STATUS REPORT: ACID RAIN RESEARCH IN THE NATIONAL PARK SERVICE 1982

WATER
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WRFSL REPORT No. 82-1

WATER RESOURCES FIELD SUPPORT LABORATORY
NATIONAL PARK SERVICE
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO 80523

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STATUS REPORT: ACID RAIN RESEARCH IN THE NATIONAL PARK SERVICE

WFRSL Report No. 82-1

by

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September 1982

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Lippincott, Wallace S. Jr., Jill Baron and Raymond Herrmann. 1982. Status Report: Acid Rain Research in the National Park Service. U.S. Department of the Interior, National Park Service, Water Resources Field Support Laboratory Report No. 82-1. 29 pp.

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SUMMARY

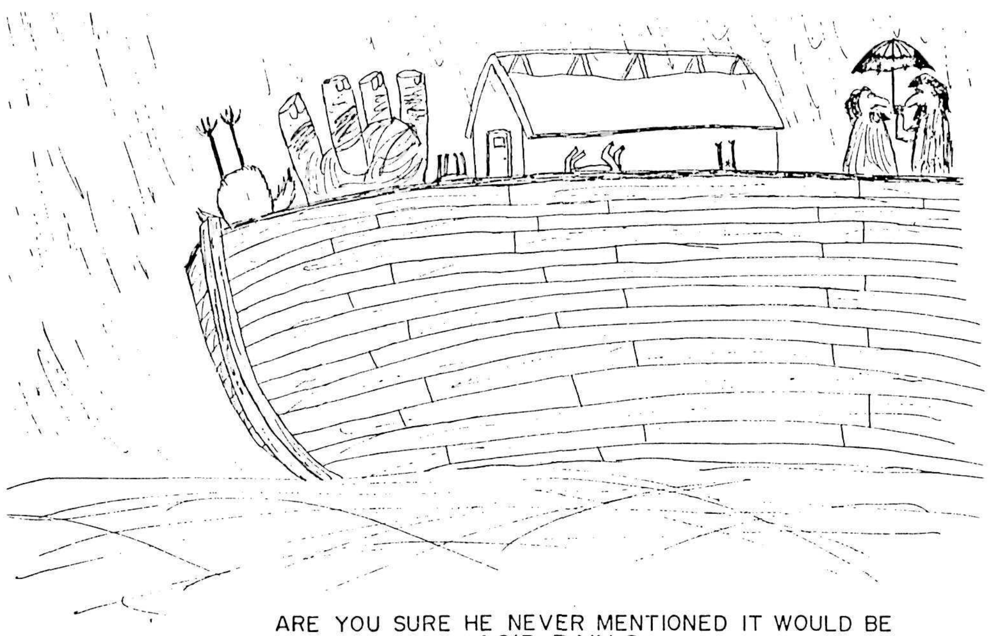
The following items in this report of acid rain research are discussed:

* Acid rain is a threat to the natural and cultural resources of the National Park Service.
* Acid rain was first documented in the northeastern United States. Monitoring now indicates it has become more widespread, occurring in the midwest, southeast, and western mountainous areas.
* Twenty-one National Park Service areas have monitoring stations.
* Studies of acid rain effects involve many disciplines including climatology, geography, geology, mineralogy, soils, limnology, hydrology, and biology.
* Fifteen parks have recently or are presently conducting ecological investigations to determine the extent of acid rain effects on natural resources. Seven of these areas are in locations with documented acid precipitation fallout and theoretically highly susceptible resources. Three of these parks are beginning long-term intensive studies.
* The major factors in determining the repercussions of acid rain on cultural resources are: climate, locality, material type, rarity of skilled craftsmen and materials, and cost.
* Mitigative measures to protect cultural resources have thus far proved ineffectual and occasionally harmful.
* Publishing of research results is an important accomplishment of NPS acid rain research.
* Providing opportunity for other researchers and expanding research programs is necessary to fully document the effects of acid fallout in NPS areas.
* Documentation of threats due to acid rain may influence NPS policy.
* Informational programs for park visitors will better acquaint the public with the threats to their resources.

INTRODUCTION

Acid rain, or more properly, acidic wet and dry deposition, is presently receiving a high level of public and governmental attention in the United States. This interest has developed because of the potential widespread threat to resources, among them some of the national parks. The occurrence of acid rain is not generally debated; however, the nature of its effects are. This report describes some of the potential effects of acid rain on park resources and why they occur. The National Park Service's studies of acid rain and the agency's participation in the Federal acid rain program have four basic goals:

1. Preservation of National Park Service resources through research monitoring, assessment, and possibly mitigation;
2. Assistance to the national acid rain effort as a part of the Interagency Task Force on Acid Precipitation by offering our strongest assets: remote, protected natural areas;
3. Development of programs with regional and broad application which can be used to improve regional resource management; and



ARE YOU SURE HE NEVER MENTIONED IT WOULD BE ACID RAIN ?

(Rocky Mountain News, 1982)

4. Understanding acid rain involves broad questions. In order to know how natural and cultural resources respond to acidification, we must also know how these systems work.

Aquatic systems are the most vulnerable of the natural systems. Acid rain has been reported to cause reductions in the abundance and diversity of certain species of plankton and invertebrates. The decline and subsequent complete extirpation of fish populations from certain lakes and streams due to long-term acid deposition is reported in Scandinavia and the northeastern United States. Other suspected long-term damages to natural systems include a lowering of plant productivity, soil decomposition rates and animal reproduction. Acid rain is also suspected to accelerate erosion of man-made materials such as statues, buildings, and painted objects. The effects on cultural resources, however, are not as well studied as those on natural systems (Figure 1). Effects of acid rain are documented in an abundance of available literature. A few general citations are included in the bibliography to provide a further introduction into the scope of the acid deposition issue.

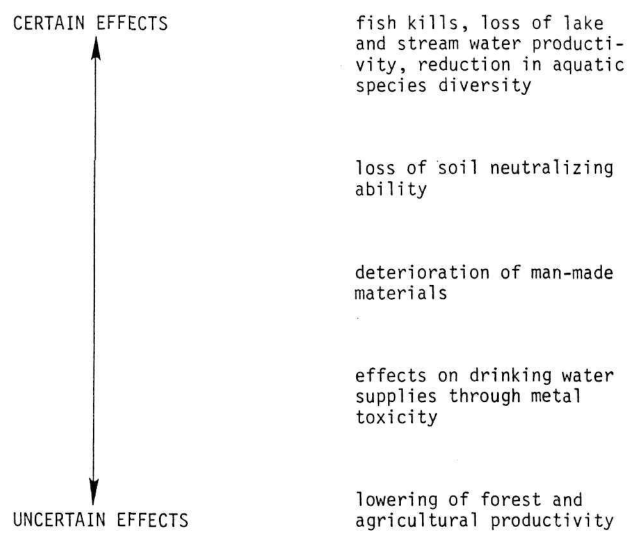


Figure 1. The state of knowledge today regarding acidic deposition effects.

The ill effects which accompany increased acid fallout pose a threat to many of the resources of the National Park Service and will directly affect our resource management. Concern for these resources has prompted the in-house acid rain investigations described herein. Specifically, this report presents (1) processes of acid precipitation, (2) documentation of acid rain occurrence, (3) research on the effects of acid rain on natural and cultural resources, and (4) actions which can be taken once acid rain has been documented.

PROCESSES OF ACID PRECIPITATION

What is acid rain?

Acid rain is defined to be wet precipitation with a pH below 5.6. More properly, acid precipitation includes snow, mist, rain, sleet, and other forms of precipitation or atmospheric deposition which is inclusive of wet and dry fallout.

Acid rain formation

The atmospheric processes which determine the pH of precipitation are complex and not completely understood. The formation and presence of acids, however, have a direct link to the hydrologic cycle that moves water around the earth--from living organisms to surface and ground waters to the ocean and back into the atmosphere to be deposited again as some form of precipitation.

Natural inputs to the hydrologic cycle are dependent upon local features of the environment and are partially responsible for variations in pH and the chemical composition of precipitation. Under theoretical normal atmospheric conditions, carbon dioxide (CO_2) dissolves in atmospheric moisture to produce carbonic acid (H_2CO_3). This dissociates slightly in pure water to produce hydrogen ions (H^+), and bicarbonate ions (HCO_3^-) with a pH of 5.6. Figure 2 puts this value on a scale in relationship to other common substances. The pH 5.6 has been much touted as the pH of "clean" rainfall, but this definition excludes the many other chemical species present in the atmosphere. Nitrogen gas alone, for example, makes up 78 percent of the air we breathe. Coastal areas have natural inputs of sodium (Na^{++}), magnesium (Mg^{++}), chloride (Cl^-), and to a lesser extent calcium (Ca^{++}), potassium (K^+), and sulfate ($SO_4^=$). These cause the pH of rainfall along the coasts to be naturally lower than 5.6.

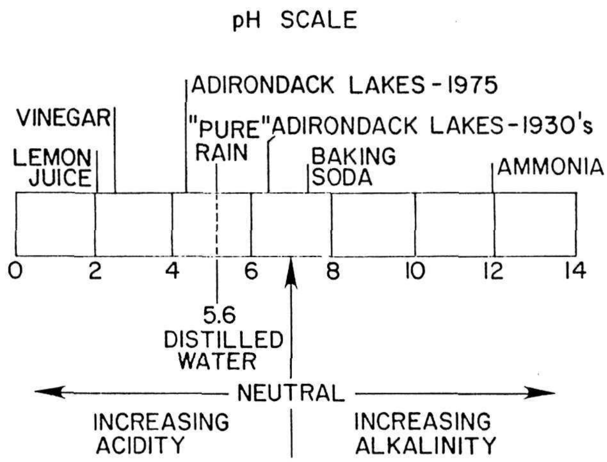


Figure 2. The pH scale with some common everyday examples.

Deserts, savannahs, and steppes, on the other hand, contribute dust, debris, and soil particles to the atmosphere. These constituents often contain base cations like Ca^{++} and Mg^{++} which cause the pH of rainfall to be higher than 5.6. Areas of calcareous soils will add calcium and bicarbonate, species which again help to raise the pH of the rainfall, making it more alkaline. The decay of organic matter produces ammonium gas which contributes ammonium ions (NH_4^+) to the ambient air.

wo gaseous inputs to the evaporation-precipitation cycle, sulfur oxides SO_x) and nitric oxides (NO_x), are key constituents in the formation of acid rain. Both gases can be produced naturally and anthropogenically, and can be transported long distances. These substances interact chemically with sunlight, moisture, oxidants, and catalysts to produce strong acids which are removed from the air as acid rain. Natural sources of these gases include volcanoes and lightning storms. Predominant man-made contributions are from the burning of fossil fuels, including power plants and automobiles and smelting of sulfide ores (Figure 3). Output from these sources has increased dramatically since 1920 and, in fact, nitric oxide emissions have more than doubled over the last 35 years. The anthropogenically derived increase in atmospheric oxides and the concurrent releases of additional hydrogen ions becomes a crucial problem not when the pH of the precipitation turns acidic (because some rainfall is naturally so) but when there is a marked lowering of acidity below what it should be because of the increased man-made inputs from fossil fuel sources.

How is acid rain measured?

The essential parameters used to document acid rain occurrence and its effects are pH, conductivity and alkalinity. The pH is a crucial parameter because it indicates the amount of hydrogen ions in a precipitation or water quality sample and thus the acidity. It requires accurate measurement because the pH is measured on a logarithmic scale where each unit change is 10 times stronger or weaker. Small errors in measurement (such as recording 5.0 when it should be 5.5) will cause large misinterpretations of results.

Conductivity reveals information about the chemical composition of the water sample. The measurement records the resistance to the flow of electric current (ohms) and conductance is the reciprocal of that measurement (mhos). The resistance is dependent on the concentration of dissolved ionic material; this can be both positive and negative. For example, both Na^+ and $SO_4^=$ contribute to a conductivity measurement. The measured ions include hydrogen ions which, as addressed above, determine the pH.

Alkalinity is the indicator of buffering capacity in aquatic systems. It is a measurement of the presence of hydroxide (OH^-), carbonate ($H_2CO_3^{\equiv}$), bicarbonate ($HCO_3^=$), and other negative ions capable of capturing a H^+ ion. This parameter indicates the ability of a water body to neutralize additions of acids by titrating them. Very roughly, waters with alkalinities below 100 micro-equivalents per liter are sensitive to acid inputs because their ability to titrate is limited.

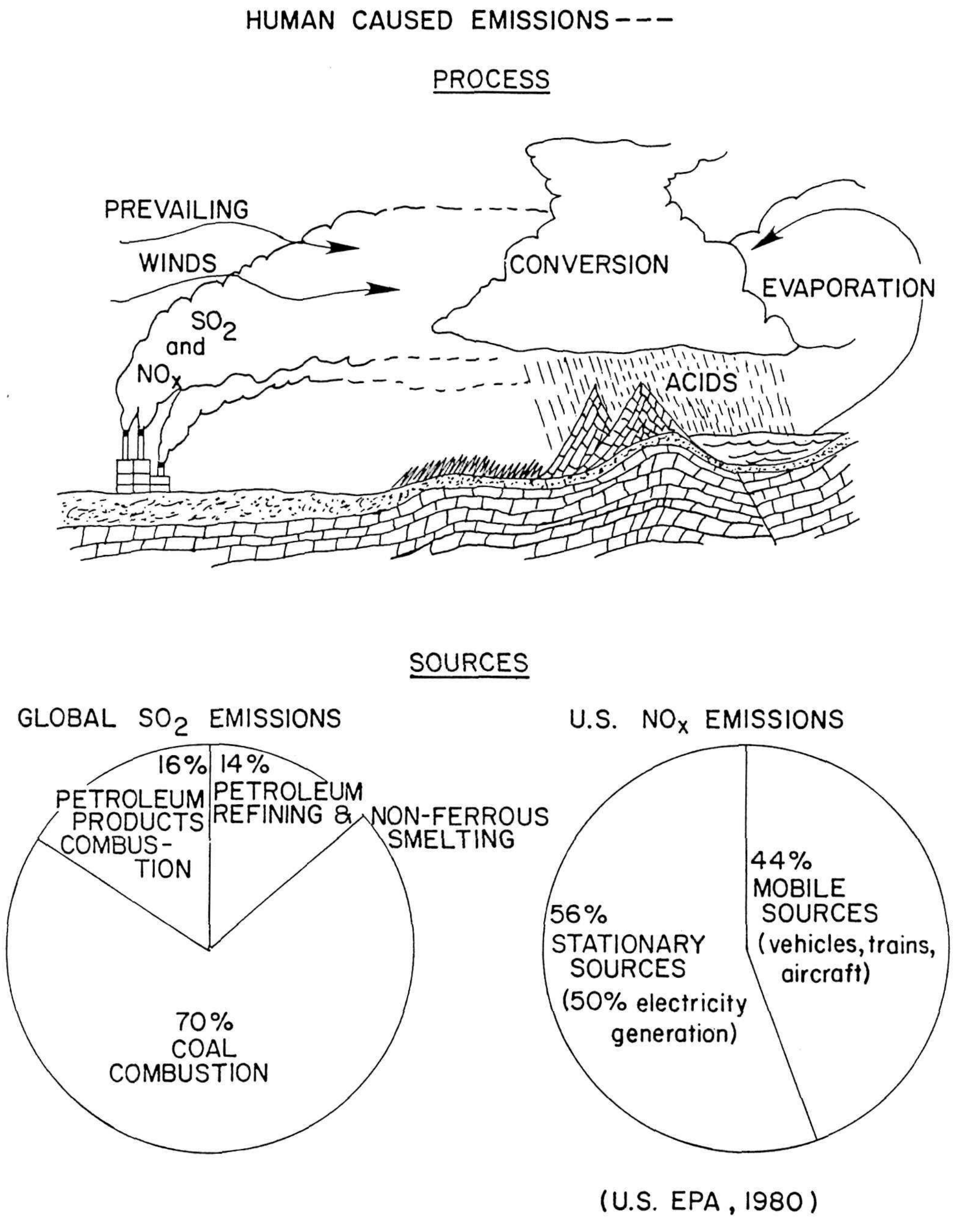


Figure 3. The general processes and sources of human-caused acid rain.

DOCUMENTING THE OCCURRENCE OF ACID PRECIPITATION

Monitoring of precipitation chemistry was conducted by the National Center for Atmospheric Research between 1959 and 1966. A national network of 30 stations, 17 east of the Mississippi, compiled data from monthly collections to report that most pH values in the west were above pH 5.6, while in the east pH was often below pH 5.6. Acid precipitation in the east was concentrated in the New England, New York, and Pennsylvania areas.

Current monitoring efforts

In 1978 a more extensive national network was initiated. The major objective of the National Atmospheric Deposition Program (NADP) is to provide accurate and representative data concerning spatial as well as temporal patterns in the chemistry of wet and dry fallout in major physiographic, agricultural, aquatic, and forested areas throughout the United States.

Today there are 101 NADP sites operating in the United States, and 21 are in National Park Service areas. The results of the collections are displayed on maps which show the spatial concentrations of rainfall constituents. Figure 4 shows an isopleth of just one parameter, pH, averaged from all the values taken in 1981. The map shows that the eastern United States, in particular New England, New York, and Pennsylvania, is still receiving acid precipitation. The new data also shows an expansion of lowered pH values to the southeast, midwest, and western mountainous areas. These data, when compared over the years, will show any trends in the distribution of acidity; they provide a signal of changing conditions.

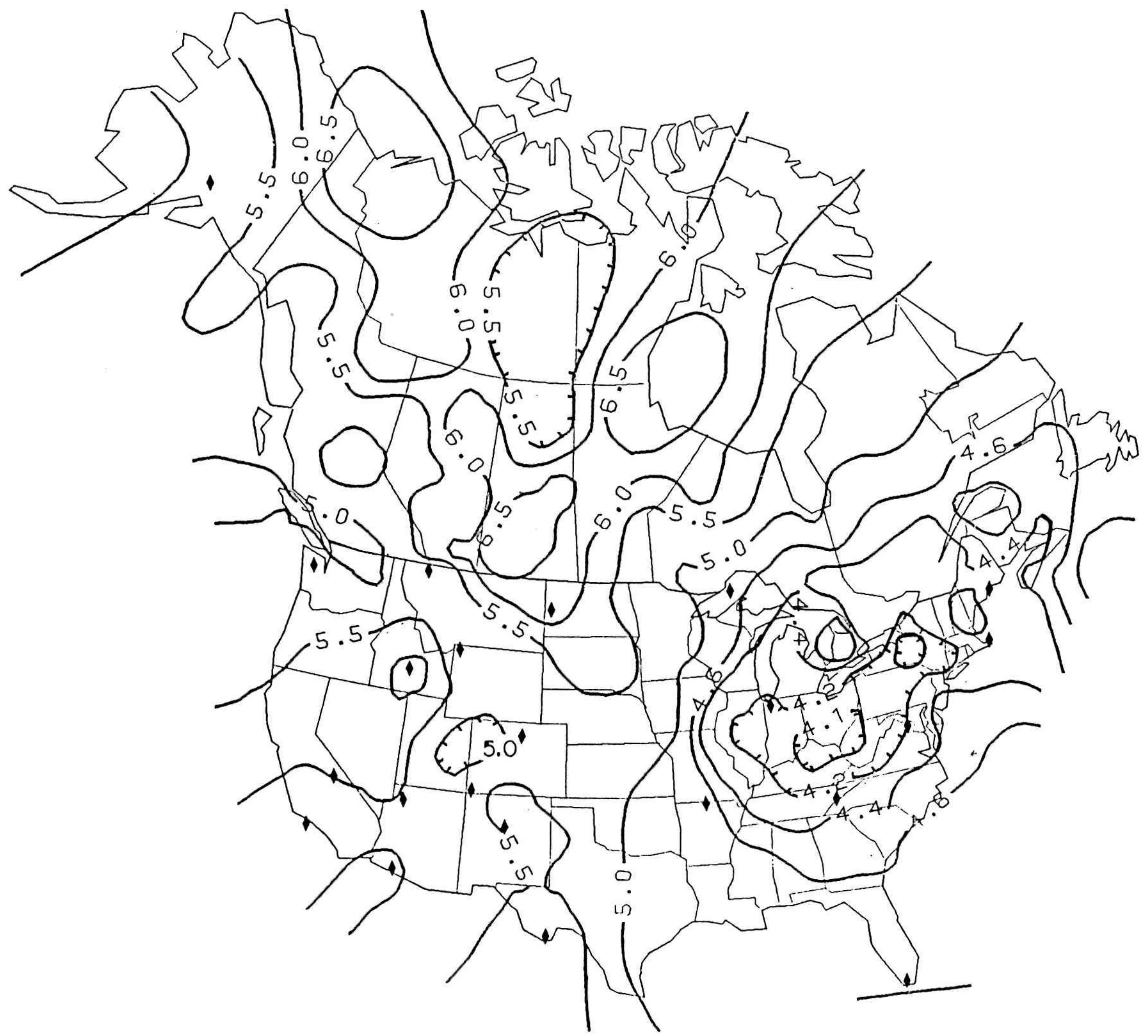


Figure 4. Isopleth of the United States showing the distribution in rainfall pH for the year 1981. Diamonds represent NPS/ NADP sites. (NADP, 1982)

Values for pH at NPS sites are depicted in Figure 5. The bars indicate high, low, and average pH values for those park sites which have accumulated enough data to analyze. The dates of site inception are listed by each park name, and the parks have been arranged geographically to show that even with a minimum of sites reporting there is a trend of increasing pH from east to west. Table 1 is a list of NPS site operators and parks.

The gathering of this type of information not only requires extensive systematic sampling stations, but rigorous consistency in sampling and rigorous precision in analyzing the samples. This is achieved through the use of standardized equipment and procedures. The necessary equipment includes a monitor consisting of a dry and wet catchment container (Figure 6), a precipitation event recorder, a pH meter, a conductivity meter and an accurate weighing scale. The procedure involves weekly collections of wet samples and eight-week interval collections of dry samples. A portion of the wet sample is analyzed for pH and conductivity at the site and the remainder is sent to a central laboratory in Illinois for repetition of pH and conductivity, as well as determination of Ca^{++}, Mg^{++}, Na^{+}, K^{+}, NH_4^{+}, NO_3^{-}, $SO_4^{=}$, Cl^{-}, and $PO_4^{\equiv}$. The dry sample is also sent to the same laboratory, where it is washed down and similarly analyzed.

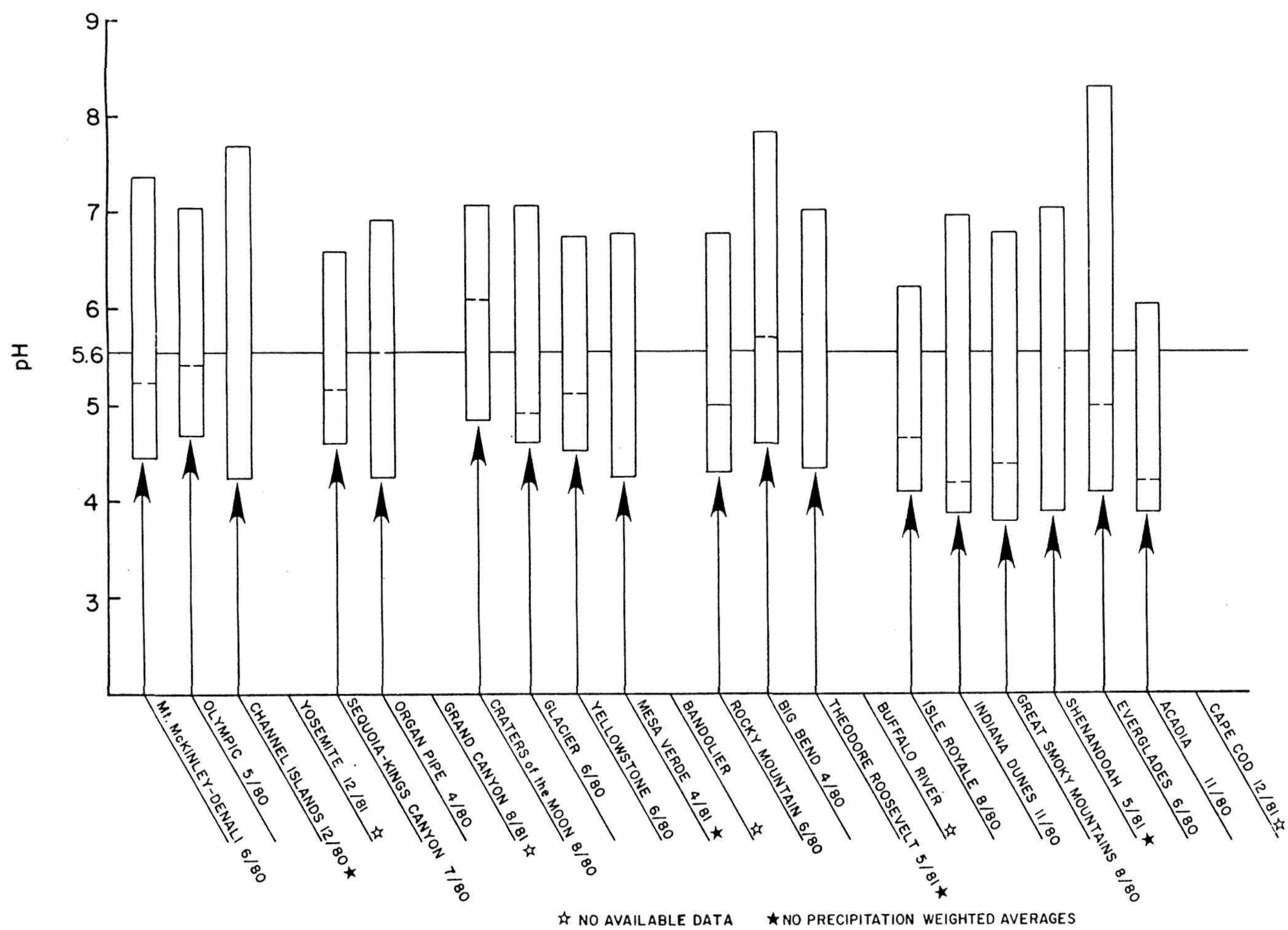


Figure 5. Histogram of high, low, and average pH values for rainfall collected in NPS/NADP areas. The beginning collection date is indicated by each park name. Parks are displayed geographically from west to east.

1. Mt. McKinley-Denali NP	AK03	John Dalle-Molle	907-683-2294
2. Organ Pipe Cactus NM	AZ06	Robert Hall	602-387-6849
3. Sequoia/Kings Canyon NP	CA75	Larry Bancroft/Tom Nichols	209-565-3341
4. Yosemite NP	CA99	Dick Reigelhuth	209-372-4461
5. Rocky Mountain NP	CO19	Dave Stevens	303-586-2371
6. Everglades NP	FL11	Mark Flora	305-245-5266
7. Isle Royale NP	MI25	J. Robert Stottlemeyer	906-487-2478
8. Glacier NPS	MT05	David Lange	406-888-5441
9. Grand Canyon NP	AZ03	Larry May	602-638-2411
10. Theodore Roosevelt NP	ND07	Steven Bone	701-842-2333
11. Great Smoky Mountains NP	TN11	Stuart Coleman	615-436-5615
12. Big Bend NP	TX07	Michael Fleming	915-477-2251
13. Shenandoah NP	VA28	David Haskell	703-999-2243
14. Olympic NP	WA14	Bruce Moorehead	206-452-4501
15. Yellowstone NP	WY08	Wayne Hamilton	307-344-7381
16. Buffalo National River	AR99	Steve Chaney	501-741-5443
17. Mesa Verde NP	CO99	Robert Heider	303-529-4465
18. Craters of the Moon NM	ID03	Neil King	208-527-3257
19. Indiana Dunes NL	IN34	Louis Brunanski	219-926-7561
20. Acadia NP	ME99	Leighton Carver	207-289-2437
21. Cape Cod NS	MA01	Mary Foley	617-223-7765
22. Bandelier NM	Proposed		505-672-3861

Table 1. List of NPS National Atmospheric Deposition Sites, Site Contacts, and Phone Numbers.

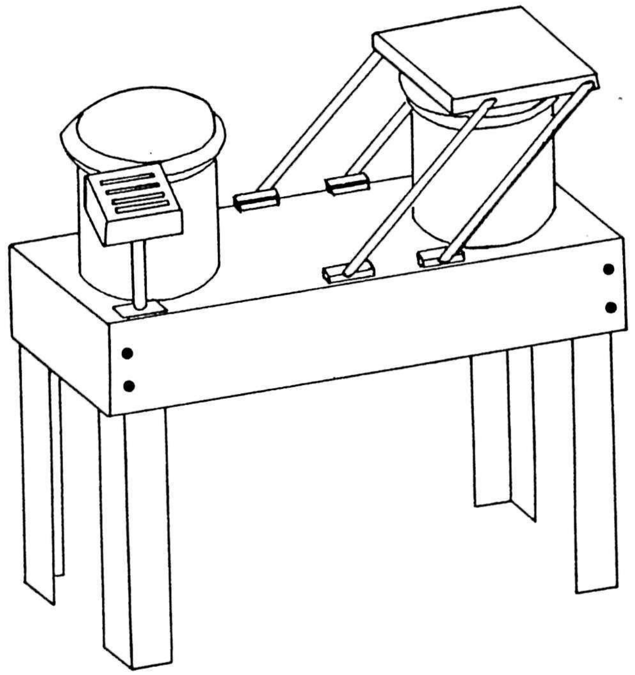


Figure 6. Standard wet-dry catchment container for collecting acidic wet and dry deposition. The sensor detects moisture, causing lid to lift off wet bucket and cover dry bucket. After a rain event the sensor causes lid to return to top of wet bucket.

THE OTHER HALF OF THE ACID RAIN PROBLEM

Resource susceptibility

For acid rain to become a problem there not only must be rainfall with lower than normal pH, there must also be a sensitive receptor. The natural environment or cultural resource must be susceptible to harmful change as a result of acidic precipitation.

The key to the sensitivity of any natural resource is buffering capacity. Buffering capacity is the ability of the resource to alter and neutralize the incoming acids before they have an effect. In very sensitive areas, buffering capacity is low; in insensitive areas, buffering capacity can be essentially infinite.

Buffering capacity combines all the ecosystem components which can come into contact with the precipitation, and includes vegetation, soils and bedrock or overlying geology. The most sensitive areas occur where vegetation and soils are scarce and the geology is unreactive. Therefore, the composition of acid rainfall in a place like this changes little before reaching streams and lakes where fish and other organisms can be affected.

The most sensitive areas to acid rain are those with granitic, gneiss, quartzite, or other slow-weathering bedrock on non-reactive sediment cover such as silica sands covered by thin or no soils. These characteristics can be found in the Canadian Shield which extends along portions of the northern United States and southern Canada and mountainous areas such as the

Appalachians, Rockies, and Pacific Coast Range (Figure 7). Variability within systems, however, may cause other characteristics to intercede and reduce sensitivity. This can occur through the interaction of overlying deposits such as glacial till or eolian sands which may be quite unlike the bedrock.

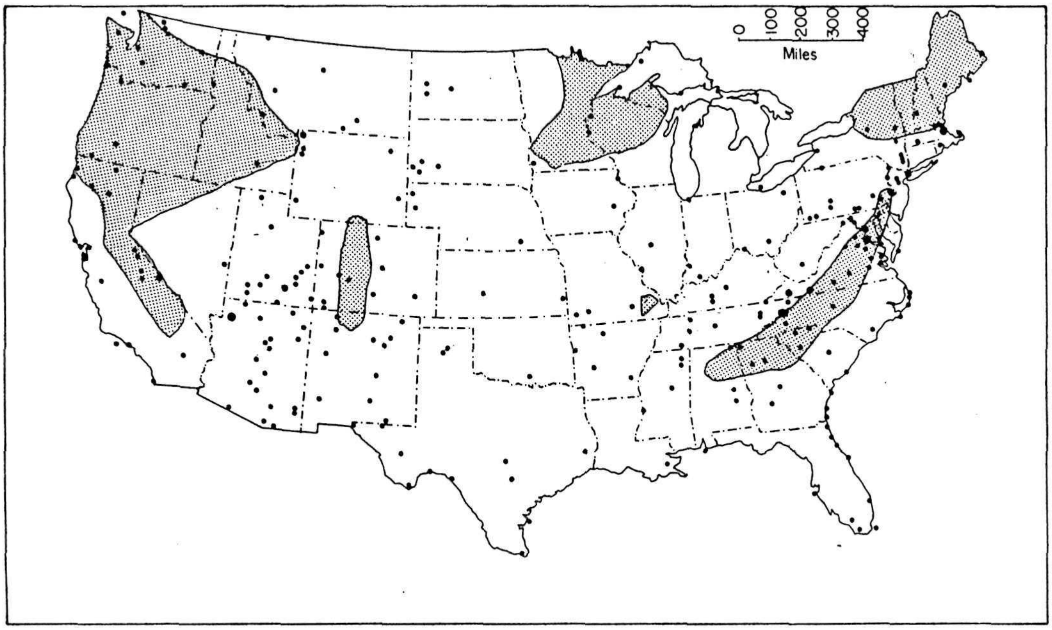


Figure 7. Map showing sensitive areas of the continental United States. NPS areas are shown as dots. (Adapted from Galloway and Cowling 1978)

Where rain falls on vegetation and flows through leaves and stems (throughfall) to the soil, the chemistry is altered. Water which flows through a thick soil mantle has ample opportunity to interact with soil chemicals. Rainfall which falls on bedrock such as bare mountainous areas has far less opportunity for alternation and that which falls directly onto lakes and streams has no chance for change before reaching the aquatic resource. Where rain falls, what it flows through, and how long it takes to travel can make all the difference in whether there is an acid precipitation problem.

ACID RAIN RESEARCH EFFORTS IN THE NATIONAL PARK SERVICE

A significant amount of acid rain research is underway in National Park Service areas. Researchers include not only National Park Service personnel but other agency scientists and university investigators.

Research to document the effects of acid rain has been and is being conducted in 15 NPS areas. The investigations range from preliminary studies of lichen sensitivity to the effects on entire watershed ecosystems. Thus far, absolute findings from this work are as follows:

1. There are park areas, both natural and cultural, which are both sensitive to inputs of acid rain, and receiving it. Those natural areas which are located in the sensitive geologic areas delineated in Figure 8 contain resources at risk; other park areas and resources may well be. (To determine local sensitivity, see Appendix A.)
2. At this time, the only <u>effects</u> we can report without reservation are a temporary drop in stream pH values in Isle Royale and Great Smoky Mountains after acid storm events and a change in soil chemical equilibrium to compensate for increased SO_4 lodging in Shenandoah. No data has yet documented any biological impacts, such as loss of fish or other aquatic populations, or damage to our cultural resource areas.

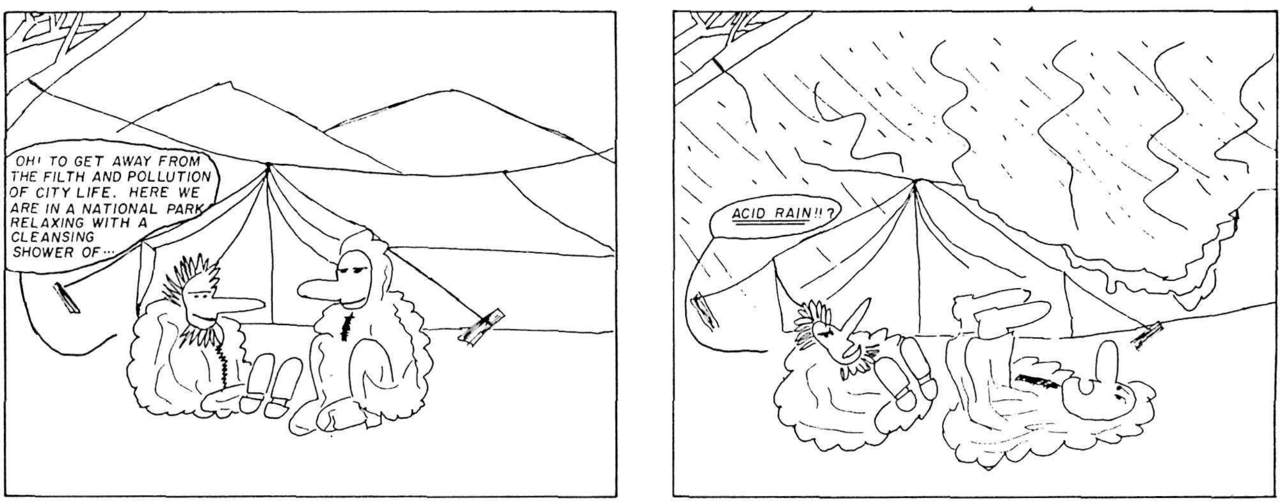
<u>Natural resources research</u>

Four parks in which water quality studies have been conducted after suspecting acidic deposition are Mount Rainier, North Cascades, Olympic, and Everglades.

A number of lakes in Mount Rainier and Olympic were inventoried in 1980 by two scientists from the University of Washington, Eugene Welch and William Chamberlain. They found lakes in Olympic to be relatively insensitive to acid rain on the average, with alkalinity values ranging around 320 micro-equivalents per liter. Lakes in the Cascades, however (where Mt. Rainier and North Cascades are located) were more sensitive, with average alkalinity values of 70-80 micro-equivalents per liter. A monitoring program to look for a loss of buffering capacity in lakes due to acidification was initiated in North Cascades in 1981 by park biologist Robert Wasem. Field monitoring of three dissimilar lakes is now ongoing, and supplemental sampling of soil and vegetation chemistry has occurred. The Park research staff in Everglades found that surface waters are receiving acidic deposition but the waters are sufficiently alkaline due to the limestone and marl bedrock to buffer the impact of such fallout. They have raised the question of effects on the local epiphytic community, however. Epiphytes receive all their nutrients from atmospheric fallout; just how sensitive are they to a change in the pH of the rain? No work to date has been done on this question.

Several parks in the Southwest Region sponsored an investigation into the effects of acid precipitation on terrestrial resources. Big Bend, Bandelier, Zion, and Chaco Canyon examined their populations of lichens (lichens have been well documented in eastern temperate climates to be susceptible to changes in air quality). Southwestern lichen species and populations were not found in these studies to be sensitive to changes in the chemistry of the rain.

More intensive programs have been conducted at parks which receive acid fall-out and have sensitive resources. Seven parks are intensively investigating selected watersheds. Great Smoky Mountains, Isle Royale, Pictured Rocks, Rocky Mountain, Sequoia, Shenandoah, and Voyageurs are all located in areas of documented acid precipitation fallout (Figure 4) and simultaneously in regions of high geologic and soil sensitivity (Figure 7). The integrated approach taken by these parks incorporates examination of physical characteristics (such as geology, soils, hydrology, and water chemistry changes) with biological characteristics, both aquatic and terrestrial.



(Mike Baron)

The overall research objective at Rocky Mountain National Park is to assess the potential effects of acid precipitation on the future viability of fish populations in the lakes and streams of the Rocky Mountains. To document the susceptibility of representative ecosystems, 80-90 soil samples from nine large watersheds have been analyzed for buffering capacity. Water chemistry and other weather parameters are part of the overall collection scheme. Research efforts also include lake sediment sampling to relate historic indicator diatom populations and trace metal content with lake water quality trends.

Aquatic investigations in Great Smoky Mountains by the park research staff and in Shenandoah by Dr. James Galloway of the University of Virginia have indicated increasing acidity in streams. At Great Smoky Mountains it has been found that the pH in certain streams has declined as much as one pH unit during storm events. Researchers in Shenandoah National Park have tentatively assigned the park's increasing stream acidity to a long-term loss of soil buffering capacity caused by many years of acid rainfall.

Experiments at Pictured Rocks National Lakeshore have been conducted to test the effects of additions of acids to streams. These studies have found very rapid neutralization of acidity with corresponding exchanges of hydrogen ions with the basic cations, calcium and magnesium. These results may provide applicable information on the processes of water acidification to areas like Voyageurs National Park, where investigators have discovered some lakes to be very poorly buffered.

Aquatic biological investigations have included surveys of macroinvertebrates, periphyton and vertebrates. Isle Royale National Park research has focused attention on the vertical distribution of phytoplankton and its relationship to lake chemistry. Bioassays on the development of salamanders in Great Smoky Mountains National Park have indicated deleterious results with increasing acidity in streams.

Terrestrial studies at Isle Royale include relating acid rain interception (throughfall) rates with different vegetation types and researching the effects on litter decomposition rates. Hardwoods have been found to be effective in neutralizing acidity of precipitation, whereas conifers tend to increase the acidity of precipitation. Other efforts at Isle Royale include testing of native lichens to determine if they could be useful as indicators of levels of acidic fallout. Most of the lichens in the Park are insensitive but one species was found to have a lower buffering capability to acids than the others.

A new program at Sequoia, begun in 1982, will combine the questions of acidic deposition effects with other ecosystem-size questions. The Sequoia effort will study the effects of fire on both forest and aquatic systems in conjunction with studies of atmospheric inputs, including acidic species.

Cultural resources research

Studies of the effects of acid precipitation on cultural resources lag far behind natural resources studies, but monitoring in France, Italy, and Sweden show a correlation between increased levels of atmospheric deposition and accelerated material deterioration. Separating out the effects of acid precipitation on materials from the effects of other air pollutants, or even from what constitutes "natural weathering," poses a very complex problem. It may not be feasible, nor sensible, to segregate it out. Control studies, documenting rates of decay in the absence of pollutants, have not been done. There are also little data on the uptake rates of pollutants by various materials. Current efforts to investigate these cultural resource problems include (1) monitoring the deterioration of structures, (2) designing a taxonomy for describing and measuring the deterioration of architectural and sculptural materials for universal application, and (3) laboratory modelling and controlled sample exposure investigations which are critical to future analysis of the combined effects measured in monitoring programs. The Park Service is just beginning to develop a cooperative program with other agencies tackling these questions.

Factors controlling the sensitivity of cultural resources are similar to those of natural resources on a smaller scale. Material pathology is a function of several factors, including macro- and micro-environment, geometry, orientation, and relative shielding of the surface to exposure, surface finish, surface material and the material's inherent propensity to attract deposition. The "macro-environment" refers to local and regional climate parameters such as temperature, relative humidity, wind and precipitation; the "micro-environment" includes these as well as other factors influenced by the structure itself. Shading, animal activities, and the accumulation of dirt, to name a few, are examples of micro-environmental factors that cause the climate within a few centimeters of the structure to differ from local and regional climate.

Most current research is directed toward the degree to which different material types are susceptible to erosion from acid fallout. Most man-made resources are covered with masonry, metals or surface coatings. Of the three material types, masonry is particularly susceptible to deterioration and the more carbonate it contains the more susceptible it is. Marble and concrete, mortar, stucco, and other materials made of limestone and sandstone are more sensitive than other stones, adobe, brick, and terra cotta. Approximately 30% of the structures managed by the NPS are masonry. Degradation involves disruption of interlocked mineral components through chemical and mechanical processes. Mechanical degradation bursts the pore structure which chemically involves ions attacking the material and altering the chemical composition. Both effects result in accelerated decay and potential crumbling of the structure.

The metals used in structures include copper, cast and wrought iron, lead, zinc, traditional alloys such as brass and bronze, and metals coating other metals, as in galvanized iron. Metal deterioration is primarily an electrochemical process. Most metals form a self-protective skin, or patina, on exposure to air. These skins, except on iron, stick tightly to the substrate and protect the metal from further corrosion. Iron will rust continually and never form a protective skin. Chemically aggressive particles such as strong acids can disrupt protective patinas. Particles that are hygroscopic, or water attracting, can attract substances and concentrate corrosion in spots causing pitting.

The third category of material is surface coating. This includes acrylic, oil-based paints, oils, varnishes and impregnation materials. Performance of these depends on the nature of the substrate material and degree of impermeability of the applied film. Other factors influence performance, such as surface preparation, but many surface coatings can be easily reapplied. Original painted works, such as frescoes, murals, and paintings, are extremely vulnerable because they are irreplaceable.

Efforts to develop acid-resistant protective coatings for the different material types have been unsuccessful. Discovery of a sacrificial coating that would protect the structure from acid damage without changing its character would be most helpful. However, to date the experimental coatings have either caused discoloration or spalling, especially when applied to stone.

Other factors, such as the availability of rare replacement materials and unique craftspersons, are important in determining the sensitivity of man-made resources. Since replacement cost is another important factor, sculptured stone and metals are regarded as most sensitive. Dimension stone closely follows. Adobe, plaster, concrete, unit masonry, and sheet metals lie on a scale between dimension stone and surface coatings.

IMPORTANCE OF ACID RAIN STUDIES TO THE NATIONAL PARK SERVICE

The National Park System affords an exceptional opportunity for scientific research on acid rain. Short-term and especially long-term monitoring produces an invaluable record with time. The expansion of specific park investigations may be warranted to fully document the extent and ramifications of acid deposition. Acid rain threatens both the cultural and natural resources the NPS is charged to protect and preserve. Beyond this consideration, however, NPS research will contribute to current international efforts to understand acid rain effects, assist in policy considerations within the NPS and the Federal government, and provide information to visitors concerning the status of their resources.

The culmination of acid rain research projects is the presentation of valid findings in scientific papers, popular articles and symposia which inform others of work within the NPS, build awareness of issues affecting national resources, elicit other research efforts in the parks, provide an opportunity for experts to critique the findings, and establish a more complete data base on effects of acid rain.

Education of park visitors about resources and the importance of the effects of acidification on resources can be accomplished through displays, evening seminars, pamphlets, and other efforts by park naturalists or information specialists based upon the results of NPS studies.

The Water Resources Field Support Laboratory in Fort Collins is the National Park Service's clearing house for acid rain/natural resources information.

Questions regarding specific parks, requests for information, or queries regarding other acid rain research findings outside of the parks can be directed to the Laboratory. Questions regarding the effects on cultural resources can be directed to the Office of Historic Architecture, National Park Service, Washington, D.C. 20240.

BIBLIOGRAPHY

La Bastille, A. 1981. Acid rain how great a menace? Natl. Geograph. 160(5):652-679.

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

Sherwood, S.I. 1981. Environmental effects on cultural resources. Literature review. U.S. Dep. Inter., Natl. Park Serv., Washington, D.C. 19pp.

U.S. Department of Agriculture, Forest Service. 1976. First International Symposium on acid precipitation and the forest ecosystem. U.S.D.A. For. Serv. Gen. Tech. Rep. NE-23.

U.S. Environmental Protection Agency, Office of Research and Development. 1980. Acid rain. U.S. Environ. Protect. Agency, Off. Res. Develop., Washington, D.C. EPA-600/9-79-036. 36pp.

An exhaustive bibliography (on microfiche) of research on acid rain listed both by author and title is available free by contacting:

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Corvallis, Oregon 97333

APPENDIX A

THIS DIAGRAM IS DESIGNED TO TEST THE PARK RESOURCE IN TERMS OF SENSITIVITY TO ACIDIC INPUTS. NO PROBLEM IS INDICATED--THERE IS NOT NOW BELIEVED TO BE A POTENTIAL FOR AN ACID RAIN PROBLEM. FIRST APPROXIMATION ANSWERS TO THESE QUESTIONS MAY BE REACHED BY CONSULTING FIGURES 5 AND 8. MORE SPECIFIC KNOWLEDGE CAN BE OBTAINED BY STAFF CONSULTATIONS, LOCAL RESOURCES DATA, LOCAL PRECIPITATION CHEMISTRY DATA FROM THE NEAREST PARK OR NADP SITE. THE WATER LAB (WRFSL) WHERE REQUIRED CAN ASSIST WITH A DETAILED PROBLEM ASSESSMENT.

NATURAL RESOURCE AREAS

1. What is the bedrock, are there sections of granite, gneiss, schists, or other slow-to-weather units?
???

yes

no → acid rain not a problem

2. is the bedrock exposed
???

yes

no

3. are the soils thin or non-porous
???

yes

no → acid rain not a problem

4. are there lakes and streams in this area with slow-to-weather bedrock and thin soils ???

yes--this area is potentially sensitive to acid rain

no → vegetation and soils might be at risk--warrants further study

is pH of rainfall averaging less than 5.6
???

yes
this area potentially receives acid rain. Further inquiry is needed.

no → acid rain not a problem

CULTURAL RESOURCE AREAS

A. Resources are structures

1. What are structures made of
???

B. Resources are works of art

Resources are structures

and/or

Resources are works of art

Resources are structures

1. Structures are made of masonry marble, concrete, mortar, stucco other limestones ???

yes

no

2. Structures made of metals which dissolve in acid rain

yes

no

3. Structures coated with something easily replaceable

no

yes--acid rain not a problem

4. Is pH of rainfall averaging less than 5.6?
???

yes
this area potentially receives acid rain.
Further inquiry needed.

no--acid rain not a problem

Resources are works of art

1. Pieces one of a kind; cannot be replaced.

yes

no

3 pieces expensive and time-consuming to replace

yes

no--acid rain not a problem

2. Is pH of rainfall averaging less than 5.6?
???

yes
Work potentially at risk. Monitoring needed.

no --acid rain not a problem

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural value of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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