Workshop Objectives

Objectives of the Forest Service in holding the regional workshop were to:

1. Obtain advice on screening criteria for the AQRVs of each Eastern Region Class I area.

2. Publish a report that can be used by National Forest managers to identify screening criteria for assessing the impacts to AQRVs and that describes the rationale for criteria selection.

Prior to this workshop, the National Forest staff had developed general wilderness and AQRV descriptions for the eight Class I wilderness areas (see Appendix I). Visibility, the only AQRV specifically mentioned in the Clean Air Act, is important in all of the Eastern Region Class I areas except Rainbow Lake Wilderness of the Chequamegon National Forest. However, establishing screening criteria for visibility is reserved for a separate national workshop.

Scientists investigating the effects of air pollution on forest and aquatic ecosystems were invited to participate at the regional workshop, as were representatives of numerous organizations with an interest in forests, wilderness, air quality, and PSD permitting. Staff of the six Eastern Region National Forests with Class I air quality areas, the Regional Office, the Forest Service Southern Region, and the Washington Office also were invited. Workshop participants are listed in Appendix II.

In developing PSD screening guidelines, terrestrial and aquatic ecosystems were initially considered separately. Workshop attendees were divided into terrestrial and aquatic ecosystem groups, and each group was subdivided into two teams which addressed the PSD screening process individually. Each ecosystem group met and identified areas of agreement and areas of divergent opinion and then developed inventory and monitoring information needs and priority research needs. Individual participants also offered advice to the chairperson of their team; chairpersons did not attempt to establish a consensus.

Each ecosystem group approached the task differently, primarily because of differences in available information and current knowledge about the systems. The terrestrial ecosystem group determined that land managers can best determine impact criteria for terrestrial AQRVs and that the criteria will vary considerably among the Class I areas. Thus, the group focused on providing a decisionmaking framework and general resources for evaluating possible impacts on AQRVs. Because acidification effects on aquatic systems are better understood than for terrestrial systems, the aquatic ecosystem group concluded that sufficient information is available to establish red line-green line values for the eight Class I areas.

Both terrestrial and aquatic ecosystem groups agreed on the need for certain basic information about current air quality and predicted changes. Participants in both groups noted the lack of basic information for the Class I areas and the uncertainty of current knowledge for predicting effects. Therefore, workshop products included identification of inventory and monitoring information needs and priority research needs.

Screening Approach

The following four-step screening approach was identified:

1. Identify the AQRVs. The FLMs must do this.

2. Obtain Resource Information. To evaluate a PSD application for possible effects on Class I area AQRVs, the FLM requires information including an inventory of flora and fauna (communities, species, and genera lists for both wildlife and plants, and threatened and endangered species present on the wilderness area); soils (pH of upper horizons, cation exchange capacity, base saturation, total bases); water resources (hydrology of lakes and streams, water chemistry information: pH, acid neutralizing capacity, base cations, sulfate, aluminum); and air quality (concentrations of ozone and sulfur dioxide, and estimates of nitrogen and sulfur loading to the ecosystems). If this information is not already available, obtaining this information should be an immediate priority.

3. Determine Exposure of AQRVs to Air Pollution. Managers use predicted increment in emissions and current levels of air pollution exposure on the wilderness to calculate the total exposure (or loading) that can be expected as a result of aproposed facility. Applicants will provide information on the projected emissions from new facilities. If information on ozone, sulfur dioxide concentrations, and N and S loadings are not provided, the FLMs should immediately notify regulators that the application is incomplete. FLMs should request that regulators evaluate air pollution emissions and projections. The Forest Service may need to convert the information provided by the applicants to values that reflect effects on the the entire ecosystem. Cumulative atmospheric deposition should be considered and concentration values should be representative of usual ambient air quality and meteorological conditions and air pollution episodes. In case of doubt about usual conditions, worst-case air quality and meteorological conditions should be used.

4. Determine Impact on AQRVs. The FLMs compare the total cumulative exposure with the evaluation criteria (red and green lines) for the sensitive wilderness components that are AQRVs. These criteria can be used, in consultation with the regulator, to determine if levels are: (1) Sufficiently high that impacts are predicted (above the red line); (2) Sufficiently low that impacts are not expected based on current knowledge (less than green line); or (3) Within the "yellow zone" and impacts are uncertain but the probability of adverse impacts increases as red-line criteria are

approached. It is critical that a cumulative impact analysis be done. Even with decreases in acidic air pollutant loading of Class I areas that may result from 1990 amendments to the CAA, adverse impacts on AQRVs can continue. Aquatic and terrestrial evaluations should be considered and compared according to the relative importance of specific AQRVs within the Class I area.

Although workshop participants generally agreed to the approach described in this report, some individuals disagreed with the screening approach developed by Fox et al. (1989). PSD permit applicants may choose to use more complex modeling approaches and there by produce more precise answers.

Current Levels of Pollution

The PSD permit screening process focuses on two types of pollutants, phytotoxic gases and acidic materials. The phytotoxic gases of concern are ozone (O_3) and sulfur dioxide (SO_2). The acidic pollutants include several forms of sulfur (S) and nitrogen (N). Data needs for the screening process are:

1. Ozone: Second highest hourly average concentrations during the growing season.

2. Sulfur: Average annual SO_2 concentrations or 3-hour maximum SO_2 concentrations; Total S deposition: precipitation, dry deposition, and cloud water deposition.

3. Nitrogen: Total N deposition: precipitation, dry deposition, and cloud water deposition.

Estimates of current air concentrations and deposition rates of these pollutants are shown in Tables 1-3. The ozone concentrations (Table 1) in some Class I areas were estimated from nearby monitoring stations in the EPA AIRS (Aerometric Information and Retrieval System) network (some analyses provided by Allen Lefohn, ASL Associates, Helena, MT), and from Forest Service ozone monitors near the Class I areas. Other ozone values were provided by the Appalachian Mountain Club, University of Massachusetts, and Wisconsin Department of Natural Resources.

Mean annual SO_2 concentrations (Table 2) were derived from the Regional Acid Deposition Model (RADM) used by the National Acid Deposition Assessment Program (NAPAP) 1990 assessment, and provided by Robin Dennis, Atmospheric Science and Modeling Division, U.S. EPA, Research Triangle Park, North Carolina.

Table 1.—Ozone concentrations, second highest 1-hr average[a]

Class I area	Elevation	Ozone concentration 1989	1988
		------- *ppb* -------	
Great Gulf/ Pres. Range-Dry River[b]	High	129	145
	Low	74	97
Lye Brook[b]	High	100	NA
	Low	101	125
Dolly Sods/Otter Creek	Low	103	146
Rainbow Lake[c]		84	99
BWCAW		80	101
Hercules Glades		64	83

[a] EPA Aerometric Information and Retrieval System network data.

[b] Data provided by Appalachian Mountain Club and University of Massachussetts.

[c] Data provided by Wisconsin Department of Natural Resources (Florence County site).

Table 2.—Mean annual SO_2 concentrations, 1982-85[a]

Class I area	SO_2 concentration
	ug/m³
Great Gulf/Pres. Range-Dry River	4.0
Lye Brook	7.3
Dolly Sods/Otter Creek	20.3
Rainbow Lake	2.4
BWCAW	1.1
Hercules Glades	3.0

[a] Derived from Regional Atmospheric Deposition Model (RADM).

Sulfur and nitrogen deposition rates (Table 3) are shown for wet deposition (rain and snow), dry deposition, and droplet or cloud deposition. For wet deposition we used data from the National Atmospheric Deposition Network/National Trends Network (NADP/NTN) to estimate mean, volume-weighted SO_4-S, NO_3-N, and NH_4-N concentrations in the rain and snow at each Class I area, then multiplied concentrations by mean annual precipitation amounts to estimate annual wet S and N deposition rates for each area.

Table 3.—Estimated mean annual S and N deposition rates

Class I area	Elevation		Sulfur deposition Wet[a]	Dry[b]	Coud[c]	Total	Nitrogen deposition Wet[a]	Dry[d]	Cloud[c]	Total
		m	*kg/ha/hr*							
Great Gulf/	High	1750	10	2	10	22	6	3	6	15
Pres. Range-	Low	275	9	3	--	11	5	3	--	8
Dry River	Mean					16				11
Lye Brook	High	850	11	3	3	17	6	3	2	11
	Low	250	10	3	--	13	5	3	--	8
	Mean					14				9
Dolly Sods/	High	1250	15	6	5	26	11	4	4	19
Otter Creek	Low	575	13	6	--	19	10	4	--	14
	Mean					21				16
Rainbow Lake	Mean	375	4	2	--	6	4	3	--	7
BWCAW	Mean	550	3	2	--	5	3	2	--	5
Hercules Glades	Mean	325	6	3	--	9	5	3	--	8

[a] From NADP/NTN network data. Wet deposition rates are the products of mean annual precipitation amounts and mean S and N concentrations in precipitation. Mean concentrations were estimated from isopleth maps derived from mean volume-weighted concentrations at NADP sites.

[b] Derived from Regional Atmospheric Deposition Model (RADM), provided by Robin Dennis, EPA, Research Triangle Park, NC.

[c] Estimated from high-elevation deposition data from several Northeastern U.S. sites, as summarized by Lovett and Kinsman (1990).

[d] Estimated from CORE/Satellite site data, as presented by Sisterson et al. (1990).

Dry deposition of S and N occurs mostly as SO_2 and HNO_3 gases. Estimates of dry S deposition were derived from the RADM model and provided by Robin Dennis. Measurements of dry N deposition at the eight CORE/Satellite sites indicate that dry N deposition is about 35 percent of wet plus dry N deposition in the Northeast, and about 45 percent of wet plus dry N deposition in the Midwest (Sisterson et al. 1990). We used these values to estimate dry N deposition on each Class I area.

At high-elevation sites, concentrations of SO_4, NO_3, and NH_4 in cloud water are 5 to 20 times greater than in precipitation. Sites above about 1,000 m in elevation can receive as much S and N from cloud deposition as from wet deposition. We used deposition data from several high-elevation sites in the Eastern United States, as summarized by Lovett and Kinsman (1990), to estimate cloud deposition on the high-elevation portions of the Class I wilderness areas in Vermont, New Hampshire, and West Virginia, locations for which there are no actual cloud deposition data.

Average annual wet deposition has been changing over time. Emission of SO_2 in the Eastern United States has declined slightly over the past 15 years, and SO_4 deposition, at least at the long-term study site at Hubbard Brook in New Hampshire, has decreased proportionally (Driscoll et al. 1989). Emission and deposition of NO_3 is constant or continues to increase. Forest managers need to be aware of the SO_4 decrease and of the years over which average values have been calculated. Year-to-year variation in deposition is large, so many years of record are needed before statistically significant trends can be detected.

Terrestrial Ecosystems

Potentially Sensitive Components

Sulfur can affect a terrestrial ecosystem in two ways: direct effects of SO_2 and indirect effects of total S loading. Sulfur dioxide may not affect the soils of an ecosystem but can have significant impacts on the health and vigor of some plant species. For example, aspen (*Populus*) exhibit leaf injury and reduced growth when exposed to SO_2 (Davis and Wilhour 1976). Total S loading includes all forms of S that enter an ecosystem: wet sulfate, dry sulfate, and SO_2. Sulfate forms of S may be detrimental to wilderness ecosystems by removing base cations from soils, causing changes in the soil solution and increasing the leaching of nutrients from the ecosystem.

The leaching of calcium and other bases from soil exchange sites, which can result from elevated sulfur deposition, increases the acidity of the soil solution, decreasing the availability of nutrients for plant growth. The reduction in pH also will increase the concentration of aluminum in the soil solution, which can lead to aluminum toxicity. Aluminum toxicity effects may be intensified by low levels of calcium which can occur after long periods of high loadings of sulfate and nitrate.

Nitrogen, unlike sulfur, is a growth-limiting nutrient in many forest ecosystems and does not accumulate in inorganic forms in the soil. It is rapidly incorporated into biological components of the ecosystem such as plants, animals, and microorganisms. Low levels of nitrogen deposition in wilderness areas may initially cause increased growth and vigor of the vegetation. However, as nitrogen loading continues, an imbalance of nutrients in the ecosystem may occur and the leaching of nitrate from the ecosystem may increase. An imbalance in nutrients could result in species replacement due to differences in nitrogen efficiencies and to changes in physiological processes such as dormancy initiation. Nitrogen deposition in excess of what the biological systems can utilize leads to nitrification and increased leaching of nitrate and associated cations. When a system reaches this point of nitrate leaching, it is considered nitrogen saturated.

Ozone is not formed directly at point sources and thus is not a PSD increment pollutant. However, it should be evaluated in all permit applications as it is considered the most widespread and phytotoxic air pollutant. It is produced in the environment by the photochemical reaction between NO_x and hydrocarbons, with the latter a "criteria" pollutant. Ambient ozone concentrations in some areas of the country are sufficiently high to cause visible injury, reduce photosynthesis and growth, and induce premature leaf senescence of many sensitive plant species.

Examples of vegetation that may be sensitive to ozone or sulfur dioxide are listed in Tables 4 and 5. These are not exhaustive listings of all potentially sensitive species, nor are they lists of plants that always will be sensitive to air pollution. Rather, they can be used by managers to assess whether there is a likelihood of sensitive vegetation on the wilderness area. Little is known about the sensitivity to these two pollutants of rare and endemic plant species and understory and shrubby vegetation, and there is little information on the sensitivity of terrestrial invertebrate or vertebrate populations to these pollutants.

Table 4.—Partial list of forest species sensitive to ozone and sulfur dioxide[a]

Common name	Scientific name
SENSITIVE TO OZONE	
Green ash	*(Fraxinus pennsylvanica)*
White oak	*(Quercus alba)*
White pine	*(Pinus strobus)*
Jack pine	*(Pinus banksiana)*
Virginia pine	*(Pinus virginiana)*
Tulip-poplar	*(Liriodendron tulipifera)*
Black cherry	*(Prunus serotina)*[b,c]
White ash	*(Fraxinus americana)*[c]
Milkweed	*(Asclepias sbriaca)*[b,c]
Aster	(*Aster* spp.)[b]
Blueberry	(*Vaccinium* spp.)[c]
Elderberry	*(Sambucus canadensis)*[c]
SENSITIVE TO SULFUR DIOXIDE	
Bigtooth aspen	*(Populus grandidentata)*
Trembling aspen	*(Populus tremuloides)*
Yellow birch	*(Betula alleghaniensis)*
White pine	*(Pinus strobus)*
Jack pine	*(Pinus banksiana)*

[a] Excerpted from Davis and Wilhour (1976) unless otherwise indicated.

[b] Based on observations of foliar symptoms in Class I wilderness areas in White Mountain National Forest and Green Mountain National Forest (Smith and Manning 1990).

[c] Based on observation of foliar symptoms in Otter Creek and Dolly Sods wilderness areas, Monongahela National Forest (Jackson and Arbucci 1989).

Table 5.—Partial list of lichens sensitive to sulfur dioxide. The most sensitive species are present only below 40 ug/m³ (average annual levels). The columns of numbers after the species names are the published limits of presence and absence in ug SO_2 / m³

Species	Presence/absence	Reference
Bryoria furcellata	13 to 26/26 to 52	3
Bryoria implexa	10 to 30/–	6
Bryoria trichodes	13 to 26/26 to 52	3
Caloplaca flavorubescens	30/35	1,6
Catillaria griffithii	26/–	2
Cetraria chlorophylla	10 to 30/–	6
Cladonia bellidiflora	8/16 to 24	8
Dimerella lutea	30/–	1
Evernia divaricata	10/–	6
Hypogymnia tubulosa	10 to 30/–	6,8
Lecanactis abietina	10/–	6
Lecidea nylanderi	13/13 to 26	3
Lecidea vernalis	26/26 to 34	4
Lobaria pulmonaria	26/26 to 34	1,4,5,6
Ochrolechia pallescens	16 to 24/–	8
Physcia semipinnata	30/35	1
Ramalina americana	13/13 to 26	3
Ramalina calicaris	30/35	1,7
Ramalina fraxinea	30/35	1,6,7
Rhinodina papillata	13/13 to 26	3
Usnea filipendula	10 to 30/–	6
Usnea florida	30/–	1
Usnea variolosa	26/–	2
Xanthoria candelaria	16 to 24/–	8

1. Hawksworth and Rose 1970.
2. LeBlanc 1969.
3. LeBlanc et al. 1972.
4. LeBlanc et al. 1974.
5. Nash 1976.
6. Trass 1973.
7. Hawksworth and Rose 1976.
8. Johnson 1979.

In general, sites that are the most sensitive to increased sulfur loading are those most likely to exhibit effects of increased levels of sulfur on soils: leaching of bases, drop in pH, and increased Al solubility. These might include sites with shallow soils or those with soils with low base saturation. Soils developed from outwash sands or sandstone weathering, coarse soils over bedrock, etc. probably are the most susceptible. Soils derived from limestone, such as those found in the Hercules Glades Wilderness Area, are not likely to be susceptible to the effects of increased deposition. Soil acidification is discussed in greater detail in the section on aquatic ecosystems.

Wilderness soils that already are N-saturated or are severely N-limited may be sensitive to increased nitrogen loading. One example of a nitrogen-saturated community is the high-elevation spruce-fir forests in the southern Appalachians. Also at risk are old-growth communities that use small amounts of nitrogen or recycle large amounts in litterfall. Shallow soils or soil of low base saturation may be susceptible to change (cation leaching, acidification, mobilization of metal ions) with increased N loading. However, deep soils with high base saturation will be affected by N leaching only after long periods.

Another scenario in which additional nitrogen could have an effect entails nitrogen acting as a fertilizer: this can be a negative or a positive effect. These impacts cannot be assessed over the short term. For example, if a particular plant association is found only on infertile sites, continuous additions of nitrogen could change that association or eliminate it by creating an environment where other plants can compete more successfully than the original species. Rare and endemic plants often are found on such unique sites. Thus, the manager should take a careful look at communities that currently are found only on nutrient-poor sites.

Relationship of Sensitive Components to AQRVs

The AQRVs describing terrestrial components of the wilderness areas are written to cover broad characteristics such as vegetation. These broad characteristics must be divided into smaller components, such as the particular species of trees, plants, and lichens, so that the sensitive components can be identified and documented. Many of the sensitive components described in the previous section may not be important components of the AQRVs for a particular wilderness area. It is important that each wilderness area be considered on a separate basis by the FLM. It also is important for the FLM to evaluate both terrestrial and aquatic systems as sensitivity will vary, as reflected in red and green line values. Assessments should incorporate the most sensitive components.

Green Line and Red Line Values

Screening criteria (Table 6) should be applied on a case-by-case basis, using air quality snd meterological conditions from each wilderness where available. However, because the available information on air quality and ecosystem components is limited, the same green and red line values have been selected for all eight Eastern Region Class I areas. Obvious exceptions are pointed out.

Table 6.—Terrestrial green and red screening values

Pollutant	Green line	Red line
	SULFUR DEPOSITION	
SO_2 (annual mean)	< 5 ug/m^3	> 40 ug/m^3
(3-hr max. mean)	< 100 ug/m^3	> 200 ug/m^3
Total (all forms of sulfur)	5 to 7 kg/ha/yr	> 20 kg/ha/yr
	NITROGEN DEPOSITION	
Total nitrogen	5 to 8 kg/ha/yr	> 20 kg/ha/yr
	OZONE	
Growing season, second highest 1 hr average	≤ 80 ppb	> 120 ppb

The total deposition or exposure values are compared with the green-line/red-line model to determine the appropriate course of action. Green line values were set at levels at which it was reasonably certain that no significant change would be observed in ecosystems that contain large numbers of sensitive components. Conversely, red line values were selected at levels at which it was reasonably certain that a significant change would occur in both the sensitive and tolerant components of the ecosystem.

Limited foliage injury or symptom development can occur on sensitive species at the selected green line values for ozone and SO_2. However, the significance to the wilderness ecosystem of this foliage injury may be minor. Studies have demonstrated that plants with foliage exhibiting air pollutant damage symptoms can continue to grow at competitive rates. Thus, the relationship of foliar injury to the AQRVs of a particular wilderness will determine the significance of such symptom development. Additionally, green line levels were not selected to assure the protection of the most sensitive genetic material in the ecosystem. This approach was taken because the AQRVs were established to protect the current ecosystem, which would be expected to continue even if part of the genetic material of one or more species was lost. If the AQRVs are revised at a later date to include sensitive genetic material, the green line values may need to be lowered.

The green line (3-hr maximum peak) SO_2 value of 100 ug/m^3 (or long-term average of 5 ug/m^3) was selected because no significant large-scale visible injury or physiological impacts are expected on any species in the ecosystem below these levels, based on published literature. The red line values (3-hr maximum peak value of 200 ug/m^3 or 40 ug/m^3 yearly average) were selected because similar levels have been demonstrated to be harmful to many of the species found in the wilderness areas in Region 9. However, the effect of SO_2 on vegetation will vary with several parameters, including the concentration, duration, and frequency of peaks in the growing season.

The green line value for total S loading is 5 to 7 kg/ha/yr. This is approximately the loading in Boundary Waters Canoe Area and Rainbow Lakes Wilderness Area; to date, no adverse effects have been observed in these areas, so the group believed that this value represents the lowest level at which we can estimate no effects. However, aquatic systems may be more sensitive and cumulative effects should be considered, particularly for watersheds approaching their sulfate adsorption capacity, as in Dolly Sods and Otter Creek wilderness areas (See discussion on aquatic ecosystems).

The red line value of 20 kg/ha/yr may be expected to cause cation leaching from most of the wilderness soils in Region 9. Supporting this observation is the calculation that soil 30 cm deep with a bulk density of 1.1 kg/L receiving a sulfur loading of 20 kg/ha/yr could achieve a reduction of 1 meq in base cations within about 2.6 yr (Fox et al. 1989). However, the loss might be less if the soil contained more free calcium carbonate, as is the case for the Hercules Glades Wilderness, or if the sulfur absorbing capacity of the soil is high.

For N, a green line of 5 to 8 kg/ha/yr was selected because these are the levels that are currently deposited in the more "pristine" wilderness areas of Region 9 (BWCAW, Rainbow Lake, Hercules Glades). To date, the decline of red spruce at high elevations is the only significant change in ecosystem structure or function that might result from increased N or S deposition. The red line value of 20 kg/ha/yr of total nitrogen was selected because most, if not all, of the wilderness soils will leach nitrate and associated base cations if this level of N input is maintained.

Ozone, like SO_2, exists in the environment as a gas and its impact on vegetation depends on many variables, including concentration, duration, frequency of peaks and environmental conditions such as temperature and humidity. The ozone values given in Table 6 represent the second highest 1-hr average in the growing season. This value is reasonably well correlated with plant response, though research is currently under way to improve on this variable by including some influence of accumulated effects. It is recommended that some type of cumulative index that weights the high concentrations more than the lower concentrations be developed as soon as possible.

The green line value for ozone for all wilderness ecosystems was set at 80 ppb (second highest 1-hr mean). No significant change is expected in the ecosystem if ozone remains below this level. However, on the basis of available information, it is reasonable to conclude that some symptom development or leaf senescence may be expected even at this low level. The red line value was set at 120 ppb (second highest 1-hr mean). At this level, ozone will reduce plant growth and the competitive ability of many species. Sensitive species may be eliminated from the ecosystem.

In addition to short-term ozone effects being important, the effect of ozone is cumulative for each individual in the ecosystem. A plant weakened by ozone in one season is in a poorer competitive position at the beginning of the second season than a nonsensitive plant. After two or more seasons it is weakened even further until it may be eliminated. The PSD recommendations will depend on the relative importance of the different plant species in the plant community as an AQRV within each wilderness.

Aquatic Ecosystems

Potentially Sensitive Components

The ability of a lake or stream to buffer incoming acids, i.e., its acid-neutralizing capacity (ANC) or alkalinity, depends primarily on the emount of bicarbonate (HCO_3) in the water and the rate at which it is supplied from the watershed. Bicarbonate supply depends on watershed geology and hydrology. In the watershed, HCO_3 is produced by the reactions of water and carbon dioxide (or acids from atmospheric deposition) with carbonate minerals such as calcite and dolomite, and cation aluminum silicate minerals like feldspars and micas. These weathering reactions release HCO_3 into solution, accompanied by approximately equal amounts (on an equivalent weight or ueq/L basis) of base cations—calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) (Stumm and Morgan 1981). How much HCO_3 and other mineral-weathering products actually reach a lake or stream depends on the flow paths of water through the watershed. Water that moves rapidly over the land surface or along shallow subsurface pathways usually contains much less dissolved material than water that takes a slow, deep route to a lake or stream. Ground water is typically high in dissolved ions. Lakes and streams with strong ground water inputs usually have high buffering capacities.

In addition to alkalinity supplied by the mineral weathering in the watershed, some alkalinity is generated by in-lake processes of SO_4 and NO_3 reduction and by ion exchange with the bottom sediments of lakes. This can be a significant source of ANC in lakes with only minimal inputs of HCO_3. In-lake alkalinity production is a much more significant source of ANC in lakes that have long hydrologic flushing times, several years, than in lakes that flush more frequently. In peatlands, the retention of SO_4 and its reduction to sulfides and organic forms as well as the reduction of NO_3 to N gasses by denitrification also are significant ANC-producing processes (Turner et al. 1989).

When a sensitive lake is subjected to acid loading, either falling directly on the lake as precipitation and dry deposition or flowing in from the surrounding watershed, incoming acids are neutralized by HCO_3, which is consumed in the process. If HCO_3 is consumed faster than it is supplied by mineral weathering in the watershed and by in-lake processes, then ANC eventually falls to zero and the lake becomes acidic.

Baker et al. (1989) found that SO_4 is the dominant acidic anion in surface waters. At present, NO_3 generally contributes little acidity to lakes in the United States. Nitrate may be a significant source of acidity in some streams, especially during episodic flow events resulting from rain storms and snowmelt. Organic anions are an important source of acidity in many lakes associated with peatlands, especially in the upper Midwest.

Concentrations of SO_4 in surface waters are typically very low where deposition is low, and increase in a nearly linear fashion as deposition increases (Sullivan et al. 1988; Baker et al. 1989). Brakke et al. (1989) estimated background, pre-industrial SO_4 levels in lakes with low base cation concentrations in the Eastern United States to be about 10 to 15 ueq/L. While surface water SO_4 generally increases with deposition, there is considerable variation in this relationship due to differences in the supply of SO_4 from natural geologic sources, as well as differences in the amounts of SO_4 retained by the watershed by soil adsorption, reduction, and other processes.

Sulfate can be retained in the soil by adsorption to hydrous oxides of iron (Fe) and aluminum (Al) and the edges of 1:1 clay mineral particles (Bohn et al. 1986). Highly weathered soils normally contain considerable quantities of Fe and Al hydrous oxides and 1:1 clays and have high capacities to adsorb SO_4. Lakes and streams in the Southeastern United States contain low amounts of SO_4 relative to SO_4 deposition. Much of the SO_4 that falls on these watersheds apparently is absorbed by the old, highly weathered soils of the region and does not reach surface waters, at least at present. In the future, less SO_4 will likely be retained by the soil as SO_4 adsorption sites become saturated. In the Northeast and Midwest, relatively little SO_4 is retained by the soil.

In contrast to SO_4, NO_3 is taken up rapidly by aquatic and terrestrial biota and thus does not appear to promote lake acidification in most cases. At present, essentially all of the N deposited from atmospheric sources in watersheds of lakes in the Northeast and Midwest appears to be retained by the terrestrial portions of the watersheds or utilized by the aquatic biota (Baker et al. 1989). One exception is a group of lakes in the Adirondack Mountains in New York where NO_3 contributes up to 17 percent of the strong acid anions and appears to be associated with short-term variation in pH and aluminum (Henriksen and Brakke 1988). Terrestrial ecosystems that have received high levels of N deposition for many years may become N saturated and export significant amounts of NO_3. Henriksen and Brakke (1988) estimated the "nitrate mobility factor" (N_F) for lakes in Norway. This factor, defined as the ratio of NO_3 to SO_4

in runoff from a watershed divided by the ratio in total NO_3 and SO_4 inputs to the watershed, expresses the mobility of NO_3 (and thus its contribution to lake acidification) as a fraction of the mobility of SO_4. Mean values of N_F for individual counties in Norway ranged from 0.05 to 0.54, and increased with NO_3 deposition rate and amount of runoff.

While lakes in the Northeast and Midwest generally appear to be little affected by N deposition, the same may not be true for some streams. Baker et al. (1989) showed an approximately linear relationship between wet N deposition and NO_3 in streams in the Eastern United States, but the effect of N deposition on streams appears to be small, compared to that of SO_4. Stream NO_3 concentrations are only 10 to 30 percent of SO_4 concentrations at the same wet S snd wet N deposition rates.

Increased amounts of SO_4 (and in some cases NO_3) anions from atmospheric deposition, moving through the soil and entering surface waters, must be accompanied by equivalent amounts of cations. In soils in which about 15 percent or more of the negative exchange sites are occupied by base cations, Ca, Mg, K, and Na, much of the increase in solution cation concentration will consist of these base cations. However, in low base-saturated soils (less than 15 percent), due to a complex series of processes involving the presence of high partial pressures of CO_2 gas in soil, the equilibrium among carbonic acid, H, and HCO_3, and the reaction of H cations with the soil exchange sites, much of the increased cation load in soil solution and in discharge water to lakes and streams will be made up of H and Al species (Reuss and Johnson 1985). These hydrogen ions have an acidifying effect on surface waters. Dissolved Al is toxic to fish and other aquatic organisms. For example, dissolved Al in excess of 200 ug/L is toxic to brook trout (Schofield and Trojnar 1980; Baker and Schofield 1982).

Acidic soil water may percolate deep into the soil rather than flowing directly into a lake or stream. If this water comes in contact with weatherable, base cation-containing minerals in the subsoil or the underlying bedrock, it may be neutralized before reaching surface waters. During base flow conditions, the water flowing in streams typically comes from relatively deep soil water or ground water. During snowmelt or following large storms, however, streamflow often is dominated by shallow soil water. In areas impacted by heavy atmospheric acid loadings, sensitive streams with neutral or slightly alkaline pH's during base flow may have severely depressed pH's and toxic levels of dissolved aluminum during episodic snowmelt and stormflow events due to the flush of acidic Al-laden soil water into the streams (Swistock et al. 1989). These episodes may have detrimental impacts on stream fisheries (Gunn and Keller 1984; Gagen snd Sharpe 1987). Similar episodes of pH depression and elevated Al levels also have been seen in lakes during snowmelt in regions of high acid deposition.

Because approximately equal amounts of base cations and HCO_3 are released by weathering of carbonate and aluminum silicate minerals, the ratio between ANC and base cations is typically close to 1:1 in lakes and streams that are unaffected by acid deposition and that do not contain large amounts of organic anions. Atmospheric deposition increases SO_4 (and in some cases NO_3) in surface waters. To maintain the charge balance between cations and anions in solution, an acid deposition-induced increase in surface water SO_4 (and NO_3) must be accompanied by an increase in cations due to increased mineral weathering and cation leaching, and/or by a decrease in ANC. In very acid waters, an increase in Al cations may occur in place of a loss of ANC.

Henriksen (1984) defined a useful factor, F, for describing the response of surface water chemistry to acidic deposition. The value of F relates the increase in the concentration of base cations in surface water to the increase in SO_4 resulting from SO_4 deposition:

$$F = \text{change in base cations/change in } SO_4$$

The value of F ranges from 0 to 1. If F = 1, base cations increase with SO_4 in response to acid deposition while surface water ANC is unchanged. If F = 0, surface water ANC decreases as SO_4 increases while the concentration of base cations remains constant. In waters in which NO_3 deposition contributes to acidification, F should be considered in terms of the change in the surface water concentration of $SO_4 + NO_3$. The value of F for a particular lake or stream is determined by the characteristics of the individual watershed. In areas of readily weatherable calcareous bedrock and soils, F approaches 1. For very dilute lakes snd streams, F approaches 0 as hydraulic residence times in soils, mineral weathering rates, and soil base saturation decrease (Brakke et al. 1990).

Brakke et al. (1990) developed a method to estimate F for individual lakes from base cation concentrations:

$$F = \sin(90\ BC^*/S),$$

where BC^* = the sum of non-marine base cations in the lake and S = the value of BC^* at which F = 1. Data from lakes in southern Norway indicate that the value of S is between about 200 and 400 ueq/L. Brakke et al. (1990) estimate that F is about 0.2 to 0.4 for dilute lakes in the Western United States and 0.4 to 0.7 for acidic lakes in the Adirondacks.

In a review of biological effects of surface water acidification, Baker et al. (1990) concluded that the chemical constituents most influencing the biota are pH, inorganic monomeric (non-polymerized) aluminum, and Ca, with surface water pH being the single most important parameter. Fish or other aquatic organisms appear to be little affected so long as the pH remains at 6.5 or higher; however, noticeable adverse effects begin to occur as pH declines to about 6.0. The most acid-sensitive fish species, such as the fathead minnow (*Pimephales promelas*), experience reproductive failure at pH's near 6.0. Some important food organisms such as the opossum shrimp (*Mysis relicta*) disappear at pH's slightly below 6.0. Between pH 6.0 and 5.5, many species of zooplankton, mayflies, mollusks, minnows, and game fish are adversely affected. In general, fish eggs snd fry are more sensitive to acidity than adult fish, and fish populations succumb to reproductive failures at pH's above which adult fish can survive. In lakes where the average pH is below 5.0, most fish species, nearly all mollusks, and many other groups of bottom-dwelling organisms are eliminated, the food web is severely disrupted, and mats of algae frequently cover lake bottoms (Magnuson et al. 1984).

In studying the relationship between pH and the distribution of fish species in 138 lakes in Wisconsin, Rahel and Magnuson (1983) found that several species of minnows (*Cyprinidae*) and darters (*Etheostoma* spp.) were absent at pH's below 6.0. Black crappie (*Pomoxis nigromaculatus*), muskellunge (*Esox masquinongy*), smallmouth bass (*Micropterus dolomieui*), walleye (*Stizostedion vitreum*), and northern pike (*Esox lucius*) were absent at pH's below 5.5. A few species such as the bluegill (*Lepomis macrochirus*) and yellow perch (*Perca flavescens*) survive and reproduce successfully at pH 4.5. In an artificially acidified Canadian lake, reproductive failure in fathead minnow occurred below about pH 6.0, in lake trout (*Salvelinus namaycush*) below about pH 5.6, and in white sucker (*Catostomus commersoni*) below about pH 5.0 (Schindler et al. 1985). Brook trout (*Salvelinus fontinalis*) cannot survive at pH levels below 4.8 to 5.2 (Baker et al. 1990).

Aluminum solubility increases rapidly as pH decreases below about 6.0 (Hem 1985), but the chemistry of Al is complex and, consequently, its toxic effects on the biota are highly variable. Some Al in surface waters is bound to organic molecules and is relatively nontoxic (Baker et al. 1990). This can be an important factor in waters colored by drainage from wetlands. Above about pH 4.5, dissolved monomeric Al ions tend to polymerize (Hem 1985). In general, the inorganic monomeric fraction is considered the toxic component. Concentrations of inorganic monomeric Al above 10 to 50 ug/L cause adverse biological effects (Baker et al. 1990). Dissolved Al (monomeric plus polymeric) in excess of 200 ug/L has been found to be toxic to brook trout (Schofield and Trojnar 1980; Baker and Schofield 1982). Aquatic organisms can generally tolerate higher Al concentrations and lower pH's in waters that contain higher concentrations of Ca. At Ca concentrations below 100 to 150 ueq/L, small changes in Al can be important (Baker et al. 1990).

Green Line and Red Line Values

Selection of green and red line values for aquatic AQRVs was a two-step process. First, we determined the surface water ANC value above which normal healthy aquatic biota would be present and aquatic ecosystems would be unlikely to be adversely affected—the green line ANC value, and the ANC below which aquatic ecosystems would likely be adversely affected—the red line ANC value. We selected green and red line ANC values that we believed were indicative of the overall health of aquatic ecosystems and were applicable to all eight Class I wilderness areas.

The second step was to estimate the green and red line deposition rates of S and N for each Class I area. The green line deposition rates are the rates of total S and N deposition at which we estimated that the ANC of the most sensitive lake or stream in each Class I area would remain above the green line value. The red line deposition rates for each Class I area are those total S and N deposition rates at which we estimated the most sensitive lake or stream would have an ANC below the red line value.

We selected 25 ueq/L as the green line ANC value. Twenty-five ueq/L is about the lower limit of the range of ANC values over which the land manager can be reasonably certain that fish and other aquatic organisms will be unaffected by low pH. As Figure 2 shows, essentially all clear lakes (color less than 25 Pt-Co units) with ANC's of 25 ueq/L or more have air-equilibrated pH's of at least 6.5. These lakes should have a normal, healthy biota. Because of inputs of organic acids from peatlands or other wetlands, some moderately colored lakes (color between 25 and 75) with ANC's of from 25 to 50 ueq/L have pH's between 6.5 and 6.0. While marginal, these lakes should still have essentially normal fauna and flora populations. A few highly colored lakes (color greater than 75) in this ANC range have pH's as low as 5.5; some of the most acid-sensitive species probably would be absent from these lakes.

Below 25 ueq/L of ANC, surface water pH's drop sharply. Small losses of ANC result in relatively large decreases in pH. Below an ANC of 10 ueq/L, air-equilibrated pH's fall into the range in which chronic adverse biological effects can be anticipated (Fig. 2). We selected 10 ueq/L as the red line value ANC value for chronic or long-term effects. This is a more conservative red line ANC value than the –5 ueq/L red line that was used in the original screening process (Fox et al. 1989).

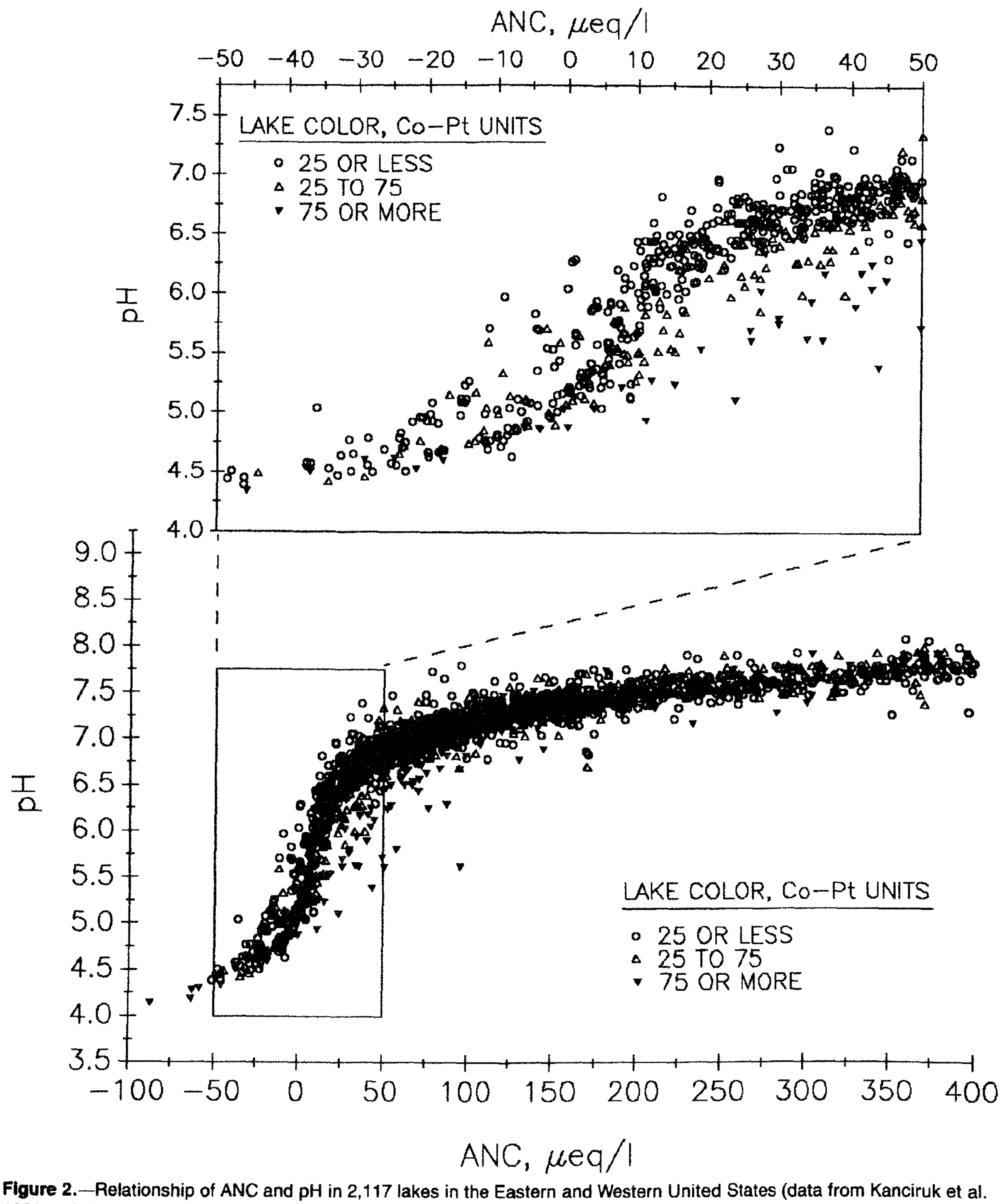

Figure 2.—Relationship of ANC and pH in 2,117 lakes in the Eastern and Western United States (data from Kanciruk et al. 1986 and Eilers et al. 1987).

In aquatic ecosystems that are adapted to natural episodic pH depressions, ANC and pH can probably fall below the chronic red line value for short periods without significant injury to the biota. For example, episodes with pH's below 5.0, ANC's below zero, and elevated Al concentrations for 2 to 5 days may be required before brook trout are adversely affected (Baker et al. 1990). In their review of episodic acidification of surface waters, Wigington et al. (1989) classified an episode as likely to impact aquatic biota if the pH minimum is 5.0 or less and the ANC falls below zero. We selected 0 ueq/L as the episodic red line ANC value.

To estimate the green and red line rates of total S deposition, i.e., the deposition rates that will result in green and red line ANC values for each wilderness area, we used available water-quality data, our best estimates of deposition rates, and empirical relationships between S deposition and concentrations of SO_4, base cations, and ANC in lake and stream water. While our estimates seem reasonable, we recommend that the green and red line deposition rates presented here be used as interim values until additional data can be collected and a more thorough analysis can be undertaken. This effort should involve comparisons of the results of multiple techniques such as other empirical models, simulations using models like MAGIC (Modelling the Acidification of Groundwater in Catchments; Cosby et al. 1985a,b) and ILWAS (Integrated Lakes-Watershed Acidification Study; Gherini et al. 1985), and paleolimnological studies (see section on research needs).

One concern is that empirical relationships such as those used here imply that surface water chemistry is currently in equilibrium with deposition. However, MAGIC simulations of water chemistry in Norway and the Eastern United States project that if deposition continues at its present rate or even decreases slightly (5 percent), sensitive lakes and streams will continue to acidify (Cosby et al. 1989; Sullivan et al. 1991).

On the basis of the relationship between N deposition and NO_3 concentrations in streams shown by Baker et al. (1989) and the NO_3 mobility factors for Norwegian lakes and streams estimated by Henriksen and Brakke (1988), we estimate that a given deposition rate of N has 20 percent of the acidification effect of the same rate of S deposition. The acidifying effects of N on surface waters cannot be considered separately from the effects of S, but at present and at the current deposition rates, S appears to be much more effective than N as an acidifying agent for surface waters in the United States. Therefore, we have estimated green and red line deposition rates for S alone and for S + 20 percent of N, but not for N alone. Again, these should be regarded as interim values until the effects of N deposition on each Class I area can be assessed more accurately.

Specific determinations were made for each wilderness area and are discussed in five sections (New Hampshire and Vermont, West Virginia, Wisconsin, Minnesota, and Missouri).

New Hampshire and Vermont: Presidential Range-Dry River, Great Gulf, and Lye Brook Wildernesses

Chemistry data from lakes and streams in and adjacent to these wilderness areas show that these waters are acidic and very sensitive to further acidification by atmospheric deposition. Base cation concentrations range from about 75 to about 150 ueq/L. ANC's range from about 10 ueq/L to less than zero, and pH's run from the low 4's to the high 5's. The pH's of waters with base cations in the 120 to 150 ueq/L range, mostly stream reaches at the lower and middle elevations, generally run from about 5.1 to 5.5. Waters with base cation concentrations below 100 ueq/L, mostly higher elevation lakes, have pH's from 4.4 to 4.8.

The most complete chemistry data set for any of the streams and ponds in the Presidential Range-Dry River/Great Gulf area is from Gibbs Brook, which originates a few hundred yards to the west of the Presidential Range/Dry River Wilderness boundary. The Gibbs Brook watershed is similar geologically and topographically to the Presidential Range-Dry River and Great Gulf Wilderness Areas, and the chemistry of Gibbs Brook should be representative of water chemistry conditions in the Wildernesses. The pH of Gibbs Brook ranges from about 5.1 and 5.4 during base flow conditions. ANC is only occasionally above zero. During high flows from snowmelt and storms, the pH falls to between 4.5 and 5.0. Base cation concentration is about 120 ueq/L. Sulfate averages about 100 ueq/L. Chloride (Cl) is low, less than 10 ueq/L.

Most of the available water chemistry data for the Lye Brook Wilderness are from Bourn Pond. Bourn Pond is chemically similar to Gibbs Brook; its pH ranges from about 4.8 to 5.5, with an average of about 5.2. ANC is typically in the –5 to +5 ueq/L range. The pH and ANC generally are lowest in the spring and early summer. Base cations average about 110 ueq/L, SO_4 about 100 ueq/L, and Cl about 10 ueq/L.

These data are indicative of surface waters that have been significantly impacted by acidic deposition. Marine sources of SO_4 and other ions appear to be small, as evidenced by the low Cl content of the waters. If we assume an average background (preindustrial) concentration of SO_4 in the surface water of about 15 ueq/L (Brakke et al. 1989), an organic anion concentration of about 10 ueq/L, and a cation enrichment factor (F) of 0.5 to 0.6 (see Brakke et al. 1990), then we estimate that Bourn Pond, Gibbs Brook, and the other ponds and streams in these areas have suffered an ANC loss of about 35 to 40 ueq/L due to acidic deposition.

Acidification of lakes in the Adirondack Mountains in New York has been estimated by use of the MAGIC model. The median change in ANC for the Adirondack lakes since preindustrial times was estimated to be –46 ueq/L (Sullivan et al. 1991). This compares well with the ANC losses estimated here for the surface waters of the Presidential Range-Dry River/Great Gulf and Lye Brook areas. Paleolimnological studies of diatoms in Adirondack lake sediments, however, suggest a somewhat smaller loss of ANC (Sullivan et al. 1991).

Many of the streams in these three wilderness areas contain populations of brook trout, typically at the lower and middle elevations. These populations are still viable but probably are stressed by the acidic conditions of the streams snd the loss of ANC. At higher elevations, in the headwaters of these streams are several small ponds that are too acidic to support permanent trout populations. Some of these, such as Bourn Pond, are thought to have supported permanent populations of brook trout in the past. In a survey of fish populations, Langdon (1984) found only two species of fish in Bourn Pond—brown bullhead (*Ictalurus nebulosus*), a highly acid-tolerant species, and brook trout, which is regularly supplemented by stocking. Fiske (1987) found a scarcity of acid-sensitive macroinvertibrate species in Bourn Pond. Langdon (1984) related the low number of fish species in Bourn Pond and other sensitive southern Vermont lakes to low pH and high Al concentrations.

Present total S and N deposition rates are estimated to be about 14 to 16 and 9 to 11 kg/ha/yr, respectively, in the Great Gulf/Presidential Range-Dry River and Lye Brook Wildernesses (Table 3). The ANC's and pH's of the ponds and streams in these areas currently are at or below both the chronic and episodic red line values. The existing brook trout and other aquatic organisms are likely to be experiencing stress and demage; additional deposition will cause additional damage. Some higher elevation populations may already have been destroyed. Therefore, we believe that the present S and N deposition rates for these wilderness areas are at or even above the red line values. We estimate the red line total S deposition rate to be 14 to 16 kg/ha/yr, and the red line S + 20 percent of N to be 16 to 18 kg/ha/yr.

To achieve the green line ANC value of 25 ueq/L, most of the surface waters in the Great Gulf/Presidential Range-Dry River and Lye Brook Wildernesses would have to increase in ANC by 15 to 25 ueq/L, which would require a substantial reduction in deposition. Galloway et al. (1984, 1987) has estimated the background (preindustrial) concentration of SO_4 in precipitation to be 5 to 7 ueq/L. Given 1,200 to 1,600 mm of annual precipitation, we estimate background S deposition (wet plus dry) in the Great Gulf/Presidential Range-Dry River and Lye Brook Wildernesses to have been 1.5 to 2 kg/ha/yr. We estimate surface water SO_4 to have increased by about 85 ueq/L over background. This is an increase in SO_4 of about 6 to 7 ueq/L for each 1 kg/ha/yr of S deposition. If we assume that surface water SO_4 will decrease at this same rate in response to a decrease in S deposition, and that ANC will increase at 40 to 50 percent of the rate of SO_4 decrease (i.e., $F = 0.5$ to 0.6), then a decrease in S deposition to about 6 to 8 kg/ha/yr will be necessary to achieve green line ANC values. This is similar to the 3 ueq/L ANC increase for each 1 kg/ha/yr decrease in S deposition projected for Adirondack lakes by the MAGIC model (Sullivan et al. 1991). Thus, we estimate the green line total S deposition rate to be 6 to 8 kg/ha/yr and the green line S + 20 percent of N deposition rate to be 7 to 9 kg/ha/yr.

West Virginia: Dolly Sods and Otter Creek Wildernesses

The bedrock of the Dolly Sods and Otter Creek Wildernesses consists of the Pennsylvanian age Conemaugh Group, Allegheny Formation, and Pottsville Group, underlain by the Mississippian age Mauch Chunk Group and Greenbrier Group (Cardwell et al. 1986). These are sedimentary materials—beds of sandstone, siltstone, shale, conglomerate, and some limestone. The Pennsylvanian strata also contain numerous coal beds. Limestone is more prevalent in the Mississippian groups; the Greenbrier is predominately limestone.

The ability of the streams in these wilderness areas to sustain populations of fish and other aquatic organisms is closely related to bedrock geology. Streams that arise in and flow through the Lower Pennsylvanian materials tend to be too acidic to support fish. Streams influenced by the Mississippian rocks tend to be more suitable for aquatic life. Similar geology extends northward into Pennsylvania. Studies in the Laurel Hill area of southwestern Pennsylvania, about 120 km north of the Otter Creek and Dolly Sods Wildernesses, showed that water from springs and seeps emanating from Allegheny and Pottsville strata had ANC's close to zero and pH's in the 4's. In contrast, water from the Mauch Chunk had ANC's of about 100 ueq/L and pH's in the 6's (Dinicola 1982; Sharpe et al. 1984). Some of the Allegheny and Pottsville strata contain pyrite (FeS_2) that produces SO_4 and acid as it oxidizes. Pyritic materials appear to be a source of natural acidity in many of the tributary streams in the Otter Creek and Red Creek systems.

In addition to natural sources of acidity, the streams in the Dolly Sods and Otter Creek Wildernesses receive a large acid load from atmospheric deposition. We estimate the mean annual total deposition rate of S and N to be about 21 and 16 kg/ha (Table 3), the highest among all the Class I wilderness areas in the Eastern Region. At present, the soils of the Dolly Sods/Otter Creek area appear to be retaining by adsorption 40 to 50 percent of the SO_4 deposited from the atmosphere based on research on an adjacent watershed (Helvey and Kunkle 1986). This retention of SO_4 provides to the streams some level of protection from the full effects of SO_4 deposition. Eventually, the SO_4 adsorption capacity of the soils will be saturated, and this protection will be lost. Decreases in the capacity of the soil to adsorb sulfate and resultant increases in stream water sulfate concentrations have been documented in recent years in some North Carolina streams (Wayne Swank, USDA Forest Service, Southeastern Forest Experiment Station, Coweeta Hydrologic Laboratory, pers. commun.).

Otter Creek, the main stream in the Otter Creek Wilderness, and Red Creek, which drains the Dolly Sods Wilderness, have many similarities. Both streams have some wetland acreage in their headwaters, particularly Red Creek, which has broad gentle slopes over much of the upper watershed. In these headwater areas, both streams are sensitive to acidification, but are still capable of supporting some fish species. During normal flow conditions, the pH in much of the Red Creek headwaters may typically be in the 6's, but the Left Fork is more acid and may be closer to pH 5 (Don Gasper, West Virginia Division of Natural Resources, unpublished data). Upper Red Creek contains a good population of creek chub (*Semotilus atromaculatus*), white sucker, and various daces. The headwaters portion of Red Creek is chemically suitable for brook trout (marginally), but often is too warm for trout because of beaver dams. The extreme headwaters of Otter Creek (upstream from the wilderness boundary) does contain brook trout.

Below these headwater reaches, both streams are affected by the influx of water from acidic tributary streams. Streams such as Fisher Spring Run, Stonecoal Run, and Little Stonecoal Run that flow into Red Creek, and Yellow Creek, Devil's Gulch, and Moore Run that enter Otter Creek, are very acidic and contain elevated concentrations of Al. Stonecoal Run typically has a pH of 4.0 to 4.5, and Al levels of about 180 to 500 ug/L. Stonecoal Run has a base cation concentration of about 90 ueq/L and a SO_4 concentration of about 170 ueq/L; ANC is less than zero. In Yellow Creek and Devil's Gulch, pH's between 3.7 and 4.0 and total Al concentrations from 400 to 600 ug/L are typical, and pH's as low as 3.3 to 3.4 and total Al concentrations as high as 900 to 1,200 ug/L have been measured during high flow conditions.

Downstream from its headwaters, Red Creek becomes too acidic to support fish except during low flow periods from late spring through the fall. Throughout the Dolly Sods Wilderness below the headwater reach, the pH of Red Creek typically ranges from the mid 4's to the high 5's. The lowest pH's occur in the late winter and in spring during snowmelt, and following rain storms. The highest pH's are recorded during low flow periods of the summer and fall. The average base cation concentration of Red Creek, just above Stonecoal Run, is about 150 ueq/L, and SO_4 averages about 140 ueq/L. ANC's range from less than zero to a high of about 15 ueq/L. Within the Dolly Sods Wilderness, the only part of the Red Creek system below the headwaters that appears capable of sustaining fish is an abandoned channel of Red Creek fed by several springs and seeps that emerge from bedrock strata of the Mauch Chunk Group. This spring-fed channel, with suitable water quality and spawning and rearing areas, harbors a small, self-sustaining population of brook trout. In the summer and fall, fish from this spring-fed channel enter Red Creek and may migrate a few miles upstream (Don Gasper, West Virginia Division of Natural Resources, pers. commun.). With no competition, these fish grow quickly; however, they do not appear to survive the acidic springtime conditions in Red Creek.

The chemistry of Otter Creek is altered just before it flows into the Otter Creek Wilderness by a facility that adds limestone to the water to raise its pH and ANC to sustain a brook trout fishery in the stream. Upstream of the liming operation, Otter Creek is acidic, with pH's of from less than 4.0 to about 5.5. The only tributary of Otter Creek in which the presence of brook trout has been documented is Turkey Run, which flows into Otter Creek from the northwest a few miles upstream from the lower Wilderness boundary. It is not known if Turkey Run still contains trout; the last fisheries survey on this stream was conducted some twenty years ago. One other stream in the Otter Creek Wilderness, Shavers Lick Run, is chemically suitable for trout in its lower reaches, but its fish population has not been documented. Shavers Lick Run rises near the lower end of the Wilderness and does not discharge into Otter Creek.

There are indications of increased acidity of the streams in the Dolly Sods and Otter Creek Wildernesses due to acidic deposition. The West Virginia Division of Natural Resources has been monitoring water quality and fish populations for many years in Otter Creek and other nearby streams. Their data show a long-term trend of increasing stream acidity and fish population effects in poorly buffered mountain streams. In early June, 1990, following several days of heavy rain, a pH of 3.7 was recorded in Otter Creek just above the liming facility (Barry Edgerton, Monongahela National Forest, pers. commun.). Fish populations in Otter Creek are artificially maintained by liming, and fish population data from Red Creek are insufficient to show a trend. Data from other nearby streams show a recent loss of fish due to acidification.

The pH and ANC of Red Creek and its tributaries are presently below both the chronic and episodic red line values, except for the headwater area and a reach of abandoned stream channel fed by several small springs and seeps from the Mauch Chunk Group, as described earlier. In the absence of the liming operation, the pH and ANC of Otter Creek would be below the red line values. The only streams in the Otter Creek Wilderness that may be capable of sustaining fish populations without liming are Turkey Run and Shavers Lick Run. The aquatic ecosystems of the Otter Creek and Dolly Sods Wildernesses are under considerable stress from a combination of natural and deposition-derived acidity. Additional acidic loadings from S and N deposition will further stress the aquatic ecosystems, and will jeopardize the existing populations of fish and other aquatic organisms.

Current total S and N deposition rates are estimated to be 21 and 16 kg/ha/yr, respectively, in the Dolly Sods and Otter Creek Wildernesses (Table 3). Due to adsorption of 40 to 50 percent of the depositional SO_4 load by the soils, the effective S deposition rate is estimated to be about 11 to 13 kg/ha/yr. As the SO_4 adsorption capacity of the soil is depleted, the effective deposition rate will increase and eventually approach the actual deposition rate. Since stream pH and ANC values already are below the red line values (or would be without liming), we estimate the red line total S deposition rate for the Otter Creek and Dolly Sods Wildernesses, given the eventual saturation of the SO_4 adsorption capacity, to be the current effective rate of 11 to 13 kg/ha/yr. We estimate the red line S + 20 percent of N deposition rate to be about 14 to 16 kg/ha/yr.

Available historical data indicate that the natural pH and ANC of Red Creek and Otter Creek, in the absence of any anthropogenic acid loadings, probably were at or below the green line values, and that any additional acid loadings from deposition would be detrimental. Thus, we estimate the green line S and N deposition rates to be close to background levels.

Wisconsin: Rainbow Lake Wilderness

The 22 lakes in the Rainbow Lake Wilderness are seepage lakes. They receive much of their water from direct on-lake precipitation; the remainder is from seepage of groundwater. They have no surface water inputs. Several of these lakes are sensitive to acidic deposition. The 13 lakes for which water chemistry data are available have ANC's from about 10 to about 60 ueq/L. Their pH's range from 5.6 to 6.3, and average about 5.9. Base cation concentrations range from about 80 to 170 ueq/L. These are summertime data; in the spring, ANC's and pH's may be lower due to melting snow. The lakes fall into two groups with regard to sensitivity. Eight of the 13 have summer ANC's of about 10 to 30 ueq/L. The other five lakes are less sensitive, with ANC's in the 55 to 60 ueq/L range.

The base cation and ANC concentrations of seepage lakes such as these depend largely on the proportion of water supplied by groundwater. A hydrologic study of four northern Wisconsin seepage lakes showed that three of the lakes with mean ANC's ranging from 21 to 118 ueq/L receive from 3 to 15 percent of their water from groundwater, while the fourth lake with a mean ANC of 384 ueq/L receives 30 percent groundwater (Garrison et al. 1987). The ANC of a seepage lake in Upper Michigan was observed to drop from 178 to 22 ueq/L over a 5-year period when drought conditions substantially reduced the input of ANC-rich groundwater (Webster et al. 1990).

Fisheries surveys have been conducted on 12 of the 13 lakes in the Rainbow Lake Wilderness for which water chemistry data are available. The two largest lakes contain largemouth bass (*Micropterus salmoides*), and another has been stocked with rainbow trout (*Salmo gairdneri*). Several hold bluegill, perch, and other panfish, and a variety of minnows and rough fish. No fish were found in four lakes. The presence or absence of fish appears to be related to winter survival. The fishless lakes are among the smallest and most shallow of the lakes surveyed.

On the basis of the relationship between base cation concentrations and F value suggested by Brakke et al. (1990), a reasonable estimate of the F value for the most sensitive of these lakes is about 0.4. However, since most of the water in these lakes is from direct on-lake precipitation and does not react with the soils and minerals in the watershed, cation enrichment probably is minimal. The ILWAS model was used to simulate water chemistry responses to changes in S deposition in two low-ANC seepage lakes, Crystal and Vandercook, in north-central Wisconsin (Chen et al. 1986; Garrison et al. 1987). These simulations indicated F values of close to zero. We estimate F to be about 0.2 for the most sensitive Rainbow Lake Wilderness lakes.

The SO_4 concentrations of the lakes in Rainbow Lake Wilderness range from about 40 to 60 ueq/L. Background SO_4 concentrations for dilute lakes in the Eastern United States have been estimated at about 15 ueq/L (Brakke et al. 1989). This indicates that the Rainbow Lake Wilderness lakes have incurred an average SO_4 increase of about 35 ueq/L above background concentrations due to anthropogenic S deposition. If F = 0.2, then they have incurred ANC losses of about 25 ueq/L due to acid deposition.

Two of the 13 lakes for which data are available have mean ANC's of 10 to 20 ueq/L, well below the green line value of 25 ueq/L and into the yellow zone. The mean ANC's of five other lakes are about equal to the green line value of 25 ueq/L—some individual ANC measurements from these lakes also fall into the yellow zone. These lake chemistry data indicate that the current S deposition rate of about 6 kg/ha/yr (Table 3) is in the yellow zone between the red line and green line values. Only a small increase in S deposition would be required to reduce the ANC of the most sensitive of these lakes to the red line value of 10 ueq/L.

On the basis of Galloway et al.'s (1984, 1987) estimate of background SO_4 concentration in precipitation of 5 to 7 ueq/L and an average annual rain and snowfall of about 800 mm in northwestern Wisconsin, we estimate the background S deposition rate on the Rainbow Lake Wilderness to have been about 1 to 1.5 kg/ha/yr. Lake water SO_4 appears have increased by about 35 ueq/L over background, an increase in SO_4 of about 7 to 8 ueq/L for each kg/ha/yr of S deposition. As a comparison, ILWAS simulations of Crystal and Vandercook Lakes (Chen et al. 1986; Garrison et al. 1987) projected a SO_4 change of about 6 to 8 ueq/L for each kg/ha/yr change in S deposition.

Given an annual average of about 800 mm of precipitation and about 300 mm of runoff (Geraghty et al. 1973), a 1 kg/ha/yr increase in S deposition could increase SO_4 concentrations in northern Wisconsin lakes by as much as 20 ueq/L, if no SO_4 were retained by reduction in wetlands and lake sediments or by adsorption in upland soils. Baker et al. (1986) developed a model that showed that in lakes with long hydraulic retention times (several years) typical of low ANC seepage lakes, SO_4 reduction in the lake sediments can reduce SO_4 concentrations in the water by 50 percent or more. On the basis of ILWAS simulations, Garrison et al. (1987) estimated that if SO_4 reduction were eliminated, the SO_4 concentrations of Crystal and Vandercook Lakes would increase by almost 100 percent.

If the F value of these lakes is about 0.2, then an increase in the current 6 kg/ha/yr total S deposition rate of about 1.5 to 2.5 kg/ha/yr would be sufficient to decrease the ANC of the most sensitive of these lakes to less than the red line value of 10 ueq/L. Similarly, a decrease in S deposition of similar proportions could increase the ANC of the most sensitive lakes to the green line value of 25 ueq/L. These estimates compare well to the ILWAS simulation of Crystal and Vandercook Lakes in which a 50 percent change in S deposition (a change of about 3 kg/ha/yr) was projected to cause a 20 ueq/L change in lake ANC (Chen et al. 1986; Garrison et al. 1987). We estimate the green and red line S deposition rates for the Rainbow Lake Wilderness to be about 3.5 to 4.5 kg/ha/yr and 7.5 to 8.5 kg/ha/yr, respectively. The corresponding estimated green and red line deposition rates of S + 20 percent of N are about 4.5 to 5.5 and 9.0 to 10.5 kg/ha/yr, respectively.

Minnesota: Boundary Waters Canoe Area Wilderness

In contrast to the Rainbow Lake Wilderness lakes, most of the BWCAW lakes are drainage lakes. Much of their hydrologic input is from surface runoff from their watersheds. BWCAW waters are moderately sensitive to sensitive with regard to acidic deposition. About 75 percent of the lakes have ANC's of 200 ueq/L or less, and about 35 percent have less than 100 ueq/L. However, only about 5 percent have ANC's below 50 ueq/L, and none is below the ANC green line value of 25 ueq/L. Base cation concentrations of the most sensitive lakes are about 130 to 140 ueq/L. The pH's of even the most sensitive lakes generally are 6.5 or greater. A small proportion, perhaps 2 percent, have pH's between 5.5 and 6.5; these are typically dark-colored lakes influenced by naturally acidic drainage from peatlands. The most sensitive BWCAW lakes appear to have sufficient buffer capacity to handle the present depositional loadings of S and N. The fish populations in lakes and streams in the BWCAW are typically healthy and abundant.

The most sensitive BWCAW lakes for which we have data have ANC's of about 40 ueq/L. They could sustain an ANC loss of 15 ueq/L without falling below the 25 ueq/L green line value. Given base cation concentrations of 130 to 140 ueq/L, we estimate (using the method of Brakke et al. 1990) the F value of these lakes to be about 0.6. Consequently, we estimate that an ANC loss of 15 ueq/L would result from a lake SO_4 increase of about 35 to 40 ueq/L.

In the BWCAW, the relationship between S deposition rate and lake SO_4 concentrations is difficult to derive from comparisons of estimated background precipitation and lake SO_4 concentrations with present values. Many of the BWCAW lakes lie on geologic formations that contain extensive low-grade sulfide deposits (Sims and Morey 1972). Therefore, estimates of average background SO_4 concentrations for eastern lakes (e.g., Brakke et al. 1989) are too low for many BWCAW lakes. Nichols and McRoberts (1986) found that lakes near the eastern end of the BWCAW contained about 50 ueq/L more SO_4 than would be expected from S deposition alone.

Average annual precipitation in the BWCAW is about 675 to 725 mm. Annual runoff averages about 250 to 300 mm (Geraghty et al. 1973). In the absence of in-lake or watershed SO_4 retention processes, an increase in S deposition of 1 kg/ha/yr could increase BWCAW lake SO_4 by 20 to 25 ueq/L. However, considering the importance of SO_4 reduction in lake bottom sediments and in peatlands in the watershed, we estimate the actual increase in lake SO_4 from each kg/ha/yr increase in S deposition to be about 12 to 15 ueq/L. Given F values of 0.6, we estimate an ANC decrease of 5 to 6 ueq/L in sensitive BWCAW lakes for each kg/ha/yr increase in S deposition.

For the most sensitive BWCAW lakes for which we have data, those with ANC's of about 40 ueq/L, we estimate that a reduction of 15 ueq/L to the green line ANC value of 25 ueq/L would result from a S deposition increase of about 2.5 to 3.0 kg/ha/yr. An additional 2.5 to 3.0 kg/ha/yr would further reduce ANC's to the red line value of 10 ueq/L. The present total S deposition rate in the BWCAW is about 5 kg/ha/yr (Table 3). We estimate the green line S deposition rate to be about 7.5 to 8.0 kg/ha/yr and the red line S deposition rate to be 10 to 11 kg/ha/yr. The green and red line values for S + 20 percent of N deposition would be about 9 to 10 and 12 to 13 kg/ha/yr, respectively.

In 1982, the State of Minnesota passed the Acid Deposition Control Act. Under this legislation, the Minnesota Pollution Control Agency conducted an analysis to determine a S deposition limit that would protect the most sensitive lakes and streams in Minnesota from acidification. This limit was set at 11 kg/ha/yr of wet SO_4 deposition. From the relationship between wet and dry S deposition in the BWCAW (Table 3), 11 kg/ha/yr of wet SO_4 is equivalent to about 6 kg/ha/yr of total (wet plus dry) S deposition. This is somewhat lower than our green line estimate for the BWCAW.

Missouri: Hercules Glades Wilderness

The Hercules Glades Wilderness lies on the southwestern portion of the Ozark Plateau. The geologic formations that make up the Ozark Plateau are predominantly limestone and dolomite. The carbonate minerals in these rocks provide a large buffering capacity against the effects of acidic deposition. Samples taken from Long Creek, the main stream in the wilderness, in the summer of 1990 had ANC and base cation concentrations of about 4,000 to 6,000 ueq/L. Springtime concentrations are probably substantially lower but should provide abundant buffering. A sample taken from Beaver Creek, which flows along the northwestern boundary of the wilderness for a short distance, had a pH of 8.0 and an ANC exceeding 2,000 ueq/L. The impoundments on the White River, just west and south of Hercules Glades Wilderness, typically have pH's in the 7.2 to 7.8 range and ANC's of 1,000 to 2,000 ueq/L. Because of the high buffering capacity of this area, the present estimated total S and N deposition rates of 9 and 8 kg/ha/yr, respectively, (Table 3) pose no threat to aquatic ecosystems. We estimate the green line S deposition rate to be greater—perhaps much greater—than 30 kg/ha/yr, and the S plus 20 percent of N rate to be greater than 35 kg/ha/yr. We did not attempt to estimate red line values.

Information Needs

Inventory and Monitoring

Workshop participants identified many information needs for successful response to PSD permit applications, but indicated the primary need was for thorough characterization and inventory of the wilderness areas. Existing inventory data for each of the wilderness areas in Region 9 should be assembled from its many sources and locations, and information gaps be filled as soon as possible. The biological resources of each area should be characterized, and should include listings of aquatic and terrestrial flora and fauna, and descriptions of ecosystems. Soils should be described to the family level (Soil Survey Staff 1987). Bedrock type and geologic formations also should be characterized. Information on pollutant delivery to each area should be quantified. Particular emphasis should be given to identifying threatened and endangered species and those that are particularly sensitive to air pollutants.

Monitoring entails continued measurement of the status of the system over time. Monitoring needs for aquatic systems include atmospheric loading of pollutants, chemical characteristics of stream or lake waters, and presence or absence of potentially sensitive receptor species. For terrestrial ecosystems, reliable monitoring of species richness as well as air quality and deposition is necessary. Monitoring for both aquatic and terrestrial systems must be consistent and of high quality.

Monitoring of ozone should be the first priority for terrestrial ecosystems. Ozone concentrations can vary significantly with elevation, and this elevational gradient should be taken into consideration when locating monitoring stations. Current ozone effects in wilderness areas also should be assessed through biomonitoring. This already has begun on the Dolly Sods, Lye Brook, and Great Gulf Wildernesses, and can be implemented fairly easily at other sites. Because of the restrictions placed on wilderness use, and due to the high biological complexity on some of these eastern wildernesses, traditional methods of ozone monitoring, although well developed, may need some modifications.

Monitoring of deposition of the major cations and anions in precipitation (wet deposition) should continue to be carried out at the existing NADP/NTN stations. The Forest Service should ensure that funding is maintained for operation of NADP/NTN sites that are relevant to Class I wilderness areas. In addition to the NADP/NTN network, applicable data may be available from several other wet deposition networks, for example, MAP3S, UAPSP, CAPMON, and APIOS-C (see Sisterson et al. 1990). If no NADP/NTN or other network sites are applicable to a certain wilderness, provision should be made for establishing and maintaining an equivalent monitoring site.

Water chemistry monitoring should be conducted on a subsample of surface waters in each Class I wilderness area. This subsample should include the most sensitive lakes and streams, or the waters of greatest concern.

Workshop participants suggested a sampling protocol of collection of water samples 3 times a year in every third year. Timing of sampling might include springtime snowmelt peak flow, summer low flow, and autumn turnover. Stream chemistry often is affected by large precipitation events. Chemistry of sensitive seepage lakes may be influenced by annual or multiyear precipitation patterns that affect groundwater levels and lake inputs. Long-term sampling is needed to separate annual and seasonal variations in water chemistry from pollutant-induced changes. The "best" times for sampling and the intensity of sampling required will depend on the area, and more detailed determinations are needed.

Monitoring of biological resources also is needed. Detection of population changes for any specified organism is extremely difficult due to high natural variation, but potentially sensitive receptor organisms should be monitored for their presence or absence. Historical records should be consulted to establish the existence of previous populations of organisms. Birds, fish, aquatic invertebrates, amphibians, and diatoms are candidates for monitoring. Biomonitoring of vegetation for pollutant injury symptoms also can be done. Biomonitoring programs may be limited because the sensitivity of many rare and endemic plants to air pollutants is not known.

Research Needs

Dry deposition is an important component of total deposition, but is not well quantified. In this report, estimates of dry S deposition were derived from the Regional Acid Deposition Model (RADM) described by Chang et al. (1987) as percentages of wet S deposition. Dry N deposition rates, as percentages of wet N deposition, were estimated from data from CORE/Satellite sites as summarized by Sisterson et al. (1990). Another method of estimating dry deposition entails measuring throughfall chemistry at specific sites. The throughfall method has been used on several research areas. See Sievering (1987) for an analysis of the method and Lindberg et al. (1986) for a case study. Dry deposition also can be estimated by multiplying ambient concentrations by "deposition velocities." Ambient concentrations of S and N forms are measured at about 50 sites in the National Dry Deposition Network (NDDN), sponsored by the U.S. EPA. Although estimates of deposition velocities are given in the USDA Forest Service's Air Resource Handbook, deposition velocities vary considerably (orders of magnitude) for different S and N species, for different surfaces such as forest, grassland, water, and bare rock, and for different atmospheric conditions. Pollutant deposition velocities should be developed for subareas of each Class I wilderness.

In mountainous areas, the deposition of pollutants dissolved in cloud droplets onto vegetation surfaces at high elevations can exceed wet plus dry deposition. Cloud deposition begins to be important at elevations of about 850 to 900 m and increases with elevation. Knowledge of high-elevation deposition by any process is sparse, although some information is available from the Mountain Cloud Chemistry Program (Mohnen 1990). To fill the information gap about high-elevation deposition, Lovett and Kinsman (1990) suggest an increased density of deposition monitoring sites in mountainous regions; specific studies of wet, dry, and cloudwater deposition along elevational gradients; and investigations of the factors that regulate deposition in mountainous areas to allow extrapolation of results to other sites. Because of the difficulties of carrying out intensive deposition studies in designated wilderness areas, the ability to extrapolate data to wilderness sites is important.

For many pollutants, models that describe the links between emissions and pollutant loading are not available. Most notably, it is not well known how ozone concentrations at a particular location are related to emissions of volatile organic compounds. Additionally, research on the relation of SO_2 emissions and SO_4 exposure is needed. Sorely needed is information about the effects of cumulative exposure on the ecosystems of concern. Deposition reductions will not necessarily be immediately reflected in improvements in water quality or diminished effects upon organisms. Continued deposition at even lower rates could result in acidification of some surface waters. At present, cumulative exposure might be best assessed by the use of simulation models.

To assess cumulative impacts and potential impacts of predicted changes in deposition, simulation models such as ILWAS (Gherini et al. 1985) and MAGIC (Cosby et al. 1985a,b) are useful. Such models can be used to estimate dose-response functions for individual wildernesses or their component parts. These functions are independent of any particular PSD, so modeling need only be done once rather than in response to each PSD application. Both ILWAS and MAGIC have been in use for several years and already may have been calibrated and run for watersheds similar to many of the Class I areas discussed here. This could significantly decrease the cost of data collection and calibration. Because of the uncertainties and biases inherent in any method, predictions of the response of the Class I wilderness areas to acidic deposition should be made using a combination of methods, including simulation models like ILWAS and MAGIC, empirical steady-state models (e.g. Brakke and Henriksen 1989) (with some adjustment for in-lake ANC production (Baker et al. 1986) where appropriate), and paleolimnological studies of diatom communities. The Forest Service should place a priority on assembling the appropriate data and running these models for all Class I areas in the Eastern Region.

The procedure described in this report is interim. The recommended criteria will change with the dramatically changing state of science in air pollution effects. Managers and scientists will have to review these changes and adjust the criteria and possibly the procedure. We recommend that:

1. Representatives of the Eastern Region, the Northeastern Forest Experiment Station, the North Central Forest Experiment Station and Northeastern Area State & Private Forestry periodically review the applicability of this screening procedure and jointly recommend changes needed in the criteria;

2. National Forest and research project staff annually meet to assure effective inventory and monitoring of resource conditions in Class I areas, to assure that managers are using recent research results and to help researchers understand the problems of managers.

Acknowledgment

Participants at the May 1990 Forest Service workshop in Oconomowoc, Wisconsin, provided advice on a screening procedure for identifying impacts to the AQRVs of National Forest Eastern Region Class I air quality areas. Workshop participants also were given an opportunity to review the draft of this report; we also obtained peer review by scientists who were not at the meeting. Dr. Lewis Ohmann of the North Central Forest Experiment Station, Dr. Christopher Eagar of the Northeastern Forest Experiment Station, and James Byrne of the Forest Service's Washington Office provided review comments on the final draft.

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Appendix I

General Description of Air Quality-Related Values for Eastern Region Class I Areas

DOLLY SODS WILDERNESS

Location: Monongahela National Forest, Eastern West Virginia	Size:	10,215 acres
	Designated:	1975
Latitude: 38° 57′ 30″ to 39° 02′ 30″	Elevation:	2,620 to 4,122 feet
Longitude: 79° 19′ to 79° 24′ 30″		

General Description

Dolly Sods Wilderness, which is on the Allegheny Plateau, is named for the pioneer Dahle family which owned and cleared some of the land for pasture ("sods" is an old term for grassland). It is about 10 miles from Petersburg, West Virginia, and 175 miles from Washington, D.C.

Evidence of human presence in the area is apparent. Remnants of the extensive network of roads and trails necessary to harvest timber in the late 1800's and early 1900's can still be seen. Grazing, once an important use, no longer occurs. A harsh climate resembling that found much farther north is a major influence.

Vegetation. Second-growth beech, birch and maple, dense rhododendron, laurel, blueberry, and other heath vegetation are common, as are wetland communities. Red spruce is common in the upper elevations, and some oak is found at lower elevations.

Wildlife. Deer, black bear, bobcat, beaver, grouse, turkey, woodcock, rabbit, and numerous other birds, mammals, amphibians, and reptiles, including the eastern timber rattler, inhabit the wilderness.

Weather. The climate is severe and temperatures are cool. Frost can occur at any time but is rare during most of the summer. Prevailing westerly winds blow most of the time, and the upper elevations often are covered by clouds or fog. Annual precipitation is about 55 inches. Frequent and sudden weather changes are common.

Air Quality-Related Values

Scenic Beauty. The scenic beauty of the Dolly Sods Wilderness is a primary attraction for its users. Features include rock escarpments which provide panoramic views of the deeply incised Red Creek, the high-elevation plateau, mountain summits, and surrounding ridge lines. Visual diversity is enhanced by contrasting wetland/bog associations, high-elevation spruce, mixed hardwoods, and early successional vegetation such as blueberry. Users enjoy the sense of solitude and a variety of landforms and associated vegetative communities and wildlife. Extensive thickets of rhododendron and mountain laurel throughout the wilderness provide pleasing diversity during their flowering period. Lower Red Creek is rock-strewn and fast flowing, and periodically flows out of the channel. Its waters are stained reddish-brown from the wetlands and other vegetation in the creek's upper reaches. Most of the recreation use within the Dolly Sods Wilderness occurs along Red Creek.

Vegetation. The overstory is dominated by a mixture of second-growth northern and Allegheny hardwoods which are 60 to 80 years old. There are separate components of oak, heath, and associated species. Spruce is present at higher elevations. There are scattered pockets of wetland/bog associations, and about 1000 acres in a grass/forb stage. Extensive thickets of rhododendron and mountain laurel are found throughout the wilderness.

Water. Red Creek is the dominant water resource of this wilderness. Fed by numerous tributaries, the creek is stained reddish-brown with tannic acids from headwater wetlands and other vegetation. All waters are acid and unproductive. Red Creek has historically been a marginal fishery.

Odor. The natural smells of the forest are an important value to wilderness users. Conifers, hardwood leaf litter, and wildflowers provide pleasant odors which enhance the outdoor experience.

Wildlife. A variety of mammals, birds, reptiles, and amphibians inhabit the wilderness, including the Cheat Mountain salamander, a federally listed threatened species. Some nongame fish species are present, including the uncommon pearl dace. There is a small population of native brook trout in Red Creek.

OTTER CREEK WILDERNESS

Location: Monongahela National Forest, Eastern West Virginia	Size:	20,000 acres
	Designated:	1975
Latitude: 38° 55′ 30″ to 39° 03′ 30″	Elevation:	1,830 to 3,912 feet
Longitude: 79° 35′ to 79° 42′ 30″		

General Description

Otter Creek Wilderness is located about 10 miles northeast of Elkins, West Virginia. Otter Creek runs 11 miles through a valley and is followed by a trail along its 1,200-foot drop to the Dry Fork River. Parallel mountain ridges that reach heights of 3,900 feet encircle a 4-mile-wide oval watershed with numerous small streams flowing into Otter Creek.

Vegetation. The wilderness was logged during the late 1800's and early 1900's and again between 1958 and 1972. Most of the wilderness is now forested with second-growth stands of northern hardwoods and Allegheny mixed hardwoods. Nearly impenetrable stands of waxy-leaved rhododendron cover extensive portions of the area, making off-trail hiking difficult. Red spruce occupies some of the higher elevations and there are some small freshwater wetland communities.

Wildlife. Black bear, white-tailed deer, bobcat, beaver, wild turkey, grouse, snowshoe hare, cottontail rabbit, salamander, and numerous other bird, mammal, amphibian, and reptile species, including the timber rattler, inhabit the wilderness. There is a small population of brook trout in Otter Creek due to improved water quality from an artificial liming station.

Weather. Cool temperatures prevail and frost may occur during any month of the year. The area receives about 55 inches of precipitation annually.

Air Quality-Related Values

Scenic Beauty. The scenic beauty of the Otter Creek watershed is highly valued by its users. Panoramic views of nearly the entire watershed are obtained from a number of large rock cliffs. The visual resource includes the Otter Creek valley and mountains which rise more than 3,800 feet above sea level. Visual diversity is provided by a number of small freshwater wetlands and rock outcrops. Many users experience a sense of solitude and peace when they are in the mature, second-growth forest that also provides visual diversity through a variety of tree and shrub species. Otter Creek itself is a clear, clean mountain stream, tumbling over boulders in alternating small waterfalls and pools. Much of the recreation use in the wilderness occurs in and near Otter Creek.

Vegetation. An overstory of second-growth northern hardwoods and Allegheny mixed hardwoods dominates the Otter Creek Wilderness. Red spruce in the higher elevations provides visual and vegetative diversity year around. A 59-acre patch of virgin red spruce and hemlock on Shavers Mountain provides a remnant of the prelogging era timber found in Otter Creek. Another interesting feature is a 50-year-old stand of planted Norway spruce, approximately 200 acres in size. Extensive rhododendron thickets are common, and their seasonal flowering provides an attractive understory. Otherwise, the ground and herbaceous understory is lacking in the richness and diversity found at other low-elevation mesic sites. There are limited areas of limestone bedrock where a more diverse understory vegetative mix provides visual variety. Small freshwater wetlands and their associated plant communities provide additional vegetative diversity.

Water. Otter Creek is the dominant water resource of this wilderness. Several smaller acid and unproductive tributaries flow into the main stream. Water quality in Otter Creek is not representative of natural conditions due to an artificial liming facility that operates in its headwaters. Waters are cold and clear, and tributaries generally are stained brown from tannic acids. Water quality is important to wilderness users for drinking purposes. Water quality of Shavers Lick Run, a perennial stream within the wilderness that is not a tributary to Otter Creek, is better than that of the tributaries.

Odor. The natural smells of the forest are an important value to wilderness users. Conifers, hardwood leaf litter, and wildflowers provide pleasant odors which enhance the enjoyment of being outdoors.

Wildlife. Wilderness visitors enjoy a variety of game and nongame animals. Otter Creek is home to numerous birds, large and small mammals, reptiles, amphibians, and fish. The Virginia northern flying squirrel, a federally listed endangered species, occupies the upper elevations of the wilderness. The threatened Cheat Mountain salamander is found in the wilderness uplands. There are populations of native brook trout in Otter Creek due to improved water quality from the artificial liming facility at its headwaters.

GREAT GULF WILDERNESS

Location:	Size:	5,552 acres
White Mountain National Forest	Designated:	1975
North Central New Hampshire		
Latitude:	Elevation:	1,680 to
44° 15′ 00″ to 44° 22′ 30″		5,807 feet
Longitude:		
71° 15′ 00″		

General Description

The Great Gulf Wilderness is shaped like a large amphitheater—the northern and western boundaries follow the ridge of the Presidential Range. The steep cliff-like walls of this range surround a clear mountain lake and numerous cascading streams. The wilderness features high mountain peaks, glacial cirques, and unique tundra and krummholz vegetation.

The Great Gulf Wilderness is small; roads parallel the boundary for considerable distances. Nearby is heavily used Mt. Washington State Park. As a result, the wilderness receives much day use.

Vegetation. Hardwoods cover the lower slopes; mixed birches, maples, and spruce-fir blanket midslopes; and pure spruce-fir covers the upper slopes. Parts of the major ridges are above timberline with krummholz vegetation.

Wildlife. Wildlife is not a prominent feature, though deer, black bear, grouse, hare, and a variety of birds associated with high mountain slopes are found in the wilderness.

Weather. The weather is strongly influenced by the elevation and geographic location. The Great Gulf Wilderness lies between two major paths of weather-system movement which can cause dramatic changes in local weather conditions. It is not uncommon for temperatures to be in the sunny 80's in the valleys and 30 to 40 degrees cooler on the summits with high winds, rain, and fog. Winds in excess of 100 miles per hour have been recorded for every month of the year. Average annual precipitation is 60 inches with 25 to 30 percent falling as snow; average annual snowfall is 160 to 240 inches.

Air Quality-Related Values

Because of contiguity and similarities, AQRVs for this wilderness are included with those for the Presidential Range-Dry River Wilderness.

PRESIDENTIAL RANGE-DRY RIVER WILDERNESS

Location:	Size:	27,380 acres
White Mountain National Forest		
North Central New Hampshire	Designated:	1975
Latitude:		
44° 07′ 30″ to 44° 15′ 00″	Elevation:	880 to
Longitude:		5,413 feet
71° 15′ 00″ to 71° 22′ 30″		

General Description

The Presidential Range-Dry River Wilderness features mountain peaks ranging from 3,000 to 5,400 feet, some areas above timberline, distinctive geologic formations, and unique biological communities. The northwest boundary is the ridge of the Presidential Range and the the Appalachian Trail (a National Scenic Trail) runs along the northern and western boundary.

Vegetation. Hardwoods occupy the lower slopes; mixed birches, maples, and spruce-fir blankets the midslopes; and pure spruce-fir covers the upper slopes. A portion of the major ridges is above timberline with typical krummholz vegetation.

Wildlife. Wildlife is not a prominent feature of this wilderness, though deer, black bear, grouse, hare, and a variety of birds associated with high mountain slopes are found here.

Weather. The weather is strongly influenced by the elevation and geographic location. The Presidential Range lies between two major paths of weather-system movement which can cause dramatic changes in local weather conditions. It is not uncommon for temperatures to be in the sunny 80's in the valleys and 30 to 40 degrees cooler on the summits with high winds, rain, and fog. Winds in excess of 100 miles per hour have been recorded for every month of the year. Average precipitation is 60 inches with 25 to 30 percent falling as snow; average annual snowfall is 160 to 240 inches.

Air Quality-Related Values

The Great Gulf and Presidential-Dry River Wildernesses are separated by the summit of Mt. Washington. Because of their proximity and because they have numerous features in common, including geology, water resources, visual range, alpine areas, wildlife, and vegetation, the AQRVs for both areas are nearly identical.

Scenic Beauty. The interplay of rugged form and varying vegetation makes both wildernesses highly scenic. They are dominated by high mountain peaks, large expanses above timberline, distinctive geologic formations, and vegetative communities ranging from deciduous low-elevation forests to unique alpine vegetation. Rock capped peaks and ridge lines provide outstanding scenic vistas.

As reported in earlier planning efforts, "...the rugged character of the slopes and surrounding peaks (in the Great Gulf Wilderness) which shut in the valley, lends a feeling of remoteness" and "The steep timbered slopes and valleys and rugged rock capped mountain peaks (in the Presidential Range/Dry River Wildernesses) allow one to find the solitude and peace one needs in the populous Northeast to refresh one physically and spiritually."

Vistas are an especially important component of the scenic values of these areas. The high elevations in and around these wildernesses allow views of many of the peaks and valleys surrounding the northern part of the White Mountain National Forest. The elevations also place portions of the wildernesses into full view for many miles around.

Views from the alpine zone, particularly that in the Presidential Range, make these wildernesses some of the most heavily hiked areas in the National Forest. The Great Gulf and Presidential Range/Dry River Wildernesses provide considerable enjoyment for visitors looking into the wildernesses from outside their boundaries. The roads encircling the areas offer scenic views of extremely varied and distinctive terrain and vegetation during and after the color seasons. The opportunity to experience these wilderness vistas is partly responsible for the great number of visitors to this part of New Hampshire.

Vegetation. There are four distinct biotic communities in these two wildernesses: alpine, subalpine, spruce-fir, and deciduous forest communities. Some of these are unique and important in themselves; others are important because their presence within the wilderness lends diversity in habitat and in experiences for recreationalists.

Within and surrounding the Great Gulf and the Presidential Range/Dry River Wildernesses is the largest alpine area in the Eastern United States, commonly called the Presidential Range alpine zone. In this region there are approximately 13 square miles of alpine plant communities. The largest single unit of this unique habitat is the Presidential Range alpine zone in the White Mountain National Forest, which covers approximately 7.5 square miles.

The alpine plants are an important resource of this zone. Many are at the extreme southern limit of their range. There are only about 110 species of plants above timberline, approximately 75 of which are considered true alpine plants. Of these, one species, *Potentilla robbinsiana*, is found nowhere else in the world.

The subalpine biotic community is often termed the "stunted forest." It represents the transition from the spruce-fir community to the krummholtz to the alpine community. Vegetation here is heavily impacted by wind, snow, and ice. Trees are a tangled and dense mat of birch, spruce, and fir which rarely exceed 15 feet in height. There is potential habitat here for the northern bog lemming and the Canada lynx.

The spruce-fir biotic community consists of high-elevation spruce-fir stands. Trees here attain normal height and the canopy appears as a mosaic of spruce-fir tops, dead masts, and small openings created by fallen dead trees. Soils are shallow to ledge and slopes generally are steep. With its protection within a wilderness and the lack of logging impacts from earlier years, this stand can continue to evolve as an old-growth stand.

Deciduous communities are found at lower elevations in the two wilderness areas. Species consist of mixed northern hardwoods along with some eastern conifers along stream bottoms. It appears as a normal deciduous forest setting from within and as an unbroken canopy from higher viewpoints. The importance of this community relates to the diversity it provides, its unbroken canopy, its spectacular colors in fall, and its potential as a protected old-growth forest.

Wildlife. Several species of animals found in the alpine zone are of particular concern. Among them are the northern bog lemming, and two species of butterfly, the White Mountain Fritillary and the White Mountain arctic. The greatest population of the latter is found in the Great Gulf in an area called the "Cow Pasture."

Water. Cool, crystal-clear streams and ever present cascades are an important component of the "close-up views and sounds" in the two wildernesses. The associated biologic communities of these water bodies also add to the diversity of the areas. Many of the larger streams contain populations of wild brook trout which are isolated from downstream populations by ledges, cascades, and waterfalls. Moss carpets the rocks of the smaller headwater streams.

With few high-elevation ponds in the White Mountains, the three named ponds within the two areas are unique. These small ponds, which could be called tarns or cirque lakes, are small and shallow with small drainage basins. Star Lake is a 1-acre pond located above 5,000 feet in the Great Gulf Wilderness. Spaulding Lake is a 0.2-acre pond located at 4,300 feet in the Great Gulf. Desolation (or Red) Pond is a shallow 3-acre pond located at 3,800 feet in the Presidential Range/Dry River Wilderness.

The Great Gulf has two major tributaries to the Peabody River: the West Branch of the Peabody and Parapet Brook. Numerous smaller mountain streams drain high in this watershed. The Presidential Range/Dry River has a major tributary to the Saco River: the Dry River. The upper half of the Rocky Branch watershed, another major Saco River tributary, also is within this wilderness. There are numerous tributary streams draining into both rivers.

Odor. Part of the experience associated with a visit to the wilderness is the natural scents of the surrounding forest. The smell of fallen leaves, the scent of a rainstorm, sweet odors from balsam fir, and the crisp, clean smell above tree line all contribute to the visitor's experience.

LYE BROOK WILDERNESS

Location:		Size:	15,503 acres
Green Mountain National Forest			
South Central Vermont		Designated:	1975
Latitude:			
43° 07′ 30″		Elevation:	800 to
Longitude:			2,900 feet
73° 00′			

General Description

Named after Lye Brook, which flows through the western half of the area, Lye Brook Wilderness is located on a high-country plateau with lakes, bogs, and three hollows where brooks flow off the plateau and into the valley below. Lye Brook Falls is one of Vermont's highest waterfalls. In 1916, a fire created a large meadow-like opening known as "The Burning," which runs along the ridgetop in the southwestern part of the area.

The area was extensively logged in the early 1900's. A network of railroad lines carried the timber from the plateau down to Manchester. Remnants of railroad grades and old logging roads remain throughout most of the area.

Weather. The general climate is cool year round. Summer temperatures range from 40°F at night to 80°F during the day. Average winter temperatures range from −10°F at night to 25°F during the day. Frequent and sudden weather changes are common. Snow usually falls at higher elevations by late November and lasts until early April.

Vegetation. Approximately 80 percent of the area has stands of northern hardwoods—maple, beech, and birch. Other important species are red spruce, balsam fir, and hemlock.

Wildlife. White-tailed deer, black bear, turkey, and beaver are common. Small ponds and streams contain brook and brown trout.

Air Quality-Related Values

Scenic Beauty. The wilderness sits on a plateau on the western edge of the Green Mountains. Much of what a person sees is dominated by the surrounding vegetation. At times it can be like walking through a green tunnel. Openings provide views of Stratton Mountain to the northeast and Mount Equinox to the west. Views also afford glimpses of the valley that lies between the Green and Teconic Mountains. Lye Brook Falls, one of the highest falls in the area, is steep and ledgy. Portions of the Brook and Falls are shaded by ancient hemlock and fir.

Vegetation. The forest within the wilderness is a mixture of spruce-fir and northern hardwood stands. Remnants of the original spruce-fir forest can be found on the steep slopes near Lye Brook. Most of the wilderness was logged earlier in this century, so most trees are less than 80 years old. Paper birch is giving way to spruce and hardwoods.

"The Burning," a 200-acre opening created by a devastating forest fire in 1916, is dominated by shrubs and scattered white pines.

Wildlife. The wilderness forms a core of mature, closed-canopy vegetation, habitat necessary for the survival of "interior" dwelling species. These species are not adapted to life outside of closed canopy woodlands and suffer greatly from predation and parasitism when forced to dwell near open lands. Several neotropical immigrant songbirds fall into this category, including Blackburnian and worm-eating warblers.

Water. Two significant attractions to the wilderness are Lye Brook and Bourn Pond. Lye Brook flows the length of and is contained almost entirely within the wilderness. The stream is a headwater tributary to Battenkill, a world-famous trout fishery. Lye Brook has its own native brook trout fishery.

Bourn Pond is a popular dispersed recreation and backpack camping area. The pond attracts a variety of wildlife. Loons, which have become uncommon within Vermont, are seen on the pond. The pond tends to be acidic with a pH range of 5.0 to 5.5. Dissolved organic matter gives the pond a light tea color. The acid neutralization capacity is nearly zero and dissolved aluminum is abnormally high.

Odor. Lye Brook is characterized by a variety of natural woodland odors. The smell of moldering hardwood leaves is evident through the hardwoods. White pines lend a distinct fragrance to "The Burning," which contrasts with the more pungent odor of nearby boggy spruce stands. The variety of scents around Bourn Pond changes with the seasons and even the time of day.

HERCULES GLADES WILDERNESS

Location: Mark Twain National Forest, Southern Missouri	Size:	12,314 acres
	Designated:	1976
Latitude: 36° 37′ 30″ to 36° 45′	Elevation:	760 to 1,360 feet
Longitude: 92° 50′ 30″ to 93° 00′		

General Description

Hercules Glades Wilderness, 60 miles southeast of Springfield, consists of open grassland, forested knobs, steep rocky hillsides, narrow drainages, and limestone rock outcroppings. There are three high knobs that stand out from the outer high ridges: Upper and Lower Pilot Knobs, and Coy Bald.

From the late 1800's to the 1950's, any area not fenced was considered "open range" and the glades were heavily grazed by large numbers of horses, cattle, and hogs. Today, cattle grazing is still permitted within the area.

Vegetation. The thinnest soils have a prairie vegetation intermingled with eastern redcedar, smoketree, winged elm, aromatic sumac, chinkapin, and post oak. As the soils become deeper, larger trees dominate with a mixture of chinkapin oak, white ash, post oak, blackjack oak, and eastern redcedar.

The glade areas support grass species common to the great prairies: big and little bluestem, Indian grass, prairie dropseed, side oats grama, and switchgrass are common. Associated forbs include black-eyed susan, several species of coneflower, shooting star, Missouri primrose, and prairie clover. Rare, threatened and endangered plants such as ciliate bluestar, blazing star, stonecrop, and treleases larkspur also are found on the glades.

Wildlife. Wildlife within the area is typical of the glade country. Big game consists of white-tailed deer and wild turkey. Small game includes squirrel, raccoon, rabbit, fox, and bobcat. Bird life includes quail, hawk, owl, and numerous small songbirds. Other wildlife found only in the glade country because of their relation to the prairie grass communities include collared lizard, stinging scorpion, road runner, and the Bachman's sparrow.

Weather. The Ozark climate is mild enough to make visits possible throughout the year. Peak use seasons are spring and fall. Hercules Glades contains limited open-water sources and only portions of Long and Cane Creeks contain water year round.

Air Quality-Related Values

Scenic Beauty. The scenic beauty of the Hercules Glades Wilderness is unique in the Ozark Region of south Missouri. The rugged landscape is characterized by high knobs, locally known as balds, which offer a spectacular view of the rugged landscape, and contrasting vegetative communities featuring both a tall grass prairie and a forested landscape. Visitors to the wilderness can, with a short hike, experience panoramic views and visual contrasts between the forest and tall grass-prairie vegetative communities from either or both of the twin Pilot Knobs, two high balds from which the entire wilderness area can be viewed. The most heavily visited spot in the wilderness is a waterfall on Long Creek.

Vegetation. Vegetation within the Hercules Glades Wilderness is a study in contrasts, and perhaps its most outstanding natural feature. At one extreme is the oak-hickory forest. At the other are extensive areas of open, tall grass-prairie vegetation featuring flowers, grasses, and forbs.

Water. Long Creek, which flows through the center of the wilderness, is an intermittent stream but has pools of water throughout the year. The entire watershed of Long Creek is contained in the Wilderness. Moderate rainfall is sufficient for water to flow swiftly down Long Creek over dolomitic-limestone boulders and natural steps, giving the creek an appearance of having thousands of small waterfalls. Tributaries to Long Creek are the numerous upland waterways or hollows which, due to the high runoff potential of the shallow soils, also become swiftly flowing streams during rainstorms. The chemistry of the water is dominated by calcium and magnesium bicarbonates, and pH is slightly alkaline. Nutrient levels are low and, in the absence of storm water runoff, stream waters are remarkably clear.

Wildlife. Visitors to the Hercules Glades Wilderness Area have the unique opportunity to observe wildlife indigenous to both forests and prairie lands. The wildlife includes many large and small mammals, reptiles, and birds. Unique and unusual species of nongame birds are the bald eagle, red-tailed hawk, great horned owl, great blue heron, and pileated woodpecker.

Species dependent on the tall grass prairie community are the collared lizard, stinging scorpion, road runner and Bachman's sparrow. Rare, threatened or endangered species include Bachman's sparrow, Cooper's hawk, snd the long-tailed weasel. Reptiles found in the forest, forest fringe, or prairie areas include the copperhead, pygmy rattlesnake, and eastern timber rattlesnake. Fish species include largemouth and smallmouthed bass, rock bass, green sunfish, longear sunfish, and numerous species of suckers and minnows capable of existing in an intermittent stream.

Odor. The natural odor of a combination of forest and grassland prevails and enhances one's enjoyment of the area.

RAINBOW LAKE WILDERNESS

Location: Chequamegon National Forest, Northwestern Wisconsin	Size:	6,388 acres
	Designated:	1975
Latitude: 46° 22′ 30″ to 46° 27′ 30″	Elevation:	1,100 to 1,325 feet
Longitude: 91° 15′ to 91° 22′ 30″		

General Description

Rainbow Lake Wilderness is a densely vegetated, primitive forest landscape containing 15 undeveloped lakes that are 5 acres or larger in size, and nine ponds. All the lakes and ponds are landlocked; there are no streams. Six miles of the North Country National Scenic Trail traverse the area. Old logging roads provide access to other parts of the wilderness.

Vegetation. Maple, white pine, balsam fir, aspen, and paper birch are dominant tree species within the wilderness.

Wildlife. Deer, black bear, ruffed grouse, red fox, skunk, otter, beaver, muskrat, weasel, snowshoe hare, grey squirrel, mink, loons, woodpeckers, warblers, flycatchers, sparrows, jays, crows, finches, hawks, owls, waterfowl, bald eagles, bass, perch, trout, and bluegill are common.

Weather. Summers are pleasantly cool and breezy with a few days of 90-degree temperatures each year. Winter nights can drop to -30°F or lower. Precipitation averages 30 inches a year and falls mostly during the summer months. Snow usually begins in November and reaches a depth of 24 to 36 inches.

Air Quality-Related Values

Scenic Beauty. Visitors in the spring and summer experience a lush, green, northern hardwood forest, colorful wildflowers, and small kettle lakes of the hummocky terrain. Autumn presents a dazzling array of colors and, as the leaves fall, the hummocky topography created by ancient glaciers is more easily seen. Subtle changes in topography are most evident in winter when snow covers the ground and deciduous leaves no longer obscure one's view.

Water. The Rainbow Lake Wilderness is noted for its beautiful lakes, which provide a rich habitat for fish, furbearers, and aquatic plants. The lakes provide recreation opportunities for anglers, naturalists, and canoeists. The wilderness contains 22 kettle lakes that range in size from 1 to 33 acres. Water enters these landlocked lakes by way of direct precipitation and underground flow from the watershed and leaves by subsurface seepage and evaporation at the surface. The lake water is extremely soft and low in nutrients and dissolved minerals.

Visitors to the wilderness gain access to 18 of the lakes along upland shorelines and are able to see several feet into the clear or light brown water. Four of the lakes have a rich, dark stain due to peatlands.

Vegetation. The vegetation contributes significantly to the scenic beauty, variety, and richness of the wilderness. Northern hardwood forest is the dominant vegetation.

Wildlife. The wilderness contains a variety of large and small mammals, birds, and fish. Unique species include the fisher, pileated woodpecker, and ovenbirds. The common loon inhabits some lakes. Although rarely seen, timber wolves enhance the wilderness's character and the experiences of visitors. At least one wolf regularly uses the Rainbow Lake Wilderness, and other wolves make occasional use of the area.

Odor. The fragrence of natural odors is a subtle but integral part of the wilderness experience. Leaf litter, conifers, fungi, water, and wildflowers provide a pleasant aroma.

BOUNDARY WATERS CANOE AREA WILDERNESS

Location: Superior National Forest, Northeastern Minnesota	Size: 1,086,954 acres
Latitude: 47° 45′ to 48° 30′	Designated: 1964
Longitude: 90° 00′ to 92° 30′	Elevation: 1,260 to 2,301 feet

General Description

The northern lakes and rivers of the Boundary Waters Canoe Area Wilderness border Canada and form part of the "Voyageurs Highway" of the fur trade. A portion of the area was set aside in 1926 to preserve its primitive character. In 1939, additional area was declared roadless, and in 1964 the wilderness received its present designation.

Pristine lakes formed when glacial ice melted centuries ago—more than 1,100 lakes are 10 acres or larger. Heavily forested land, rock formations, wetlands, and lakes dominate the landscape.

Vegetation. The variety of flowers in this wilderness includes subarctic species and nearly 30 native species of wild orchids. Principal conifers are jack pine, white pine, and red pine. Also common are white and black spruce, balsam fir, northern white-cedar, and tamarack. Principal broad-leaved trees are quaking aspen and paper birch.

Wildlife. White-tailed deer, moose, black bear, fisher, loon, and the last substantial population of timber wolves in the contiguous United States inhabit the wilderness. Game fish include walleye, northern pike, lake trout, and smallmouthed bass.

Weather. The area has variable temperatures and rain from May through September. Average high-low temperatures: 77° to 42°F; days of rain: 14 to 16 per month. Average seasonal temperatures are 42°F in spring, 64°F in summer, 45°F in fall, and 12°F in winter.

Air Quality-Related Values

Scenic Beauty. The scenic beauty of the BWCAW is highly valued by its users. Visual experiences encountered by most users consist of shoreline views and inspiring water-reflected sunsets across lakes/rivers from campsites, portages, or midlake vantage points (from boats or canoes). Outstanding shoreline features include lichen-covered bedrock cliffs and boulders; boulder-strewn lake inlets and outlets; waterfalls and rapids; shoreline wetlands with sphagnum, labrador tea, or leather leaf and sparsely timbered with black spruce or tamarack; the big-tree character of individual or clustered old-growth red and white pine, and the contrast established by intermingled aspen and conifer stands.

Water. Approximately 1,175 lakes of 10 acres or larger comprise 260,000 acres (24 percent) of the BWCAW surface area. The unique opportunity for recreational canoe/boat travel offered by high-quality interconnected lakes and waterways in a largely undisturbed scenic forest environment was the primary force behind the wilderness designation for the BWCAW.

Fifty-seven percent of the lakes have an acid neutralizing capacity less than 200 ueq/L, but only 1 percent has a pH less than 6. Seventy percent of the lakes are considered "dark water" due to dissolved organic carbon resulting from extensive peatland.

Bedrock exposures are a common feature, shaping the beds, shores, and bottoms of BWCAW lakes and streams. The presence of sulfide ores in bedrock likely contributes to relatively high concentrations of background sulfate in some of these waters.

Lakes and streams are habitat for walleye, northern pike, bass, crappie, sunfish, lake, brook, and brown trout, and several other fish species. Fishing is a popular wilderness use.

Vegetation. BWCAW is characterized by the species associated with the northern Minnesota Glacial Lake Basin. Visual diversity is highest during the fall. Ground and herbaceous understory of native berries and aquatic species like wild rice are gathered by some recreationists and are a valuable food source for many animal species. Many species of sensitive plants, including ram's-head ladyslipper and northern comandra, inhabit portions of the BWCAW. Lichen flora of the BWCAW is diverse. and lichen species known to be sensitive to air pollutants are common throughout the area (no significant voids in distribution).

Wildlife. Wildlife viewing or experiencing evidence of wildlife (e.g., observing tracks or hearing howls and bird calls) is highly valued by BWCAW users. Hundreds of species of birds, mammals, reptiles, amphibians, and insects inhabit the wilderness. The BWCAW is one of the last vestiges of a viable timber wolf population in the United States. The sounds of a distant howling wolfpack have formed a lasting impression on the part of many users who have camped overnight in or near the wilderness. Campsite-raiding black bears often form a similar though sometimes less favorable impression.

Bald eagles and osprey are common near the shorelines of lakes and rivers, and these birds and their nests are commonly seen by boaters and canoeists. Common loons are plentiful, their sighting and calls an expected part of the BWCAW experience for most wilderness users during the open-water season.

Odor. The natural smells of the forest are an important value to wilderness users. Odors in this wilderness are associated with natural features such as conifers and wildflowers and the sulfurous odors of gases that escape from swamps and shallow lakes.

Appendix II

Additional Information

Protocol for Monitoring Atmospheric Deposition

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