ACIDIC DEPOSITIONS IN WYOMING

An Assessment of Current Information to Design a Wyoming Monitoring and Research Program

Prepared by

Michael D. Marcus and Benjamin R. Parkhurst
Western Aquatics, Inc.

and

Robert W. Brocksen
Wyoming Water Research Center

Final Report Submitted to

Wyoming Water Research Center
Laramie, Wyoming

February 1984

ACKNOWLEDGEMENTS

For reviewing and providing valuable comments on an earlier draft of this report, we thank Charles Powers and Marvin Allum of the U.S. Environmental Protection Agency's Corvallis (Oregon) Environmental Research Laboratory; Allen Lefohn of A.S.L. & Associates in Helena, Montana; Michael Stone and Robert Wiley of the Wyoming Game and Fish Department; and Richard Moore and his associates at the Wyoming Office of Industrial Siting Administration.

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	1
INTRODUCTION	8
CHARACTERISTICS OF ACIDIC DEPOSITION	10
POTENTIAL EFFECTS FROM ACIDIC DEPOSITIONS	17
SOILS	17
CROPS AND FORESTS	20
SURFACE WATERS	23
AQUATIC ORGANISMS	38
HUMAN HEALTH	44
CULTURAL MATERIALS	46
DESIGN OF A WYOMING ACIDIC DEPOSITION MONITORING AND RESEARCH PROGRAM	48
GENERAL RESEARCH AREAS REQUIRING ADDITIONAL DATA	49
MONITORING AND RESEARCH OPTIONS FOR WYOMING	51
SUGGESTED MONITORING AND RESEARCH ACTIONS FOR WYOMING	63
POTENTIAL INTERESTS AND INVOLVEMENTS IN A STATE PROGRAM	77
WYOMING STATE GOVERNMENT - EXECUTIVE BRANCH	77
WYOMING STATE GOVERNMENT - LEGISLATIVE BRANCH	83
PRINCIPAL FEDERAL AGENCIES	83
OTHER MAJOR GROUPS	88
CONCLUSION	90
LITERATURE CITED	91
APPENDIX A - SAMPLING AND ANALYSIS PROTOCOL FOR CHEMICAL CHARACTERISTICS OF LAKES AND STREAMS SENSITIVE TO ACIDIC DEPOSITION	
APPENDIX B - POTENTIAL INTERESTS AND INVOLVEMENT BY VARIOUS STATE ORGANIZATIONS CONCERNED WITH ACIDIC DEPOSITIONS	

LIST OF TABLES

		Page
Table 1.	Recorded pH levels in precipitation for various locations.	12
Table 2.	Discharge limitations for sulfur dioxide and nitrogen oxides from gas sweetening plants in the Overthrust Belt, and coal-fired power plants and a copper smelter in the Rocky Mountain Region.	15
Table 3.	Watershed and surface water characteristics that influence sensitivity to acidic depositions.	26
Table 4.	Critical pH values for some fish species found in acid-sensitive Wyoming lakes.	39
Table 5.	General research areas having ongoing efforts to provide data useful to understanding cause and effects of acidic depositions.	50
Table 6.	Monitoring and research options from the atmospheric sciences for a Wyoming program to assess the significance to the state of acidic depositions.	52
Table 7.	Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on aquatic chemistry.	55
Table 8.	Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on aquatic biology.	57
Table 9.	Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on soil systems.	59
Table 10.	Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition on terrestrial vegetation.	61
Table 11.	Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on material and cultural resources.	62

LIST OF TABLES
(continued)

		Page
Table 12.	Five questions used to develop the suggested Wyoming program for concerns about the possible importance and impacts of acidic deposition to Wyoming.	65
Table 13.	Suggested research directed at the question, "Are acidity levels in atmospheric depositions in Wyoming great enough to potentially cause adverse impacts?"	67
Table 14.	Suggested research directed at the question, "What are the sources of acids in depositions in Wyoming?"	69
Table 15.	Suggested research directed at the question, "What natural and cultural resources in Wyoming are potentially at risk from acidic depositions?"	71
Table 16.	Suggested research directed at the question, "Are acidic depositions adversely impacting the sensitive resources of Wyoming?"	73
Table 17.	Principal areas of potential interests and involvements by organizations within the Executive Branch of Wyoming state government in issues related to acidic depositions.	78
Table 18.	Committees within the Legislative Branch of Wyoming state government having potential involvement in issues related to acidic depositions.	84
Table 19.	Locations of principal Federal organizations having potential interests or involvements with issues related to acidic depositions in Wyoming.	85
Table 20.	Coordinating agencies for each of the working Task Groups included in the National Acid Precipitation Assessment Program.	87
Table 21.	Other major groups having potential interests or involvements with issues related to acidic depositions in Wyoming.	89

EXECUTIVE SUMMARY

Recent reports indicate that two-thirds of the United States and one-half of Canada receive acidic depositions. Commonly referred to as "acid rain", acidic depositions have been defined as precipitation that has a pH level less than 5.65, the theoretical natural acidity level of distilled water in equilibrium with atmospheric carbon dioxide. Acidic depositions can include rain, sleet, snow, fog, dew, dry particles, and gases. The major causes of acidity in acidic depositions are sulfates, nitrates, and possibly organic anions. Chemical analyses indicate that petroleum and coal burning, and ore smelting may all be important emission sources for these chemicals in the West.

While not currently perceived as a problem in Wyoming, acidic depositions have been found in this State and others in the Rocky Mountain Region. And, industrial developments are planned in the region (e.g., gas sweetening plants near the Overthrust Belt of southwestern Wyoming) that will have atmospheric emissions of potentially acid forming chemicals. Consequently, concerns about potential adverse impacts from acidic depositions in Wyoming are increasing. The following report is a result of requests from the Wyoming Game and Fish Department and the Wyoming Environmental Quality Council to the Wyoming Water Research Center for information and advice useful in addressing these concerns.

Acidic depositions have been suggested to produce adverse effects upon a number of resources. In this document are reviewed the current state of the scientific knowledge for the known effects of acidic depositions on soils, crops, forests, surface-water quality, aquatic organisms, human health, and cultural materials. Overall, the most significant effects have been suggested to occur in poorly buffered surface-waters.

Although no actual effects have been observed in the State, a number of general conclusions can be made about the possible effects by acidic depositions on the resources of Wyoming.

- Soils - Within the non-mountainous regions of Wyoming, natural conditions have created alkaline soils generally considered as insensitive to acidic depositions. Potentially sensitive soils would be limited to thin, poorly buffered soils present on slowly-weathered bedrock, such as granite. These areas are generally confined to higher elevations in some mountain ranges.
- Crops - Since virtually all crops in Wyoming are grown in relatively arid areas that have insensitive alkaline soils, acidic depositions should have no adverse effects. Such depositions, in fact, may produce fertilizing effects.
- Forests - Forest tree species which have been suggested to be potentially sensitive to acidic depositions in the northeastern United States also grow in Wyoming. These species include spruce, firs, and pines. There are no data, however, demonstrating whether Wyoming forests are potentially sensitive to acidic depositions.

- *Surface-water quality* - While few data are generally available, enough exist to indicate that some high mountain areas contain a relatively high proportion of lakes potentially sensitive to acidic depositions. Such lakes have alkalinity levels less than 200 μeq/l. For example, one data set indicates that about 70 percent of the lakes over 9,000 feet elevation in the Wind River Range may be potentially sensitive to acid inputs. Because of natural characteristics, lakes and streams at lower elevations and in non-mountainous regions are generally well buffered and are, therefore, considered insensitive to any probable future inputs of acidic depositions. It should be emphasized, however, that present acidic deposition rates in Wyoming do not appear to pose a threat to Wyoming surface waters.
- *Aquatic organisms* - Wyoming lakes and streams that are potentially sensitive to acidification by acidic depositions contain many aquatic species potentially sensitive to acidity. If these waters were to become acidic (pH levels below 6.0), many of these species would be adversely affected. Depending on the degree of acidification, some species populations could become locally extinct. However, acidic deposition rates would have to be many times greater than currently reported for the State before these affects would be likely to occur.

- <u>Human health</u> - While potential adverse effects to human health from acidic depositions have been hypothesized, actual effects have not been documented for any human population. Therefore, although the potential may exist for acidic depositions to cause health effects in Wyoming, the possibility of such effects developing is unknown and probably very small.
- <u>Cultural materials</u> - Cultural materials exist in Wyoming that are potentially sensitive to acidic depositions, but these materials are primarily located in the more populated, non-mountainous, relatively arid regions of the State. Therefore, potentially adverse effects from future acidic depositions in Wyoming will likely have little detectable effects on most cultural materials of concern.

In this review a number of research needs were identified as valuable in helping to understand the possible significance of acidic depositions in Wyoming. Lists of environmental monitoring and research projects were then presented that could help supply needed information. From these, various projects were recommended for a Wyoming sponsored monitoring and research program to investigate acidic depositions. Considerations involved in selection of the projects included probability of impacts, information gaps, data applicability, feasibility of completion, and costs.

The suggested monitoring and research program addresses five general areas viewed as important to an overall State sponsored program:

1) It must be determined whether acidity levels in atmospheric depositions are great enough to potentially cause future adverse impacts.

2) Sources emitting potentially acid forming chemicals, both in-state and out-of-state, must be identified and quantified to help in determining where controls may be needed and where downwind resources may be impacted.

3) Potentially sensitive natural and cultural resources must be identified to determine the location and the extent of resources potentially at risk from acidic depositions.

4) To definitively determine whether acidic depositions adversely impact any resource requires establishment of a monitoring and research program to determine possible trends of change for these resources and actual cause(s) of these changes.

5) As a result of efforts under the above four categories, additional actions will be defined that can help to evaluate potential effects of and mitigations and management measures for acidic depositions in Wyoming.

In relation to these five areas, nine monitoring and research projects are suggested:

- Compile and evaluate existing atmospheric deposition data.
- Monitor present atmospheric depositions.
- Inventory emission sources.
- Develop instate/out-of-state source budgets for acids in Wyoming airshed.

- Develop inventories of resources at potential risk, based on existing information.
- Select study sites for long-term collection of monitoring and baseline environmental data.
- Monitor for long-term changes in surface water quality and fish populations.
- Monitor for short-term changes in surface water quality following snowmelts and major rainfalls.
- Conduct soil surveys in watersheds surrounding the long-term study sites.

Of these, many can readily be completed using existing data, and several can be rapidly undertaken with Federal funding.

Due to the widespread concern about possible impacts from acidic depostions, many groups and individuals have potential interests and involvements in a State sponsored monitoring and research program. These potentially include 21 organizations in the Executive Branch of State government, 10 Standing Committees in the State Legislative Branch, over 25 Federal organizations, and a variety of industrial groups, environmental and conservation organizations, plus other miscellaneous groups. The possible interests and involvements of these organizations and individuals are briefly discussed.

It is concluded that acidic depositions pose an unique environmental problem. Assessing the significance of the potential impacts to Wyoming will require an extensive state-wide monitoring and research program, coordinated by a single authority. Only through the cooperation among many State and Federal agencies, and a selection of other interested groups and individuals, can the present or future impacts from acidic depositions in Wyoming be accurately assessed.

INTRODUCTION

Concerns for the environmental effects of acidic depositions are widespread. Recent reports indicate that two-thirds of the United States and one-half of Canada receive acidic precipitation. Although not currently perceived as a problem in Wyoming, acidic precipitation has been measured in this state and others in the Rocky Mountain Region (e.g., Lewis and Grant 1980). And, industrial developments, which will have atmospheric emissions of potentially acid forming chemicals, are underway in areas of Wyoming upwind from sensitive natural resources. As a result, concerns for potential effects from acidic depositions in Wyoming are increasing.

The following report is a result of requests from the Wyoming Game and Fish Department and the Wyoming Environmental Quality Council to the Wyoming Water Research Center for information and advice useful in addressing potential concerns for acidic depositions in Wyoming. This report reviews the state of the science regarding potential causes and effects of acidic depositions and environmental acidification and evaluates their potential importance to Wyoming. Then, monitoring and research options are presented that can help to evaluate the extent and effects of acid depositions in Wyoming. A number of these options are compiled into a suggested Wyoming monitoring and research program for sponsorship by the State. Finally, those organizations within the State and Federal governments, plus other major non-governmental organizations and groups having potential interests and involvements in such a State program are discussed. Overall, this document is intended to provide a common starting point from which discussions and plans can be based in developing a possible state-wide Wyoming acidic deposition monitoring and research program.

CHARACTERISTICS OF ACIDIC DEPOSITION

Acidic depositions are commonly referred to as "acid rain". However, atmospheric borne acids can be deposited onto the land and water in a variety of forms, including rain, snow, sleet, fog, dew, dry particles, and gases.

Acidic depositions are generally classified as either wet or dry. Most deposition monitoring to date has been of rain and snow because depositions of dry particles and gases are much more difficult to monitor. It is generally believed, however, that on an annual basis dry deposition rates equal or exceed the wet depositions rates (U.S. EPA 1983).

The acidity of acidic depositions is caused by its hydrogen ion (H^+) concentration. This acidity is generally measured using the pH scale, where pH is the negative logarithm of the hydrogen ion concentration measured in moles/liter. The pH scale ranges from 1 to 14. On this scale pH 7 is neutral, less than pH 7 is acidic, and greater than pH 7 is basic. Since this is a logarithmic scale, a one unit decrease in pH (e.g., 7 to 6) refers to a 10-fold increase in hydrogen ion concentration, and a two unit decrease (e.g., 7 to 5) refers to a 100-fold increase in hydrogen ion concentration.

The theoretical pH of distilled water in equilibrium with the CO_2 present in the atmosphere is 5.65. This value has been derived under laboratory conditions where distilled water was equilibrated with uncontaminated air. The acidity is derived from carbonic acid formed by the dissolved CO_2. Therefore, both distilled water and uncontaminated precipitation naturally tend to be slightly acidic.

"Acidic precipitation" has been defined as precipitation having a pH less than the theoretical natural pH of precipitation, 5.65. To obtain a precipitation pH that is less than 5.65 generally requires strong inorganic or organic acids.

Although pH 5.65 is the theoretical pH of pure rain, pure rain probably has rarely existed in nature due to natural sources of strong acids to the atmosphere. Even at remote sites far from any obvious sources of strong acids, precipitation pH may be highly acidic (Table 1). For example, on Amsterdam Island in the southern Indian Ocean, precipitation pH ranges 4.5 to 5.0. In comparison, the Adirondack Mountains of New York, where losses of brook trout from acidic lakes have been attributed to acidic depositions, precipitation pH in 1980 averaged about 4.2 (U.S. EPA 1983). In contrast for the northern Great Plains, precipitation pH ranges 5.5 to 7.0 due to alkaline dusts blown into the atmosphere (U.S. EPA 1983). The natural pH of precipitation has been suggested to range 4.8 to 5.2 (Gibson 1983).

Although few data exist for Wyoming, precipitation in the state appears to generally range from about pH 5 to 6 (U.S. EPA 1983). Data reported from the National Atmospheric Deposition Program monitoring site in Yellowstone National Park indicate that the pH in weekly collections ranged from 7.34 to 4.64, with a mean of 5.51 during September 30, 1980 to July 7, 1981 (NREL 1982, 1983a, 1983b).

Unpublished data on precipitation pH are available for the Snowy Range in southeast Wyoming. During the winter of 1980, Baird (cited

Table 1. Recorded pH levels in precipitation for various locations.

Location	Average pH of Precipitation	Source
Distilled Water	5.65	U.S. EPA 1983
Adirondack Mountains, New York, 1980	4.2	U.S. EPA 1983
San Cailor, Venezuela (Amazon Forest)	4.8	U.S. EPA 1983
Amsterdam Island (South Indian Ocean)	4.9	U.S. EPA 1983
Natural pH of Precipitation in Eastern United States	5.0	U.S. EPA 1983
Snowy Range, Wyoming, Winter, 1980	4.8	Baird (in Treece 1982)
Snowy Range, Wyoming, August-November, 1982	5.4	Treece 1982
Wyoming, 1980 (range for state)	4.8 - 5.7	U.S. EPA 1983

by Treece 1982) reported that precipitation pH averaged 4.8. Treece (1982) conducted a survey during the late summer and fall of 1982 using the same methods as Baird and found that precipitation pH (rain and snow) ranged 4.8 to 7.2 with a mean of 5.4.

The chemical ions of primary interest in acidic precipitation have been hydrogen (H^+), sulfate (SO_4^{2-}), nitrate (NO_3^-), and ammonium (NH_4^+). Of these, sulfate and nitrate are the anions (negatively charged ions) that generally contribute most to the inorganic acidity of acidic deposition. Sulfate and nitrate in the atmosphere are derived from emissions of oxides (oxygen containing compounds) of sulfur (commonly referred to as SO_x) and oxides of nitrogen (commonly referred to as NO_x) that are converted to acids. In North America, the primary sources of SO_x and NO_x emissions are coal and petroleum burning and ore smelting. Natural sources of atmospheric SO_x and NO_x also exist. These include volcanoes, lightning, and biological processes. SO_x and NO_x can have atmospheric residence times of several days or more, and travel hundreds or thousands of miles before being deposited in precipitation and/or as dry particles or gases.

In eastern North America, the primary inorganic anions associated with strong acidity in precipitation is SO_x, with a SO_4^{2-} to NO_3^- ratio in precipitation commonly of 2:1. For the West, however, nitrates play a more important role, with SO_4^{2-} to NO_3^- ratios ranging from 1:1 to 1:1.4. In Wyoming's Snowy Range, Baird (cited by Treece 1982) reported that concentrations of nitrates in precipitation were slightly more abundant than sulfates. The higher proportion of nitrates in precipitation suggests that petroleum combustion products are important sources of precipitation acidity in the West.

Of particular concern in the State is that oil and gas developments in the Overthrust Belt of southwestern Wyoming will potentially produce adverse impacts downwind on sensitive resources. Meyer and Bergman (1983) recently reviewed potential impacts from these developments. The major sources of SO_x and NO_x in this area were expected to be gas sweetening plants. SO_x will be emitted primarily from sulfur gas incinerators; whereas NO_x will be discharged from several point sources, including gas turbine compressors and steam boilers. Depending on the sulfur recovery efficiencies and the use of internal combustion versus electric power for compressors and boilers, the relative contributions of these air pollutants will vary between sweetening plants.

To provide an indication of potentially acid forming emissions from some anthropogenic point sources, which could affect Wyoming's resources, Table 2 presents discharge limitations for sulfur dioxide (SO_2) and NO_x from gas sweetening plants in the Overthrust Belt, and coal-fired power plants and a copper smelter in the Rocky Mountain Region. These values indicate that the combined discharges from the two sweetening plants are approximately equal to the discharge from one coal-fired power plant, and less than a copper smelter. Because new power plants are regulated more strictly than old facilities, the large Basin Electric plant has about one-half as much SO_2 emissions permitted as permitted from the smaller but older Naughton plant.

Table 2. Discharge limitations for sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from gas sweetening plants in the Overthrust Belt, and coal-fired power plants and a copper smelter in the Rocky Mountain Region (from Meyer and Bergman 1983).

Emission Source	Production Capacity	Discharge limitation (lb/hr)	
		SO_2	NO_x
Amoco Whitney Canyon gas sweetening plant[a]	250 MM SCFD[b]	3,100	34
Chevron Carter Creek gas sweetening plant[a]	520 MM SCFD	1,500[c]	260
Naughton coal-fired power plant, Kemmerer, WY[d]	710 MW[e]	6,300	5,430
Basin Electric coal-fired power plant, Wheatland, WY[d]	1,500 MW	3,300	11,600
Colorado-Ute coal-fired power plant, Hayden, CO[f]	465 MW	2,900	---[g]
Utah copper smelter[f]	---	19,000	---[g]

[a]Values obtained from Permit Application Analysis, Wyoming Department of Environmental Quality, Air Quality Division, Cheyenne, Wyoming.

[b]MM SCFD = million standard cubic feet of gas per day.

[c]Value reported as SO_2 equivalents; projected composition is approximately 95% COS (carbonyl sulfide), 3% H_2S (hydrogen sulfide and 2% SO_2.

[d]Values from Bernie Daley, Wyoming Department of Environmental Quality, Air Quality Division, Cheyenne, Wyoming, personal communication.

[e]MW = megawatts of generating capacity.

[f]Values reported in Ferraro and Nazaryk 1982.

[g]--- = value not reported.

These figures highlight the fact that effects from acidic depositions are greater when sensitive resources are located nearer large power sources, where emission concentrations tend to be greatest. However, while the potential risk of resource impact by emissions from a single plant tends to decrease with distance from the plant, the risk will be increased by cumulative emissions when several plants are sited within a localized area.

POTENTIAL EFFECTS FROM ACIDIC DEPOSITIONS

Potential effects from acidic depositions are largely dependent on the characteristics of the landscape or surface water into which they enter. Such depositions either will be neutralized or buffered or that particular environment will become more acidic. In the following sections some of the potential effects of acidic depositions are discussed, and those factors influencing whether significant effects will occur are described.

SOILS

The principal effects on sensitive soils attributed to acidic depositions include nutrient and cation leaching, solubilization of toxic aluminum, and acidification of soil solutions. However, actual documentation of such effects in nature is poor, except at those sites impacted by large point-source emissions, such as are found in the vicinity of smelting located near Sudbury, Ontario, and Copper Hill, Tennessee.

The U.S. EPA (1983) summarized the state of the science concerning known effects of acid depositions on soils:

- Agricultural soils will not be harmed by acidic depositions.
- Most soils that would be easily acidified by acidic depositions are already acidic from natural soil processes.
- Depositions of nitrates will have a fertilizing effect on most soils; however, sulfate deposition probably will not.

- Long-term cation leaching from acid depositions is possible, but its significance is presently unclear.
- The most likely adverse effect of acid deposition is increased aluminum solubility leading to aluminum toxicity in both terrestrial and aquatic environments.
- Effects on microbes are possible but their significance is unknown.

Characteristics of Sensitive Soils

Soils considered to be most sensitive to acid depositions are young soils without well developed substrata and having low buffering capacities (U.S. EPA 1983). Well developed soils with medium to high buffering capacities are considered to be less sensitive or insensitive. Agricultural soils, since their pH can be managed by applications of fertilizers and lime, are also considered insensitive to acid depositions.

In areas with poorly developed soils, bedrock geology will largely determine potential sensitivity to acidic depositions. Soils underlain by limestones or other well-buffered, easily weathered, or calcite-containing parent materials will be relatively insensitive. In contrast, those that are underlain by poorly buffered, weather-resistant parent materials will be more sensitive to acidic depositions.

Additional characteristics of sensitive soils suggested by the U.S. EPA (1983) include:

- Soils that are not renewed by flooding such as alluvial soils.
- Soils that are free of carbonates to at least one meter of depth.
- Soils that have a low cation exchange capacity, but a pH of at least 5.5 to 6.0
- Soils that have a low sulfate absorption capacity.

Naturally Acidic Soils

Naturally acidic soils appear to be relatively insensitive to acid depositions, even when such soils are present on poorly buffered, weathering-resistant bedrock. Those factors considered to make landscapes sensitive to acid depositions are also those that develop highly acidic soils through the natural process of soil formation (Krug and Frink 1983). Acidities of such soils are frequently less than pH 4.0.

The results of natural soil formation are the same as those attributed to acidic depositions: leaching of nutrients, release of aluminum, and acidification of soils and surface waters. Naturally acidic soils generally have high total exchangeable acidity levels due to the presence of high levels of humus materials. These humus materials can act as weak acid buffers and can create very high buffering capacities capable of effectively buffering acidic depositions (Krug and Frink 1983, Jones et al. 1983).

Potential Susceptibility of Wyoming Soils to Acid Depositions

Within the non-mountainous areas of Wyoming, low rates of precipitation, lack of leaching, and high evapo-transpiration rates have created generally alkaline soils (Young and Singleton 1977). Such soils are generally considered to be insensitive to acidic depositions. Such depositions, especially of nitrates or ammonia, would tend to fertilize these soils.

Sensitive soils would generally be confined to higher mountain elevations where soils tend to be thin and poorly developed and where bedrock geology is predominated by very slowly weathered formations, such as granites and sandstones.

Such soils are present at higher elevations in most of the mountain ranges of the state (Young and Singleton 1977). However, those soils that are already highly acidic and well buffered as a result of natural soil processes are probably not potentially sensitive. Determining actual sensitivity requires site specific studies in these potentially sensitive areas.

CROPS AND FORESTS

There is no direct evidence that acidic depositions have caused significant damage to crops or forests in North America. However, various laboratory, greenhouse, and field experiments have demonstrated that simulated rain with very high acidity levels (i.e., pH 3.0) may damage a few crop and tree species (Cowling and Linthurst 1981). These effects include:

- Induction of necrotic lesions on foliage.

- Loss of nutrients due to leaching from foliage.
- Increased susceptibility to infection by pathogenic bacteria and fungi.
- Increased erosion of waxes on leaf surfaces.
- Inhibition of nitrogen fixation by legumes.
- Reduced decomposition and mineral recycling.

In contrast, these studies also have demonstrated that acidic depositions may have positive or negligible effects on many other crop and forest species. It should be emphasized that both sulfates and nitrates are essential plant nutrients and may have a fertilizing effect when deposited on soils (U.S. EPA 1983). In most soils, nitrates are not present in excess of plant requirements, therefore, they are rapidly assimilated. This results in increased plant growth and a net increase in soil solution alkalinity. The same effect occurs when sulfate is assimilated by plant; however, sulfate requirements of plants are only infrequently limited by available supplies. Therefore, complete assimilation of sulfate depositions by plants is uncommon.

The U.S. EPA (1983) presented the following general conclusions on the known effects of present levels of acidic depositions on agricultural crops and natural plant communities in North America.

- At present there is no direct evidence that acid depositions limit forest growth in North America. There have been indications, however, of growth reductions in areas receiving highly acidic precipitation. Specific causes of the North America forest growth reductions are unknown.

- In Scandanavia, areas receiving highly acidic precipitation have shown increased forest growth; while in Germany, areas receiving highly acidic precipitation have shown forest die-back. As a result of such conflicting observations, the actual effects of acid depositions on forests are unknown.
- The majority of crop species are not affected by simulated acid precipitation (pH 3.0); however, some crop species show negative and some show positive responses.
- Available experimental results do not indicate that the negative effects of acid depositions outweigh the positive effects. However, not all crops have been adequately studied.
- A major difficulty in evaluating effects of acid depositions on forests and crops is in separating potential acid effects from those caused by other air pollutants (e.g., ozone) and the effects of forest pests and droughts.

Potential Effects on Crops and Forests of Wyoming

Most research results indicate that direct foliar damage from acidic precipitation occurs only following prolonged exposures to acidic precipitation levels below those found in the environment (pH 3.0). Consequently, the primary mode of possible damage to plants from acidic deposition is through soil interactions. However, since virtually all crops in Wyoming are grown in relatively arid areas where soils are both alkaline and relatively deep, acid depositions are unlikely to adversely affect these crops. It is more likely that acidic depositions would tend to have negligible or fertilizing effects on most crops grown in Wyoming. The fertilization effect could result from depositions of nitrates or from the increased availability of nutrients resulting from increased soil acidity.

Forest tree species reported to be potentially sensitive to acid depositions in the northwest United States are also present in Wyoming. These species include spruce, fir, and pine. However, at present there are no data demonstrating whether Wyoming forests are potentially sensitive to acid depositions. This requires additional research before even preliminary assessments of potential risks can be completed.

SURFACE WATERS

The predominant concern about potential impacts from acidic depositions is potential effects on water quality in lakes and streams and resulting effects on the fish populations inhabiting these waters. Therefore, this section provides an extensive consideration of potential effects from acidic depositions on surface water quality. The next section focuses on potential impacts on aquatic organisms.

Effects on Water Quality

In addition to potentially increasing the acidity of sensitive surface waters, acidic depositions may have other indirect effects on water quality. The most important of these is the effect of increased acidity on metals. As pH decreases below neutrality, the solubility of many toxic metals increases (Drever 1982). Thus, acidic surface waters tend to have elevated levels of metals. Of these, aluminum, the most abundant metal in the earth's crust, may be the most important.

Aluminum is present in elevated levels in virtually all acidic waters. In addition, manganese, iron, and zinc are naturally occurring metals that are also commonly present at elevated levels in such waters. Other metals also may be present in surface waters as a result of atmospheric depositions. For example, cadmium, copper, lead, mercury, and nickel are all present at elevated levels in acidic lakes near Sudbury, Ontario due to smelter emissions (Spry et al. 1981).

Another hypothesized chemical effect of increased acidity is decreased nutrient availability, especially for phosphorus. However, this effect has not yet been documented (U.S. EPA 1983).

Acidification of surface waters by acidic depositions has been viewed as a large scale titration of the alkalinity or acid neutralizing capacity of the surface water (Henriksen 1980). It is believed that as long as the surface water and its watershed retain sufficient acid neutralizing capacity, the pH of surface waters will not be significantly decreased due to acidic deposition inputs. However, when acid neutralizing capacity becomes depleted, pH levels may drop rapidly with continued acid inputs.

Two types of acidification can occur in lakes, chronic and episodic. Chronic acidification refers to the long-term, gradual, and more or less permanent decreases in the alkalinity and pH of surface waters. Episodic acidification refers to a short-term, rapid, and temporary decreases in alkalinity and pH. Episodic acidification has been observed following rapid snowmelt and large rainfalls. During such events, large quantities of acids may be flushed into surface waters, thereby temporarily depleting alkalinities and depressing pH levels of poorly buffered waters. This phenomenon is especially common during early snowmelts. During these periods, acids deposited in an entire winter's snowpack can be released to surface waters over a relatively short period. Some data suggest, however, that the accumulations of acidic depositions in snowpacks may be a relatively minor proportion of the acids accompanying early snowmelt runoff; these data indicate that the majority of the acids may originate with natural soil and/or vegetative processes occurring throughout the winter (Rosenqvist 1978, Seip et al. 1982).

Factors Influencing the Sensitivities of Surface Waters to Acidic Depositions

Surface waters are not equally sensitive to acidic depositions. Only those with very poorly buffered water, generally alkalinities less than 200 μeq/l (10 mg/l as $CaCO_3$), are considered to be sensitive to the levels of acidic depositions currently found in the northeastern United States and eastern Canada (U.S. EPA 1983). However, since many factors influence surface water quality, the actual ability of lakes, streams, and their watersheds to neutralize or buffer acid depositions is dependent on many factors in addition to surface water alkalinity (Table 3).

Table 3. Watershed and surface water characteristics that influence sensitivity to acidic depositions (from Marcus et al. 1983).

Category	Increased Sensitivity	Decreased Sensitivity
Bedrock geology	Resistant to weathering (metamorphic, igneous)	Easily weathered (sedimentary, calcite-containing)
Soils		
Buffering capacity	Low	High
Depth	Shallow	Deep
SO_4 absorption capacity	Low	High
Topography	Steep-sloped	Shallow-sloped
Watershed to surface water area ratio	Low	High
Lake flushing rate	High	Low
Watershed vegetation		
Dominant vegetation	Coniferous	Deciduous
Forest management	Reforestation	Clearcutting
Land use	Forestry	Agricultural, municipal
Water quality		
Alkalinity	Low (<200 μeq/l)	High (≥200 μeq/l)
Trophic status	Highly oligotrophic	Less oligotrophic, mesotrophic, eutrophic

Table 3 (continued).

Category	Increased Sensitivity	Decreased Sensitivity
Humic substances	Absent	Present
Sphagnum moss	Present	Absent
Sulfate reduction potential	Low	High
Climate/meteorology		
Precipitation	High	Low
Snow accumulation	High	Low
Growing season	Short	Long
Alkaline dusts	Low	High

Bedrock Geology. The characteristic most frequently applied to estimate potential sensitivities of surface waters to acidic depositions is bedrock geology (Galloway and Cowling 1978, Hendrey et al. 1980a, Kaplan et al. 1981, Likens et al. 1979). Because of relatively slow weathering rates, lakes in areas dominated by metamorphic and igneous bedrock (granites, gneiss, sandstone) tend to have low concentrations of dissolved substances and low alkalinities. Consequently, these lakes tend to be more sensitive to potential acidification (Galloway and Cowling 1978).

Conversely, areas underlaid by limestone, or other bedrocks containing calcite and other carbonate minerals have extensive acid neutralizing capacities. Even small deposits of limestone in watersheds can overwhelmingly influence buffering capacities of surface waters in areas that would otherwise be considered potentially sensitive to potential acidification (Norton 1980). Thus, any assessment of potential sensitivity of surface waters to acidic inputs must characterize the geology of the surrounding watershed. Any assessment based on broad-scale geological characterizations will tend to overestimate potential sensitivity.

Soils. Except when precipitation falls directly onto surface waters or onto exposed bedrock, it must either flow over or percolate through soils. Therefore, soils extensively influence surface water quality and soils are probably the major factor determining the potential sensitivity of landscapes and surface waters to acidic depositions.

Kaplan et al. (1981) analyzed the relationship between bedrock geology, soils, and surface water quality in the northeastern United States. They concluded that for most counties the distribution of surface water quality (i.e., alkalinity and pH) was more strongly related to soil type than bedrock geology. Areas most susceptible to acidification were in counties having high percentages of soils with low buffering capacities. Less susceptible areas were dominated by soils having medium to high buffering capacities. These include many naturally acidic soils (Krug and Frink 1983, Jones et al. 1983).

Soil depth is also an important determinant of sensitivity. For regions with very deep soils, bedrock is irrelevant in determining surface water chemistry, regardless of soil type (Glass et al. 1982, Kaplan et al. 1981). In contrast, water bodies in high mountain areas over metamorphic or igneous bedrocks with little or no soil cover are likely to be most susceptible to acidification (Galloway et al. 1980, Patrick et al. 1981).

Differences in soil depths have been suggested as a primary factor causing differences in pH levels observed in three Adirondack lakes (Galloway et al. 1980). Due to steeper topography and shallower soil depths surrounding Woods Lake, it was suggested that incomplete neutralization of acid inputs to the watershed resulted in low pH levels in the lake. Moreover, the relatively deeper soils and tills surrounding both Panther and Sagamore lakes as well as the larger watershed of Sagamore Lake appeared to neutralize acidic depositions to a greater degree.

Some soils can absorb and bind sulfate in insoluble complexes (Johnson et al. 1980). This can additionally reduce sensitivity to sulfate depositions.

Topography, Surface Water, and Watershed Relationships. As briefly noted above for the three Adirondack lakes, both topography and watershed to lake area ratios can affect the sensitivity of surface waters to acidic depositions. These factors can be especially important during episodic pH depressions that accompany snowmelt and heavy rainfall events.

Watersheds with steep slopes have rapid runoff, which limits contact of runoff waters with soil. Surface waters in such watersheds receive atmospheric precipitation largely unchanged from its chemical composition at the time of deposition. But in shallower catchments, contact of runoff water with soil is increased. Hence, there is greater opportunity for acid neutralization.

Similarly, surface waters in drainages having relatively high watershed to surface water area ratios tend to be less sensitive to acidic depositions. Runoff from these watersheds often has greater contact with soils, which permits additional neutralization of acids.

Finally, lakes with slower flushing rates are also less sensitive to episodic pH depressions during snowmelt runoff. Increased dilution of acidic inflowing waters by the relatively large volumes of lake water reduces pH declines compared to lakes with short residence times (U.S. EPA, 1983).

Watershed Vegetation and Land Use. Terrestrial vegetation in watersheds can markedly influence surface water pH. Succession and accumulation of terrestrial vegetation, especially forests, result in increased soil acidity (Gorham et al. 1979). In particular, soils in coniferous forests can become extremely acidic, with pH values frequently as low as 3.5 (Buckman and Brady 1960). However, as discussed previously, such highly acidic soils are well buffered and have low sensitivity to acidic depositions.

Forest management practices such as timber harvesting generally cause increases in surface water pH levels while reforestation causes decreases in surface water pH (Brakke 1981, Krug and Frink 1983).

Runoff of agriculturally applied nitrate fertilizers and limestone and discharge of domestic sewage effluents as well as storm runoff can also increase surface water alkalinity and pH levels (Brakke 1981, Hornbeck et al. 1975, Hunt and Boyd 1981, Patrick et al. 1979, Shapiro and Pfannkuch 1973). In contrast, application of ammonium- and sulfate-containing fertilizers can result in decreased surface water alkalinity and pH levels (Brakke 1981, Hunt and Boyd 1981, Rosenqvist 1978).

For surface waters that might otherwise be susceptible to acidification, fertilization or eutrophication (nutrient enrichment) can substantially reduce their sensitivity. As a result of nutrient enrichment, primary productivity increases. This leads to increased alkalinity and pH levels in poorly buffered and even naturally acidic lakes (Patrick et al. 1979). Indeed, acidification and eutrophication have been viewed as competing processes in surface waters (Eilers and Webster 1981).

Naturally Acidic Waters. Naturally acidic waters are widely distributed in much of North America (Wetzel 1975). These waters are generally characterized by low pH and alkalinity levels, high dissolved organic matter concentrations, and extensive growths of *Sphagnum* moss. Both weak organic acids and *Sphagnum* can chelate toxic metals, including aluminum, which are often present at toxic concentrations in acidic surface waters. Thus, these naturally acidic waters often contain valuable fish communities with numerous species, and appear relatively insensitive to acidic inputs. For example, Hastings (1979) reports that 36 species of fish occur in the acidic (generally pH <6) lakes and streams of the New Jersey Pine Barrens. Further, Rahel and Magnuson (1980) found the species diversity of fish in naturally acidic lakes of Wisconsin to equal that found in near-neutral lakes having otherwise similar habitat characteristics. And, Patrick et al. (1981) notes that many of the lakes in New Hampshire and New York containing peat and *Sphagnum* have become more acidic in recent decades. These lakes contain considerable aquatic life not greatly affected by this increase.

Due to the high cation exchange capacity of *Sphagnum*, its colonization around alkaline marl lakes, which are generally considered to be insensitive to acidification, can lead to the acidification of these lakes (Wetzel 1975).

Sulfate Reduction. Many lakes that stratify during summer or winter, or shallow lakes that have long extended periods of ice and snow cover, develop oxygen depleted waters. In such waters. sulfates can be reduced to hydrogen sulfides. If iron is present, insoluble iron sulfides will form and precipitate into the sediments. This process results in a net increase in the acid neutralizing capacity of the lake (Schindler et al. 1980). Such lakes will be relatively less sensitive to acid depositions.

Climatic and Meteorological Conditions. Input rates for atmospheric chemicals into watersheds depend largely upon the volume of precipitation input into these watersheds. Therefore, surface waters in areas receiving higher precipitation volumes tend to be more susceptible to potential acidification than those in areas having lower precipitation rates. In the Adirondack Mountains, for example, acidified lakes tend to be in areas receiving the highest annual precipitation (Pfeiffer and Festa 1980). Arid regions, such as are present in virtually all non-mountainous areas of Wyoming, are generally considered to be insensitive to acidic depositions, because of both low precipitation volumes and high soil and surface water alkalinities.

Potential sensitivity to acidification is greatly influenced by climate, especially snowpack accumulation and length of growing season. This phenomenon may be a primary reason why all reported cases of fish population losses attributed to acidic depositions have been from colder, temperate-region locales.

An additional meteorological factor affecting the susceptibility of surface waters to potential impacts from acidic inputs is the content of alkaline dusts in the atmosphere. Increases in proportions of alkaline dusts tend to reduce acidities of atmospheric depositions (Hansen et al. 1981), thus reducing the possibility of surface water acidification. Consequently, the influence of alkaline dusts in the atmosphere in much of the western United States, including Wyoming, may overwhelm other factors in determining the sensitivity of surface water to acidification.

The Integrated Lake-Watershed Acidification Study. An example of the complexity of predicting lake sensitivity to acidification occurred in the Integrated Lake-Watershed Acidification Study (ILWAS; Tetra Tech Inc. 1981). The purpose of this study was to determine why three neighboring Adirondack watersheds exhibit different acidic dynamics. Despite similar Cambrian bedrock geologies and similar acidic precipitation inputs, these watersheds contain lakes that display notably different pH values. On an annual basis, Woods Lake is acid (pH = 5.0); Sagamore Lake is slightly acid (pH = 6.0); and Panther Lake is neutral (pH = 7.0).

ILWAS researchers have hypothesized that pH differences among these lakes are primarily due to different residence times of atmospheric depositions within watershed soils and glacial till. The acidic Woods Lake watershed contains approximately 80 percent bedrock outcrop, while Sagamore and Panther watersheds contain only approximately 40 percent bedrock outcrop exposure. Moreover, glacial till is shallow in Woods watershed, moderately thick in Sagamore watershed, and thick in Panther watershed. Consequently, mean groundwater residence times are estimated to be 8 to 12 months in Woods Lake watershed and 8 to 12 years in Panther Lake watershed; groundwater residence time was not reported for Sagamore Lake watershed. Therefore, increased contact with soil and glacial till appears to increase neutralization of acidic depositions in Sagamore and Panther Lake watersheds.

Cultural activities may also influence the ILWAS lake acidic dynamics. Only Sagamore Lake has human residences on its shores, and only Sagamore watershed has been logged. Both cultural activities may increase the lake's resistance to acidification.

While all three lakes should probably be classified as sensitive to acidification, their relative realized sensitivities suggest Woods to be most sensitive then Sagamore then Panther. Woods Lake is already acidified, although in 1976 a pH value of 5.8 was recorded and it was classified as a brook trout pond (Pfeiffer and Festa 1980). During the same survey, Sagamore Lake contained both warm-water and cold-water fishes. The fishery status of Panther Lake was not reported, though its water quality appears to be acceptable for fish.

Although less sensitive to long-term acidification, severe episodic pH depressions occur in both Sagamore and Panther lakes. In 1979, pH values decreased from 6.0 to 4.2-4.8 in the upper 6-m of Sagamore Lake (Hendrey et al. 1980b). Yet in the more temperature stratified Panther Lake, acidic snowmelt water was confined to the upper 1-m of the lake; pH values as low as 5.0 were recorded in this layer. Therefore, fish populations in Panther Lake were probably not exposed as much to low pH during snowmelt as were fish in Sagamore Lake.

Sensitivity of Wyoming Surface Waters to Acidic Depositions

Relatively few data are available on pH and alkalinity levels for Wyoming lakes found in potentially sensitive areas. Also, few site-specific data are available that permit evaluation of other factors influencing sensitivity of these waters such as soil type and depth, vegetation, and land use. However, some data indicate that high mountain areas contain a relatively high proportion of potentially sensitive lakes. Hudelson et al. (1980) surveyed lakes of the Bridger Wilderness Area of the Wind River Range. They found that about 70 percent of the lakes present at altitudes greater than 9,000 feet had alkalinities less than 200 μeq/l and were therefore potentially sensitive to acidic depositions.

A study having potential usefulness in predicting lake sensitivities in Wyoming is reported by Turk and Adams (1983). They surveyed the lakes of the Flat Tops Wilderness Area in northwestern Colorado to identify potentially sensitive lakes and to determine factors related to this sensitivity. About 30 percent of the lakes in the Flat Tops were determined to have alkalinities less than 200 μeq/l. Altitude was found to be the parameter most highly correlated with sensitivity. Sensitive lakes were primarily confined to altitudes greater than 11,100 feet (3,383 m). Above this altitude, vegetation and soils are poorly developed. Exposed, slowly weathered, poorly buffered bedrock comprises much of these watersheds. In addition, very high snowpack accumulations could increase potential susceptibilities of surface waters to episodic pH depressions during snowmelt.

Obviously many characteristics may influence surface water sensitivity to acidification. The relative importance of each characteristic depends on site-specific conditions. For instance, snowpack accumulation and subsequent episodic pH depressions during snowmelt may affect fish populations most dramatically. Individual watershed surveys as well as analyses of current and projected acidifying deposition rates are necessary to identify lakes and streams likely to become significantly acidified within a geographic region. These surveys should also include rate estimates for internal acidification sources (cf., Lefohn and Klock 1983, Marcus et al. 1983).

If the characteristics of potentially sensitive surface waters, shown in Table 3, are applied to Wyoming, it is apparent that sensitive water bodies will be confined largely to high mountain ranges containing high proportions of igneous and metamorphic bedrocks, such as granite, gneiss, and sandstone. These areas will primarily be located above treeline. In such areas, surface water quality will be highly influenced and largely determined by precipitation quality and quantity. If average acidity levels in depositions were to increase to levels currently present in the northeast U.S. (less than about pH 4.2), some of these lakes could be adversely impacted. However, these levels are 8 to 200 times the acidity level of present precipitation in Wyoming (pH 4.8-5.7; U.S. EPA 1983). Consequently, present acidity levels in precipitation to Wyoming are likely to widely affect surface water quality in the State. However, emissions from new point sources (e.g., gas sweetening plants in the Overthrust Belt) could affect localized downwind areas of potentially sensitive resources. To determine this potential requires future monitoring and research efforts.

AQUATIC ORGANISMS

General Effects of Acidification

Effects of acidity on aquatic organisms have received considerable study. Most research has been conducted in the laboratory and has been limited to relatively few species. Field research has been of two types: (1) studies on lakes undergoing acidification, and (2) comparisons of populations in acidic and non-acidic lakes. Most of this work has focused on fish; however, microbes, plants, invertebrates, and amphibians have also been studied. As a result of this effort, a number of general conclusions concerning the effects of acidity on aquatic organisms and ecosystems can be made. These conclusions apply to both the effects of a decrease in pH within a lake and to comparisons between non-acidic and acidic lakes:

1. There are wide ranges among and within species in sensitivities to acidity. For example, Table 4 lists the range of reported critical pH levels for several fish species present in poorly buffered Wyoming lakes potentially

Table 4. Critical pH values for some fish species found in acid-sensitive Wyoming lakes (from Marcus et al. 1983).

Species	Critical pH* (Range of reported values)
Lake Trout	6.8 - 4.4
Rainbow Trout	6.0 - 5.5
Brown Trout	6.0 - 4.5
White Sucker	5.2 - 4.2
Brook Trout	5.0 - 4.5

*The critical pH values are those at which these species were reported to have ceased reproduction, declined, disappeared, or died in acidic surface waters.

sensitive to acidification. Critical pH levels reported for lake trout range from 6.8 to 4.4, a 400-fold range in hydrogen-ion concentrations. In comparison, critical pH levels reported for brook trout are 5.0 to 4.5, and critical levels for rainbow trout are 6.0 to 5.5. Rainbow trout appear to be more sensitive than brook trout to acidity; however, it is unclear whether lake trout, brown trout, or white suckers are more sensitive than brook trout. Much of this apparent variability may be due to genetic differences among different strains of the same species in sensitivities to acidity. For example, some strains of brook trout inhabit naturally acidic waters and have apparently adapted to acidity levels that are intolerable to other strains of brook trout. Similar variations in sensitivity are found among species of algae, zooplankton, and insects (U.S. EPA 1983).

2. In acidic waters, many toxic effects attributed to acidity alone probably result from the combined toxicity of acids and metals. As discussed previously, concentrations of many metals, especially aluminum, are greatly increased in acid waters.

3. Acidification may potentially affect aquatic organisms via two types of exposures: episodic and chronic. Episodic exposures following snowmelts or large rainstorms may expose sensitive life stages to relatively brief but acutely toxic pH depressions resulting in mortalities. Chronic, long-term

acidification may result in gradual decreases in reproduction, growth, and survival leading to the gradual extinction of the species from affected water bodies.

4. As pH decreases, both the number of species and species diversity tends to decrease. This relationship has been found for fish, insects, zooplankton, and algae (U.S. EPA 1983).

5. It is currently unclear whether acidification decreases surface water productivities (U.S. EPA 1983). Since potentially sensitive waters are by their very nature unproductive, it is difficult to monitor productivity trends in them. Acidification appears to reduce microbial decomposition rates and this could lead to decreased nutrient cycling, and decreased primary production. The high aluminum levels present in acidic waters may also cause the complexation and precipitation of phosphorus.

6. A common result of acidification is increased water clarity. This commonly leads to the development of a thick benthic mat of algae.

7. In North America, aquatic macrophytes appear to be relatively unaffected by acidification; however, in Scandanavia, some acidified lakes have become colonized by Sphagnum, an aquatic moss characteristically present in many naturally acidic, brown water lakes.

8. In acidic waters, some toxic metals, including mercury, appear to be significantly bioaccumulated by fish. Also,

aluminum has been observed to be bioaccumulated by macrophytes in these waters.

Effects of Acidification on Fish

The primary concern of potential effects from acidic depositions has been for effects on fish. Within the United States, documented fish losses attributed to acidic depositions have only been reported for the Adirondack Mountains of New York. In the Adirondacks approximately 180 lakes and ponds, which formerly supported brook trout populations, no longer have brook trout. These lakes represent about 6 percent of the total number of lakes and about 3 percent of the total lake area present in the Adirondacks. Other fish species lost from some of these lakes include lake trout, smallmouth bass, and white suckers.

Within Canada, two areas have experienced fish losses attributable to acidic depositions. Lakes in the LaCloche Mountains of Ontario have become acidified as a result of SO_2 depositions originating from smelters near Sudbury, Ontario. Fifty-six percent of 68 lakes surveyed are known or suspected to have had fish losses (U.S. EPA 1983). In Nova Scotia, 9 acidic rivers have lost or experienced severe declines in their Atlantic salmon populations.

Three mechanisms have been hypothesized to explain these fish losses: (1) recruitment failure, (2) fish kills, and (3) loss of food resources. The general consensus is that recruitment failure is the most common cause of these fish losses, although for some lakes the other two mechanisms may have contributed (U.S. EPA 1983). A common characteristic of many fish populations experiencing declines in acidic waters is missing year classes. These could result from failure of egg development (oogenesis), failure to successfully spawn, or mortalities of eggs, fry, or young juveniles. In Adirondack Mountain lakes where losses of brook trout have occurred, the mechanism of these losses is believed to be mortality of eggs, fry, and young juveniles during spring snowmelts. During these episodic events, these sensitive life stages are generally present in small tributary streams where they may be exposed to maximum concentrations of acids and soluble aluminum.

Chronic long-term acidification could also potentially cause missing year classes by causing reproductive failure, or spawning failure. This mechanism has been proposed to explain fish losses from the lakes in the LaCloche Mountains of Ontario (Beamish 1976).

Potential Effects in Wyoming

Wyoming surface waters potentially sensitive to acidification by acidic depositions contain many aquatic species sensitive to acidity. If these waters were to become acidic (pH levels below 6.0), biological effects would become apparent, and the types of effects previously described would probably occur.

Of major concern in Wyoming are the potential effects of acidic depositions on trout populations in high mountain lakes since these waters are potentially highly sensitive to acidification. The most likely mechanisms for effects to first appear in these trout populations would be through recruitment failure. During spring and early summer, the most sensitive life stages of trout (i.e., eggs, fry, and young juveniles) will be present in these lakes and their tributaries. Then with snowmelt, the entire winter's accumulation of acids from atmospheric and internal watershed sources will be washed into these poorly buffered waters. This could potentially cause episodic decreases in pH and possibly increases in soluble aluminum concentrations. If critical toxic pH and aluminum levels were reached, mortalities of these sensitive life stages would occur. These would become manifested as missing year classes. Several such successive events could lead to the extinction of the population.

It should be emphasized, however, that present acidic deposition rates in Wyoming do not appear sufficient to pose a potential threat to Wyoming surface waters or their resident organisms. Before the fish and other aquatic organisms present in sensitive Wyoming waters may be threatened, acidic depositions rates have to increase substantially. Industrial development underway in areas of the State upwind from potential sensitive resources could produce impacts on downwind resources. To adequately evaluate this potential requires future monitoring and research efforts.

HUMAN HEALTH

There are three major concerns about potential impacts of acidic depositions on human health. These all relate to effects of increased acidity on increasing concentrations of toxic metals in water (U.S. EPA 1983).

1. It has been demonstrated that bioaccumulation in fish of some toxic metals, such as mercury, is increased in acidic surface waters. Consumption of these fish by humans could potentially pose a health hazard if such fish were consumed in significant numbers.
2. Consumption of acidic ground or surface water containing elevated levels of toxic metals could potentially produce a health hazard.
3. Acidification of domestic water supplies could lead to the leaching of lead or copper from pipes containing these metals and produce a health hazard if such waters were consumed in significant volumes.

These potential health effects that could result from acidic depositions have not been actually documented in human populations (U.S. EPA 1983). However, this may be due to an actual lack of such effects or to the limited effort devoted to studying such effects.

Potential Effects in Wyoming

Although the potential may exist for acidic deposition-caused health effects in Wyoming, the possibility of such effects developing is unknown and probably small. Due to the general inaccessibility and low productivity of lakes in Wyoming that are potentially sensitive to depositions, individual consumption of fish from these lakes is small. Therefore, even if these lakes became more acidic and if resident fish populations developed high body burdens of toxic metals (it is unknown if they would), it is unlikely that individual consumption of fish would likely be sufficient to produce metal poisoning.

Some municipalities or households in Wyoming may have domestic waters supplied from watersheds having characteristics of those sensitive to acidic depositions. If surface waters in these watersheds were to become acidic, solubilization of toxic metals from the watershed or from lead or copper piping could potentially produce human health effects. These potential effects, however, can be readily remedied by liming, a common treatment practice for municipal water supplies. While smaller communities in Wyoming may not have treatment facilities for liming, technologies are readily available to construct such facilities for any community water supplies possibly needing such treatment.

CULTURAL MATERIALS

Potential effects of acidic depositions on cultural materials include: (1) corrosion of metals, (2) erosion and discoloration of paint, (3) decay of stone buildings and statues, and (4) weakening and fading of textiles (U.S. EPA 1983). Although these effects can be caused by both long-range and local sources of acids, it is currently not possible to separate the effects of acidic depositions and other types of air pollutants. However, long-range transport is considered to account for only a small fraction of the total damage to materials attributable to air pollutants (U.S. EPA 1983).

Potential Effects in Wyoming

Within Wyoming, many cultural materials exist that are potentially sensitive to acidic depositions. However, these materials are largely located in the non-mountainous, relatively arid regions of the state. Due to the influence of alkaline dusts derived from the alkaline soils, the pH of depositions in these arid regions is likely to remain relatively basic. In general, then, potential adverse effects from future acidic depositions to Wyoming will likely have little detectable effect on most cultural materials of concern.

DESIGN OF A WYOMING ACIDIC DEPOSITION MONITORING AND RESEARCH PROGRAM

Acidic depositions could in the future impact a diversity of natural and cultural resources in Wyoming, as discussed in previous sections. Evaluating these possibilities requires compiling existing data and developing new data and information, as necessary, for evaluation. Only through such efforts can there be an accurate appraisal of potential future impacts due to acidic depositions in Wyoming.

Acidic depositions have become a complex environmental issue and produced substantial international controversy. A concentrated effort, well coordinated by a single authority, is required to analyze, in an efficient and cost-effective manner, the significance of acidic depositions in Wyoming. Such an effort will potentially involve many state and federal organizations. Coordination could involve the Governor's State Planning Coordinator. To aid this office, an expert advisory panel could be formed. This panel could be composed of representatives from government, industry, academics, public interest groups, and/or other organizations. Panel advice could be used to guide delegation of responsibilities and activities to various groups involved in the overall state effort.

The remainder of this section is devoted to designing a suggested monitoring and research program directed at evaluating the present and future significance of acidic depositions in Wyoming. First, relevant ongoing research areas are identified in the atmospheric and environmental effects sciences. Second, a selection of possible monitoring and research options for a Wyoming program are presented. Finally, a specific research and monitoring program is suggested for Wyoming sponsorship.

GENERAL RESEARCH AREAS REQUIRING ADDITIONAL DATA

Extensive national and international research efforts are directed at understanding causes, mechanisms, and effects of acidic depositions. These efforts can be classed into two generalized categories: atmospheric sciences and environmental effects research (Table 5). For various of the research areas, ongoing efforts will likely yield results applicable to Wyoming. Therefore, due to this fact and the costs involved to duplicate such efforts, not all of these research areas are appropriate for inclusion in a Wyoming sponsored program.

Based on these considerations and on the review presented in previous sections, it is recommended that a state sponsored program primarily concentrate on monitoring and research efforts included in four areas identified in Table 5. This program would produce results useful in determining the significance to Wyoming of acidic depositions.

Within the atmospheric sciences, projects inventorying emission sources and monitoring deposition rates will yield results having greatest potential value to Wyoming. As the state-of-the-science

Table 5. General research areas having ongoing efforts to provide data useful to understanding cause and effects of acidic depositions.

ATMOSPHERIC SCIENCES

- Emission sources*
- Transport
- Transformation
- Chemical concentrations and distributions
- Precipitation scavenging processes
- Dry deposition processes
- Deposition Monitoring*
- Atmospheric Modeling

ENVIRONMENTAL EFFECTS

- Aquatic chemistry*
- Aquatic biology*
- Soils
- Terrestrial Vegetation
- Materials
- Health

*Topics recommended for primary emphasis in a Wyoming monitoring and research program.

advances in the other atmospheric sciences categories, these results can be also applied to Wyoming.

Within environmental effects sciences, research and/or monitoring efforts potentially valuable to a state program are included primarily in the aquatic chemistry and biology categories (Table 5). As discussed in the previous sections, lakes, streams, and their resident organisms are the resources most often hypothesized as being at greatest potential risk from acidic depositions.

MONITORING AND RESEARCH OPTIONS FOR WYOMING

Emission Sources (Table 6)

Any comprehensive analysis for potential causes and effects of acidic depositions requires inventorying sources emitting acids to the atmosphere. This inventory could include locations and emission rates for both natural and anthropogenic (man-caused) sources. Also of potential value is information on the budget for atmospheric acids in Wyoming. That is, proportions of atmospheric acids in Wyoming that originate from instate sources versus out-of-state sources could be estimated using data available for existing emission sources and deposition rates. These data could also be used to estimate output from the State of atmospheric acids emitted from instate sources. For the atmospheric studies, the chemicals of principal concern are hydrogen ions (H^+), ammonium (NH_4^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), nitrate (NO_3^-), and chloride (Cl^-).

Table 6. Monitoring and research options from the atmospheric sciences for a Wyoming program to assess the significance to the state of acidic depositions.

EMISSION SOURCES

- Major natural source inventory
- Major anthropogenic source inventory
- Instate/out-of-state budgets for acids in the state's airshed

DEPOSITION MONITORING

- Bulk depositions
- Wet/dry depositions
  - Event collections
- Snowpack accumulations

Deposition Monitoring (Table 6)

To establish whether there is any potential for atmospheric depositions causing acidic impacts in Wyoming, it must first be established that acidity levels in depositions are sufficiently great to potentially cause adverse impacts. This requires that the chemical composition of depositions be monitored.

Three principal options exist for precipitation monitoring (Table 6). In order to clarify the difference between the three, it is helpful to briefly review the procedures followed for collection and analysis of each. First, collections can be made of "bulk depositions", which includes both "wet" precipitation and "dry" particles deposited from the atmosphere. Typically, containers for collecting bulk depositions are left at collection sites for a fixed period, usually one week. After this period the containers are replaced and the collected materials taken to a laboratory for analysis.

For the second method, separate collections are made of wet and dry depositions. Devices for these collections generally consist of two containers and one cover that moves from one container to the other when an electrical switch is triggered by the presence or absence of precipitation. As with bulk depositions, collected materials are retrieved, generally once per week, for laboratory analysis. A variation of the wet/dry collection is the "event collection". Here, containers are put out at the beginning of a precipitation event (i.e., a rainfall or snowfall). Following completion of the event, the collected materials are retrieved for laboratory analysis.

Finally, the third form of deposition monitoring involves snowpack analysis. For this, snowpack accumulations are collected, generally using a coring device. The collected snow is returned for laboratory analysis. This can include analysis of the entire core or of separate sections from the core to develop vertical profiles for the distributions of various chemicals down through the snowpack.

In analyzing any samples collected using these various techniques, it is of critical importance that appropriate quantitative and qualitative chemical analytical methods be used. Descriptions of appropriate methods are available from the National Atmospheric Deposition Program and from the U.S. Environmental Protection Agency.

Effects on Aquatic Chemistry (Table 7)

As indicated in previous sections, the greatest concern about potential effects from acidic depositions is possible damage to lakes and streams and to their resident organisms. Therefore, efforts to assess these potential impacts require high priority. Various monitoring and research options are available for a state sponsored program (Table 7). Early efforts could include compiling and evaluating existing data on surface water chemistries in the state. Based on these data, and perhaps on some additional efforts to fill data gaps, an inventory could be developed for potentially sensitive surface waters in the state. Efforts also could be directed toward monitoring short-term (episodic) changes in surface water quality at

Table 7. Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on aquatic chemistry.

EFFECTS ON AQUATIC CHEMISTRY
• Compile and evaluate existing data
• Inventory locations and characteristics of sensitive surface waters
• Monitor short-term (episodic) changes in surface water quality
• Monitor long-term (chronic) changes in surface water quality
• Lake sediment core analyses
• Evaluate mitigation and management strategies for acidic surface waters

selected lake and stream sites during periods of major precipitation and snowmelt runoff events. At these and other selected sites additional monitoring efforts could be directed toward determining possible long-term (chronic) changes in surface water quality. Additionally, to provide a historical perspective of water quality changes in sensitive lakes, sediment cores could be analyzed. Finally, research also could be conducted to evaluate various possible mitigation and management strategies for acidic surface waters. Direct research efforts on this last option would be most valuable to the state after acidic waters have been identified and a high potential for problems has been determined.

Effects on Aquatic Biology (Table 8)

As with water chemistry, many adverse impacts have been hypothesized to affect aquatic organisms due to acidic depositions. Evaluating potential or actual impacts in Wyoming requires collection of considerable data. This could include a compilation of existing data on fish and other aquatic populations in sensitive lakes and streams. From these data, plus additional possible field data to fill information gaps, an inventory could be compiled for aquatic populations in sensitive waters.

As surface waters become increasingly acidic, one of the first apparent responses is the loss of year classes by acid sensitive fish species. Therefore, additional effort could be directed toward monitoring the year class structure and reproduction success of populations in sensitive surface waters. Also, algae and invertebrate

Table 8. Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on aquatic biology.

EFFECTS ON AQUATIC BIOLOGY • Compile and evaluate existing data • Inventory species and population stocks in sensitive surface waters • Monitor fish reproduction, recruitment, and/or age structure in sensitive surface waters • Monitor algae and invertebrate communities in sensitive surface waters • Investigate mechanisms of aquatic population loss • Evaluate mitigation and management strategies for populations in acidic surface waters

communities could be monitored to detect changes in structure; it should be noted, however, that for most such changes in these communities not associated with the point source discharge, the actual cause of the change is very difficult, if not impossible, to identify.

Additional effort could also be directed toward identifying mechanisms of population loss in acidifying surface waters. Through knowledge of actual physiological, toxicological, or ecological mechanism(s) of loss, better methods could be developed to mitigate or manage such losses in surface waters that may become acidic in the future.

Effects on Soil Systems (Table 9)

Soils are a principal parameter determining sensitivities of aquatic and terrestrial environments to acidification. As such, information could be compiled for potentially sensitive areas on soil types, depths, acidities, buffering capabilities, alkalinities, and related chemical factors. Using such data that are available, plus additional information gathered from site specific surveys of selected areas, an inventory could be compiled for the primary sensitive soil areas in Wyoming. In sensitive areas, leachate studies could be conducted to investigate the chemical compositions of drainages from soils leached by natural and simulated precipitation having various pH levels. Soil acidities in these areas could be monitored to determine short-term and/or chronic changes. Studies also could be conducted to investigate possible changes in microbial populations and/or litter decomposition rates in any acidifying soils identified. Whole

Table 9. Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on scil systems.

EFFECTS ON SOIL SYSTEMS

- Compile and evaluate existing data
- Inventory soil depths and chemistries in sensitive areas
- Determine soil acidities and chemistries of precipitation leachates in sensitive soils
- Monitor changes of soil pH in sensitive areas
- Investigate long-term changes in microbial populations and litter degradation rates in acidifying soils
- Monitor changes in input-output budgets, and internal stores and dynamics of acidic materials in sensitive watersheds
- Evaluate mitigation and management strategies for acidified soil systems

---

watershed studies could be instigated to detect possible long-term changes in input-output budgets for various chemicals. And, methods could be investigated to determine effective ways of mitigating and managing acidifying soils.

Effects on Terrestrial Vegetation (Table 10)

Available data do not clearly indicate that terrestrial vegetation is adversely impacted by present rates of acidic depositions in the environment. In laboratory studies using simulated precipitation having pH levels much more acidic than found in the environment (i.e., pH 3.0), both negative and positive effects on plants have been observed. As a result of these studies, certain sensitive terrestrial plant species have been identified. It is of potential value to compile and review existing data and to survey selected areas in order to provide a Wyoming State inventory of plant species potentially sensitive to acidic depositions. Additionally, monitoring could be conducted to determine if adverse effects are occurring to lichens, trees, or crops in areas receiving acidic depositions. And, various mitigation and management methods could be evaluated to determine those most appropriate for use with plants growing in sensitive areas of Wyoming.

Effects on Material and Cultural Resources (Table 11)

Acidic depositions have been hypothesized to produce various effects on materials and cultural resources. However, in most examples the effects of acidic depositions have not been separated

Table 10. Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on terrestrial vegetation.

EFFECTS ON TERRESTRIAL VEGETATION

- Compile and evaluate exiting data
- Inventory species and population stocks in sensitive areas
- Monitor long-term changes in lichen growth and damage
- Monitor long-term changes in forest tree growth and damage
- Monitor long-term changes in agricultural crops growth and damage
- Evaluate mitigation and management strategies for potentially acid damaged terrestrial vegetation

Table 11. Monitoring and research options for a Wyoming program to assess the significance to the state of acidic deposition effects on material and cultural resources.

EFFECTS ON MATERIAL AND CULTURAL RESOURCES
• Compile and evaluate existing data
• Inventory sensitive resources
• Monitor long-term material erosion
• Evaluate strategies for protecting and rehabilitating acid-sensitive materials and finishes

from those due to other atmospheric pollutants. For a Wyoming program, existing data could be compiled and evaluated to provide a baseline inventory of important material and cultural resources in the State potentially sensitive to acidic depositions. Then, monitoring of damage could be conducted. For materials damaged by acidic depositions, protective or rehabilitative methods could be evaluated.

SUGGESTED MONITORING AND RESEARCH ACTIONS FOR WYOMING

The following projects suggested for a Wyoming monitoring and research program were selected from the above options. This program is presented as a starting point for designing a state-wide coordinated program. That is, this proposed program may be altered by the addition or subtraction of selected research projects to tailor it to the needs of the involved organizations.

In designing this monitoring and research program, four important considerations were involved:

- Information Gaps - Where are additional data needed that contribute most to increasing the understanding about causes effects, and remedies related to acidic depositions?
- Applicability - Will the proposed research effort produce data having application to similar problems in other regions of the State?
- Feasibility - Is it possible under the proposed research effort to collect the necessary data with a reasonable expenditure of time and manpower?

- Economics - Are the monetary costs of completing the proposed research efforts reasonable in relation to the scientific or social value of the data collected?

These considerations also should be included in altering the proposed State program by the addition or deletion of research project.

The proposed monitoring and research program assumes no existing effort in the State. While there are several ongoing projects, this assumption was made to simplify the effort necessary to design an overall State program. When the goals of this program are finalized, anticipated results from some of the ongoing research may fall outside of these goals. However, since such efforts provide valuable supplemental information to the State program, these efforts should not be discouraged. To be of greatest value, all research projects should be conducted using comparable methods.

The proposed monitoring and research program is designed to answer five questions of concern to Wyoming (Table 12). In answering these questions, scientifically sound information will result that can serve as a basis for the State in making informal regulatory and management decisions.

The five questions are grouped into three priority levels. The first level contains three questions that can be at least preliminarily answered using existing data. The second level presents one question that requires development of new data through site-specific research projects. Efforts directed toward Levels 1 and 2 may proceed sequentially or concurrently, though for the purposes of this report concurrent efforts are assumed. Finally, for the single

Table 12. Five questions used to develop the suggested Wyoming program for concerns about the possible importance and impacts of acidic deposition to Wyoming.

LEVEL 1

- Are acidity levels in atmospheric depositions in Wyoming great enough to potentially cause adverse impacts?
- What are the sources of acids in depositions in Wyoming?
- What natural and cultural resources in Wyoming are potentially at risk from acidic depositions?

LEVEL 2

- Are acidic depositions adversely impacting the sensitive resources of Wyoming?

LEVEL 3

- What actions, indicated by results from the previous levels, can help to evaluate potential effects of and mitigation and management measures for acidic depositions in Wyoming?

---

question presented in the third level, data from Levels 1 and 2 are required before this research can be defined.

Level 1

Are acidity levels in atmospheric depositions in Wyoming great enough to potentially cause adverse impacts?

This question relates not only to acidity levels in current precipitation in Wyoming but also to future changes in these levels. As such, addressing this question requires that both existing and new data be compiled for the quality and quantity of atmospheric depositions in the State (Table 13). Existing data are available for a number of locations in the state. The sources for these data must be identified and available data compiled. These sources will include the Wyoming Water Research Center, the University of Wyoming Departments of Botany and Atmospheric Sciences, Western Wyoming College Water Laboratory, the Electric Power Research Institute, and the National Atmospheric Deposition Program (NADP). In compiling these data it is critical to evaluate whether data from the various sources are comparable. That is, do the analytical methods that were used yield results that can be compared to other data with or without making conversions or assumptions. Assumptions used should be documented. Compiling these data will help to provide a historical perspective of changing precipitation patterns in the State.

It will also be necessary to establish the qualitative and quantitative nature of present deposition patterns in the State. This requires implementing a deposition monitoring program that employs

Table 13. Suggested research directed at the question, "Are acidity levels in atmospheric depositions in Wyoming great enough to potentially cause adverse impacts?"

- Compile and evaluate existing atmospheric deposition data
  - Identify sources for existing data
  - Evaluate collection and analysis methods
  - Document assumptions
  - Determine past qualitative and quantitative deposition patterns

- Monitor present atmospheric depositions
  - Site selection - 4 minimum
  - Collect weekly dry and "events" wet depositions
  - Monitor snowpack accumulations
  - Analyze using NADP methods

standard analytical procedures, such as developed by the NADP. And, data should be provided on wet and dry inputs, and snowpack accumulations. Monitoring should be conducted at a minimum of four sites, one each in the Wind River, Absaroka, Big Horn, and Snowy Mountain Ranges. Specific sites should be selected by the advisory panel at locations that best suit study objectives. If possible these sites should be near other program study sites.

<u>What are the sources of acids in depositions to Wyoming?</u>

Determining causes of any acidic depositions found in Wyoming requires an inventory of instate sources and completion of a budget for instate versus out-of-state sources (Table 14). The inventory should include locations and amounts of both anthropogenic (man-caused) and natural emission sources. For major anthropogenic sources, necessary information should be easily obtained from various industrial permits issued by the State (e.g., see Table 2). Quantification of emissions from minor anthropogenic sources and natural sources will likely be more difficult, and may rely upon estimations based upon comparable values obtained from the open literature, EPA technical reports, or other sources. These inventories should emphasize the five inorganic chemicals primarily related to acidity levels in atmospheric depositions: hydrogen ions, ammonium, oxides of sulfur and nitrogen, and chlorides. In addition, sources and quantities of potentially acid forming organic chemicals should be inventoried.

Table 14. Suggested research directed at the question, "What are the sources of acids in depositions to Wyoming?"

- Inventory emission source locations
  - Locate man-caused and natural sources
  - Quantify emission rates for major man-caused sources using information contained in State permits
  - Estimate emission rates for sources lacking specific information

- Develop instate/out-of-state source budgets for acids in the Wyoming airshed
  - Identify sources for existing data
  - Compile and evaluate data

The second effort to evaluate sources of acids in depositions to the State involves determining budgets for contributions of acidic forming ions originating from instate versus out-of-state emission sources. Data useful for completing this inventory are available from various sources, including permitting information from various agencies in surrounding states, the U.S. Environmental Protection Agency, and the Environmental Defense Fund. Data from these various sources could be compiled and compared to provide the most reasonable estimate of the proportional inputs from the various sources to Wyoming's airshed. These data also could be used to estimate outputs from the State of emissions from instate sources.

<u>What natural and cultural resources in Wyoming are potentially at risk from acidic depositions?</u>

Determining whether sensitive Wyoming resources may be threatened by acidic depositions requires knowledge of not only where acidic depositions occur but also where potentially sensitive resources are located. Thus, an inventory of potentially sensitive resources should be completed (Table 15). This can be largely completed using existing data. The inventory should include, where possible, information on lake and stream chemistries, biological communities, soils, terrestrial vegetation, and material and cultural resources.

Table 15. Suggested research directed at the question, "What natural and cultural resources in Wyoming are potentially at risk from acidic depositions?"

- Develop inventory of resources at potential risk using existing information
  - Lakes and streams
  - Biological communities
  - Geology and soils
  - Terrestrial vegetation
  - Material and cultural resources

Level 2

Are acidic depositions adversely impacting the sensitive resources of Wyoming?

This question relates primarily to future possible impacts from acidic depositions. To address this question requires site-specific monitoring to collect data primarily from aquatic ecosystems, the resource system hypothesized as most sensitive (Table 16). Before this effort begins, the specific study sites must be chosen by the advisory panel. It is recommended that one set of three to four sites be selected in the Wind River Range, an area of high concern for potential adverse impact. (These sites may be the same as those currently under study by the U.S. Forest Service.) At least one other set of sites should be selected for study in the Absaroka, Big Horn, or Snowy Mountain Ranges. Because the Snowy Range is located downwind from two major power plants and Salt Lake City, plus being relatively near Denver, it is recommended that this be selected for the second set of sites. If adequate funds are available, studies should be conducted in each of these mountain ranges.

For the studies in each range, a minimum of three to five lake and/or stream study sites should be selected. Criteria for selection should include considerations of each parameter presented in Table 3. Sites selected should have characteristics of those sensitive to potential acidification and have characteristics typical of other sensitive waters within that mountain range. The process of site selection should be completed with considerable care, and should be supported by a preliminary sampling effort. Additional detail on

Table 16. Suggested research directed at the question, "Are acidic depositions adversely impacting the sensitive resources of Wyoming?"

- Selection of study sites for long-term collection of monitoring and baseline environmental data
    - Characteristics of sensitive resources
    - Probability of impacts
    - Preliminary sampling

- Monitoring for long-term changes in aquatic ecosystems
    - Lake and/or stream sites
    - Chemical sampling frequency - 1/wk for ice free and 1/mo for ice cover
    - Use U.S. EPA analytical methods
    - Fish population monitoring frequency - 1/yr

- Monitoring for short-term changes in aquatic ecosystems
    - Stream sites at or near long-term monitoring sites
    - Sampling frequency - hourly, when possible
    - Use U.S. EPA analytical methods

- Soil survey
    - Survey the chemical compositions of soil solution in watershed soils
    - Employ standardized analytical chemistry methods

---

considerations necessary for site selection is provided in "Sampling and Analysis Protocol for Chemical Characteristics of Lakes and Streams Sensitive to Acidic Deposition" (see Appendix A).

Upon selection of the study sites, long-term monitoring should begin. To detect possible long-term changes in water quality, it will be necessary for the studies to continue for at least five years. Typically, lakes should be sampled near their deepest point and 0.5 m below the surface if the water column is homogeneous. If the lake is stratified, two samples should be collected: (1) from 0.5 m below the surface, and (2) from midway between the thermocline and the lake bottom (see Appendix A). To determine seasonal variation, samples for chemical analyses should be collected once per week during the ice free season, and once per month, as possible, during ice cover. To determine typical diurnal variations, concentrated sampling conducted once every 4 hours for 24 hours should be completed once each in the spring, summer, and fall in at least one lake per set of study sites. Chemical analyses should be conducted for total acidity, weak versus strong acids, alkalinity, sulfate, nitrate, chloride, aluminum, and calcium. To adequately interpret the results, morphometric data and flushing rates for each lake sampled and required (see also Appendix A). All analyses should be completed following standardized U.S. EPA procedures.

These long-term studies should be accompanied by studies to detect possible changes in sensitive fish populations resident in the study waters. These populations would likely include trout and sucker species, depending on those present. The fish monitoring should be conducted once per year to determine the age-class structure in the populations. Detection of missing age classes in the populations would suggest reproductive or recruiting failures, an occurrence hypothesized to be one of the earliest results of surface-water acidification.

Besides the above long-term monitoring studies of water quality and fish populations, additional study should focus on possible short-term changes accompanying major rainfalls and snowmelts. Changes associated with these types of events are frequently thought to be the first signs of adverse impacts caused by acidic depositions. It is suggested, therefore, that these intensive studies be conducted using at least four stream sites that most directly correspond to four lake/stream sites investigated in the long-term studies. Additional sites also may be selected. The studies at all sites should continue for three years during the spring snowmelts and early summer rains. Chemical parameters included for analysis should be the same as those included in the long-term studies (see also Appendix A). Analytical methods also follow standardized U.S. EPA procedures. Sample collection frequencies should be close as practical, approaching every four to eight hours for snowmelt and every hour for rainfall runoff.

Finally, to complete these initial Level 2 efforts, soil systems should be studied. These studies should emphasize the chemistry of soil solutions in watershed soils surrounding sites selected for long-term aquatic ecosystem studies. Chemical parameters included in these analyses should be the same as conducted in the aquatic studies, and standardized methods should again be employed. Particular emphasis should be placed upon determining sources and types of acids present in the soils.

Level 3

What actions, indicated by results from the previous levels, can help to evaluate potential effects of and mitigation and management measures for acidic depositions in Wyoming?

As a result of the monitoring and research efforts conducted for the previous levels, a variety of questions will arise. Each of these questions will require additional research. Such research could include site-specific studies to help evaluate resources at risk, efforts to monitor lichen growth and damage, monitoring of aquatic algae and invertebrate communities, analyses of sediment cores to provide histories of sensitive lakes, soil leachate studies, and monitoring of material erosion in areas having high inputs of acids. At this time none of these projects are recommended for inclusion into the State program until other data are first developed. Then, these Level 3 projects may be ranked and included in plans for future years monitoring and research efforts.

POTENTIAL INTERESTS AND INVOLVEMENTS IN A STATE PROGRAM

Since acidic depositions may potentially impact a wide range of both natural and cultural resources, there are widespread concerns about their possible impacts. Consequently, many governmental, industrial, and environmental organizations, plus private individuals have potential interests and involvements in assessing the significance of acidic depositions in Wyoming. This section lists these organizations and highlights their potential interests and involvements. The presentation emphasizes the Executive Branch of Wyoming State Government, the State's Legislative Branch, the Federal Government, and non-governmental groups.

WYOMING STATE GOVERNMENT - EXECUTIVE BRANCH

A total of 21 organizations within Wyoming's Executive Branch are included in Table 17 as having potential interests or involvements in issues related to acidic depositions in Wyoming. The degree of concern for each issue within these organizations ranges from maintaining awareness of important issues to collecting and analyzing critical data. This section highlights the types of interests and involvements that these state organizations may have in relation to acidic depositions. Appendix B expands on the listings in Table 17 by briefly discussing various potential interests and involvements for each state organization.

The Governor's Office has potential involvements with all efforts to assess the significance of acidic depositions in the State. This

Table 17. Principal areas of potential interests and involvements by organizations within the Executive Branch of Wyoming state government in issues related to acidic depositions (ESI = emission source inventories; DM = deposition monitoring; AC&B = aquatic chemistry and biology; SC& B = soil chemistry and biology; TV = terrestrial vegetation; M&CR = material and cultural resources; HH = human health; E&T = economics and tourism; M&R = monitoring and research; D = direct involvement; I = interest).

Organization	ESI	DM	AC&B	SC&B	TV	M&CR	HH	E&T	M&R
Department of Agriculture		I		I	I				
Attorney General	I		I	I	I	I	I	I	
Community Colleges	D	D	D	D	D	D	D	D	D
Conservation Commission			I	I					
Department of Economic Planning & Development			I		I	I		D	
Department of Education	I	I	I	I	I	I	I	I	
Department of Environmental Quality	D	D	D	I	I	I	I	I	D
Game and Fish Department	I	I	D	I	I			I	D
Geological Survey			D	D					D
Governor's Office	D	D	D	D	D	D	D	D	D
Department of Health & Social Services							D	D	
Industrial Siting Administration	D	I	I	I	I	I	I	I	D

Table 17. (continued)

Organization	ESI	DM	AC&B	SC&B	TV	M&CR	HH	E&T	M&R
Public Service Commission	D								
Recreation Commission							I	I	
State Archives, Museums & Historical Department							I	I	I
State Engineer			I			I			
State Forester		I		I	I				
Travel Commission						I		I	
University of Wyoming	D	D	D	D	D	D	D	D	D
Water Development Commission			I	I				I	I
Water Research Center		D	D	I					D

could include coordination of the overall program, perhaps, through the State Planning Coordinator.

The Department of Economic Planning possibly will become involved in projecting how various possible impact scenarios for the State's resources may affect the State's economy. Therefore, DEPAD will likely be interested in following the results from monitoring and research efforts to determine what impacts are occurring and to plan for mitigating any resulting economic impacts.

The Coordinator of Science, Mathematics, and Environmental Education in the Department of Education is potentially interested in the overall results from the State program. This information could then be transferred through this office to the appropriate educators in the State for inclusion in appropriate curriculums.

The Industrial Siting Administration will have a general interest and involvement in most aspects of the State program. For example, existing data and information contained in siting applications and permits will be valuable for identifying locations and quantifying emission outputs from major instate sources. And, the results produced in the overall State program will be useful to the Administration staff for assessing potential cumulative downwind impacts on sensitive resources due to acidic emissions from proposed facilities.

Several State agencies will be potentially involved in efforts to inventorying instate sources of acid forming emissions. Information for major man-caused emission sources will come from application and permit information contained in files at the Department of

Environmental Quality, the Industrial Siting Administration, and the Public Service Commission. Information on minor man-caused and natural sources could involve researchers at the University of Wyoming or the State's community colleges to estimate possible emissions based on information in the literature or to conduct site-specific investigations. Results from this inventory is of potential value to various State agencies, including Game and Fish for determining potential impacts to sensitive lakes and streams, and the Attorney General for possible litigation involving source emissions.

Monitoring acidic depositions in Wyoming could involve several organizations. These could include researchers of the Wyoming Water Research Center, DEQ, UW, and the community colleges. Results from this effort are potentially valuable to many State agencies because of the implications of these data in extrapolating potential impacts to the State's resources.

The greatest concern about potential adverse impacts from acidic depositions is directed at possible impacts to lakes, streams, their resident fish, and other aquatic organisms. To collect and evaluate data necessary to assess the significance of possible impacts from acidic depositions to Wyoming's aquatic ecosystems will likely involve various State agencies. Primary among these are Game and Fish, the Wyoming Water Research Center, the Department of Environmental Quality, the Geological Survey, plus researchers at the University of Wyoming and the State's community colleges.

Various acidic deposition induced impacts also have been suggested for soil chemistry and biology and for agricultural crops and forest timber resources. Interests in the potential consequences from such impacts in Wyoming can concern the Department of Agriculture, Department of Environmental Quality, the State Forester, plus university and community college researchers, among others.

Potential damage to material and cultural resources, particularly in relation to the State's historical sites, is the primary concern of the Recreation Commission and the State Archives, Museums, and Historical Department. Help in assessing these potential impacts and identifying potentially sensitive resources in Wyoming could be provided by these two organizations and university and community college researchers.

Possible human health effects due to acidic depositions is one of two primary concerns of the Department of Health and Social Services. This department could also become directly involved if impacts affect employment in the State. This may occur if acidic depositions adversely impact resources important to the tourist industry, reducing employment opportunities.

In summary, assessing the potential impacts that acidic depositions may pose to Wyoming's natural and cultural resources can directly involved a number of State agencies in a variety of monitoring and research efforts (Table 17). Data and analyses resulting from these various efforts will be of general interest to other agencies in the State in their efforts to assess the overall potential significance of acidic depositions to Wyoming.

WYOMING STATE GOVERNMENT - LEGISLATIVE BRANCH

Due to the complexity of issues involved with acidic depositions, various legislative involvements are possible. Among these are (1) possible legislation to limit atmospheric emission of acids from instate sources; (2) appropriations to help finance monitoring and research efforts conducted during a State assessment program; (3) ratification of interstate compacts to, for example, limit transboundary exports of atmospheric acids; and (4) oversight of State sponsored assessment efforts. Table 18 presents several of the State Senate and House Standing Committees that have potential involvement in possible legislative issues.

PRINCIPAL FEDERAL AGENCIES

Assessing possible impacts from acidic depositions in Wyoming will potentially involve various Federal agencies (Table 19). In particular, those agencies responsible for management of Federal lands and resources (including the Forest Service, Bureau of Land Management, National Park Service, and Fish and Wildlife Service) are concerned about any potential adverse impacts to the resources for which they are responsible. Also, such organizations as the Department of Energy and the Environmental Protection Agency are concerned about possible impacts due to emissions from facilities under their regulation.

In addition to these general concerns, various agencies have specific responsibilities for individual issues within the Interagency Task Force on Acid Precipitation (Table 20). The monitoring,

Table 18. Committees within the Legislative Branch of Wyoming state government having potential involvement in issues related to acidic depositions.

Senate Standing Committees
Agriculture, Public Lands, and Water Resources
Appropriations
Education, Health, and Welfare
Travel, Recreation, and Wildlife
House of Representatives Standing Committees
Agriculture, Public Lands, and Water Resources
Appropriations
Education
Labor, Health, and Social Services
Mines, Minerals, and Industrial Development
Travel, Recreation, and Wildlife

Table 19. Locations of principal Federal organizations having potential interests or involvements with issues related to acidic depositions in Wyoming.

Department of Agriculture
- Forest Service
  - Intermountain Regional Forester - Ogden, Utah
    - Bridger and Teton National Forests - Jackson, Wyoming
    - Shoshone National Forest - West Yellowstone, Montana
    - Targhee National Forest - St. Anthony, Idaho
    - Wasatch National Forest - Salt Lake City, Utah
    - Forest and Range Experiment Station - Ogden, Utah
  - Rocky Mountain Regional Forester - Lakewood, Colorado
    - Bighorn National Forest - Sheridan, Wyoming
    - Black Hills National Forest - Custer, South Dakota
    - Medicine Bow National Forest - Laramie, Wyoming
    - Forest and Range Experiment Station, Fort Collins, Colorado
- Soil Conservation Service
  - Field Biologist - Casper, Wyoming
  - State Conservationist - Casper, Wyoming
- State Agriculture Experiment Station Director - Laramie, Wyoming

Department of Commerce
- National Oceanic and Atmospheric Administration - Boulder, Colorado

Department of Energy - Washington, D.C.
- Office of Fossil Energy
- Office of Energy Research
  - Office of Health and Environmental Research
  - Office of Program Analysis
- Office of Environmental Protection, Safety and Emergency Preparedness

Department of Interior
- Bureau of Indian Affairs - Lander, Wyoming
- Bureau of Land Management - Cheyenne, Wyoming
- Bureau of Reclamation - Cheyenne, Wyoming
- U.S. Geological Survey - Cheyenne, Wyoming
- National Park Service
  - Grand Teton National Park - Moose, Wyoming
  - Yellowstone National Park - Mammoth Springs, Wyoming
- Office of Water Research
  - Wyoming Water Research Center - Laramie, Wyoming
- U.S. Fish and Wildlife Service
  - Regional Office - Denver, Colorado
  - Wyoming Cooperative Fisheries and Wildlife Unit - Laramie, Wyoming

Table 19. (continued)

Environmental Protection Agency Region VIII - Denver, Colorado
Interagency Task Force on Acid Precipitation - Washington, D.C.
National Atmospheric Deposition Program - Fort Collins, Colorado

Table 20. Coordinating agencies for each of the working Task Groups included in the National Acid Precipitation Assessment Program.

Task Group		Coordinating Agency
A.	Natural Sources	NOAA
B.	Man-Made Sources	DOE
C.	Atmospheric Processes	NOAA
D.	Deposition Monitoring	DOI
E.	Aquatic Effects	EPA
F.	Terrestrial Effects	DOA
G.	Material and Cultural Resource Effects	DOI
H.	Control Technologies	EPA
I.	Assessment and Policy Analysis	EPA
J.	International Activities	DOS

research, and assessment efforts conducted by these various agencies will provide data of substantial value in assessing the significance of potential impacts from acidic depositions in Wyoming (for example see U.S. EPA 1983).

OTHER MAJOR GROUPS

In addition to the potential interests and involvements by various State and Federal organizations, there are similar concerns within an assortment of industrial groups, environmental and conservation organizations, and other miscellaneous groups. A selection of these is presented in Table 21. In general, the industrial groups are concerned about (1) public perceptions held of an industry's impacts on the environment and its willingness to undertake measures to reduce possible impacts, (2) potential regulations that will increase operating costs for an industry, and (3) scientific assessments of cause/effect relationships used to justify such potential regulations. In turn, the various environmental and conservation organizations are concerned about any potential impacts on the environment. And, other groups are concerned about effects that can result in either adverse economic or environmental impacts.

Table 21. Other major groups having potential interests or involvements with issues related to acidic depositions in Wyoming.

Industrial Groups

American Petroleum Institute
Edison Electric Institute
Electric Power Research Institute
Overthrust Industrial Association
Rocky Mountain Oil and Gas Association
Utility Air Regulator Group
Individual Energy Companies
Individual Consulting Firms

Environmental and Conservation Organizations

Colorado-Wyoming Chapter of the American Fisheries Society
Environmental Defense Fund
Izaak Walton League
Jackson Hole Preserve
National Audubon Society
National Resources Defense Council
Nature Conservancy
Powder River Basin Resource Council
Sierra Club
Snowy Range Fly Fishers
Trout Unlimited - Wyoming Chapter
Wilderness Society
Wildlife Society - Wyoming Chapter
Wyoming Association of Conservation Districts
Wyoming Outdoor Council
Wyoming Wildlife Federation

Miscellaneous Groups

Chamber of Commerce
Indian Reservation/Tribal Governments
Local and County Governments near potentially affected areas
Individual users of potentially affected areas

CONCLUSION

Acidic deposition poses an unique environmental problem because of the diversity of natural and cultural resources hypothesized to be potentially impacted. To assess the significance of these potential impacts to Wyoming will require an extensive state-wide monitoring and research program coordinated by a single authority. Successful completion of this program requires cooperation among many State and Federal agencies and a selection of other interested groups and individuals. Only through such a coordinated effort can it become known whether acidic depositions are now, or will likely have in the future, any adverse impact on Wyoming and its resources.

LITERATURE CITED

Beamish, R.J. 1976. Acidification of lakes in Canada by acid precipitation and the resulting effects on fishes. Water Soil Air Pollut. 6(2-4): 501-514.

Brakke, D.F. 1981. Historical changes in cladoceran communities associated with lake acidification. Bull. Ecol. Soc. Am. 62(2): 155.

Buckman, H.O. and N.C. Brady. 1960. The Nature and Properties of Soils. McMillan Co., New York, 567 p.

Cowling E.B. and R.A. Linthurst. 1981. The acid precipitation phenomenon and its ecological consequences. Bioscience 31(9): 649-654.

Drever, J.I. 1982. The Geochemistry of Natural Waters. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Eilers, J.M. and K.E. Webster. 1981. Acidification and eutrophication: Competing processes in Northern Wisconsin Lakes. p. 20. In: Abstracts of papers for the 44th Annual Meeting of the American Society of Limnology and Oceanography, Milwaukee, Wisconsin.

Galloway, J.N. and E.B. Cowling. 1978. The effects of precipitation on aquatic and terrestrial ecosystems: A proposed precipitation chemistry network. J. Air Pollut. Control. Assoc. 28(3): 229-235.

Galloway, J.N., C.L. Schofield, G.R. Hendrey, N.E. Peters and A.H. Johannes. 1980. Sources of acidity in three lakes during snowmelt. p. 264-265. In: Drablos, D. and A. Tollan (eds.) Proceedings of an International Conference on the Ecological Impact of Acid Precipitation - Effects on Forest and Fish, Oslo, Norway.

Gibson, J. 1983. Colorado and Acid Rain. p. 81-99. In: Acid Rain in the Rocky Mountain West - Transcript of Proceedings. Colorado Department of Health, Denver, Colorado.

Glass, G.E., J.M. Eilers and T. Bydalek. 1982. Relationships between susceptibility to acidification and factors controlling water quality. Am. Chem. Soc. Div. Environ. Chem. 22(1): 521-522.

Gorham, E., P.M. Vitousek and W.A. Reiners. 1979. The regulation of chemical budgets over the course of terrestrial ecosystem succession. Ann. Rev. Ecol. Syst. 10: 53-84.

Hansen, D.A., G.M. Hidy and G.J. Stensland. 1981. Examination of the Bases for Trend Interpretation of Historical Rain Chemistry in the Eastern United States. Environmental Research and Technology, Inc. Document No. P-A097R.

Hastings, R.W. 1979. Fish in the Pine Barrens. p. 489-504. In: Forman, R.T.T. (Ed.) Pine Barrens: Ecosystem and Landscape. Academic Press, New York.

Hendrey, G.R., J.N. Galloway, S.A. Norton, C.L. Schofield and P.W. Shaffer. 1980a. Geological and Hydro-chemical Sensitivity of the Eastern United States to Acid Precipitation. Brookhaven National Laboratory. U.S. Department of Energy. BNL-51189. 100 p.

Hendrey, G.R., J.N. Galloway and C.L. Schofield. 1980b. Temporal and Spatial Trends in the Chemistry of Acidified Lakes Under Ice Cover. Brookhaven National Laboratory. BNL-27850. 7 p.

Henriksen, A. 1980. Acidification of freshwaters: A large-scale titration. p. 68-74. In: Drablos, D. and A. Tollan (eds.) Proceedings of an International Conference on the Ecological Impact of Acid Precipitation - Effects on Forest and Fish, Oslo, Norway.

Hornbeck, J.W., R.S. Pierce, G.E. Likens, and C.W. Martin. 1975. Moderating the impact of contemporary forest cutting on hydrologic and nutrient cycles, p. 423-433. In: Proceeding of a symposium on hydrological characteristics of river basins. Int. Assoc. Hydrol. Sci. Pub. No. 117.

Hudelson, R., G. Boyer and J. McMillan. 1980. High Mountain Lake and Stream Survey of the Bridger Wilderness Area: 1969-1975. Wyoming Game and Fish Department, Fish Division. Completion Report: D.J. Report F-1-R-8, 9, 10, 11, 12.

Hunt, D. and C.E. Boyd. 1981. Alkalinity losses from ammonia fertilizers used in fish ponds. Trans. Amer. Fish. Soc. 110: 81-85.

Johnson, D.W., J.W. Hornbeck, J.M. Kelly, W.T. Swank and D.E. Todd. 1980. Regional patterns of soil sulfate accumulation. Relevance to ecosystem sulfur budgets. pp. 507-520. In: Shriner, D.S., C.R. Richmond and S.E. Lindberg. Atmospheric Sulfur Depositions Environmental Impact and Health Effects. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

Jones, H.C., J.C. Noggle, R.C. Young, J.M. Kelly, H. Olem, R.J. Ruane, R.W. Pasch, G.J. Hyfantis and W.J. Parkhurst. 1983. Investigations of the Cause of Fishkills in Fish-rearing Facilities in Raven Fork Watershed. Division of Air and Water Resources, Tennessee Valley Authority.

Kaplan, E., H.C. Thode and A. Protas. 1981. Rocks, soils and water quality: Relationships and implications on surface water in Northeastern United States. Environ. Sci. Technol. 15(5): 539-544.

Krug, E.C. and C.R. Frink. 1983. Acid rain on acid soil: A new perspective. Science. 221: 520-525.

Lefohn, A.S., and G.O. Klock. 1983. The possible importance of naturally occurring soil processes in defining short-term pH depressions observed in United States' surface waters. Report to Office of Research and Development, United States Environmental Protection Agency, Washington, D.C.

Lewis, W.M. and M.G. Grant. 1980. Acid precipitation in the Western United States. Science 207 (4427): 176-177.

Likens, G.E., R.E. Wright, J.N. Galloway and T.J. Butler. 1979. Acid Rain. Sci. Am. 241(4): 43-51.

Marcus, M.D., B.R. Parkhurst and F.E. Payne. 1983. An Assessment of the Relationship Among Acidifying Depositions, Surface Water Acidification, and Fish Populations in North America. Volume 1. Electric Power Research Institute. Research Project 1910-2, Final Report No. EA-3127, Volume 1.

Meyer, J.S. and H.L. Bergman. 1983. Water quality problems associated with oil and gas development, timber harvesting, livestock grazing, and recreational activities in the Overthrust Belt. Wyoming Cooperative Fish and Wildlife Research Unit Report. 45 pp.

Natural Resources Ecology Laboratory (NREL). 1982. NADP Data Report. Precipitation Chemistry. National Atmospheric Deposition Program. NC-141. Fourth Quarter, 1980, Volume 3, Number 4.

Natural Resources Ecology Laboratory (NREL). 1983a. NADP Data Report. Precipitation Chemistry. National Atmospheric Deposition Program. NC-141. First Quarter, 1981, Volume 4, Number 1.

Natural Resources Ecology Laboratory (NREL). 1983b. NADP Data Report. Precipitation Chemistry. National Atmospheric Deposition Program. NC-141. Second Quarter, 1981, Volume 4, Number 2.

Norton, S.A. 1980. Geological factors controlling the sensitivity of aquatic ecosystems to acidic precipitation. p. 521-529. In: Shriner, D.S., C.R. Richmond and S.E. Lindberg (eds.) Atmospheric Sulfur Deposition: Environmental Impact and Health Effects. Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan.

Patrick, R., V.P. Binnetti and S.G. Halterman. 1981. Acid lakes from natural and anthropogenic causes. Science 211: 446-448.

Patrick R., B. Matson and L. Anderson. 1979. Streams and lakes in the Pine Barrens: Ecosystem and Landscape. Academic Press, New York.

Pfeiffer, M.H. and P.J. Festa. 1980. Acidity Status of Lakes in the Adirondack Region of New York in Relation to Fish Resources. New York State Department of Conservation, Bureau of Fisheries, Stonybrook, New York. FW-P168 (10/80). 36 p.

Rahel, F.J. and J.J. Magnuson. 1980. Fish in naturally acidic lakes of Northern Wisconsin, U.S.A. p. 334-335. In: Drablos, D. and A. Tollan (eds.) Proceedings on an International Conference on the Ecological Impact of Acid Precipitation - Effects on Forest and Fish, Oslo, Norway.

Rosenqvist, I.T. 1978. Alternate sources for acidification of river water in Norway. Sci. Total Environ. 10(1): 39-49.

Schindler, D.W., R. Wagemann, R.B. Cook, R. Ruszczynski and J. Prokopowich. 1980. Experimental acidification of Lake 223, Experimental Lakes Area: Background data and the first three years of acidification. Can. J. Fish. Aquat. Sci. 37(3): 342-354.

Seip, H.M., S. Andersen, and B. Halsvik. 1982. Snowmelt studied in a mini-catchment with neutralized snow. SNSF Project, Internal Report IR 65/80. ISBN 82-90153-96-1.

Shapiro, J. and H.O. Pfannkuch. 1973. The Minneapolis Chain of Lakes: A Study of Urban Drainage and its Effects 1971-1973. Interim Report No. 9, Limnological Research Center, University of Minnesota, Minneapolis. 250 p.

Spry, D.J., C.M. Wood and P.V. Hodson. 1981. The Effects of Environmental Acid on Freshwater Fish with Particular Reference to the Softwater Lakes in Ontario and Modifying Effects of Heavy Metals: A Literature Review. Canadian Technical Report of Fisheries and Aquatic Science No. 999, Fisheries and Oceans, Government of Canada. 144 p.

Tetra Tech, Inc. 1981. The Integrated Lake - Watershed Acidification Study (ILWAS): Contributions to the International Conference on the Ecological Impact of Acid Precipitation. Electric Power Research Institute, Interim Report No. EA-1825. 120 p.

Treece, R. 1982. Acid Precipitation in Southeastern Wyoming. A Study in the Snowy Range Mountains of Medicine Bow National Forest. Submitted to Dr. George Baxter, Department of Zoology & Physiology, University of Wyoming, Laramie, Wyoming.

Turk, J.T. and D.B. Adams. 1983. Sensitivity to acidification of lakes in the Flat Tops Wilderness area. Water Resources Res. 19(2): 346-350.

U.S. Environmental Protection Agency (U.S. EPA). 1983. The Acidic Deposition Phenomenon and Its Effects. Critical Assessment Review Papers, Volume II, Effects Sciences. Public Review Draft EPA-600/8-83-0168. U.S. Environmental Protection Agency, Washington, D.C.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Company, Philadelphia. 743 p.

Young, J.F. and P.C. Singleton. 1977. Wyoming general soils map Univ. Wyo. Ag. Exp. St. Res. Jour. 117: 1-41.

APPENDIX A

Sampling and Analysis Protocol for Chemical Characteristics of Lakes and Streams Sensitive to Acidic Deposition

prepared for

The Aquatic Effects Task Group
Interagency Task Force on Acid Precipitation

Lake and stream sampling and analysis programs by agencies comprising the Acid Precipitation Aquatic Effects Task Group, Interagency Task Force on Acid Precipitation, include both exploratory surveys for areal coverage over limited time periods, and long-term studies at selected sites to determine time trends. In order for results from different agencies to be comparable and compatible, it is necessary to agree upon which measurements are to be made; that the approaches and methods used in obtaining, handling, preserving, and analyzing samples are standardized or are compatible; and that mutually satisfactory quality assurance and reporting procedures are employed.

This document addresses measurements to be made, selection of study sites, sampling protocols, analytical methods, quality assurance, and data management. Consideration of these topics is limited here to studies of water chemistry only. We recognize also the need for concurrent biological studies, particularly in long-term monitoring programs where a primary objective is detection of ecosystem change. Approaches to biological monitoring in lakes and streams were considered at a recent EPA-sponsored workshop, and work on a protocol is progressing.

Those primarily responsible for the content of this document are Owen Bricker, U.S. Geological Survey; George Hendrey, Brookhaven National Laboratory; Raymond Herrmann, U.S. National Park Service; Vance Kennedy, U.S. Geological Survey; Harvey Olem, Tennessee Valley Authority; Charles Powers, U.S Environmental Protection Agency; Arthur Schipper, U.S. Department of Agriculture - Forest Service; Kent Schreiber, U.S. Fish and Wildlife Service.

We thank the many persons who have contributed their expertise during the evolution of this protocol over the past six months.

I. Measurements

A. Basic Variables

The variables to be measured will depend in part on the objectives of the study. For exploratory surveys and basic monitoring, the following measurements provide sufficient characterization of stream or lake water quality for assessment of sensitivity and changes related to acidification:

pH	color
total alkalinity	Ca, Mg, Na, K
specific conductance	SO_4, NO_3, Cl
temperature	

These basic measurements provide reliable documentation of the status of a stream or lake. Buffering capacity and acidity are quickly determined by the "field measurements" (pH, alkalinity, conductivity). Presence of color may indicate natural acidity (as well as possible interferences in sulfate determination). Measurement of the basic ions provides data for modeling exercises (e.g., Henriksen, CDR), cation-ion balance calculations, indication of strong acids, etc. Some investigators may wish to add aluminum to this list. However, see Section B (following).

B. Additional Variables

It is the opinion of a number of the contributers to this document that long-term monitoring studies should include additional measurements to provide an understanding of the processes involved in observed changes and to facilitate relation of those changes in water chemistry to observed effects on biota. These measurements focus on metals and metals chemistry. The recommended additions are:

Al	F
Mn	PO_4 (dissolved)
Fe	DOC (dissolved organic carbon)
SiO_2	NH_4^+

(Note: all metals determinations are for the dissolved forms).

These additional measurements, together with the basic set, are considered to constitute a minimal group for evaluation of geochemical kinetics and toxicity at extended study sites. Aluminum is the metal of major concern relative to toxicity effects, and, further, aluminum and silica are both essential to an understanding of silicate mineral weathering and precipitation processes. There is some evidence that manganese may be toxic to biota at levels observed in acidified waters. Both dissolution and precipitation of iron and manganese oxide compounds may have significant effects on the concentrations of other metals. Fluoride, phosphate, and DOC are important in complexing aluminum and hence affect its action as a toxic agent.

These additions add to the complexity and expense of a monitoring program and would have to be carefully justified in terms of the use for which the data were intended. Process studies imply use of calibrated watersheds, with development of input-output budgets; monitoring sites do not have to be this elaborate. Systematic measurement of the basic variables can yield useful information on changes in lakes and streams related to acidic deposition. The additional variables allow investigation and interpretation of the processes associated with these changes, but are not necessary for detection of the change itself. Consequently, some monitoring efforts will include all or some of the additional protocol, while others will consist of the basic minumum. Programs following the latter course would be able to add collection of additional information in the event that biotic effects, for example, began to appear.

II. Selection of Study Sites

A. For reconnaissance and exploratory sampling, and for long-term studies, a detailed written description of each site is required. This should include size of the watershed, bedrock geology and soil class(es) of the watershed, order of stream (if known), mean annual discharge of stream, size of lake or pond, altitude of site, general existing land use in watershed, and available historical data on land use and water quality. In the field, any recent changes in land use should be noted, together with an estimate of percent of bedrock exposure in the watershed, and descriptions of any other features such as pollution sources, old mine workings, and nearby emission sources. (Such features, of course, would probably eliminate the site as a monitoring location). Detailed geologic and soils maps should be made for extended study sites, if such maps are not otherwise available.

B. Lake Monitoring

"Clusters" of sensitive lakes will be selected for long-term monitoring. A cluster consists of a group of at least six such lakes, located in the same geographical area, in geologically similar conditions, exposed to essentially the same precipitation regime. They should be "headwater" lakes with watershed areas not exceeding 260 km^2 (100 mi^2). The lakes must be selected to provide a range of alkalinity values representative of the area and should contain, to the extent possible, the same species of fish. Most of the lakes in a cluster should exhibit average total alkalinity values less then 200 μeq/l (the generally accepted definition of "sensitivity"), and none should exceed 500 μeq/l. However, lakes in the upper portion of the alkalinity range (i.e., 200-500 μeq/l), while less sensitive, are useful as controls on those with lower alkalinities. This can be particularly important with respect to fish populations, where decreases in numbers could result from causes other than acidification.

C. Stream Monitoring

Monitoring is more complex for streams than for lakes because of the influence of flow stage and season. Base flow tends to display uniform, representative composition, but flood flow and snowmelt runoff may significantly alter stream chemistry. Some recent observations have shown severe pH depressions in streams following storm events, after which conditions return to the base flow norm. Proper stream monitoring, therefore, requires continuous recording of flow and provision for sampling during and following storm events and snowmelt as well as during base flow. This will likely necessitate use of automated sampling equipment, the occurrence of meteorological events often being difficult or impossible to anticipate sufficiently far ahead of time to permit adequate manual sampling. The expense involved in such instrumentation probably would preclude monitoring clusters of streams (as described for lakes). It is suggested therefore, that one stream in a sensitive area be sampled intensively with several other streams in the immediate vicinity sampled on a regular but less intensive schedule.

III. Sampling and Analysis

A. Streams

1. General

Sampling will be confined to the upper headwaters. No attempt is made here to specify order of stream; selection should be a function of the particular area of interest. Large streams and rivers are poor sites because the effects of acidic deposition are frequently masked downstream by the mixing of waters from various tributaries and by other riverine processes.

As previously pointed out, the chemistry of streams is strongly influenced by flow stage and season. Base flow usually displays the most uniform composition and represents water that has had maximum interaction with watershed materials. For survey purposes, base flow should be sampled. Most nearly average conditions will be measured in that way, yielding a reasonable estimate of sensitivity to acidification. Recommended sampling frequency is monthly, at least until a "feel" for the system is acquired.

For monitoring, samples should also be taken during events (flood, snowmelt) to provide information on changes in stream chemistry as a function of discharge and of season. A range of flows and seasons should be sampled.

2. Sampling. Streams should be sampled at mid-depth in the main flow channel following the procedure below:

(a) Measure or estimate flow stage (discharge) of stream at time of sampling.

(b) Collect sufficient sample for requirements listed below from mid-depth of main flow channel. Rinse container thoroughly three times with stream water before taking sample.

(c) Pour appropriate amounts of sample into plastic beakers for pH and conductivity measurements.

(d) Record temperature and measure pH and conductivity in the field as soon after sampling as possible.

(e) Measure color by comprison to Pt-Co standard.

(f) Obtain sample for major ion analysis: Rinse a 250 ml (acid washed and distilled water rinsed) polyethylene bottle (see Sect. IV) three times with 25 ml volumes of sample water which has been filtered directly into the sample bottle (discarding each rinse). Then fill to 250 ml with filtered sample. Use a <u>0.45 μm pore size</u> filter. If filtration cannot be done in the field, samples from well-oxygenated lakes and streams can be refrigerated and filtered in the laboratory as soon as possible.

(g) Obtain sample(s) for metals analysis (if relevant): For dissolved Al, Mn, and Fe a 0.1 μm pore size filter is recommended to achieve the greatest possible degree of separation of particulate and dissolved material. (In reporting results, always specify filter size). Filter 100 ml of sample into an acid-washed plastic bottle after rinsing three times with filtered water. Add 1 ml ampoule of concentrated ultrapure nitric acid to the sample. This bottle may be kept at ambient temperature.

(h) Obtain samples for determination of dissolved organic matter (if relevant): In obtaining and preparing samples for DOM, care must be taken to avoid contamination with organic material. The samples should be filtered and collected in oven-fired glass bottles. Tentatively, the protocol calls for filtration through a 0.45 μm silver filter. However, there is evidence that some particulate organic matter may pass a filter of this pore size. The U.S. Geological Survey has offered to perform parallel checks between 0.45 μm and 0.22 μm silver filters during the coming year. Water from various sources will be used. A final recommendation for pore size will be made on the basis of those tests.

(i) Sample blanks should be included with every tenth field sample, both acidified and non-acidified, using high quality deionized water. For blanks to accompany acidified samples, prepare one acidified deionized water sample and one non-acidified deionized water sample.

B. Lakes

1. General

Lakes should be sampled near their deepest points at least 20 m from shore. If the water column is homogeneous, one sample should be collected approximately one-half meter beneath the water surface. If the water body is stratified, one sample should be collected approximately one-half meter beneath the water surface and a second half-way between the thermocline and the lake bottom. A plastic closing sampling device of the Van Dorn type should be used to obtain samples at depth; do not use a metal sampler. A means for measuring subsurface temperature is necessary to locate the thermocline; this requires an instrument capable of in situ measurement, such as a thermistor equipped with a sufficiently long lead. Samples should be collected from the sampling device in plastic bottles treated according to the procedure described in Sections III-A and V-A. Near-surface samples can be taken by simply dipping the plastic bottle directly into the lake (taking care not to sample the surface film).

Minimum sampling intervals for lakes are (1) prior to summer stratification (for ice-covered lakes, the period of snowmelt runoff following ice-out); (2) during summer stratification; and (3) during the completely mixed conditions following summer stratification (fall overturn). Spring sampling of northern lakes during snow-melt is not an easy task. Access to lakes can be difficult, and proper timing is uncertain. However, data from Adirondack lakes show that the period of pH and alkalinity depression during snowmelt may last for approximately two weeks, increasing the probability of obtaining data during that event. The importance of this period in the acidification history of lakes emphasizes the desirability of its inclusion in the sampling schedule.

2. Sampling. Follow steps c - i under "Stream Sampling" (Section III-A-2) for processing of samples.

IV. Sample Containers

Polyethylene bottles with polyseal caps are recommended (except for dissolved oxygen and DOC samples which should be collected in glass). Because of the very dilute waters being considered here, and the consequent enhancement of contamination problems, acid rinsing of all bottles used for major ion chemistry samples, as well as for metals samples, is recommended (0.1N HCl). Acid rinsing should be followed by at least three rinses with deionized water. Rinsed bottles should be kept filled with deionized water until their use in the field.

V. Field and Laboratory Analyses

A. Field

Temperature, specific conductance, color, pH, and alkalinity are preferably measured in the field. Otherwise, the samples should be iced and analyzed as soon as possible.

1. Temperature. Measured to ± 0.5°C with a thermometer or other reliable temperature sensing device, such as a thermistor.
2. pH should be measured to ± 0.02 units using a pH meter with expanded scale. The electrode should be calibrated in two buffer solutions that bracket the pH of the sample and checked with a sulfuric acid solution with a theoretical pH of 4 (5×10^{-5} molar H_2SO_4). The electrode should be immersed in an aliquot of the sample and stirred for three minutes. Then the electrode should be removed, the sample discarded, and the electrode immersed in a fresh aliquot of the sample with no stirring. The electrode should remain in the sample until there is no discernable drift in the pH reading, but no longer than 15 minutes. The sample should not be stirred during the determination.
3. Specific conductance (µmho/cm @ 25°C). Measured on a wheatstone bridge-type conductivity meter.

4. Color. Measured by comparison to Pt-Co standards.

5. Total alkalinity (μeq/l). Measured by titration at 25°C with 0.020 N H_2SO_4, with stirring, using Gran plot calculations.

B. Laboratory

Preferred methods of analysis are as follows:

Cations -- Atomic absorption spectrophotometer (AA) or inductively coupled plasma emission spectrophotometer (ICP)

Anions -- Ion chromatograph

Metals -- AA, ICP, ASV (anodic stripping voltametry)

For laboratories lacking any of the above instrumentation, acceptable alternative methods include:

Sulfate -- microthorin method

Chloride -- ferricyanide method; ion-selective electrode

Fluoride -- ion-selective electrode

Nitrate, phosphate -- wet chemistry (standard methods)

IV. Quality Assurance

An overall quality assurance program will be administered by the USGS central laboratory facility. Audit samples will be sent to each participating laboratory by USGS twice a year. The audit samples will be analyzed for each of the elements in the protocol and pH, conductivity and alkalinity will be determined. This is not intended to replace or supercede those QA/QC procedures regularly followed by each of the participating agencies, but rather to provide a system of cross-checks to ensure continuing comparability of results.

V. Data Management

Each agency is responsible for its own sample collection and analysis, data analysis, data management, and data storage. Each agency will deliver the core data to STORET and ACID (Brookhaven National Laboratory), providing that the data are of a routine survey or monitoring nature which does not preclude their release. Monitoring data from lake or stream clusters supported and/or operated by EPA, USGS, and TVA will be entered into these data bases on routine schedules determined by the length of time required for sample analysis and data verification. In addition, annual reports will be prepared by the Principal Investigators responsible for the monitoring projects.

VI. Additional Information

Requests for additional information or copies of this document should be forwarded to Charles F. Powers, U.S.E.P.A., Environmental Research Laboratory, Corvallis, Oregon 97333.

APPENDIX B

POTENTIAL INTERESTS AND INVOLVEMENTS BY VARIOUS STATE ORGANIZATIONS CONCERNED WITH ACIDIC DEPOSITIONS

This appendix expands on information presented in Table 5 of the text. It presents brief discussions on the potential interests and involvements that each state agency may have in assessing possible adverse impacts from any acidic depositions occurring in Wyoming. These discussions are not intended to provide complete descriptions for each agency. They are intended to provide brief backgrounds for individuals outside of the listed agency on the possible involvements by that agency. In some cases, the descriptions may provide a starting point for considerations by agency personnel on their possible involvement in a coordinated state program. The agencies included in this discussion are listed in order of presentation in Table B1.

BOARD OF AGRICULTURE - DEPARTMENT OF AGRICULTURE STAFF

Acidic depositions potentially may affect some agricultural crops or soils. The Department, therefore, has potential concerns on whether levels of acidic depositions in Wyoming pose potential adverse impacts to the crops and/or soils of the State. Therefore, this department may support efforts (1) to monitor the effects of acidic depositions on sensitive crops in Wyoming and (2) to mitigate and manage any adverse impacts observed. The results from these monitoring and research efforts will then need to be distributed to

Table B1. Organizations within Wyoming state government having potential involvement with issues related to acidic depositions.

<u>Executive Branch</u>

Board of Agriculture
- Department of Agriculture Staff

Attorney General
- Assistant Attorney General, Natural Resources

Community Colleges
- Casper College
- Central Wyoming College
- Eastern Wyoming College
- Laramie County Community College
- Northern Wyoming College (Sheridan College)
- Northwest Community College
- Western Wyoming College

Conservation Commission
- Conservation Commission Staff

Department of Economic Planning and Development

Department of Education
- Coordinator of Science, Mathematics, and Environmental Education

Department of Environmental Quality

Game and Fish Commission
- Game and Fish Department Staff

Geological Survey Advisory Board
- Geological Survey Staff

Governor's Office
- State Planning Coordinator

Department of Health and Social Services
- Advisory Council of Health and Medical Services
- Division of Health and Medical Services Staff

Industrial Siting Council
- Industrial Siting Administration Staff

Table B1. (continued)

Public Service Commission
Public Service Commission Staff
Recreation Commission
State Archives, Museums, and Historical Department
State Engineer
State Forester
Travel Commission
Travel Commission Staff
University of Wyoming
Water Development Commission
Water Development Commission Staff
Wyoming Water Research Center

farmers and ranchers, informing them about observed effects on the State and on possible measures to mitigate these effects.

ATTORNEY GENERAL - ASSISTANT ATTORNEY GENERAL, NATURAL RESOURCES

Acidic depositions pose potential problems that span many natural and cultural resources and extend across state boundaries. Therefore, the Attorney General's Office may become involved in litigation concerning various potential issues relating to acidic depositions. These include possible suits involving instate emissions of acid forming compounds. Litigation also may involve out-of-state emissions that subsequently impact instate resources, violating interstate agreements and compacts. The Attorney General will likely also be involved in assessing the legality of regulations issued to lessen potential instate impacts from acidic depositions.

COMMUNITY COLLEGES

Community colleges in Wyoming have various potential involvements with both education and research aspects of issues related to acidic depositions as are also discussed below for the University of Wyoming. Course work should, and likely does in many cases, involve instruction on the current knowledge of effects related to acidic depositions. Also, various research opportunities exist. For example, the Water Laboratory at Western Wyoming College is currently involved with a project helping the U.S. Forest Service to assess the potential for impacts from acidic depositions in wilderness areas.

CONSERVATION COMMISSION AND STAFF

This commission is responsible for conservation of water and soil resources in Wyoming. As such, it has potential concerns about the potential for acidic depositions to degrade these resources. It is possible that the Commission staff and its Water Quality Program Consultant will work with other State agencies to evaluate these potential resource impacts. Cooperating agencies will likely include Game and Fish, DEQ, the State Department of Agriculture, and the State Forester.

DEPARTMENT OF ECONOMIC PLANNING AND DEVELOPMENT

DEPAD develops plans for and aids in developing the physical and economic resources of Wyoming. Acidic depositions may adversely affect various resources important to tourism, including aquatic and cultural resources. Since tourism is one of the major sources of income to the State, DEPAD has potential concerns about possible deterioration in this revenue base, and how this deterioration could adversely impact future state economics. Projections of extensive deterioration would indicate that alternative planning strategies are needed, which could generate supplemental revenue, replacing those potentially lost due to acidic deposition impacts.

DEPARTMENT OF EDUCATION - COORDINATOR OR SCIENCE, MATHEMATICS, AND ENVIRONMENTAL EDUCATION

Much confusion and incomplete information surrounds perceptions of impacts associated with acidic depositions. This results from the fact that the knowledge concerning the actual impact is very incomplete. Due to these many unknowns and the general interest and concern of the public at large about these issues, this department has potential interests and involvements with educating the public about the current state of the scientific knowledge. This could include furnishing supplemental information to public school educators for inclusion with curriculum materials, presentation or sponsorship of public lectures and discussions by recognized experts, and systematic news releases highlighting advances in Wyoming on understanding effects related to acidic depositions.

DEPARTMENT OF ENVIRONMENTAL QUALITY

DEQ is empowered to safeguard the air, water, and land resources of Wyoming. As such, DEQ has potential involvement with various issues related to acidic depositions. First, and perhaps foremost, DEQ Rules and Regulations require that for Wyoming surface waters, ". . . wastes attributable to or influenced by the activities of man shall not be present in amounts which will cause the pH to be less than 6.5 . . ." While this limitation was written in consideration of point sources discharges, it is unknown if the limit may be eventually extended in review of atmospheric emissions. If so, future permits granted by DEQ to industrial facilities that emit acid forming compounds to the atmosphere will likely give increasing consideration to potential downwind impacts on sensitive resources.

Under the Wyoming Environmental Quality Act, DEQ is charged with ". . . reclamation, preservation, and enhancement of the air, land, and water resources of the state . . ." As such, activities related to reclamation and mitigation of potential impacts from acidic depositions on lands and waters of Wyoming appear to be the responsibility of DEQ.

Finally, the Wyoming Environmental Quality Act gives DEQ the responsibility "to retain for the state the control over its air, land, and water and to secure cooperation between agencies of the state, agencies of other states, interstate agencies, and the federal government in carrying out these objectives." Therefore, when emission sources outside of the State cause impacts to Wyoming's air, land, and water resources, it appears to be the responsibility of DEQ to attempt reductions in these emissions. This requires the cooperation of out-of-state agencies.

GAME AND FISH COMMISSION AND STAFF

Of the possible adverse impacts from acidic deposition, currently available data suggest that sensitive aquatic ecosystems, in general, and fisheries inhabiting these systems, in particular, are the resources most susceptible. Therefore, Game and Fish is the organization within Wyoming State Government that has the greatest potential concern and involvement in assessing effects from acidic depositions.

In some respects, acidification-induced changes in aquatic systems and organisms may serve as an early warning that other adverse impacts related to acidity may potentially occur with other resources. Therefore, if effects attributable to acidification were detected in aquatic ecosystems and fish communities, it would indicate that increased efforts are appropriate to detect effects in other resources. This fact could be a justification for broad-based financial support from the State for Game and Fish acidic deposition assessment, monitoring, and research efforts.

GEOLOGICAL SURVEY ADVISORY BOARD - GEOLOGICAL SURVEY STAFF

The State Geological Survey serves the State as a clearing house for all geological information, a consultant to the Governor and legislature, and an advisor to other state agencies. The Survey also conducts geological investigations to compile new geological data for Wyoming.

One criterion influencing the potential sensitivity of natural resources to acidic depositions is the nature of the underlying geology. Therefore, evaluating potential effects of acidic depositions on various natural resources can involve the Survey in (1) supplying necessary file data and (2) conducting additional investigations to help assess geologically sensitive areas in Wyoming.

GOVERNOR'S OFFICE

As the chief executive of the State, the Governor is interested in all issues potentially affecting the State and in efforts by the State agencies to deal with these possible impacts. Therefore, the Governor's Office may become involved with any of the important issues related to acidic depositions. In particular, the Governor's Office may be directly involved in coordination of an overall State program to deal with acidic depositions. That is, because there appears to be potential involvements by many State agencies in assessing acidic depositions, there exists the potential for overlapping efforts and/or cross purposes by various agencies. To reduce or prevent this, and to increase the efficiency of any State efforts, the Governor's State Planning Coordinator, for example, could become responsible for organizing a coordinated State program. Technical advice originating from a panel of expert advisors, could funnel into this office. Then, individual agencies could be delegated responsibilities for data collection, analysis, synthesis, impact projection, etc. (various State agencies have such existing capabilities). Also, this office could assure distribution of findings to all appropriate individuals within the state, including agency personnel, public interest groups, and educational facilities.

DEPARTMENT OF HEALTH AND SOCIAL SERVICES

Among the concerns about the possible impacts resulting from acidic depositions are the potentials for adverse effects to human health and for loss of jobs. The principal concern for health effects is that surface-water acidification leads to increased concentrations of toxic metals that may potentially adversely affect human health through drinking of contaminated waters or through consumption of contaminated fish. Also, due to potential loss of fishery resources, acidic depositions may cause job losses in the State's recreation and tourism industry. This could subsequently increase demands for social services and public assistance. Due to both possible impacts, this department has potential concerns for maintaining an awareness on (1) the state of the knowledge concerning adverse human health effects related to acidic depositions; (2) if levels of acidity in depositions to Wyoming are approaching levels that have been found to adversely affect human health elsewhere (though data supporting such a relationship are currently lacking); and (3) if jobs in the State are being lost as a result of acidic depositions, causing changing needs for social services and public assistance.

INDUSTRIAL SITING COUNCIL - INDUSTRIAL SITING ADMINISTRATION STAFF

Under the Industrial Development Information and Siting Act, the Office of Industrial Siting Administration must consider ". . . preservation of historic sites, forests and parks, fish and wildlife, air quality, water supply and quality, agriculture resources, and land areas possessing sensitive ecological condition" in granting permits to site industrial facilities. As such, this office has potential concerns that acid forming emissions from a proposed facility may adversely impact downwind sensitive resources. When atmospheric emissions from facilities are judged to pose substantial impairments to such resources, either due to individual effects or due to cumulative effects with other such facilities, the permit to site a plant can be denied. It is possible, therefore, during the siting of future industrial facilities that the Administration Staff will analyze the potential for downwind impacts from acidic forming emissions. These analyses will likely include not only emissions from the facility in question, but also in combination with similar emissions from other facilities.

PUBLIC SERVICE COMMISSION

The PSC requires that an application for a Certificate of Public Convenience and Necessary be submitted prior to construction or operation of large utility facilities. These include electric generating facilities, coal gasification plants, and gas processing plants. For such facilities not under the jurisdiction of the Industrial Siting Council (the Siting Act pre-empts environmental authority by the PSC over such facilities), the PSC may require environmental information in the application for the Certificate. In such cases, the PSC has potential concerns about possible downwind impacts on sensitive resources due to atmospheric emissions of potentially acid forming compounds from these facilities.

RECREATION COMMISSION AND STATE ARCHIVES, MUSEUMS, AND HISTORICAL DEPARTMENT

Together these organizations are responsible for selecting, acquiring, and managing all state parks, recreation areas, historical sites, and archaeological sites. Due to possible adverse impacts to cultural resources, these organizations have potential concerns on (1) the degree of acidity present in depositions to Wyoming, (2) any significant increases in the acidity levels for depositions, and (3) the results of research and monitoring activities directed toward quantifying material damage.

STATE ENGINEER

Under the Wyoming Constitution all of the waters within the State are the property of the State, and the Wyoming State Engineer is charged with administration of these waters. In allocating use of these waters, it is necessary to consider whether the water quality is appropriate for a proposed use. Therefore, the State Engineer has potential concerns on possible alterations that acidic depositions may produce in surface waters and how these alterations may affect proposed uses.

STATE FORESTER

The State Forester administers programs for protection and management of forests on state lands. Among the adverse effects potentially induced by acidic depositions are tree damage and reduced forest productivity. Forest species that have been suggested to be potentially sensitive to acidic depositions grow in Wyoming. Therefore, to effectively protect and manage Wyoming's forests, the State Forester has potential concerns on the effects that any acidic depositions in the State may have on the state forests. If damage is expected, it may become desirable to monitor productivity and damage in potentially sensitive forests downwind from significant point-source emissions.

TRAVEL COMMISSION AND STAFF

The Commission initiates and implements efforts to generate tourist and business travel to Wyoming. A principal appeal for those traveling to Wyoming is the quality of the scenic and recreational resources. Acidic deposition has been suggested to pose potential adverse impact to such resources as surface waters and fish populations, resources important to many tourists drawn into Wyoming. Therefore, the Travel Commission has potential concerns about how acidic depositions are or could be affecting the state's resources, and, consequently, the tourist industry.

UNIVERSITY OF WYOMING

Due to its combined education and research function, the University of Wyoming has numerous potentials for involvement with issues related to acidic depositions. First, because of the wide-spread interest and concern about potential effects from acidic depositions, accurate information about causes and consequences of acid depositions should be introduced to students during their regular course work. Also, because of the many unknowns associated with issues related to acidic depositions, there are many potential areas for research involvements by university personnel. Currently, various university departments are involved with both education and research aspects of acidic deposition issues.

WATER DEVELOPMENT COMMISSION AND STAFF

WDC is charged with developing the water resources of Wyoming. Among the priorities for developing water projects are human consumption, public use, commercial use, industrial use, and agricultural use. Therefore, the WDC has potential concerns on whether any acidic depositions in Wyoming are adversely affecting the

State's water resources such that water qualities are becoming impaired for any uses proposed for developed waters.

WYOMING WATER RESEARCH CENTER

The principal charge of the WWRC is to conduct a comprehensive water research program. This program is to address specifically the preservation and management of Wyoming's water resources, in response to needs dictated by various state agencies. Due to (1) the various unknowns associated with acidic depositions and (2) the probable needs by various state agencies to address these unknowns, the WWRC could possibly have a substantial involvement in any state effort to assess acidic depositions impacts on Wyoming's water resources. This could involve roles coordinating, supporting, and conducting monitoring and/or research projects on deposition chemistry and water quality changes.