Evaluation of Lake and Stream Acidification in Nine National Parks

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FOREWORD

The evaluation described in this document is not intended to provide a comprehensive assessment of lake and stream sensitivity to acidification in certain national parks. The evaluation was limited to waterbodies with available data and may not have included the most sensitive lakes and streams, which are often in high elevation areas with limited access. Rather, the evaluation was intended to test the utility of the Decision Support System (DSS) of the Air Quality Information Management System. This document describes the data requirements of the DSS that should be considered for future evaluations.

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The report can be downloaded from
http://www2.nature.nps.gov/air/Pubs/pdf/EvalAcidificationNineParks.pdf

Chapter 1 - Introduction

The National Park Service (NPS) is responsible for protecting the lands and resources under its jurisdiction. Air pollution has the potential to affect these lands and resources, including water quality. The effects of pollution are a substantial concern because of the sizeable increase in pollution levels since the beginning of industrialization in the United States. For example, concentrations of anthropogenically-fixed nitrogen (N) measured in the early 1980's at Niwot Ridge in the Colorado Front Range were 30-fold greater than pre-industrial levels (Fahey et al., 1986). From 1850 to 1990, sulfur (S) emissions in North America increased almost 60-fold (Lefohn et al., 1999); more recently, regulations enacted under the Clean Air Act to combat acid rain have reduced S emissions significantly, and N emissions to a lesser degree.

N and S compounds enter the atmosphere from many sources, including automobiles and other transportation sources, power plants, industry, agriculture, and burning. In the U.S., about two-thirds of all sulfur dioxide (SO_2) and one-fourth of all nitrogen oxides (NO_x) come from electric power generation that relies on burning fossil fuels like coal. Automobiles, road transport, shipping, and aircraft are also significant sources of NO_x emissions. Agricultural activities such as storage of manure, soil fertilizing, and animal husbandry emit N in the form of ammonia. These sources are increasingly significant contributors of atmospheric N. N and S compounds are transported and transformed in the atmosphere and eventually deposit into ecosystems as sulfates, nitrates, and ammonium compounds. In streams and lakes, these compounds can lead to acidification and eventual decline or loss of aquatic invertebrates, phytoplankton, and fish. In addition, the fertilizing effects of N can cause major changes in ecosystem structure and diversity by altering competitive interactions among organisms.

Streams and lakes vary in their sensitivity to acidification. High elevation aquatic ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, and certain areas of the eastern U.S. are generally the most sensitive to atmospheric deposition due to their limited capacity to neutralize acid deposition.

The following report contains an evaluation of the sensitivity of certain lakes and streams in nine 'Class I' national parks to acidification by deposition of atmospheric S and N compounds. The first section of the report describes a decision support system (DSS) developed by NPS to evaluate the sensitivity of lakes and streams in nine parks in five regions of the country. The next section discusses the methods used for retrieving and processing water quality data for the evaluation. Subsequent sections provide overviews of pollutant emissions and their effect on water quality in the nine parks plus the results of running the processed data through the DSS and an interpretation of these results. Air and water quality overviews are provided for the New England, Pacific Northwest, Rocky Mountain, and Sierra Nevada regions.

The evaluation was undertaken not only to assess lake and stream sensitivity to acidification, but also to evaluate the utility of the DSS. The evaluation was limited by available water quality data obtained from the National Park Service's Baseline Water Quality Inventory and Analysis Reports (http://www.nature.nps.gov/water/horizon.cfm), which were generally completed in the 1990's. Often the reports did not contain all the data required for the DSS, or had data for a very limited (and not necessarily representative) number of waterbodies in a park. Lakes and streams thought to be most sensitive (high-elevation) are generally difficult to access and sampled infrequently, if at all. Therefore, some of the most sensitive waterbodies are not included in this analysis. Some of the data are over 30 years old and unlikely to reflect current conditions. The National Park Service has since undertaken a comprehensive water quality monitoring program at many national parks, and this more recent data should be considered when making management decisions.

Data from Rocky Mountain NP were processed by the DSS, but the analysis of the DSS output was not completed due to lack of available personnel time.

Chapter 2 - Aquatic Chemistry Decision Support System

In 1994, the NPS began developing the Air Quality Information Management System (AQUIMS), designed to organize and archive air quality information for report generation and to provide decision support for resource management in parks. Within AQUIMS, NPS constructed a knowledge base to assist in identifying the status of the chemical condition of park waters. The information and systems in AQUIMS evolved into a more comprehensive information management system called "Synthesis," which has further evolved into a web-based system, the Air Resources Information System (ARIS).

The knowledge base, or expert system, is entitled the "Aquatic Chemistry Decision Support System" (DSS).

NPS developed the Aquatic Chemistry DSS using knowledge-engineering methodology with NetWeaver software. Its goal is to classify waters in five acid-sensitive regions of the United States, according to their sensitivity to acidification. The five regions are:

- Cascade Mountains
- Central Rocky Mountains
- Northeastern United States
- Northern Rocky Mountains
- Sierra Nevada

A panel of nationally recognized aquatic chemistry domain experts (including university and governmental scientists) participated in knowledge engineering sessions to develop the Aquatic Chemistry DSS. They identified the information needed for the water body classification, including water chemistry data and the criteria values for classification.

The Aquatic Chemistry DSS classifies water bodies into six categories based on sensitivity to acidic deposition, extent of impact from acidic deposition, and influence from other factors, including geologic sources of S, natural organic acidity, and the influence of disturbance and land use on water quality. Criteria values for classification vary among regions to reflect differences in historic S and N deposition loadings and likely changes in future deposition.

Waterbody Categories

Sensitive and Unimpacted

Sensitive but unimpacted waters have low buffering levels and are sensitive to acidification under continued or increased S or N deposition. There is no indication that the water body has acidified yet. Low acid neutralizing capacity (ANC), with low sulfate and nitrate concentrations, characterize such waters. Other indicators include low levels of organic matter and low to medium levels of specific conductance, pH, and base cations.

Potentially Acid Deposition Impacted

Water bodies in this category appear to be impacted by acidic deposition. The classification is based on ANC plus information on pH and the concentrations of sulfate and nitrate. ANC is used preferentially over pH for classification; pH is not a good indicator of acidification until the lake has lost most of its ANC. In general, the lower the ANC (or pH), the greater the likelihood of acid deposition impact.

Other factors are also considered, including specific conductance and base cations. Low specific conductance suggests that the lake may be sensitive to, or has already been impacted by, acidic deposition; high specific conductance suggests that the lake may be "insensitive", exhibiting high buffering capacity, or that it may have been impacted by geological S. If either the ANC or pH is too low to have been the result of acidic deposition levels encountered in the region, then the low ANC and pH likely results from geological S. High ANC and, less reliably, high pH or base cation concentration suggest that the lake is insensitive. If sulfate concentration is very low, the lake is not likely to have been impacted, whereas if sulfate concentration is high, the lake is likely to have been impacted. However, if the sulfate concentration is very high, relative to expected concentrations for the region, based on levels of atmospheric input coupled with the concentration-enhancement effects of evapotranspiration, then much of the water's sulfate is likely not of atmospheric origin. In such cases, the acidity is more likely associated with geological sources of S.

High nitrate concentration suggests impact from deposition, but if the concentration of nitrate is very high, it is more likely associated with surface water runoff from agriculture or other land use activities, rather than acidic deposition. If dissolved organic carbon is high, then acid deposition is less likely to have caused acidification, and the low ANC and pH of the lake are more likely to have resulted from natural organic, rather than anthropogenic, acidity. Natural organic acids impart substantial buffering, and resist further acidification from acidic deposition.

Natural Organic Acid Impacted

Lakes in this category are classified as natural organic acid impacted if they have high levels of organic material, as measured by high concentrations of dissolved organic carbon, and there is evidence that the high dissolved organic carbon appreciably contributed to low ANC and/or pH. Such conditions indicate that the lakes have substantial wetlands in their watershed and biota influences the water's chemistry more than any other factor.

Insensitive to Acid Deposition

The DSS classifies lakes as insensitive to acidic deposition primarily on the basis of ANC. High ANC indicates that the lake is insensitive; low ANC suggests that the lake is not insensitive, but rather is sensitive but not yet impacted, or it is impacted by acidic deposition, geological S, or natural organic acidity. High concentrations of base cations or organic material, or a high specific conductance are also indicative of high buffering capacity.

Geologic Sulfur Impacted

Lakes are classified by the DSS as geological sulfur impacted if water sulfate concentration is too high to be reasonably attributable to acidic deposition and if there is evidence that the high sulfate concentration has appreciably altered the water acid-base chemistry by causing low ANC and/or pH. Mine drainage is one source of geological S. The higher the concentration of sulfate in water, the greater is the likelihood that much of the sulfate is of geological, rather than atmospheric, origin. However, high sulfate levels without low values of pH and ANC are not sufficient to classify a lake as geologic S impacted. In addition, the DSS recognizes that lakes that are close to the coast are likely to have higher concentrations of sulfate than inland lakes; the high sulfate does not indicate a geological S influence, but rather a marine influence.

Disturbance/Land Use Impacted

Lakes categorized as disturbance/land use impacted have impacts associated with watershed disturbance or land use. In particular, the DSS identifies lakes that have been impacted by high nitrate concentration as a consequence of agricultural activities, forestry, or other land use in the watershed. The DSS does not attempt to identify other impacts, such as severe insect defoliation.

Values

The DSS produces a numerical value for each category corresponding to its trueness for each site based on the input data. The value is a number from -1 to 1. Table 2-1 shows the meaning of the value for each category.

Table 2-1: Value Interpretations

Value	Meaning
-1.00	This category is untrue for this site
-0.99 to -0.01	This category may be untrue for this site. The lower the number, the greater certainty that the category is untrue
0.00	There is no certainty about the trueness of this category
0.01 to 0.99	This category may be true for this site. The higher the number, the greater certainty that the category is true
1.00	This category is true for this site

The individual values were categorized into an arbitrary set of ranges selected to facilitate discussion of the DSS results. Table 2-2 lists a level of certainty defined by ranges of result values.

Table 2-2: DSS Value Ranges

Range	Meaning
-1.00 to -0.60	It is almost absolutely certain this category is untrue
-0.59 to -0.20	It is fairly certain this category is untrue
-0.19 to 0.20	No certainty
0.21 to 0.60	It is fairly certain this category is true
0.61 to 1.00	It is almost absolutely certain this category is true

Regional Variation

The DSS structure varied from region to region, in response to observed differences in regional water chemistry, which are partly due to different regional histories of atmospheric S and N deposition. The northeast region was tested using data from the Eastern Lakes Survey, Adirondack Mountains and Maine subregions, and additional lake data from Maine. Each of the four western regions was tested with data derived from the Western Lakes Survey and a group of acid-sensitive waters modeled with the Model of Acidification of Groundwater in Catchments (MAGIC). Each region was adjusted in structure and in terms of decision criteria values until it consistently represented both the expert judgment regarding lake classification and the perceived uncertainty inherent in that classification judgment.

Figure 2-1 gives examples of how the DSS interprets a given parameter in a given category on a region-by-region basis. In the northeast region, an ANC value less than 45 microequivalents per liter (μeq/L) results in a value of false (-1) in the 'Insensitive to Acid' category. If the ANC value is greater than 100 μeq/L in this region, it results in a value of true (1) in this category. An ANC value greater than 45 μeq/L and less than 100 μeq/L will return a value between -1 and 1, with the most uncertain value being half-way between 45 and 100, or 72.5. The value for this parameter is logically combined with other parameter values as deemed appropriate by the subject-matter experts for the 'Insensitive to Acid' category to determine the final value for the category.

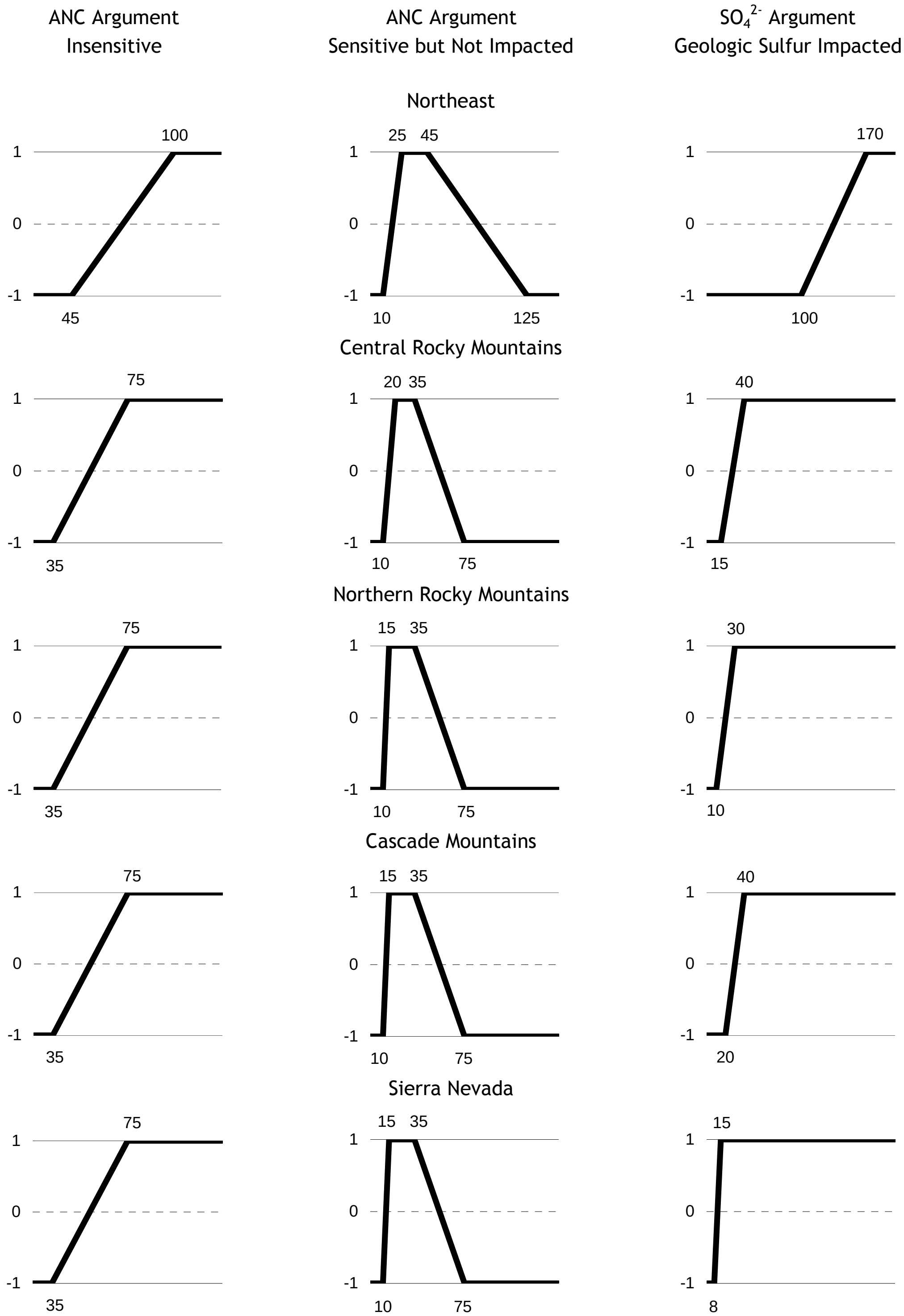
Regional variation allows equal values for a parameter to mean different things across regions. For example, in the northeast region, an ANC value of 80 μeq/L would result in a degree of uncertainty in the 'Insensitive to Acid' category (a value less than 1) but would equal a value of true (1) in all of the other regions. This reflects the need of a higher buffering capacity keep water insensitive to future acidic episodes in the northeast, due to the effects of acid rain compared to the cleaner air over western mountain regions.

In the northeast, an ANC value of less than 10 μeq/L results in a value of false (-1) in the 'Sensitive but Not Impacted' category. Waters with such low ANC values are deemed to already have been impacted. ANC values between 10 and 25 μeq/L result in a value between -1 and 1, meaning that the DSS is uncertain as to whether to ANC is low enough to signal impaction. ANCs between 25 and 45 μeq/L return a value of true (1) in this category. If other parameters for this water body indicate it is not acidic, the water will be found to be sensitive to future acid increases but not yet impacted. ANCs between 45 and 125 μeq/L result in uncertainty as to whether the ANC is high enough for the water to be considered insensitive to acid. ANCs above 125 μeq/L return a false value (-1), indicating that the water is insensitive to acid.

A sulfate (SO_4^{2-}) value of less than 100 μeq/L results in a value of false (-1) for the 'Geologic Sulfur Impacted' category in the northeast. A sulfate value greater than 170 μeq/L results in a value of true. These values are substantially higher in the northeast region than the western mountain regions due to this region's proximity to the ocean, historically higher sulfate concentrations in atmospheric deposition, and greater evapotranspiration. Near-coastal waters receive atmospheric deposition of marine aerosols, which contain appreciable concentrations of sulfate derived from seawater (Sullivan et al. in review).

However, this is not the sole criterion of the rating for the 'Geologic Sulfur Impacted' category. The DSS decides its rating for this category based on ANC, specific conductance, DOC, pH, and the sum of base cations. Thus, Figure 2-1 shows only part of the criteria for classification.

Figure 2-1: Schematic illustration of three DSS arguments within each of the study regions. The arguments selected for illustration are: (1) ANC arguments for 'Insensitive to Acid' waters, (2) ANC arguments for 'Sensitive but Not Impacted' waters, and (3) sulfate (SO_4^{2-}) arguments for 'Geologic Sulfur Impacted' waters. Values range from -1 (false) to +1 (true). Source: Sullivan et al, in review.



Data Requirements

The water quality data used in the Aquatic Chemistry DSS to classify lakes in parks comes from the NPS Baseline Water Quality and Analysis Reports. Because Horizon Systems Corporation in conjunction with NPS's Servicewide Inventory and Monitoring Program and the NPS's Water Resources Division (WRD) gathered the data, these reports are known as Horizon reports. The goal of these reports is "to provide descriptive water quality information in a format useable for park planning purposes." The data in the Horizon reports was obtained from the Environmental Protection Agency's STORET (STOrage and RETrieval) system. The Horizon reports are available from the National Park Service Water Resources Division at http://www.nature.nps.gov/water/horizon.cfm.

The data extracted from the Horizon reports is summary data, including both mean values and extreme values. Conclusions drawn from using the mean data are likely to underestimate the extent of problems such as acid mine drainage impacts or acid rain impacts. One possible way to bracket the true situation regarding impacts is by using a worst-case combination of the extreme values. This worst-case combination would include a site's lowest values for parameters that measure the protection of the water from impact (ANC, sum of base cations, and specific conductance) and its highest values for parameters that contribute to acidification (sulfate, nitrate, and DOC). The worst-case combination would also include minimum pH values, an indication of acidity, and minimum chloride values, to report the lowest fraction of sulfate may have come from neutral sea spray as opposed to sulfuric acid.

A number of water chemistry parameters are required for the Aquatic Chemistry DSS. These parameters are closely associated with acid-sensitivity. In general, acid-sensitive waters have specific conductance below 25 μmhos/cm, acid neutralizing capacity (ANC) below 100 μeq/L for episodic acidification (50 μeq/L for chronic acidification), total base cations (calcium, magnesium, sodium, and potassium) concentration below 100 μeq/L, and a pH below 6.0. There are exceptions to this, depending on geology and other factors. Therefore, the DSS considers other parameters in addition to ANC, total base cations, and pH.

Water Chemistry Parameters

As mentioned above, an expert panel determined which water chemistry data to include in the DSS. Table 2-3 lists the seven parameters decided upon.

Table 2-3: Required Water Chemistry Data for Aquatic Chemistry Decision Support System (DSS)

Data types	Meaning
ANC	Acid neutralizing capacity (microequivalents per liter = μeq/L)
SO_4^{2-}	Sulfate concentration (μeq/L)
NO_3^-	Nitrate concentration (μeq/L)
DOC	Dissolved organic carbon (milligrams per liter = mg/L)
Conductivity	Specific conductance (microSiemens per centimeter at 25 degrees Celsius =

	μS/cm@25C)
pH	Water pH
Sum of base cations	Sum of potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), and sodium (Na^+) concentrations (μeq/L)

In addition to the water chemistry parameters, other location-related parameters are extracted from the Horizon reports. Site number, agency code, STORET ID, and location identify the data, in case it is necessary to go back and look at the data in the reports. Data such as the period of record and the number of observations are used to gain a sense of how much confidence can be expressed in the data at a location. Other values, such as temperature and chloride and fluoride concentrations, are used to further assess waters that are on the borderline in categories.

Below is a list of the data extracted from the Horizon reports and recorded in the spreadsheets and a brief description.

Site Number

The recorded site number is a simplified version of the 8-digit site number found on the Horizon report. In the report, the number is the 4-digit park code followed by the four-digit site number. In the spreadsheet, the site number is the four-digit site number without any leading zeros. For example, site NOCA0042 in the Horizon report becomes site number 42.

Agency Code and STORET ID

These codes enable retrieval of the Horizon report from STORET. STORET (short for STOrage and RETrieval) is a repository for water quality, biological, and physical data and used by state environmental agencies, federal agencies, universities, and private citizens.

Location

This field records the name of the location of the water sample. The Horizon reports provide latitudinal and longitudinal coordinate points, but the DSS does not use them so they are not recorded.

Sample Type

There are seven basic sample types: lakes and reservoirs, streams, springs, oceans, estuaries, wetlands, and canals. The DSS handles aquatic chemistry data for lakes and streams only. These two sample types make up 90% of all of the water locations identified in the Horizon reports for the 9 parks in the study. The values in this column serve to separate the data into lake and stream data prior to running the DSS.

Period of Record

The period of record indicates the first and last sampling dates for a location. The DSS is not time sensitive. However, recording the period of record allows for an analysis of the age of the data.

Number of Observations

This column captures the number of observations of any water quality parameter at the site. This data assists in analyzing the frequency of sampling at a particular location and throughout the park.

Depth of Water

Eepth measurements pertain almost exclusively to lakes. This value is not used in Synthesis, but serves as a reminder that the samples taken and reported on in the reports are from the lake surface. A lake's water chemistry may be radically different at different depths, especially if the lake is seasonally stratified.

Temperature

Temperature is generally in degrees Centigrade. However, at some sites, the temperature measurements are in Fahrenheit. These sites have the temperature marked in bold. In either case, the mean temperature value is recorded.

Specific Conductance

Conductivity is a measure of the ability of water to pass an electrical current. The presence of inorganic dissolved solids such as chloride, nitrate, and sulfate anions (negatively charged ions) or sodium, magnesium, calcium, and potassium cations (positively charged ions) affects conductivity in water. The DSS uses specific conductance as an indication of buffering capacity. Higher values indicate greater ionic concentration in the water and in general, greater buffering capacity. For this reason, the spreadsheet records the mean and the minimum values of specific conductance. This is to give a general idea of the effect of specific conductance on average and at its most extreme.

Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Temperature also affects conductivity: the warmer the water, the higher the conductivity (USEPA, 1997).

The units for specific conductance are microSiemens per centimeter at 25 degrees Celsius (μS/cm@25C). Specific conductance data in the Horizon report use units of micromhos per centimeter (μmho/cm), which is equivalent to the newer unit of microSiemens per centimeter. Field measurements of specific conductance were used for the DSS preferentially over laboratory measurements.

pH

The pH value is a measure of acidity and is an important parameter in the DSS. Whenever possible, a field value of pH is used. The spreadsheet contains both the mean and the minimum value (highest acidity) to give an idea of the effect of pH on average and at its most extreme.

Alkalinity and ANC

ANC is derived from various alkalinity measurements or, in rare cases, is measured directly. It is used as a basis for determining the impact of acid deposition on a water body as well as the resistance of that water body to future acid deposition. The DSS uses the ANC value. Both the mean and minimum values are recorded to determine the effect of ANC on average and at its most extreme.

Alkalinity is generally measured in two ways: total alkalinity (milligrams per liter - mg/L as $CaCO_3$), or total low level Gran analysis. The total alkalinity value is converted to μeq/L before it is entered in the ANC (Acid Neutralizing Capacity) column. The units of total low level Gran analysis are μeq/L; thus, this value is placed directly in the 'ANC' column. In some cases, a sample's alkalinity was measured using two color indicators of the endpoint of an acid/base titration, methyl orange and phenolphthalein. The endpoint measurements are converted to μeq/L using the same conversion as a total alkalinity measurement; their values are totaled and entered in the total alkalinity column in the spreadsheet. The total alkalinity measurement is the preferred measurement over the addition of methyl orange and phenolphthalein measurements.

Dissolved Organic Carbon (DOC)

The DSS determines the impact of natural organic acid by evaluating dissolved organic carbon concentrations. High organic acid levels may lower a waters pH. Some waters may be naturally acidic; the DSS uses the DOC measurement to distinguish these systems from waters impacted by anthropogenic factors. Both the mean and maximum values are recorded to see the effect of DOC on average and at its most extreme.

Nitrate

The DSS uses the microequivalent nitrate (NO_3^-) concentration as a measure of the effect of acid deposition on a body of water. NO_3^- is highly soluble in water and is stable over a wide range of environmental conditions. Higher values indicate greater acidic or land use effect. For this reason, the mean and maximum values of nitrate are taken to determine the effect of nitrate nitrogen on average and at its most extreme.

Nitrate measurements may be derived from one of three measurements in the Horizon Reports:

- NO_3^-
- NO_3^- as N (nitrate nitrogen as N)
- NO_3NO_2 (nitrate plus nitrite - NO_2^-)

'NO_3' or 'NO_3 as N' are the preferred values. They measure only the effect of nitrate. For use in the DSS, the nitrate concentration is expressed in μeq/L. If values exist for both 'NO_3' and 'NO_3 as N', the higher value of the two is used. If both are absent, 'NO_3NO_2' is an acceptable substitute, as the concentration of nitrite nitrogen is generally small enough to ignore. NO_2^- is relatively short-lived in water because it is quickly converted to nitrate by bacteria. The NO_3NO_2 concentration is also expressed as μeq/L.

The reports contain additional measurements of N:

- Ammonia as N (NH_3 as N)
- Ammonium ion (NH_4^+)
- Kjeldahl N (ammonia plus organic N)
- Total N

The DSS does not use the additional N values; however, the mean values are recorded and consulted when making a decision on the degree of impact on borderline parks.

The Base Cations: Calcium, Magnesium, Sodium, and Potassium

Concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+), are measured in mg/L. In some locations, the calcium concentration is expressed as calcium carbonate ($CaCO_3$). Together, these four elements make up the base cations. They are a measure of resistance of the water to acid deposition. These values are converted to μeq/L and summed to find the sum of base cations (SBC) for the DSS. Because they are a measure of protection against acid deposition, the mean and minimum values are recorded to determine the effect of the SBC on average and at its most extreme.

All of the base cation components were not measured at some locations. Not having data for any component will underestimate the true value of 'sum of base cations'. For a given park the ratio of Ca to Mg, Na to K, and (Ca + Mg) to (Na + K) are fairly constant. Thus, it is possible to calculate these ratios from sites with complete data and apply it to those with missing data. The calculation of each ratio involves all locations with complete data in a park.

Chloride and Fluoride

Chloride (Cl^-) and fluoride (F^-) concentrations are used to evaluate borderline sites, especially those near coastal areas. The fluoride measurement is not used directly by the DSS. While chloride is not used in all of the regional knowledge bases, it is used for coastal locations to estimate what fraction of sulfate may have come from neutral sea spray as opposed to sulfuric acid. Both the mean and minimum values are recorded to see the effect of chloride on average and at its most extreme, while only the average level of fluoride is captured.

Sulfate

Sulfate measurements (SO_4^{2-} or SO_4^{2-} as/S) help to determine the effect of acid deposition and the impact of geologic S on a site. Because higher values indicate a greater impact, the mean and maximum values are recorded to see the effect of sulfate on average and at its most extreme.

Missing Data

If some of the data used by the classification algorithms in the DSS are missing, the DSS reports less confidence in the classification. As progressively more variables are missing from the data set, there is progressively less confidence in the results (Sullivan et al., in review). In addition to generating values for the six categories, the DSS reports a classification concerning insufficient data in the data set. Obviously, more missing data results in a greater level of certainty that the data set is incomplete. Resource managers may choose to collect additional data to increase confidence in the classification results.

Data Limitations

Since the DSS uses statistical summaries of the data, the DSS results only distinguish between parks that clearly have no problem and those parks that clearly do or that may have problems. For some sites in some parks, it may be advisable to process data for individual samples through the DSS.

For each park there are a number of water quality sampling sites. Multiple agencies, including NPS and the U.S. Geological Survey, took these samples. Sampling occurred at varying times of year and in different years. As a result, each site has varying amounts of data, depending upon the tests on the water performed for that site.

The method of data collection varied from site to site, and the number and location of sites may not be representative of the entire park. Because the most acid-sensitive lakes are likely to be in very high elevation areas, they tend to be remote and difficult to access. **The report may not contain data for the most sensitive lakes; therefore, the analysis does not give a true representation of the extent or severity of impact by acid deposition for the entire park.**

Of the 2953 sample locations identified in the Horizon reports for the nine parks in this analysis, 21% of them had no data for any of the parameters used by the DSS.

Another 27% had one or two of these parameters. Only 5% of locations had all of the parameters used by the DSS. When the DSS does not have enough data to make a decision, it places a high degree of uncertainty on that site. It is difficult to come to any conclusions about locations that have such uncertainty.

Another issue concerns the infrequency of sampling. Often, sampling occurred frequently at a location for temperature but infrequently for other parameters. Many results contain data from one or two samples. For example, of the 1200 locations that contain alkalinity data, 60% of them contain only one measurement. In these cases, the result is 'extreme' values that are the same as the mean values. Therefore, in many instances, the analysis with extreme water chemistry values is nearly or exactly the same as the analysis with mean water chemistry values. Only 6% of all alkalinity results were the result of more than 10 sample tests. With so few samples, it is difficult to ascertain if the data assembled is representative of the water body in question. Further sampling is necessary in most locations to gain a true sense of a location's water chemistry.

Of the seven water quality parameters used by the DDS, data for pH and specific conductance are most abundant. Of the 2338 locations that have one or more data elements used by the DSS, 84% have pH data and 87% have specific conductance data. These data have a greater frequency of collection because most times those collecting the sample perform these measurements in the field.

Data concerning ANC, and nitrate, sulfate, and base cation concentrations is relatively abundant. ANC data was available at 52% of sites with data, nitrate data at 65%, sulfate data at 51%, and base cation data at 56%.

Dissolved organic carbon is the least available parameter. Only 10% of all locations with data contain DOC measurements. The lack of DOC data is more prevalent for samples taken before 1980. In the DSS, this leads to a finding of uncertain for most locations in terms of the Natural Organic Acid Impacted category.

Information is more complete for lakes than for streams. Of the 746 lakes in the parks included in this evaluation, 94% have at least one data component used by the DSS, as compared to 76% of the 1912 streams. Both lake and stream data are moderately complete, with 45% of lakes and 40% of streams with data containing 6 or 7 data elements used by the DSS.

Much of the data contained in the Horizon reports reviewed for this analysis is historical data. Some of the reports were issued up to a decade ago. Sampling occurred at most of these locations in the 1970s and 1980s. In fact, of the 2620 locations that have recorded data, 77% were sampled before 1990, and 51% were sampled before 1980. The last samples from a few locations came from the 1930s. The condition of these waters has probably changed over the past 15 years, much less over 20 to 30 years. Even if the location has enough data to input into the DSS to make an assessment with some certainty, it is unlikely that assessment reflects the current conditions at that location. However, the National Park Service continues to improve the quality of water chemistry information for parks, with enhanced water quality monitoring and data management.

Locations

As mentioned above, the DSS classifies lakes in five acid-sensitive regions of the United States according to their sensitivity to acidification. Each region has its own unique calibration within the DSS to take into account distinct factors within the region.

NPS administers 48 "Class I" areas; this analysis looks at nine "Class I" national parks. Class I areas were designated by the Clean Air Act amendments of 1977 and include national parks over 6,000 acres and national wilderness areas over 5,000 acres that were in existence before August of 1977. The nine parks, and their park codes, are listed below.

• Acadia (ACAD)	• Rocky Mountain (ROMO)
• Grand Teton (GRTE)	• Sequoia/Kings Canyon (SEKI)
• Mount Rainier (MORA)	• Yellowstone (YELL)
• North Cascades (NOCA)	• Yosemite (YOSE)
• Olympic (OLYM)	

For this report, parks are grouped by their acid-sensitive region. Each section provides an introduction to the air and water quality in the region, followed by an introduction and the DSS results for the individual parks in that region. Table 2-4 lists the parks by their region.

Table 2-4: Included Parks by Region

Acid-sensitive Region	Park
Cascade Mountains	Mount Rainier, North Cascades, Olympic
Central Rocky Mountains	Rocky Mountain
Northeastern U.S.	Acadia
Northern Rocky Mountains	Grand Teton, Yellowstone*
Sierra Nevada	Sequoia, Yosemite

*The analysis intended to include Glacier National Park (GLAC), a Class I park in the Northern Rocky Mountains region. However, a Horizon report had not yet been done for GLAC at the time of this analysis.

Chapter 3 – Air and Water Quality in the New England Region

The information in this section was obtained from a document entitled "New England's Changing Climate, Weather, and Air Quality Climate" produced by the Change Research Center at the University of New Hampshire in 1998. This document is available on the Internet at http://www.neci.sr.unh.edu/neccwaq.html. This section is not meant to be a complete discussion of air and water quality in the New England Region nor a complete bibliography. Instead it provides an introduction to some of the environmental factors that are thought to most influence the lakes and streams described in this chapter. Some of the sources of emissions discussed here have changed greatly during the time that the data on the region's lakes and streams were collected and likely will continue to change as a result of emissions controls. Similarly, additional research continues in the region and improves our ability to understand the changes in the chemistry of lakes and streams.

Environmental Setting

The Atlantic Northeast contains land of bare rock, thin soils, rugged coastlines, swift streams, and slow-growing forests. Natural forces have contributed greatly to the present-day geography of this region. Mountains and hills consisting of hard crystalline rock were scoured by ice sheets that receded from the region 10,000 years ago. When the ice receded, it left thin soils and an undulating surface favorable for fast-running streams and bright, clear lakes.

New England regional weather and climate are highly variable. This holds true at time scales of from days to weeks, years to decades, and thousands to millions of years. Regional variability includes extremes of both hot and cold temperatures, droughts, heavy rainfall, hurricanes, tornadoes, blizzards, and more. Such variations in New England regional weather are influenced by many factors which relate to the region's physical geographic setting, including its latitude and coastal orientation, its topographic variability, and its position relative to the North American continent and prevailing storm tracks.

Air Quality

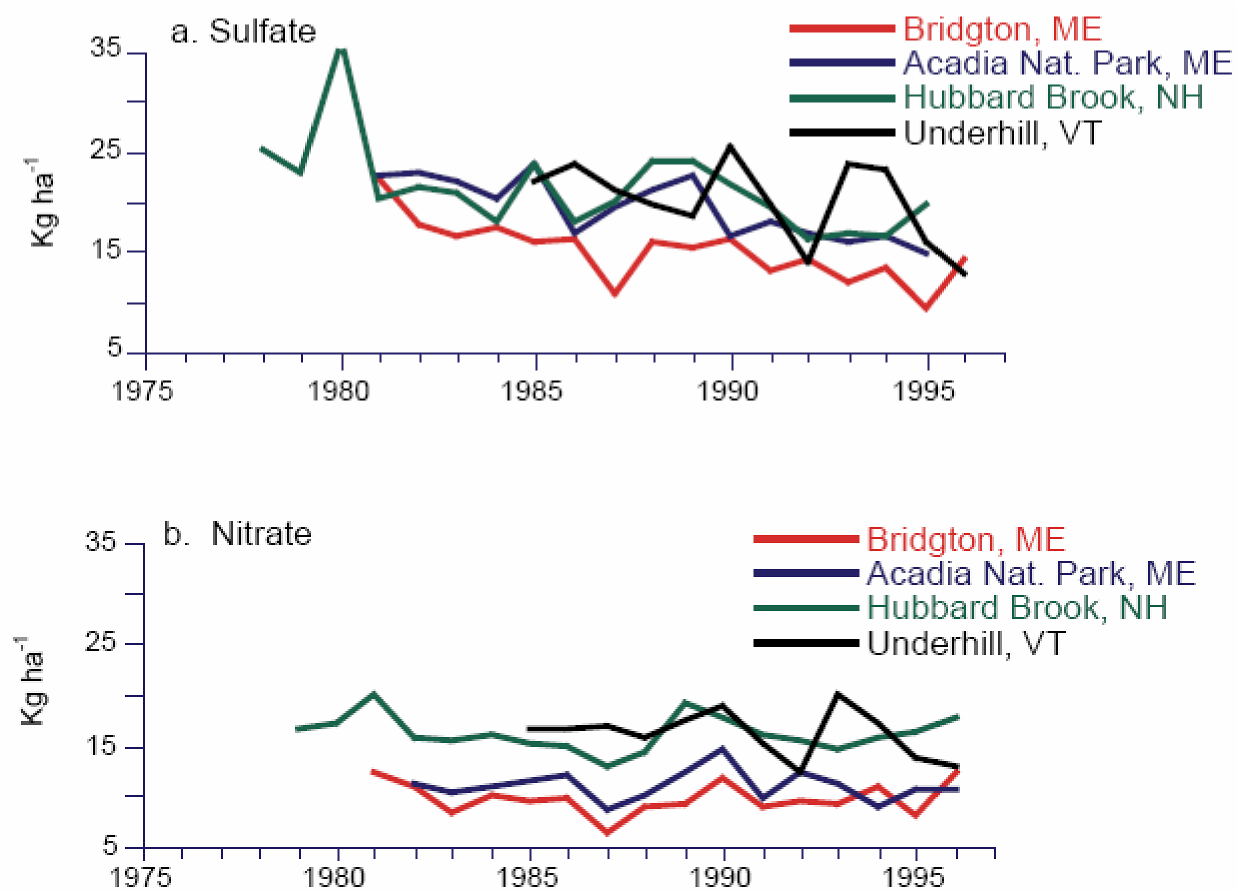
Certain New England aquatic and terrestrial ecosystems have been impacted by acid rain. This is largely the result of the influx of airborne pollutants originating from industrial regions, metropolitan centers, and transportation corridors located in upwind source regions (especially in the Midwestern and mid-Atlantic United States). Emissions from within northern New England from transportation and industrial sources also play a key role.

Acid rain is caused primarily by the emission of sulfur dioxide (SO_2) and nitrogen oxides (NO_X) from the combustion of fossil fuels in power plants, automobiles, and other sources. In the Northeast, this phenomenon has caused lakes and stream to become unsuitable for many fish (Baker and Schofield, 1985; Park, 1987). Acid rain has been known to leach heavy metals such as mercury from rocks, thereby causing contamination of water supplies and introducing human health risks (Brakke et al., 1988). Acid rain can also alter soil chemistry in agricultural and forested lands and causes significant damage to human made structures, especially those consisting of limestone and marble. In addition to contributing to acid rain, sulfate aerosols also play a significant role in Earth's radiation balance. The increase in sulfate aerosol in the troposphere adjacent to industrial regions of the globe over the past century has in fact served to cool climate on a regional scale (Charlson et al., 1992; Mayewski et al., 1993, IPCC, 1995).

Marine air masses (those coming from the east) show high levels of sea salt (composed primarily of sodium and chloride); air-masses from the eastern seaboard south of New England show high levels of acidic species, indicative of anthropogenic emissions from the burning of fossil fuels in the mid-Atlantic states; and air-masses from Canada show very low sea-salt, indicative of their continental origin. Air masses from the northwest (i.e., those originating in Canada) also show high levels of ammonium, likely reflecting agricultural sources from rural areas to the northwest of New Hampshire's seacoast (Lefer, 1997).

Aerosol chemistry samples from Whiteface Mountain in upstate New York show a strong correlation between the decrease in SO_2 emissions in the mid-western states since 1970 and the decrease in average sulfate concentrations in the Northeast (Husain et al., 1998). The deposition of sulfate in precipitation in northern New England measured at four locations has decreased on the order of 30% since the early 1980s (Figure 3-1a). The deposition of nitrate has shown no significant change since the early 1980s (Figure 3-1b).

Figure 3-1: Annual average (a) sulfate and (b) nitrate deposition (kilograms of sulfate or nitrate per hectare) measured in precipitation at four National Atmospheric Deposition Program (NADP) sampling stations in northern New England.



The decrease in sulfate deposition and precipitation acidity can be directly linked to the reduction in SO_2 emissions as a result of the Clean Air Act. Annual SO_2 emissions from anthropogenic sources in the U.S. have decreased from 28.3 million metric tons in 1970 to 17.4 million metric tons in 1996. At the same time, nitrogen oxides emission rates have increased from 19.7 million metric tons in 1970 to 21.3 million metric tons in 1996.

Lake and Stream Chemistry

Bedrock geology controls the natural quality of surface waters in the study area. The presence of weather-resistant igneous and metamorphic rock units and thin soils results in surface waters that naturally contain low concentrations of dissolved and suspended solids. Rainwater (1962) notes that surface waters in New England contain less than 100 mg/L of dissolved solids and 275 mg/L of and suspended solids; these amounts are small compared to waters nationally. Calcium and magnesium ions are the prevalent cations in New England waters (Rainwater, 1962). Carbonate-bicarbonate anions are the principal anions in waters found in the high altitudes and sulfate and chloride anions are the principal anions in waters near the Atlantic Coast.

Alkalinity generally is low in the highest elevations and high in valleys having agricultural and urban lands. Most streams have alkalinity values less than 200 μeq/L (Griffith and Omernik, 1988). In comparison to other areas of the Eastern United States, Hendrey et al. (1980) found that the New England Coastal Basins are underlain by large amounts of bedrock with low to no buffering capacity. As a result, the surface waters of the study area are highly susceptible to acidification by acidic precipitation.

The influence of human activities on streamwater quality varies from the headwaters or upstream sections of the major river basins to the outlets of the rivers near their discharge to coastal waters. Human population is generally greatest near the coast and, as a result, water-quality and habitat degradation is more pronounced. The discharge of raw sewage from population centers and wastes from tanneries, textile, and pulp and paper mills was pervasive early in the 20th century. River water quality has improved throughout New England since the passage of the Federal Water Pollution Control Act in 1972 (U.S. Environmental Protection Agency, 1995).

The chemistry of surface waters in the Hubbard Brook Experimental Forest (HBEF), White Mountain National Forest, New Hampshire, has been studied extensively since the early 1960s and the conclusions are summarized by Likens and Bormann (1995). HBEF streams are acidic (pH of 4-5) because of the dominating presence of sulfuric and nitric acids from precipitation. Geochemical-weathering reactions neutralize the acids and bicarbonate alkalinity increases as water travels through the watersheds. Likens and Bormann (1995) found that even though there are steep slopes and high precipitation rates, erosion and transport of suspended (particulate) matter from forested watersheds is relatively low.

Research performed at the HBEF since the 1960s has described the effects of both atmospheric deposition and silvicultural activities on the hydrology of small headwater basins in environmental settings that are common in the northern part of the study area (Likens and Bormann, 1995; Likens, 1985). The changing chemistry of streams in the HBEF closely mimics the change in precipitation chemistry from the combustion of fossil fuel and industrial processes (Likens and Bormann, 1995). During 1963-93, hydrogen ion and sulfate concentration in HBEF streams decreased as sulfate emissions have decreased. Even with these decreases, sulfate deposition is more than three times the amount that the watershed can neutralize (Likens and Bormann, 1995). Because of the inadequate buffering ability of HBEF streams to neutralize acids, the acidity of streams has increased. Other effects of atmospheric deposition include depletion of calcium from the watersheds, which has been linked to declines in northern forest growth (Likens and Bormann, 1995), and nitrogen enrichment of surface waters that can lead to eutrophication of coastal waters (Jaworski et al., 1997). Jaworski et al. (1997) estimated that about 64% of the total nitrogen exported to coastal waters from 10 basins in the Northeastern United States was due to nitrogen-oxide emissions from fossil fuel combustion. Nitrate fluxes from these basins increased 300-800 percent since the early 1900s and correlate to increases in nitrogen-oxide emissions.

Other sources of contamination in the study area are the introduction of chloride and sodium to wells from road-salting and elevated concentrations of nitrates from agricultural activities and on-site septic systems. Concentrations of chloride in many New Hampshire public-supply wells in urban areas have increased significantly since the 1940's when the use of salt to de-ice roads greatly increased (Hall, 1975). Contamination from road-salt storage piles and facilities and spreading of salts on roadways was the cause of 79% of the contaminated wells in New Hampshire (Morrissey, 1988). Sodium chloride from seawater intrusion, coastal flooding, and high-water deicing salt is the most common cause for elevated concentrations of dissolved solids in ground water on Cape Cod (Frimpter and Gay, 1979).

Chapter 4 - Acadia National Park

Background

Much of the information in this section was obtained from a document entitled "Acadia National Park Long-Term Ambient Air Quality and Air Pollution Effects Monitoring and Research Strategy".

Description

Acadia National Park (NP), designated in 1929, is located along the mid-coast of Maine and is the only National Park in the northeastern United States (the National Park Service administers additional sites in the Northeast, including national historic sites. With more than 40,000 acres it is one of the largest publicly owned and protected natural areas in the region. Park owned lands are scattered across more than a dozen islands and a portion of the mainland on the Schoodic peninsula. In addition, the park has responsibility for administering approximately 160 conservation easements on more than ten thousand acres of privately owned lands within the Acadian archipelago.

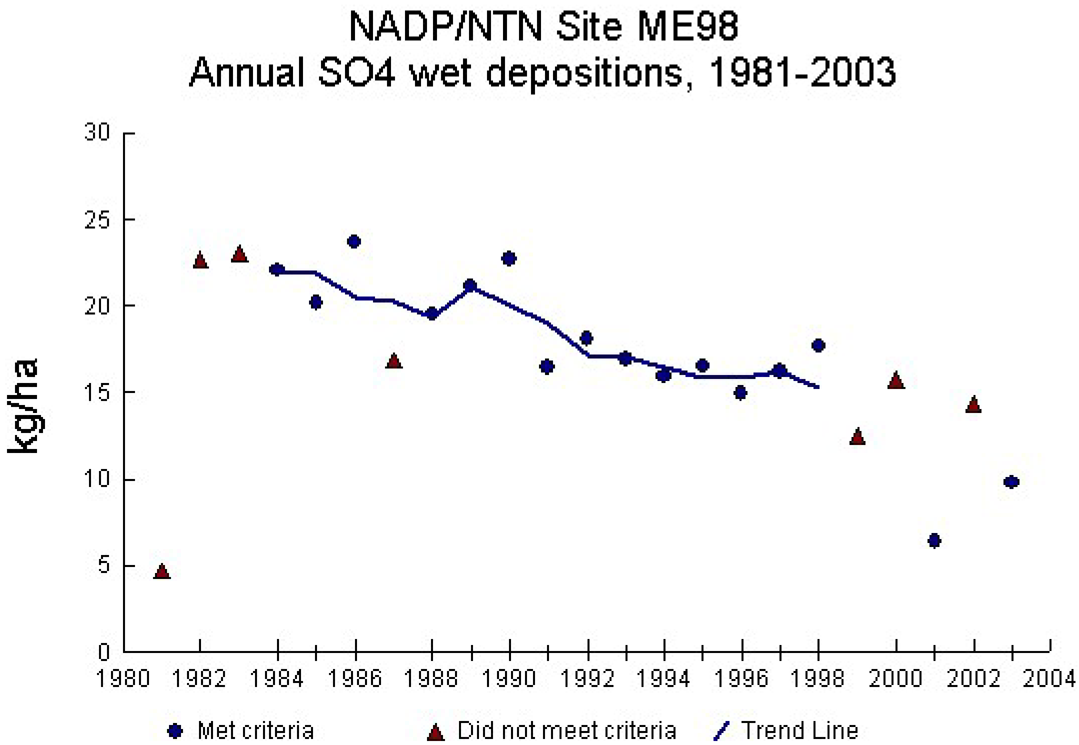
The weather in Acadia National Park is moderate compared to the rest of northern New England. Frequent thawing periods prevent large, long-term snow accumulations. Ice storms are common in winter and early spring, and rain occurs in every month. Fog is also a frequent phenomenon at the park that tends to peak in June, tapering off in winter. Northeastern storms, occurring mainly in late fall and winter, are generally severe windstorms. Hurricanes occasionally pass through the region.

Deposition

Primarily as a result of long-range transport by prevailing winds, Acadia NP periodically experiences high concentrations of a variety of air pollutants. Located along the mid-coast, the park is downwind from large urban and industrial areas in states to the south and west.

A NADP/NTN site was installed at McFarland Hill, in Acadia NP, in November 1981 (site ME98, elevation of 499 feet (152 m)). In agreement with the regional assessment, sulfate levels measured from wet deposition at have decreased from levels measured in the early 1980s, as shown in Figure 4-1. There is a strong correlation between the decrease in SO_2 emissions in the mid-western states since 1970 and the decrease in average sulfate concentrations in the Northeast (Husain et al., 1998). This reflects emission reduction efforts pursuant to the terms of the Clean Air Act, enacted in 1970.

Figure 4-1: Sulfate wet deposition, 1981-2003, at McFarland Hill NADP site

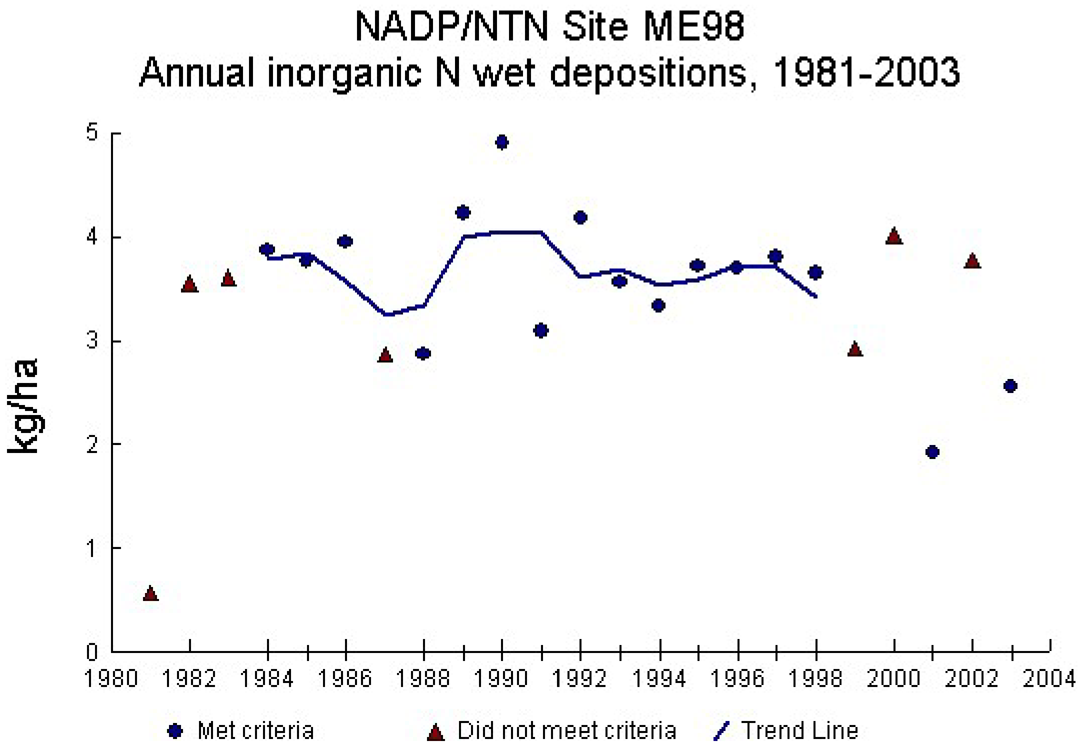


The level of inorganic nitrogen in wet deposition at McFarland Hill, depicted in Figure 4-2, also agrees with the regional data. There was not a substantial change in these levels throughout the 1980s or 1990s. Standards designed to reduce NO_X emissions have likely been offset by increases of anthropogenic emissions from the burning of fossil fuels in the Mid-Atlantic States and the Ohio River Valley and reflecting agricultural sources from rural areas to the northwest of New Hampshire's seacoast (Lefer, 1997).

Water Quality

Acadia NP contains at least 22 named lakes and ponds, more than 25 perennial and intermittent streams, and numerous wetlands located partially or entirely within its boundaries. These water bodies are exposed to impacts resulting from development within and adjacent to park lands, including sewage disposal, and non-point source pollution. Other impacts to ACAD water resources may come from oil or hazardous waste spills, landfill activity, high visitor use, and atmospheric deposition.

Figure 4-2: Inorganic nitrogen wet deposition, 1981-2003, at McFarland Hill NADP site



Davis et al. (1994) studied sediment cores from 12 acidic lakes in granitic, forested and uninhabited catchments in northern New England to reconstruct changes in pH and ANC. Trace metal chemistry data (lead, zinc, vanadium, and copper) suggested increased atmospheric deposition of metals started in New England in the early 1800s to 1900s. The cores indicated the 12 lakes were naturally acidic and had low ANC values in pre-industrial times. All of the lakes showed additional acidification since about 1920. Davis et al. concluded the recent acidification was due to atmospheric deposition.

Research and monitoring at ACAD since the mid -1980's has found that most park surface waters (lakes and streams), on average, are non-acidic. However, short-term episodic acidification of many lakes and streams does occur, especially during spring snowmelt and runoff. In addition, alkalinity values at ACAD are among the lowest in the region.

According to Kahl et al. (1992), the factors that contributed to episodic acidification included dilution from increased discharge, sulfuric acid input from precipitation or natural sources, nitric acid input from precipitation or natural processes in upper soil horizons, organic acid input from watershed soils or wetlands, and hydrochloric acid production from salt-effect reactions within watershed soils.

Heath et al. (1993) concluded that the most significant contributing factors to episodic acidification included input of natural acids from soil solutions, and input of sulfuric acid from precipitation. Less important mechanisms of episodic acidification included dilution by increased flow, increased NO_3 concentrations from precipitation or the large soil N pool, and increased export of organic acidity from soils. They interpreted many of the episodic acidification events as being due primarily to an ion-exchange salt effect of sodium ion for hydrogen ion in soil solution, and secondarily to dilution, neither of which is directly related to acidic deposition. They reported acid precipitation was a contributing, but non-essential, factor in these episodic acidifications.

Over the past 15 years, several studies have been conducted to document the effect of atmospheric and marine aerosol deposition on ACAD water bodies. Despite significant reductions in sulfur dioxide emissions and sulfate deposition during the past decade as a result of the Clean Air Act Amendments of 1990, the pH and acid neutralizing capacity of park waters remains relatively unchanged (Heath et al).

Kahl et al. (1993) collected lake chemistry data in Acadia NP from 1982 to 1989 and compared changes in lake chemistry to changes in deposition chemistry. They reported the NADP/NTN data showed non-significant declining concentrations of all solutes. During the same timeframe, 11 park lakes showed a slight increase in acid neutralizing capacity (ANC), a decrease in the sum of base cations, but no decrease in SO_4 concentrations.

Kahl (1999) reported on the status of Maine lakes after 1995 implementation of the SO_2 reductions mandated by the 1990 amendments to the Clean Air Act. He found SO_4 concentrations in sensitive Maine lakes had declined by 12 to 22 percent since 1982; however, there was not a concurrent decrease in lake acidity. Kahl reported a decline in base cation concentrations (e.g., Ca and Mg) as the reason for the lack of recovery. The base cation decline had been observed in sensitive watersheds over the entire northeastern U.S. According to Kahl, potential causes for the decline included continued high atmospheric deposition of N, a lag time in response, or the interrelated influence of climate and acidic deposition on watershed response.

Aquatic Chemistry Data and DSS Results

Horizon Report

The Horizon report was released for Acadia NP in August 1994. The report contains information on 16 water bodies in the parks. More water bodies exist, but were not sampled. More than half of the water bodies (56%) in the report contained data relevant to the DSS. The report details 10 lakes, 5 streams, and 1 ocean location in ACAD. Table 4-1 lists the number of sites that have data for each DSS component. With the exception of DOC, data are complete for streams, but are sparse for lakes.

Table 4-1: Chemistry Component Summary - ACAD

	Total	Lakes	Streams	Ocean
Number	16	10	5	1
Conductance	8	3	5	0
pH	9	4	5	0
ANC	9	4	5	0
DOC	3	3	0	0
Nitrate	8	3	5	0
Base Cations	8	3	5	0
Sulfate	8	3	5	0

None of the stream sites had no data elements used by the DSS, compared to 60% of lake sites. For those sites with data, the data is substantially complete. Three of four lake sites with DSS data and all of the stream sites with DSS data contained six or more of the data elements. As is typical at the parks studied, DOC data is fairly limited. With the exception of DOC data a standard set of chemical analyses were performed on water samples taken in ACAD.

Table 4-2: Number of Elements Summary - ACAD

# of Elements	Total	Lakes	Streams	Ocean
0	7	6	0	1
1	0	0	0	0
2	1	1	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	5	0	5	0
7	3	3	0	0

Of the 14 sites that had any data collection, including parameters not used by the DSS, 10 sites were last sampled in the 1970s and 4 in the 1980s. All of the data in this report are 15 years old or older and may not indicate current water chemistry conditions.

Of the 9 locations that had alkalinity data, sampling occurred only once at 33% of them. At these locations, the mean and extreme ANC values are the same. Alkalinity results were based on more than 10 samples at none of the locations.

ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

Mean ANC

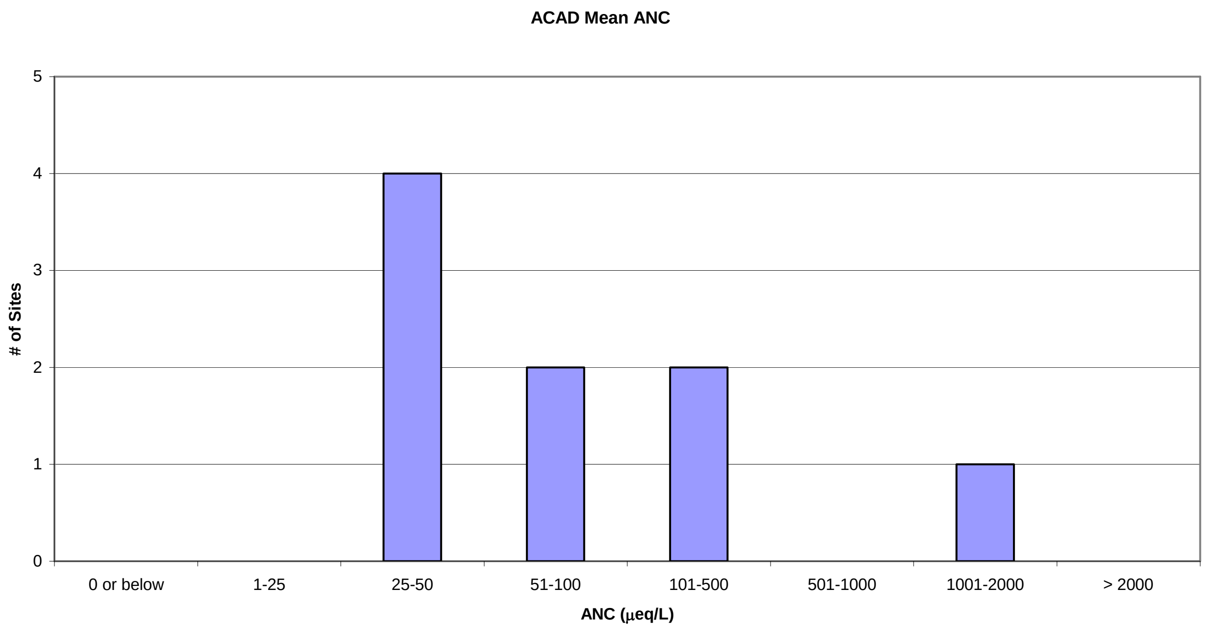
Of the 9 sampling locations which contained data for ANC calculations, 44% had a mean ANC below 50 μeq/L. These locations are listed below in Table 4-3.

Table 4-3: Locations with mean ANC below 50 μeq/L - ACAD

Site Code	Location Name	ANC (μeq/L)
ACAD0006	Marshall Brook at Mountain Rd; Southwest Harbor, ME	30.0
ACAD0009	Lower Hadlock Pond	38.7
ACAD0001	Long Pond	45.9
ACAD0005	Marshall Brook Tributary at Mountain Rd J; Southwest Harbor, ME	50.0

Figure 4-3 contains a graph of the frequency distribution of mean ANC values in Acadia National Park.

Figure 4-3: Frequency Distribution of Mean ANC Values - ACAD



Minimum ANC

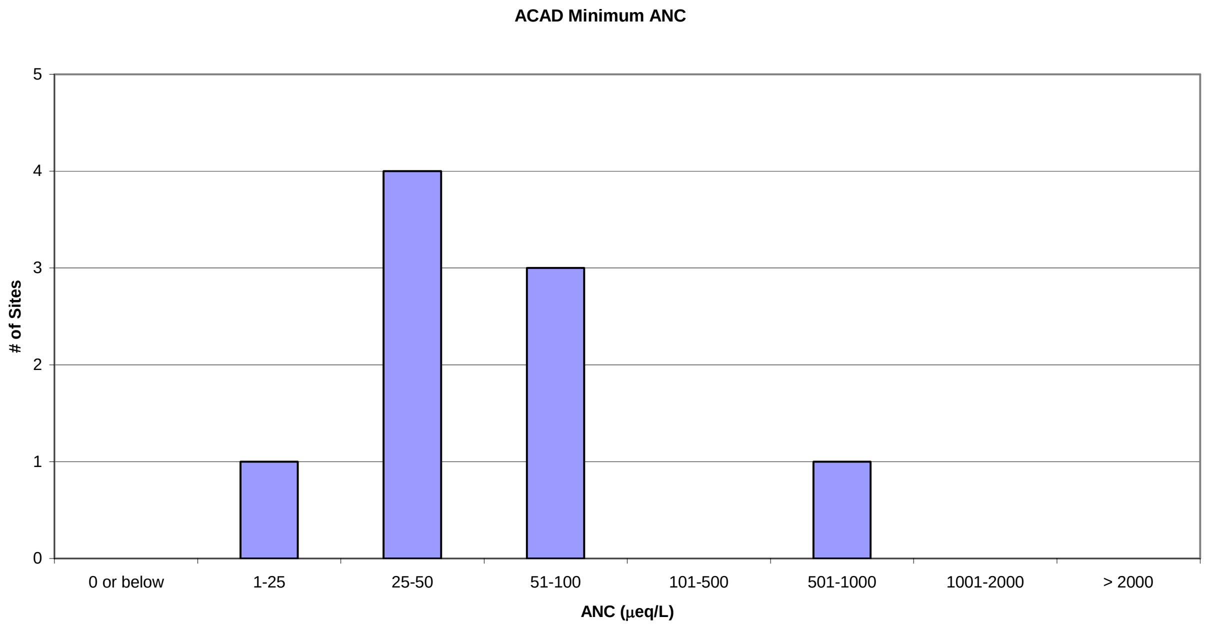
Of the 9 sampling locations which contained data for ANC calculations, 55% had minimum ANCs below 50 μeq/L. These locations are listed in Table 4-4.

Table 4-4: Locations with minimum ANC below 50 μeq/L - ACAD

Site Code	Location Name	ANC (μeq/L)
ACAD0006	Marshall Brook at Mountain Rd; Southwest Harbor, ME	20.0
ACAD0009	Lower Hadlock Pond	38.7
ACAD0002	Marshall Brook below Seal Cove Rd; Southwest Harbor, ME	40.0
ACAD0005	Marshall Brook Tributary at Mountain Rd J; Southwest Harbor, ME	40.0
ACAD0001	Long Pond	45.9

Figure 4-4 contains a graph of the frequency distribution of minimum ANC values in Acadia National Park.

Figure 4-4: Frequency Distribution of Minimum ANC Values - ACAD



Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

Lakes - Average Water Chemistry Values

Table 4-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Acadia National Park and Figure 4-5 includes graphical representations of this data.

Table 4-5: DSS Results for Average Lake Values - ACAD

DSS Score	Acid Deposition Impacted	Sensitive but Not Acid Deposition Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid Deposition	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	0	0	0	0	3	3	0
-0.59 to -0.20	0	0	4	0	1	0	3
-0.19 to 0.20	4	4	0	4	0	1	0
0.21 to 0.60	0	0	0	0	0	0	0
0.61 to 1.00	0	0	0	0	0	0	1

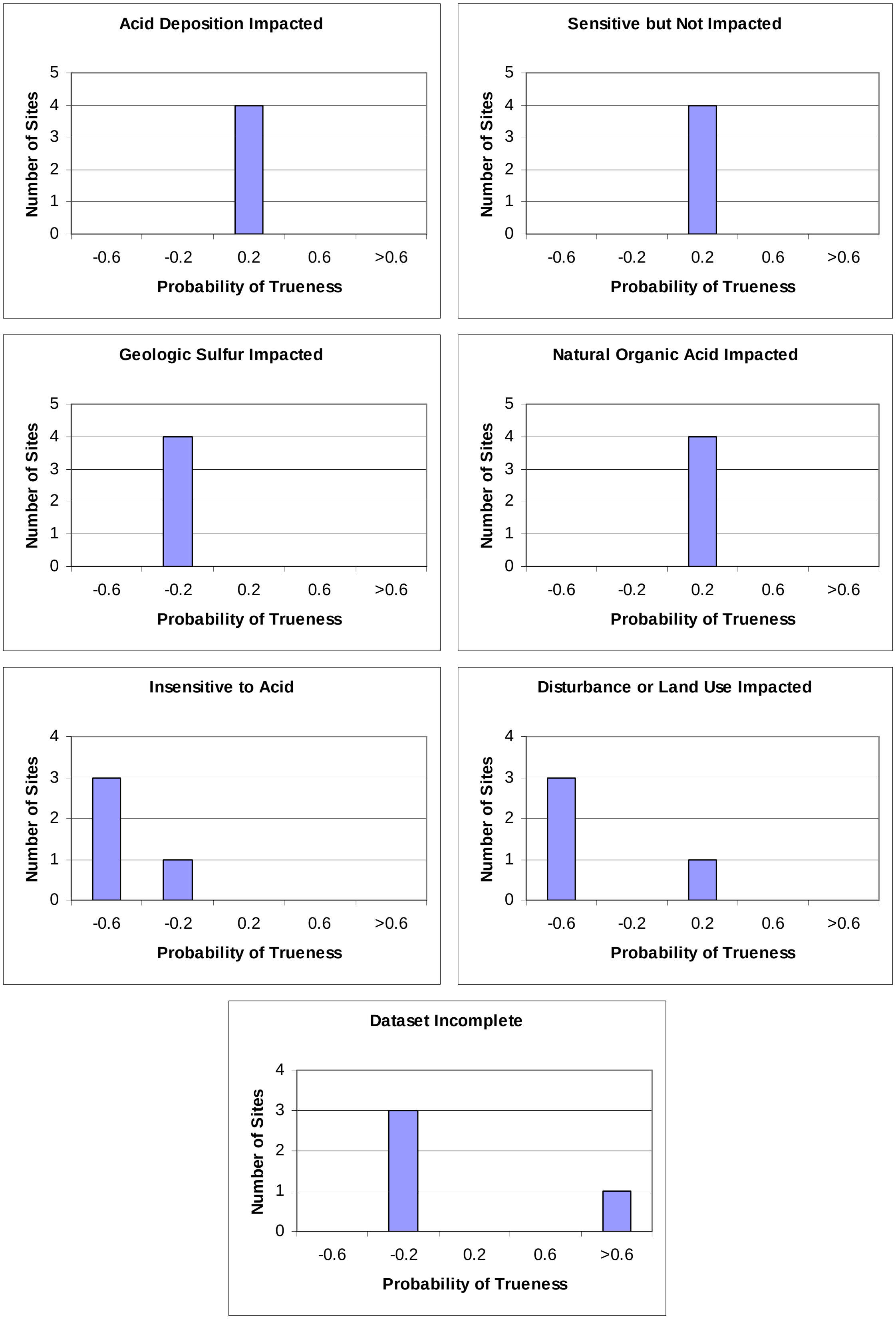
The DSS made no assessment (categories were neither true nor false) on lakes being impacted by atmospheric deposition ('Acid Deposition Impacted' category) or by high levels of organic material ('Natural Organic Acid Impacted' category). It also did not make an assessment on whether lakes were sensitive to future acid deposition, but not yet impacted ('Sensitive but not Impacted' category). Atmospheric deposition is influenced by nitrate and sulfate concentrations; nitrate levels were low (<1 μeq/L) while sulfate levels were high (>280 μeq/L). However, chloride levels were also high (≥169 μeq/L); high chloride levels at coastal locations indicate that much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. The DSS could not make recommendations based on the levels of nitrate and sulfate provided. Organic impacts are influenced mainly by DOC levels; at medium levels (2-3 mg/L) in this region, the DSS could not make a recommendation in this category.

The DSS found all of the lakes to not be impacted by high levels of geologic sulfur (false in the 'Geologically Sulfur Impacted' category). As stated above, much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. High sulfate levels are expected at coastal locations (Sullivan et al., in review).

All four lakes were considered sensitive to acid input (false in the 'Insensitive to Acid' category). This results from low ANC values; 3 of the four lakes had ANCs < 55 μeq/L). These lakes are Long Pond (ACAD0001), Lower Hadlock Pond (ACAD0009), Echo Lake (Mount Desert) (ACAD0010), and Upper Hadlock Pond (ACAD0012). Given this result and since no assessment was made concerning the lakes being sensitive to acid inputs but not yet impacted, the DSS is unsure about whether or not the lakes are impacted, but concludes if they probably are sensitive.

The three lakes with nitrate data were categorized by the DSS as not being effected by extremely high levels of nitrate caused by land use or disturbances (false in the 'Land Use/Disturbance' category). The nitrate levels for all 3 lakes were very low (<1 μeq/L).

Figure 4-5: Charts of DSS Results for Average Lake Values - ACAD



The DSS evaluates all of the locations in terms of the completeness of the input data. All of the locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data.

Lakes – Extreme Water Chemistry Values

Table 4-6 lists the results of the DSS for extreme values of water chemistry parameters in lakes in Acadia NP. Figure 4-6 graphically represents these results.

Table 4-6: DSS Results for Extreme Lake Values - ACAD

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	0	0	0	0	3	3	0
-0.59 to -0.20	0	0	4	0	1	0	3
-0.19 to 0.20	4	4	0	4	0	1	0
0.21 to 0.60	0	0	0	0	0	0	0
0.61 to 1.00	0	0	0	0	0	0	1

The DSS result distribution for extreme lake values are exactly the same as that for average lake values. This occurred for two reasons. First, results at 75% of the lake locations came from a single test at that location. Therefore, the mean value for a parameter and its minimum value are the same. Second, the remaining lake was sampled on only three occasions; the mean and extreme values for this lake were quite similar.

Streams - Average Water Chemistry Values

Table 4-7 lists the results of the Synthesis DSS for average water chemistry values at streams in Acadia NP and Figure 4-7 represents this data graphically.

Table 4-7: DSS Results for Average Stream Values - ACAD

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	0	0	1	0	3	3	0
-0.59 to -0.20	0	0	4	0	0	0	0
-0.19 to 0.20	5	5	0	5	0	0	5
0.21 to 0.60	0	0	0	0	2	0	0
0.61 to 1.00	0	0	0	0	0	2	0

Figure 4-6: Charts of DSS Results for Extreme Lake Values - ACAD

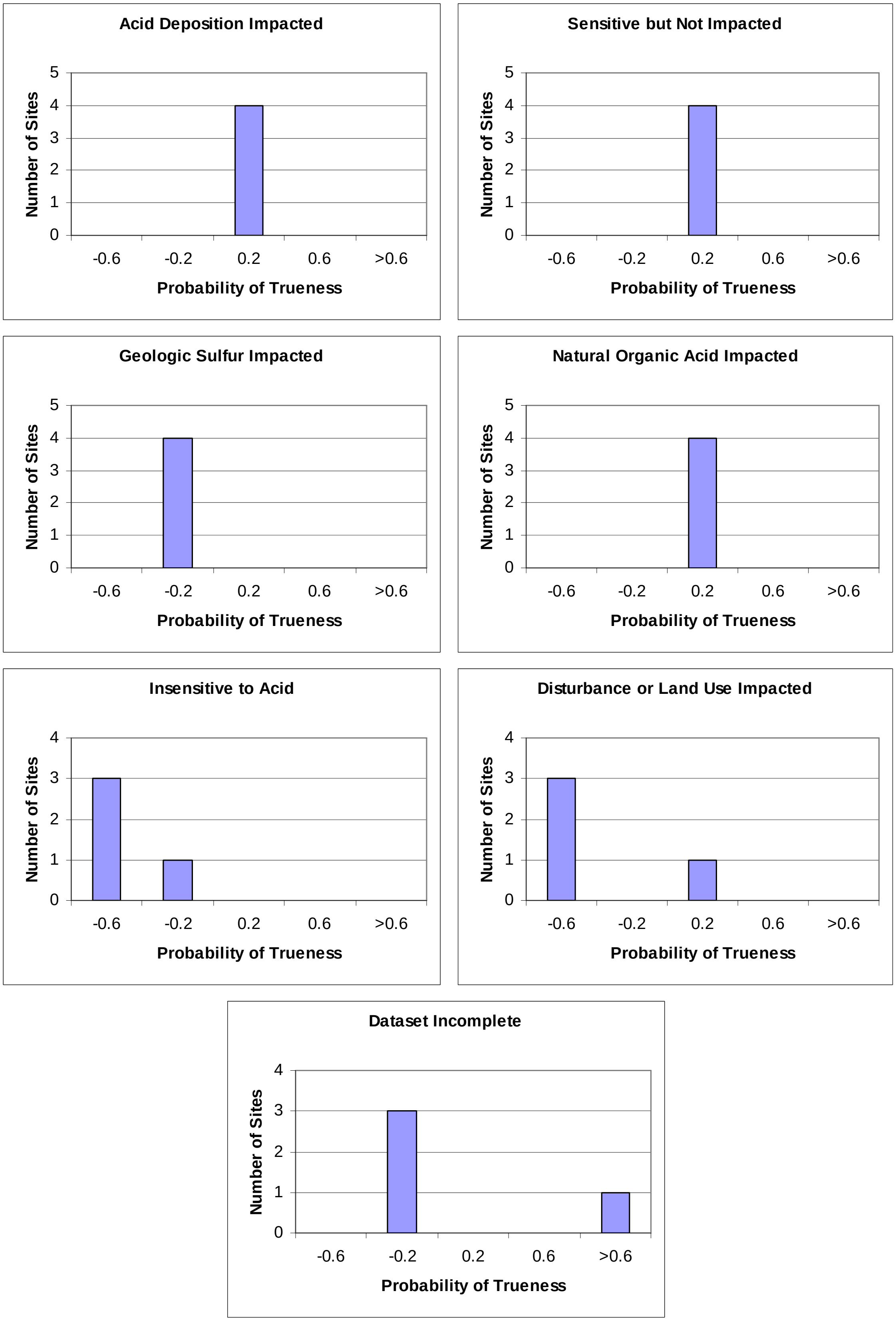
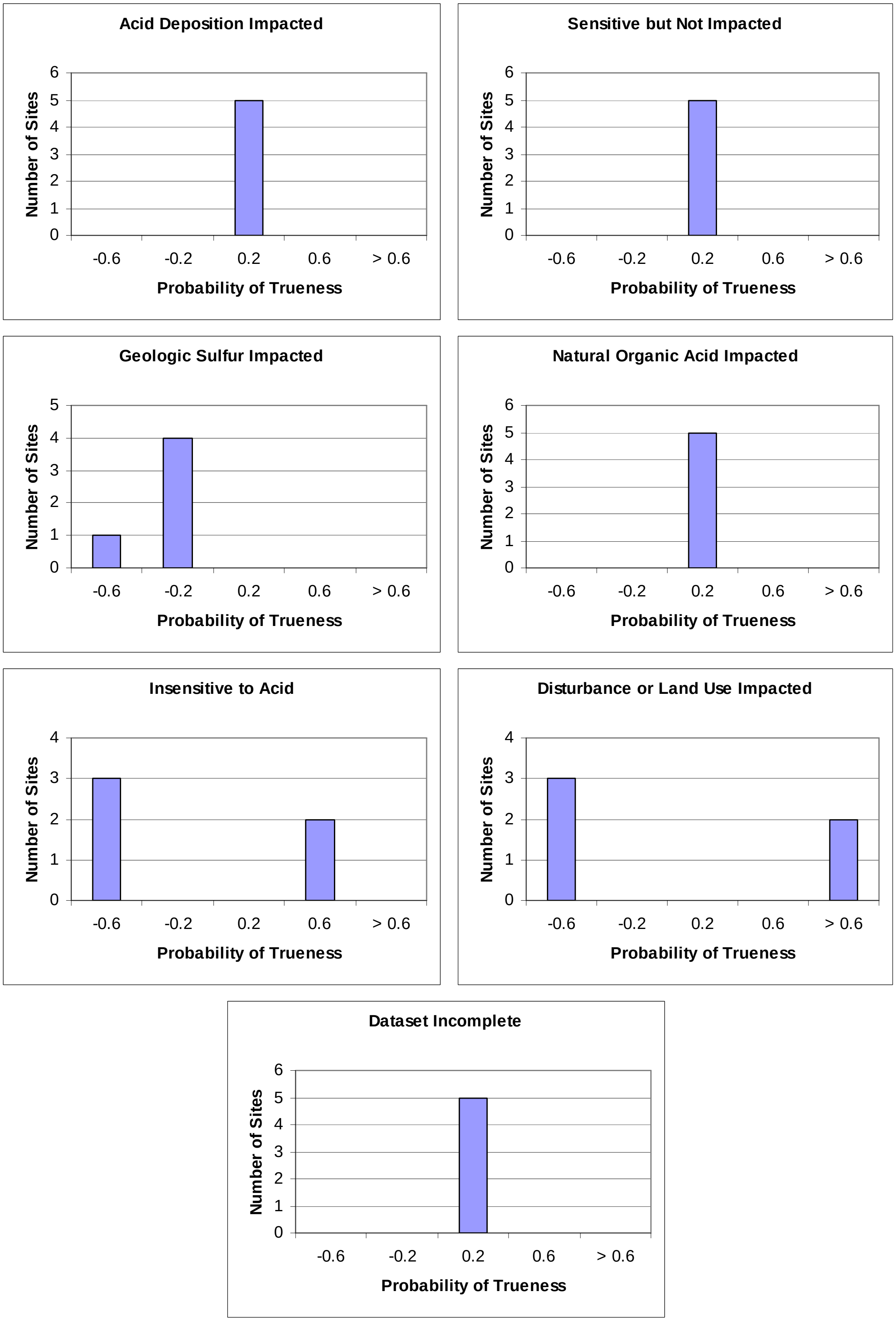


Figure 4-7: Charts of DSS Results for Average Stream Values - ACAD



The DSS made no assessment (categories were neither true nor false) on streams being impacted by atmospheric deposition ('Acid Deposition Impacted' category) or by high levels of organic material ('Natural Organic Acid Impacted' category). It also did not make an assessment on whether streams were sensitive to future acid deposition, but not yet impacted ('Sensitive but not Impacted' category). Nitrate levels for 3 of the streams were low (≤5 μeq/L) and the DSS concludes there is no disturbance or land use impact on these streams. Nitrate levels are high for the other 2 streams (>50 μeq/L), too high to be solely from anthropogenic deposition but likely a result of possible disturbance or land use impact. Sulfate levels were moderate, between 125 μeq/L and 156 μeq/L. Chloride levels were high (≥169 μeq/L); high chloride levels at coastal locations indicate that much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. The DSS could not make recommendations regarding possible acid deposition impact based on the levels of nitrate and sulfate provided. Organic impacts are influenced mainly by DOC levels; since there was no DOC data for any of the streams, the DSS could not make a recommendation in this category.

The DSS found all of the streams to not be impacted by high levels of geologic sulfur (false in the 'Geologically Sulfur Impaired' category). As stated above, much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. In addition, high sulfate levels are expected at coastal locations (Sullivan, in review).

Three of the five streams sampled were considered sensitive to acid input (false in the 'Insensitive to Acid' category). This results from low ANC values; these streams had ANCs ≤60 μeq/L). These streams are the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006). Given this result and since no assessment was made concerning the streams being sensitive to acid inputs but not yet impacted, the DSS is unsure about whether or not the streams are impacted, but not if they are sensitive. The other two streams were considered probably not sensitive to acidic inputs due to high buffering capacity (true in the 'Insensitive to Acid' category). This is reflected in their high mean ANC values (>150 μeq/L).

These same three streams that were considered sensitive to acidic inputs, the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006), are considered by the DSS as not being affected by extremely high levels of nitrate caused by land use or disturbances (false in the 'Land Use/Disturbance' category). The nitrate levels for all 3 streams were low (≤5 μeq/L). The DSS is unsure if these streams are not impacted or impacted by acid deposition or high organic content.

The two streams considered insensitive to acid, Marshall Brook below Seal Cove Road (ACAD0002) and Marshall Brook at Seal Cove Road (ACAD0004), were found to be impacted by land use or disturbance (true in the 'Land Use/Disturbance' category). This is due to nitrate levels (>50 μeq/L) too high to be solely from anthropogenic deposition.

While it may seem counterintuitive that a water body can be both impacted (in this case by land use or disturbance) and insensitive to acid, this outcome is reasonable. These results demonstrate that the model allows for some uncertainty in definitely adding a stream into one category at the exclusion of all others. These streams are unlikely to be affected by relatively low concentrations of sulfate and the acid associated with acid deposition due to their high buffering capacity; however, they probably have been impacted by high levels of nitrogen from disturbance or land use. The impact to these streams would be worse if they were not so well buffered.

The DSS evaluates all of the locations in terms of the completeness of the input data. All of the stream locations had less than complete datasets (no DOC data). This prevents the DSS from concluding if there is impact from natural organic acid.

Streams - Extreme Water Chemistry Values

Table 4-8 contains the results of the Synthesis DSS of extreme water chemistry value for streams in Acadia National Park. Figure 4-8 includes graphs of the data in this table.

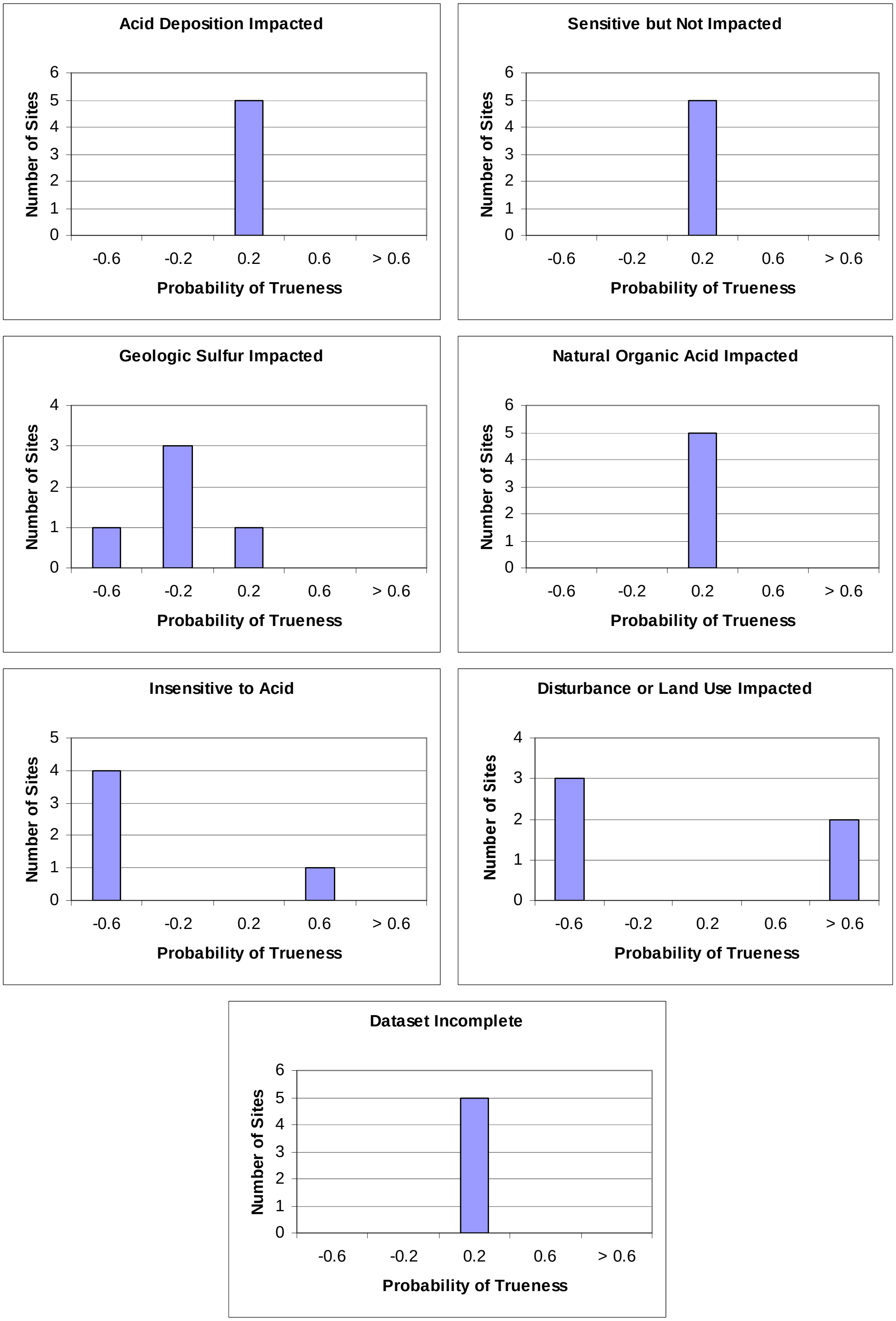
Table 4-8: DSS Results for Extreme Stream Values - ACAD

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	0	0	1	0	4	3	0
-0.59 to -0.20	0	0	3	0	0	0	0
-0.19 to 0.20	5	5	1	5	0	0	5
0.21 to 0.60	0	0	0	0	1	0	0
0.61 to 1.00	0	0	0	0	0	2	0

All of the stream data was based on two samples at each location; many of the mean and extreme values are quite similar. As it did with the average stream data, the DSS made no assessment (categories were neither true nor false) on streams being impacted by atmospheric deposition (‘Acid Deposition Impacted’ category), high levels of organic material (‘Natural Organic Acid Impacted’ category), and on whether streams were sensitive to future acid deposition, but not yet impacted (‘Sensitive but not Impacted’ category). Again, this is mainly due the uncertainty found in the nitrate and sulfate levels and the lack of DOC data.

The DSS found four of the streams probably not to be impacted by high levels of geologic sulfur (false in the ‘Geologically Sulfur Impaired’ category). Sulfate levels were moderate, between 125 μeq/L and 167 μeq/L. Chloride levels were high (>160 μeq/L), indicating that much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid.

Figure 4-8: Charts of DSS Results for Extreme Stream Values - ACAD



Four streams were considered sensitive to acid input (false in the 'Insensitive to Acid' category). This results from low ANC values; the streams had minimum ANCs <60 μeq/L. These streams are Marshall Brook below Seal Cove Road (ACAD0002),the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006). Marshall Brook at Seal Cove Road (ACAD0004) had a minimum ANC value of 720 μeq/L, indicating it has high buffering capacity. This stream should not be adversely impacted by future acidic inputs (true in the 'Insensitive to Acid' category).

Three streams, the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006), are considered as by the DSS as not being effected by extremely high levels of nitrate caused by land use or disturbances (false in the 'Land Use/Disturbance' category). The nitrate levels for all 3 streams were low (≤8 μeq/L). The DSS is unsure if these streams are not impacted or impacted by acid deposition or high organic content.

Two streams, Marshall Brook below Seal Cove Road (ACAD0002) and Marshall Brook at Seal Cove Road (ACAD0004), were found to be impacted by land use or disturbance (true in the 'Land Use/Disturbance' category). This is due to nitrate levels (>70 μeq/L) too high to be solely from anthropogenic deposition.

Marshall Brook at Seal Cove Road (ACAD0004) was found to be both impacted (in this case by land use or disturbance) and insensitive to acid. These results demonstrate that the model allows a site into more than one category.

The DSS evaluates all of the locations in terms of the completeness of the input data. All of the locations had less than complete datasets and are missing DOC data.

Analysis

In agreement with the Acadia NP Water Resources Fact Sheet, the data from the Horizon report shows alkalinity values at ACAD are low. Five of the 9 lake or stream locations tested had minimum ANC values below 50 μeq/L; two locations had minimum ANC values between 50 and 60 μeq/L. Waters with low buffering capacity are more susceptible to both episodic and chronic acidification.

The Fact Sheet also states that most park surface waters, on average, are non-acidic. The DSS results do not give support for or evidence against this statement. Consistent with the low alkalinity of these waters, the DSS found 8 of the 9 waters to be sensitive to future acidic episodes. The DSS comments that nitrate levels, with 2 exceptions, are not high enough to indicate that the waters have been impacted by land use or disturbance. Sulfate levels are too low, give the proximity of the park to the ocean, to indicate acidification from geologic sulfur. The DSS cannot determine whether these waters are already impacted by acid deposition.

Whether these results are representative for the entire park is questionable as only 18% of lakes and 20% of streams had data in the Horizon report. Also, with the exception of a single lake, the data in the report are based on one or two samples at each location; this data may not indicative of the true chemistry of the water body. It is possible that some of the more sensitive waters in ACAD were not captured in the Horizon report.

Nitrate and sulfate in these lakes and streams may not indicate the effects of air pollution. The average level of nitrate across these waters is very low. 75% of locations that have nitrate data are at levels below 8 μeq/L. Although absolute sulfate levels are high, much of the sulfate probably comes from neutral sea salts from the nearby ocean and not from atmospheric deposition or geologic sources. Figure 4-1 shows that sulfate in wet deposition has declined throughout the last decade. Further evidence is that none of the measured pH levels, in both the average and extreme cases, measured below 6.

Dissolved organic carbon levels are available only for three lakes and for no streams. DOC values range from 2.4 to 3.1 mg/L. The DSS results are uncertain regarding organic acid effects.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. The 5 water bodies that had ANC values that met this criterion are listed in Table 4-9.

Table 4-9: ACAD Water Bodies with Minimum ANC <50 μeq/L

Location ID	Location Name	Sample Type	Impact(s)*	# Obs	Last Sampled**
ACAD0001	Long Pond	Lake	Sensitive to Acid	1	1984
ACAD0002	Marshall Brook below Seal Cove Road	Stream	Sensitive to Acid; Disturbance/Land Use	2	1979
ACAD0005	Marshall Brook Tributary at Mountain Road J	Stream	Sensitive to Acid	2	1979
ACAD0006	Marshall Brook at Mountain Road	Stream	Sensitive to Acid	2	1979
ACAD0009	Lower Hadlock Pond	Lake	Sensitive to Acid	1	1984

For the Acid Impacted and Sensitive/Unimpaired categories, the DSS returned a 'true' value for these locations; for the Insensitive to Acid category, the DSS returned a 'false' value.

**"Last sampled" refers to last documented sample in the Horizon Report used in this report.

In addition to the five locations listed in Table 4-9, using extreme water chemistry values, the DSS suggested that one lake and one stream are sensitive to future acid deposition, while one stream location was already impacted by geologic sulfur. Table 4-10 lists all sites the DSS flagged as currently or potentially impacted by acid at ACAD, using the extreme water chemistry values. A discussion of these locations will follow.

Table 4-10: Currently and Potentially Sensitive ACAD Waters Based on Extreme Water Chemistry Values

Location ID	Location Name	Impact(s)*	# Obs	Last Sample
ACAD0001	Long Pond	Sensitive to Acid	1	1984
ACAD0002	Marshall Brook below Seal Cove Rd	Sensitive to Acid Disturbance/Land Use	2	1979
ACAD0003	Marshall Brook Tributary at Seal Cove Rd	Sensitive to Acid	2	1979
ACAD0004	Marshall Brook at Seal Cove Rd	Disturbance/Land Use	2	1979
ACAD0005	Marshall Brook Tributary at Mountain Rd J	Sensitive to Acid	2	1979
ACAD0006	Marshall Brook at Mountain Rd	Sensitive to Acid	2	1979
ACAD0009	Lower Hadlock Pond	Sensitive to Acid	1	1984
ACAD0010	Echo Lake Mount Desert	Sensitive to Acid	3	1984

* For the Disturbance/Land Use Impacted category, the DSS returned a 'true' value for these locations; for the Insensitive to Acid category, the DSS returned a 'false' value.

One of the main findings identified in research performed in ACAD and in New England is that waters in this area tend to have low buffering capacities. This is consistent with the data used in the DSS. The DSS suggested that 7 of the 9 sampled waters are sensitive to future acid deposition. This includes the five locations where the minimum ANC value was less than 50 μeq/L; the two other locations are ACAD0003, Marshall Brook Tributary at Seal Cove Rd (minimum ANC = 60 μeq/L), and ACAD0010, Echo Lake Mount Desert (minimum ANC = 100 μeq/L). With the exception of Echo Lake Mount Desert, the classification was based on the low minimum ANC value.

Another research result shows that despite being subject to acid rain, waters tend not to be acidic. The DSS suggested that only 2 of the 9 locations with data were acid impacted, both by disturbance or land use. At both of these locations, nitrate levels were at much higher levels than could be reasonably accounted for by atmospheric deposition. At ACAD0002 (Marshall Brook below Seal Cove Rd), the maximum nitrate level was 70 μeq/L; at ACAD0004 (Marshall Brook at Seal Cove Rd), it was 107 μeq/L. Since the data at each location are based on only 2 samples, it is not possible to say whether the nitrate levels are episodic or chronic in nature.

While the DSS does not suggest that waters in ACAD are generally acidic, it does not the show the opposite to be true either. In fact, at all locations, the DSS was unable to make a recommendation with any certainty in the 'Acid Deposition Impacted, 'Sensitive but Unimpacted', and 'Organic Acid Impacted' categories. In the 'Organic Acid Impacted' category, this is due to the lack of DOC data collected. For the other categories, there are data but the DSS is unable to provide a classification with significant certainty.

At first glance, the sulfate concentrations at all ACAD locations appear to be high (≥ 125 μeq/L). However, as shown in Figure 2-1, the sulfate levels for the 'Geologic Sulfur Acid Impacted' category are much higher for the Northeastern Region than they are for the other regions. Much of this sulfate comes from neutral sea salts from the ocean as opposed to primarily acidic atmospheric or geologic sources.

Conclusion

Sulfate and nitrate are the most important anionic components in acidic deposition. The deposition of sulfate in precipitation in northern New England measured at four locations, including Acadia National Park, has decreased approximately 30% since the early 1980s, mainly in response to meeting the standards specified in the Clean Air Act. Nitrate deposition concentrations do not show a pattern over the same time period.

This evaluation focuses on Acadia NP (ACAD). The water quality data were extracted from the Horizon report, completed in August 1994. Values for specific conductance, pH, ANC, DOC, nitrate, the sum of base cations, and sulfate were obtained. These reports may not contain data for the most sensitive water bodies; for example, the report contains data only 9.1% of lakes and 20% of streams in ACAD. Therefore, the analysis may not give a true representation of the sensitivity or level of impact by acid deposition for the entire park.

Waters in the Atlantic Northeast are under great scrutiny for two reasons. First, they have historically low buffering capacity. Second, despite the decline in sulfur deposition, this region has been greatly affected by acid rain. A regional report for New England found that acidification in waters has not decreased despite decreases in sulfate concentrations. However, the Aquatic Chemistry DSS, using the Horizon data, found only 2 of the 9 water bodies to be currently acid impacted, both due to high nitrate concentration as a consequence of agricultural activities, forestry, or other land use. At both locations, nitrate concentrations were extremely high ($\geq$ 70 μeq/L). These concentrations are higher than any that can reasonably be explained by atmospheric deposition. Due to a limited number of sample observations, it cannot be determined if the acidification is episodic or chronic in nature.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. Five of the 9 water bodies that had ANC values met this criterion: Long Pond, Marshall Brook below Seal Cove Road, Marshall Brook Tributary at Mountain Road J, Marshall Brook at Mountain Road, and Lower Hadlock Pond. Two other waters suggest sensitivity to future acid deposition based on extreme stream values: Marshall Brook Tributary at Seal Cove Rd (minimum ANC of 60 μeq/L), and Echo Lake Mount Desert. The DSS could not make a recommendation with any certainty concerning acidification due to acid deposition or organic sources, the latter because there were no data for DOC.

Data issues that affected this analysis include a general lack of data, infrequent sampling, and old data. At most, the results contain data from three samples. All of the stream locations were sampled twice; with the exception of the lake that was sampled three times, the rest of the lakes in ACAD were sampled once. In these cases, the result is 'extreme' values that are the same as the mean values. In general, extreme water chemistry values were very similar to average values. With so few samples, it is difficult to ascertain if the data assembled are representative of the water body in question. Only 56% of water bodies in the report contained data relevant to the DSS. Of the 9 sites with data, 89% of them had six or seven data elements available for use by the DSS. Data representing present conditions are needed. The lakes were last sampled in 1984; the streams in 1979. The Horizon report is 10 years old. It is likely the condition of these waters has changed during this period.

The DSS does not show evidence of high levels of acidification in the waters within Acadia National Park. The DSS has identified two areas of Marshall Brook that may require attention. These two locations, at and below Seal Cove Road, are primary spots where further sampling is recommended. The six other locations that the DSS flagged as sensitive to acid, four of which have ANC values of less than 50 μeq/L and one less than 60 μeq/L, should be monitored for changes.

Chapter 5 - Air and Water Quality in the Pacific Northwest Region

The information in this section was taken from the Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service (Eilers et al. 1994). The complete report is available on the Internet at the following site:

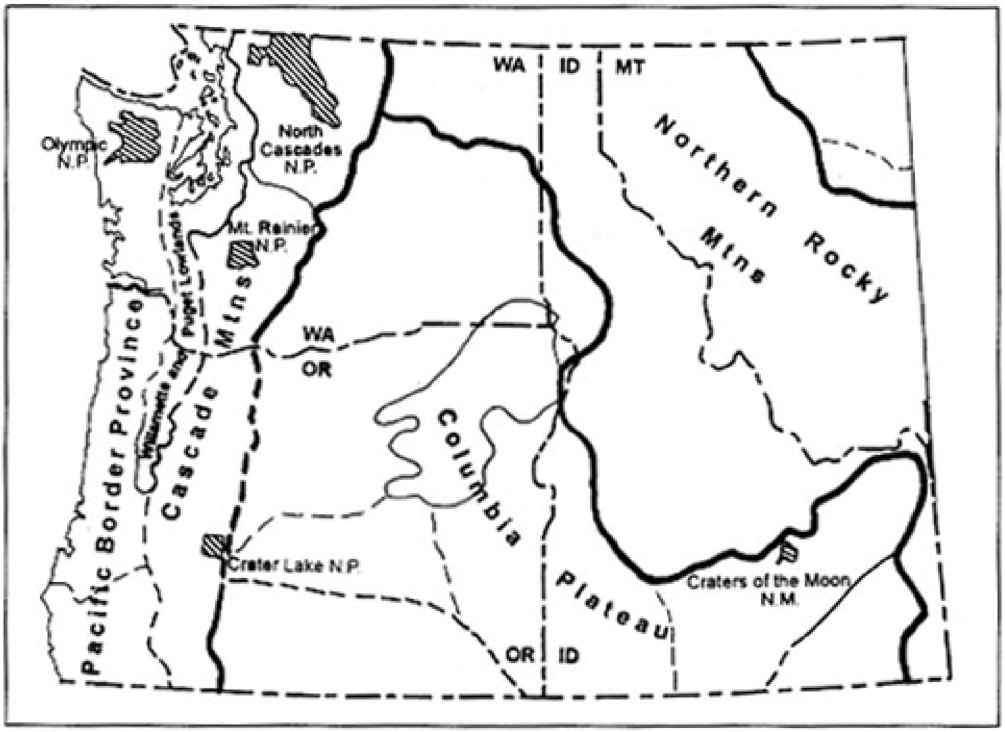
http://www2.nature.nps.gov/air/Pubs/regionPark.cfm

This section is not meant to be a complete discussion of air and water quality in the Pacific Northwest Region nor a complete bibliography. Instead it provides an introduction to some of the environmental factors that are thought to most influence the lakes and streams described in this chapter. Some of the sources of emissions discussed here have changed greatly during the time that the data on the region's lakes and streams were collected and likely will continue to change as a result of emissions controls. Similarly, additional monitoring and research continue in the region and improve our ability to understand the changes in the chemistry of lakes and streams.

Environmental Setting

The Pacific Northwest is a diverse region comprised of a coastal zone, the Cascade Range, and the Columbia Plateau provinces. Figure 5-1 follows the regionalization scheme of Fenneman (1946), based on broad patterns in precipitation, vegetation, soils, and geology. These patterns reflect the major distinction in the region between the wet, mountainous areas in the west and the more arid climate to the east.

Figure 5-1: Physiographic provinces of the Pacific Northwest (Fenneman 1946) and location of class I national parks and monuments.



Air Quality

The air quality in the Pacific Northwest region is very good compared to other areas of the U.S. Accumulated air pollutant loads are low because principal air masses derive from the atmosphere over the Pacific Ocean. Also, emissions of principal air pollutants within the Pacific Northwest are low relative to other regions. Thus, precipitation quality in the region generally is high. However, non-marine sulfate and hydrogen ion concentrations in precipitation for portions of the Washington Cascades, including Mount Rainier National Park (MORA) and North Cascades National Park (NOCA), are slightly elevated compared to concentrations in precipitation measured on the west side of Olympic National Park (OLYM).

Lake and Stream Chemistry

Overview

At the time of this report, complete water chemistry data existed for relatively few lakes and streams in the parks. The available data generally lack analysis of key variables or are inadequate for these dilute waters (e.g., single-end-point alkalinity given instead of Gran acid neutralizing capacity; Gran acid neutralizing capacity is now considered more appropriate for such dilute waters). Sampled surface waters were not selected in a fashion statistically representative of waters within the parks.

As a result, the relative sensitivity of lakes and streams in the parks to acidic deposition can only be estimated based on available data for a few documented highly sensitive lakes.

Based on assessments of current surface water chemistry, lakes in this region are likely among the most sensitive aquatic systems anywhere in the world (Eilers et al. 1990, 1991). Sampling of high-elevation lakes by Brakke (1984, 1985), Landers et al. (1987), and Liss et al. (1991) shows that low-ANC (~ 10 μeq/L) lakes are present and presumably sensitive to acidic deposition. It is clear that potentially highly-sensitive lakes and streams are found in North Cascades and Mount Rainier NPs. The lowest measured ANC was for Lake Ann, located just outside the park boundaries of North Cascades. With ANC of 3.5 μeq/L, a pH of 5.4, and conductivity of 2.8 μS/cm, this lake clearly represents the extreme of watershed sensitivity (Brakke 1984).

Sulfate

Sulfate is the most important anion, on a quantitative basis, in acidic deposition in most parts of the United States. The responses of watersheds to S inputs, particularly chronic effects on surface water quality, are now reasonably well understood.

Relatively minor increases in lakewater SO_4^{2-} concentration could lead to chronic acidity (ANC less than 0) in many lakes in the Cascade Range because of their low ANC.

Nitrate

The second important acid anion found in acidic deposition is nitrate. Nitrate and ammonium, which can be converted to nitrate within the watershed, have the potential to acidify drainage waters and leach potentially toxic aluminum (Al) from watershed soils. An important form of N deposition to these forests may be fog, especially in higher elevation sites of MORA and NOCA (Eilers et al. 1994).

In many watersheds, N is the limiting nutrient for plant growth, and therefore most N inputs are quickly incorporated into biomass as organic N with little leaching of nitrate into surface waters. However, under certain circumstances, atmospherically-deposited N can exceed the capacity of forest ecosystems to take it up. This N saturation can lead to base cation depletion, soil acidification, and leaching of NO_3^- from soils to surface waters.

Nitrate in snowmelt runoff is an important component of biological damage resulting from atmospheric deposition (cf. Wigington et al. 1990). Nitrate is the principal acid anion in snowmelt in many areas of the northeastern and western United States. Selective separation of NO_3^- from the snowpack can result in early spring runoff having concentrations substantially greater than the average snowpack concentrations.

Nitrate concentrations in surface waters exhibit a strong seasonality; NO_3^- is typically elevated during late winter and spring, particularly during periods of snowmelt, and reduced to low or non-detectable levels throughout summer and fall. This can be attributed to seasonal growth patterns of forest vegetation. Vegetation growth is reduced or stopped entirely during winter months, and microbial assimilation of N is also reduced during this season. Spring snowmelt can act to flush into lakes and streams N that was deposited in the snowpack from atmospheric deposition or N mineralized within the soil during winter.

Episodic Effects

Acidic deposition may cause episodic acidification of surface waters at even lower levels of increased deposition. There is limited data availability concerning stream and lake chemistry during snowmelt and precipitation events, seasonal surface water chemistry data, watershed dynamics, and deposition data, particularly at high-elevation sites. Both S and N may be important agents of episodic and seasonal acidification. Acidic deposition contributes to episodic acidification particularly via enhanced NO_3^- leaching. Under some conditions, episodes can also be partially caused by increased SO_4^{2-} concentration. There is also the possibility that chronic acidification by acid deposition can pre-condition a watershed, thereby increasing the severity of episodic acidification.

Lakes and streams that have been studied throughout the United States, Canada, and Europe nearly all experience loss of ANC during hydrologic events (Wigington et al. 1990). Periods of episodic acidification may last for hours to weeks, and sometimes result in depletion of ANC to negative values with concurrent increases in potentially-toxic inorganic Al in solution. Chemical changes during episodes are controlled by a number of natural processes, including dilution of base cation concentrations, nitrification, flushing of organic acids from terrestrial to aquatic systems, and the neutral salt effect.

The effects of N deposition on surface waters are expected to be primarily episodic in nature. Unfortunately, data required to make regional assessments of episodic effects are generally not available. Sampling during snowmelt can be particularly difficult in the high mountains of the West, when study sites are often inaccessible, and when motorized transport (e.g., via snowmobile) is often not allowed due to wilderness restrictions.

Chapter 6 - Mount Rainier National Park

Background

The information in this section was taken from the Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service (Eilers et al. 1994). The complete report is available on the Internet at the following site:

http://www2.nature.nps.gov/air/pubs/PacificNW.Review/index.html

Description

Mount Rainier National Park was established as the nation's fifth national park in 1899. At 4392 m, Mount Rainier is the fifth tallest peak in the contiguous 48 states. The mountain occupies more than one-fourth of the park's 98,000 ha area. Sixty miles southeast of Seattle, Washington, Mount Rainier is the highest in the chain of volcanoes comprising the Cascade Range. The 27 major glaciers on its slopes form the largest mass of year-round ice in the United States outside Alaska.

Orographic effects of the Cascade Range produce dramatic patterns of precipitation along an east-west gradient through the park. Rain and snowfall are abundant on the west side, averaging about 250 cm per year at Paradise; most of this precipitation falls as snow. The abundant precipitation also produces many lakes, streams, and glaciers, which contribute to an abundant and diverse floral and faunal assemblage.

Mount Rainier National Park has an extensive network of rivers radiating from the mountain and the glacial activity has created nearly 200 lakes and ponds. The glaciers that remain on the mountain feed the rivers and some of the lakes with meltwaters. The lakes are distributed around the face of the mountain and extend from montane to alpine settings. The lakes at the higher elevations may remain ice-free only three to four months of the year.

Deposition

Mount Rainier National Park is within 40 km of the Puget Sound urban zone and is downwind of the largest SO_2 source in Washington, the Centralia power plant. The four counties adjacent to MORA emit 56% of the State's SO_2 and 21% of the NO_x.

There is an NADP/NTN site located in LaGrande, Washington, west of MORA. This site has operated since April 1984. Figure 6-1 shows that sulfate wet deposition has fluctuated between 4-6 kg/ha/yr since data collection began. The initial decrease occurred as SO_2 emissions from Mount St. Helens decreased from 222,000 metric tons (244,000 tons) in 1980 to about 3,000 metric tons (3,300 tons) in 1988 (Eilers et al. 1994). Also, the ASARCO copper smelter in Tacoma discontinued operation in 1984, thereby eliminating over 100,000 tons per year of SO_2 emissions. After a slight increase in the middle and late 1980s, there was a slight decrease in the early 1990s.

Figure 6-1: Sulfate wet deposition at LaGrande NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA21&inpanalyte=SO4-kg&PlotSize=Small)

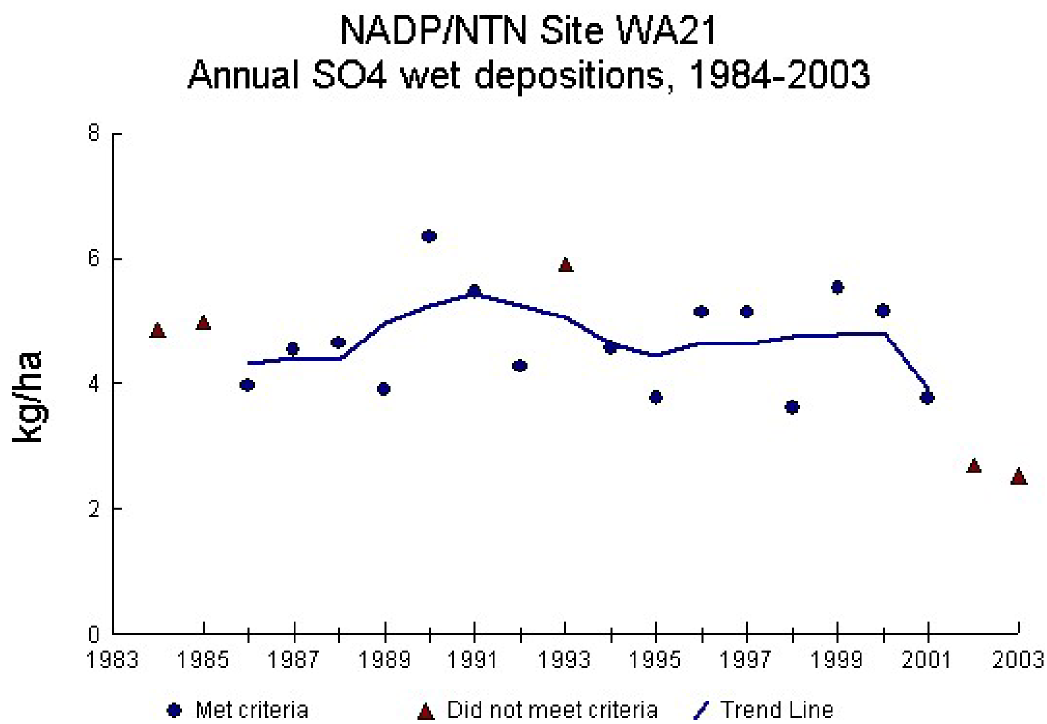
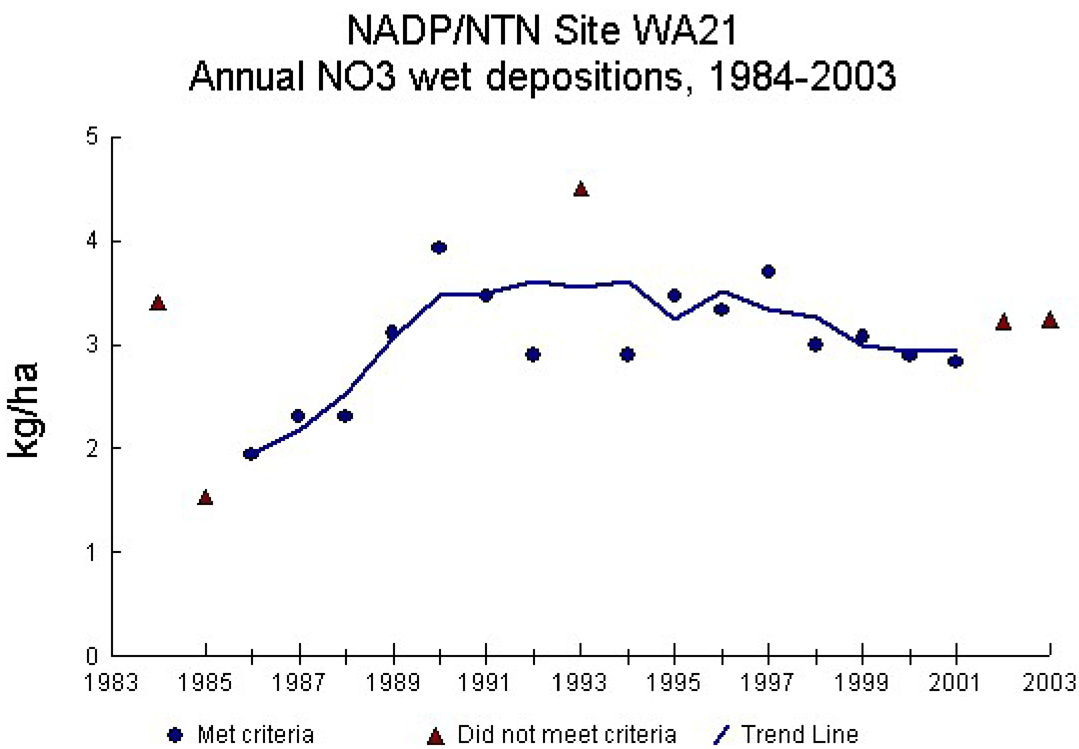


Figure 6-2 shows that nitrate wet deposition doubled from 2 kg/ha/yr in 1985 to 4 kg/ha/yr in 1990, and then declined in the last half of the 1990s to about 3 kg/ha/yr.

Water Quality

Water quality studies in MORA have found different results between lakes and streams. Studies of lakes in MORA were conducted by Turney et al. (1986), Nelson and Baumgartner (1986), and Larson et al. (1992). Neither Turney et al. (1986) nor Nelson and Baumgartner (1986) found evidence for lake acidification in the MORA lakes. However, Nelson and Baumgartner (1986) found that the lakes sampled were "highly susceptible to acidification due to their diluteness and poor buffering capacity." The analysis by Larson et al. (1992) is consistent with the findings of the previously cited studies for MORA about lack of evidence of acidification.

Figure 6-2: Nitrate wet deposition at LaGrande NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA21&inpanalyte=NO3-kg&PlotSize=Small)



The Western Lake Survey (WLS) found Southwest Golden Lake, located on the west side of the park, to be among the most sensitive lakes sampled in the survey (Landers et al. 1987, Eilers et al. 1987). The lake is small (2 ha), relatively shallow (6 m), and is the type of lake that would be expected to respond quickly to changes in atmospheric deposition.

Studies of large streams in the park were initiated by Larson et al. (1990) who sampled the water quality in both glacial and non-glacial streams. In general, the larger streams in the park are relatively well buffered and are not expected to be sensitive to effects from atmospheric deposition. It is unknown if this sample can be extrapolated to the smaller streams.

Aquatic Chemistry Data and DSS Results

Horizon Report

The Horizon report was released for Mount Rainier NP in May 1995. The report contains information on 63 water bodies in the park. More water bodies exist, but were not sampled; 31% of the approximately 200 water bodies in MORA were listed in the report. 68% of water bodies in the report contained data relevant to the DSS. The report details 20 lakes, 35 streams, and 8 springs in Mount Rainier NP. Table 6-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for the lakes is relatively complete, while data for the streams is quite sparse.

Table 6-1: Chemistry Component Summary - MORA

	Total	Lakes	Streams	Springs
Number	63	20	35	8
Conductance	43	20	16	7
pH	41	19	15	7
ANC	13	6	3	4
DOC	29	19	10	0
Nitrate	38	20	11	7
Base Cations	41	19	15	7
Sulfate	41	19	15	7

While 54% of stream sites had no data elements used by the DSS, 95% of the lake sites had six of or all seven of the data elements required by the DSS. Of the sites with data, 91% had 5 or more elements. This indicates that a standard set of chemical analyses was performed on many of water samples taken in the park.

Table 6-2: Number of Elements Summary - MORA

# of Elements	Total	Lakes	Streams	Springs
0	20	0	19	1
1	1	0	1	0
2	1	1	0	0
3	0	0	0	0
4	2	0	2	0
5	5	0	2	3
6	28	13	11	4
7	6	6	0	0

Of the 56 sites that had any data collection, including parameters not used by the DSS, 8 sites were last sampled in the 1970s, 47 in the 1980s, and 1 in the 1990s.

The lake data and the stream data were about the same age, with 95% of lakes and 75% of streams last sampled during the 1980s. At best, the data in this report is 15 years old and may not indicate current water chemistry conditions. It highlights the need for additional sampling to take place so that the DSS can have up to date data for making recommendations.

Of the 13 locations that had alkalinity data, sampling occurred only once at all of them. Additional sampling may be needed to gain information that the DSS can use to make more accurate assessments.

ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

Mean ANC

Of the 13 sampling locations which contained data for ANC calculations, only 1 had a mean ANC below 50 μeq/L. This is site MORA0033, Golden Lakes Southwest, which had a mean ANC of 12 μeq/L.

Figure 6-3 contains a graph of the frequency distribution of mean ANC values in Mount Rainier NP.

Minimum ANC

Since there is only one alkalinity measurement at each location, the results for mean ANC and minimum ANC values are the same. Golden Lake Southwest, MORA0033, is the only site that had an ANC below 50 μeq/L.

Figure 6-4 contains a graph of the frequency distribution of minimum ANC values in Mount Rainier NP.

Figure 6-3: Frequency Distribution of Mean ANC Values - MORA

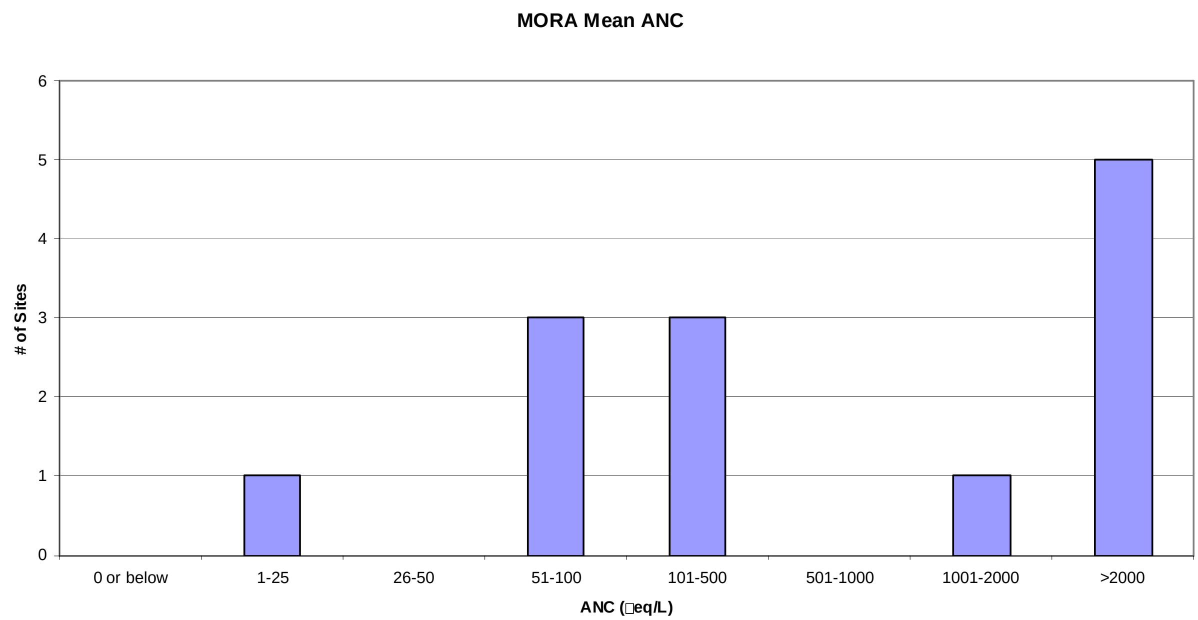
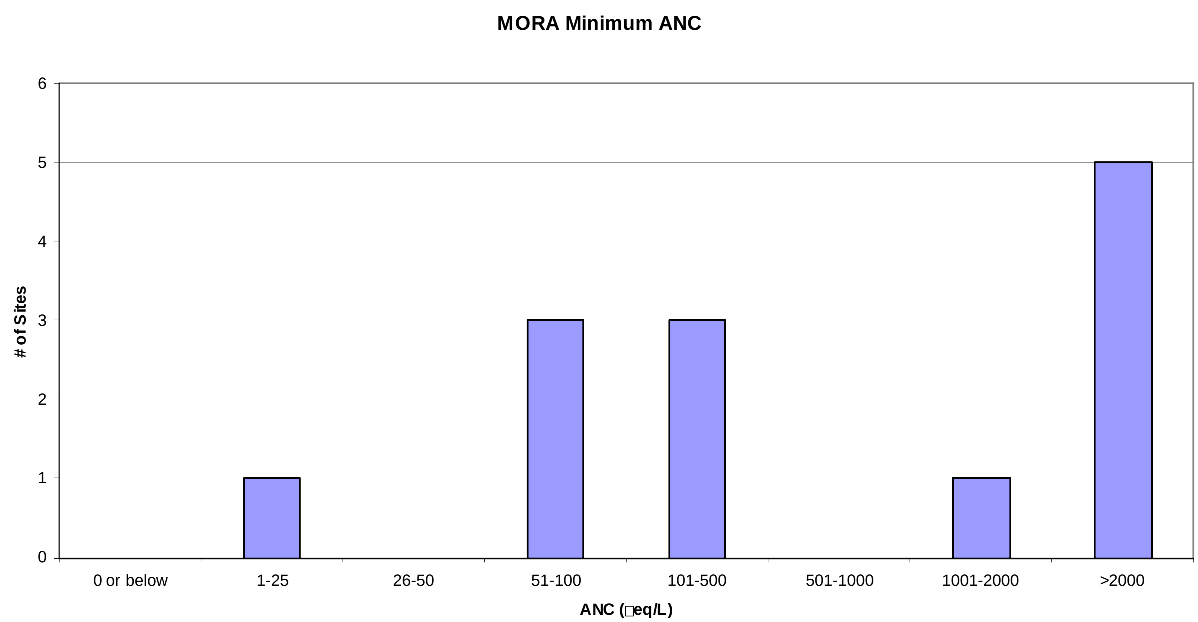


Figure 6-4: Frequency Distribution of Minimum ANC Values - MORA



Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

Lakes - Average Water Chemistry Values

Table 6-3 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Mount Rainier NP and Figure 6-5 includes graphical representations of this data.

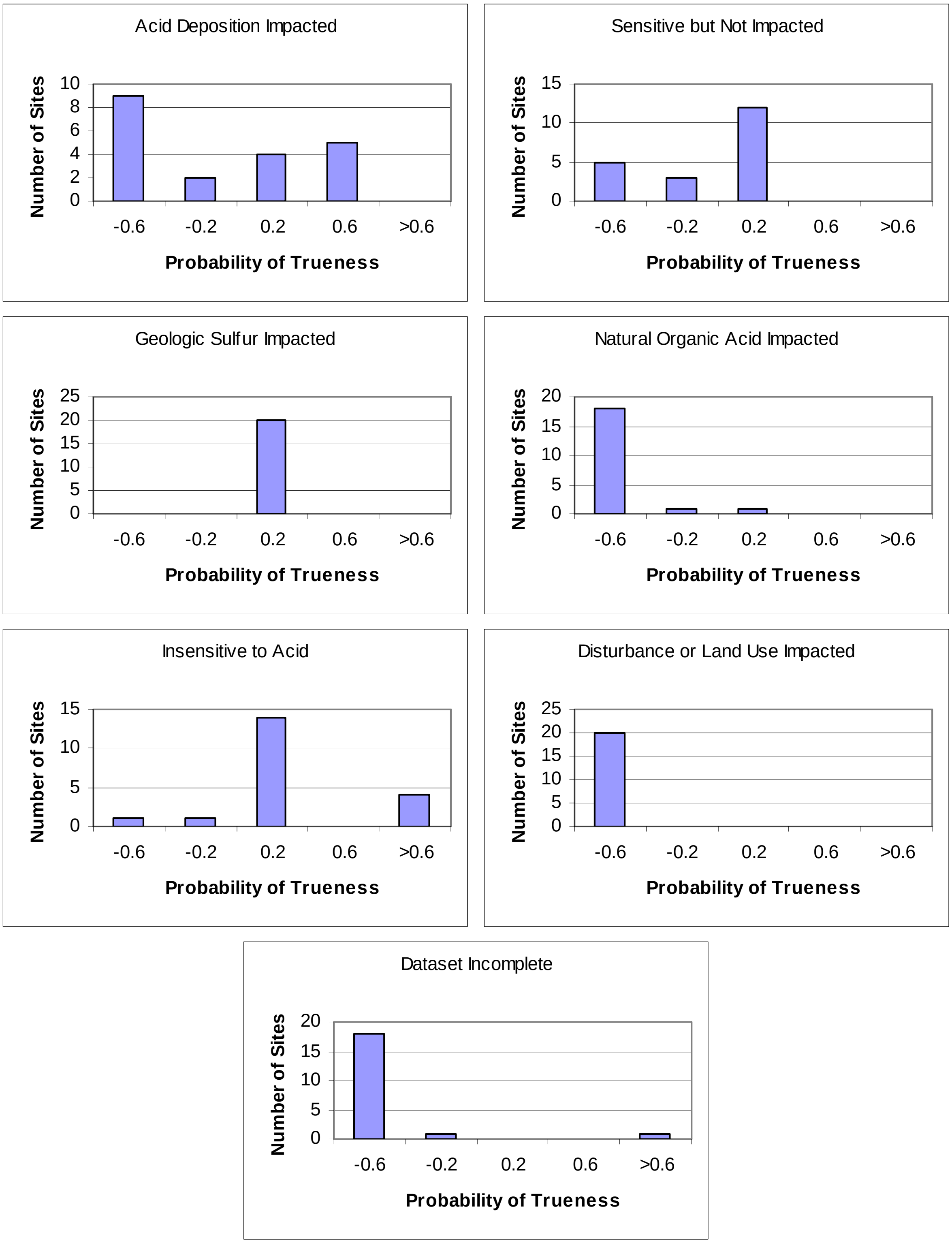
One lake, MORA0063, Lonesome Lake, had only two data parameters for the DSS (specific conductance and nitrate concentration). The DSS makes recommendations with no certainty for all of the categories for this lake except for Disturbance or Land Use Impacted.

Table 6-3: DSS Results for Average Lake Values - MORA

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	9	5	0	18	1	20	12
-0.59 to -0.20	2	3	0	1	1	0	7
-0.19 to 0.20	4	12	20	1	14	0	0
0.21 to 0.60	5	0	0	0	0	0	0
0.61 to 1.00	0	0	0	0	4	0	1

Of the lakes for which the DSS made an assessment about acid deposition, 11 are rated as not being acid deposition impacted (false in the ‘Acid Deposition Impacted’ category), 9 with a high degree of certainty. These lakes have low nitrate and sulfate concentrations or high ANC values and base cation concentrations. The lakes identified as acid deposition impacted (true in the ‘Acid Deposition Impacted’ category) are poorly buffered as indicated by low specific conductance ($\leq$ 12 μS/cm) and few base cations ($\leq$ 100 μeq/L). Low specific conductance suggests that lakes may already have been impacted by acid deposition (Sullivan et al., in review). These five locations are Marsh Lake (MORA0016), Unnamed Lake (16/07-34) (MORA0031), Golden Lake (MORA0036), Mowich Lake (MORA0045), and Chenuis Lake (MORA0049).

Figure 6-5: Charts of DSS Results for Average Lake Values - MORA



The DSS classified 8 lakes as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes are characterized by high ANC values (> 80 μeq/L) or high base cation concentrations (> 200 μeq/L). No lakes were found to be sensitive but not impacted (true in the "Sensitive but Unimpacted' category). The DSS did not make an assessment about a majority of locations in this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

All 19 of the lakes with data were found to be not impacted by natural organic acid (false in 'Natural Organic Acid Impaired' category). This is due to the low levels of DOC found in the samples (< 3 μeq/L).

Four lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (> 80 μeq/L). Two lakes were found to be sensitive to potential changes in acidic conditions due to their low buffering capacity (false in the 'Insensitive to Acid' category). These locations had specific conductance values < 10 μS/cm and base cation concentrations < 100 μeq/L. The two sensitive lakes are Golden Lakes Southwest (MORA0033) and Chenuis Lakes Southern (MORA0048). The DSS did not make an assessment about a majority of the locations in this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

No lakes were found to suffer from the results of disturbance or land use (i.e., were false in the 'Disturbance or Land Use Impacted' category). In all cases, the nitrate concentration was ≤ 2 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The six locations containing all seven inputs have complete datasets. The remaining locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

Lakes – Extreme Water Chemistry Values

Table 6-4 lists the results of the DSS for extreme values of water chemistry parameters in lakes in MORA. Figure 6-6 graphically represents these results.

Table 6-4: DSS Results for Extreme Lake Values - MORA

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	9	5	0	18	1	20	18
-0.59 to -0.20	2	3	0	1	1	0	1
-0.19 to 0.20	4	12	20	1	14	0	0
0.21 to 0.60	5	0	0	0	0	0	0
0.61 to 1.00	0	0	0	0	4	0	1

The DSS result distribution for extreme lake values are exactly the same as that for average lake values. This occurred because results at all of the lake locations came from a single test at that location. Therefore, the mean value for a parameter and its extreme value are the same.

Streams - Average Water Chemistry Values

Table 6-5 lists the results of the Synthesis DSS for average water chemistry values at streams in Mount Rainier NP and Figure 6-7 represents this data graphically.

Table 6-5: DSS Results for Average Stream Values - MORA

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	14	15	0	14	0	7	10
-0.59 to -0.20	0	0	0	0	0	0	1
-0.19 to 0.20	0	1	16	1	13	5	2
0.21 to 0.60	2	0	0	1	0	0	2
0.61 to 1.00	0	0	0	0	3	4	1

One stream site had only one data parameter for the DSS. Huckleberry Creek, MORA0057, had only specific conductance data. The DSS makes recommendations with no certainty for all of the categories for these streams except for Acid Deposition Impacted and Sensitive but Unimpacted.

Figure 6-6: Charts of DSS Results for Extreme Lake Values - MORA

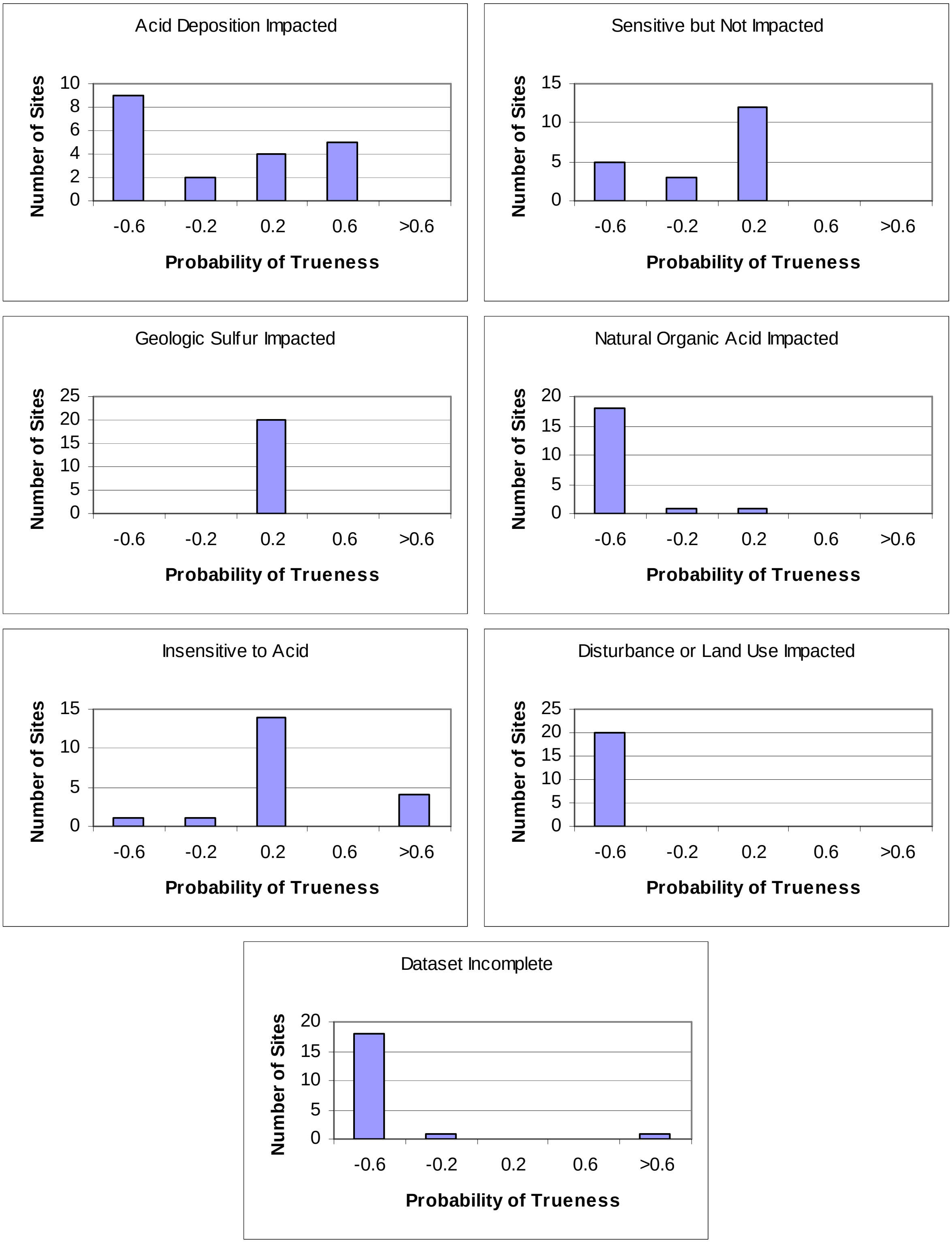
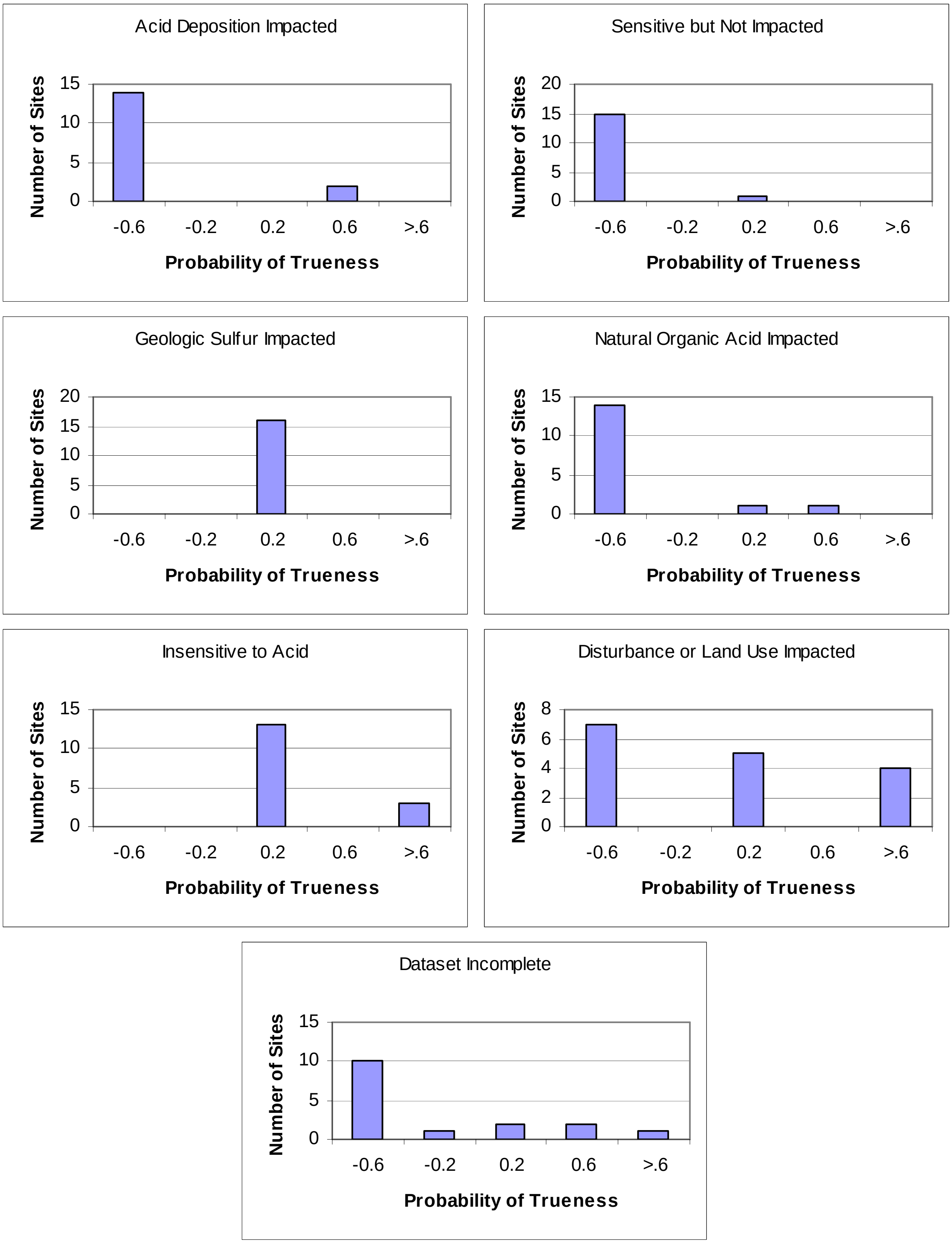


Figure 6-7: Charts of DSS Results for Average Stream Values - MORA



Of the 16 streams for which the DSS made an assessment, 14 were found to not be impacted by acid deposition, (false in the ‘Acid Deposition Impacted’ category). With one exception, these streams have high buffering capabilities, as indicated by high ANC values (> 100 μeq/L), high specific conductance values (> 20 μS/cm), and/or high base cation concentrations (> 200 μeq/L). Winthrop Cold Stream (MORA0039) does not have high buffering capacity; however, there is no evidence that it has been impacted by acid deposition. Two streams were found to be impacted by acid deposition (true in the ‘Acid Deposition Impacted’ category). Ohanapecosh River (MORA0027) and Carbon River (MORA0050) are both characterized by low base cation concentrations (< 180 μeq/L) and high nitrate concentrations (> 6 μeq/L).

Fifteen streams are rated false in the ‘Sensitive but Unimpacted’ category. This is mainly due to the high buffering capacity of these streams; the 14 streams not impacted by acid deposition fall into this category for the reasons listed above.

The DSS did not make an assessment about any of the locations in the ‘Geologically Sulfur Impaired’ category. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

Fourteen streams do not have evidence of impact due to organic acids (false in the ‘Natural Organic Acid Impaired’ category). Again, this is largely due to the high buffering capacity of streams in MORA. One stream was determined probably to be impacted by organic acids, Withrop Cold Stream (MORA0039).

No streams are considered sensitive to acid (false in the ‘Insensitive to Acid’ category). For a majority of the stream locations, the DSS did not make an assessment in this category. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category. Three streams were found to be insensitive to acid (true in the ‘Insensitive to Acid’ category). All three of these locations had ANC values > 350 μeq/L.

The DSS determined 7 streams were not impacted due to disturbance or land use purposes (false in the ‘Disturbance or Land Use Impacted’ category). In all cases, the nitrate concentration was ≤ 7 μeq/L. Four sites with nitrate concentrations > 19 μeq/L were determined to be disturbance or land use impacted by the DSS (true in the ‘Disturbance or Land Use Impacted’ category). Nitrate concentrations at the Muddy Fork of the Cowlitz River (MORA0021), 25.8 μeq/L, the Nisqually River (MORA0022), 19.4 μeq/L, the Inter Fork of the White River (MORA0040), 38.7 μeq/L, and the Carbon River (MORA0050), 24.2 μeq/L, are high enough that the DSS was fairly confident that the impacts found at this location came from anthropogenic inputs.

The DSS evaluates all of the locations in terms of the completeness of the input data. The 11 sites with six inputs are reasonably certain to have complete datasets.

The other 5 locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to acid.

Streams - Extreme Water Chemistry Values

Table 6-6 contains the results of the Synthesis DSS of extreme water chemistry value for streams in Mount Rainier NP. Figure 6-8 shows the data graphically.

Table 6-6: DSS Results for Extreme Stream Values - MORA

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	14	15	0	13	0	7	10
-0.59 to -0.20	0	0	0	0	0	0	1
-0.19 to 0.20	0	1	16	1	13	5	2
0.21 to 0.60	2	0	0	2	0	0	2
0.61 to 1.00	0	0	0	0	3	4	1

The DSS result distribution for extreme stream values are exactly the same as that for average stream values. This occurred because results at all of the stream locations came from a single test at that location. Therefore, the mean value for a parameter and its minimum value are the same.

Analysis

Three of the main findings from previous water quality research within MORA were (1) lakes have low buffering capacity, based primarily on low ANC values; (2) streams have high buffering capacity, based primarily on high ANC values; and (3) park waters had not yet been impacted by acidification. This section will review these findings in terms of the DSS results.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. Only 1 water body had an ANC value that met this criterion. It is listed in Table 6-7:

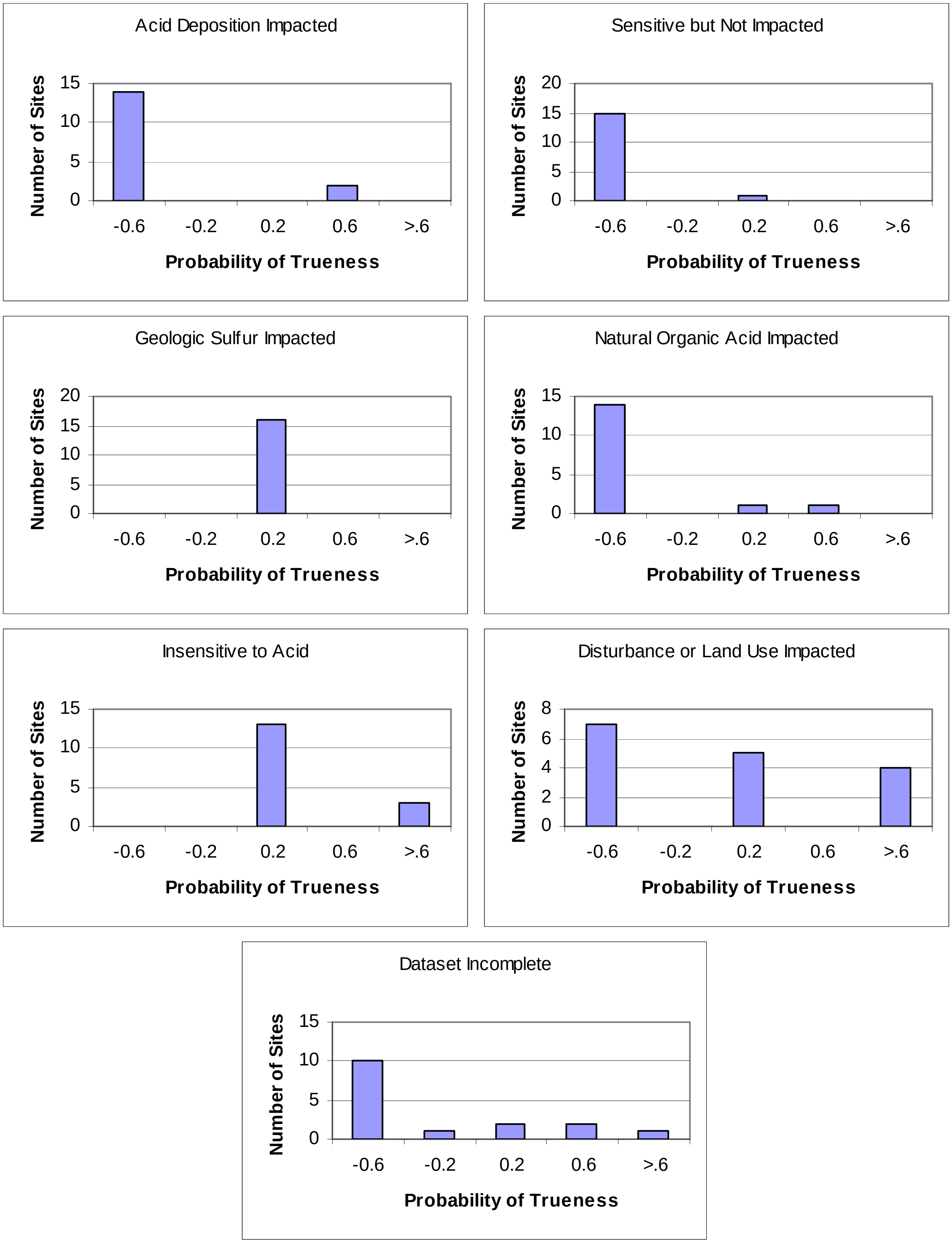
Table 6-7: MORA Water Bodies with Minimum ANC <50 μeq/L

Location ID	Location Name	Sample Type	Impact(s)*	# Obs	Last Sampled**
MORA0033	Golden Lake Southwest	Lake	Sensitive to Acid	1	1985

*For the Acid Impacted and Sensitive/Unimpaired categories, the DSS returned a ‘true’ value for these locations; for the Insensitive to Acid category, the DSS returned a ‘false’ value.

**”Last Sampled” refers to the last documented sample from the Horizon Report used in this analysis.

Figure 6-8: Charts of DSS Results for Extreme Stream Values - MORA



This location was identified in the Western Lake Survey as being highly sensitive to future acid deposition. None of the other locations sampled had ANC values below 50 μeq/L. Several factors can account for this apparent discrepancy. First is that ANC data for many sensitive locations simply may not be present in the Horizon report. Only 63 water bodies of the more than 200 contained in MORA are listed in the report. Of these, only 13 contain ANC data. Second is that only one ANC measurement was obtained at each location with ANC data, taken in either late August, September, or early October. Conditions on the sampling date may not indicate the sensitive nature of MORA lakes that occur at other times throughout the year. Also, other data in the Horizon Report, such as low base cation concentrations (< 100 μeq/L) and low specific conductance values (< 10 μS/cm) suggest that MORA lakes have low buffering capabilities.

The data indicate that streams in MORA have high buffering capacity. Only 3 of the 16 stream sites had ANC data; at all of these locations, ANC values were > 350 μeq/L. Other data, such as high base cation concentrations (> 200 μeq/L) and high specific conductance values (> 20 μS/cm) also indicate high stream buffering capacity.

In contrast to previous research, which found no impacted waters, the DSS considered 14 water bodies to be acid impacted or sensitive to future acid deposition based on extreme stream values. These locations are listed in Table 6-8. These locations are where additional sampling should take place. Among these waters, Golden Lake Southwest (MORA0033) is a high priority due to its high potential sensitivity to acidity as indicated by its extremely low ANC value (12 μeq/L).

Table 6-8: Potentially Sensitive MORA Water Bodies Based on Extreme Water Chemistry Values

Location ID	Location Name	Flagged Categories*	Last Sampled**
MORA0016	Marsh Lake	Acid Deposition Impacted	1983
MORA0021	Muddy Fork Cowlitz River	Disturbance/Land Use Impacted	1981
MORA0022	Nisqually River above Longmire	Disturbance/Land Use Impacted	1981
MORA0025	Paradise Cold Stream	Natural Organic Acid Impacted	1982
MORA0027	Ohanapecosh River near Chinook Creek	Acid Deposition Impacted	1981
MORA0031	Unnamed Lake (16/07-34)	Acid Deposition Impacted	1983
MORA0033	Golden Lake, Southwest	Sensitive to Acid	1985
MORA0036	Golden Lake	Acid Deposition Impacted	1983
MORA0039	Winthrop Cold Stream	Natural Organic Acid Impacted	1982
MORA0040	Inter Fork above White River	Disturbance/Land Use Impacted	1981
MORA0045	Mowich Lake	Acid Deposition Impacted	1983
MORA0048	Chenuis Lake (Southern)	Sensitive to Acid	1985
MORA0049	Chenuis Lake	Acid Deposition Impacted	1983
MORA0050	Carbon River at Ipsut Creek Campground	Acid Deposition Impacted Disturbance/Land Use Impacted	1981

*For the Disturbance/Land Use Impacted and Natural Organic Acid Impacted categories, the DSS returned a 'true' value for these locations; for the Insensitive to Acid category, the DSS returned a 'false' value.

**"Last Sampled" refers to the last documented sample from the Horizon Report used in this analysis.

Seven of the 14 locations were considered to be impacted by acid deposition of nitrate and sulfur. At each of these locations, buffering capacity was low. Nitrate levels consistent with possible atmospheric deposition (> 6 μeq/L) were found at the 2 stream sites, Ohanapecosh River (MORA0027) and Carbon River (MORA0050). At the five lake locations, Marsh Lake (MORA0016), Unnamed Lake (16/07-34) (MORA0031), Golden Lake (MORA0036), Mowich Lake (MORA0045), and Chenuis Lake (MORA0049), low specific conductance suggests that these waters may already have been impacted by acid deposition.

Extremely high nitrate concentrations (> 19 μeq/L) were found at the 4 stream locations identified as impacted by disturbance or land use. Nitrate concentrations at the Muddy Fork of the Cowlitz River (MORA0021), 25.8 μeq/L, the Nisqually River (MORA0022), 19.4 μeq/L, the Inter Fork of the White River (MORA0040), 38.7 μeq/L, and the Carbon River (MORA0050), 24.2 μeq/L, are high enough that the DSS was fairly confident that the impacts found at this location came from anthropogenic inputs or disturbance and land use sources. Given that its nitrate concentration is relatively high, the DSS has more confidence that the Carbon River location is disturbance or land use impacted rather than acid deposition impacted.

The two locations considered sensitive to acid have low buffering capacity. Both sites have low levels of specific conductance; Chenuis Lake - Southern (MORA0048) reported conductance at 8 μS/cm and at Golden Lake - Southwest (MORA0033), conductance was measured at 6 μS/cm. As listed in Table 6-7 above, Golden Lake – Southwest was the only park water body to have an ANC of less than 50 μeq/L (12 μeq/L).

Two streams were considered probably to be acid impacted by natural organic acids. Both Paradise Cold Stream (MORA0025) and Withrop Cold Stream (MORA0039) had low pH (≤ 6) and were not impacted by nitrogen or sulfur deposition.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

Compared to other parks, a consistent set of water chemistry tests were performed on the samples taken from MORA. Thirty of the 36 locations (83%) that had data contained six or seven of the data elements used by the DSS. The classifications made at these locations are likely based on adequate data.

It is difficult to know how applicable the classifications reported by the DSS for Mount Rainier NP are to the current state of the water bodies. Just 1 of the 63 sites that had any data collected after 1990. At best, the data in this report is 15 years old and may not indicate current water chemistry conditions. It highlights the need for additional sampling to take place or be reported on so that the DSS can utilize current data for making recommendations.

It may be more important to sample sensitive sites or areas more frequently than to sample all water bodies, especially those deemed not to be susceptible to acid deposition. This would assist in determining if these water bodies are subject to episodic or chronic acidification.

Conclusion

Pollution levels have substantially increased over the last 150 years. Sulfate and nitrate are the most important anionic components in acidic deposition. The air quality in the Pacific Northwest region is very good compared to other areas of the U.S. A regional NPS report showed that this region had low levels of S deposition (0.5 to 4 kg S/ha/yr) and N deposition (0.5 to 2.4 kg N ha/yr) during the early 1990s. However, emissions from areas outside the park, such as Seattle and Vancouver, British Columbia, have the potential to impact the park.

Pollution effects are of concern in this region because its lakes are likely among the most sensitive aquatic systems anywhere in the world. Acidic deposition of both S and N may cause chronic or episodic acidification of surface waters at low levels of deposition.

This evaluation focuses on Mount Rainier NP (MORA). The water quality data was extracted from the Horizon report, completed in May 1995. Values for specific conductance, pH, ANC, DOC, nitrate, the sum of base cations, and sulfate were obtained. These reports may not contain data for the most sensitive water bodies; for example, the report contains only 31% of the approximately 200 water bodies in MORA. Therefore, the analysis may not give a true representation of the sensitivity or level of impact by acid deposition for the entire park.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. Only 1 of the 9 lakes and streams that had ANC values met this criterion: Golden Lake – Southwest (MORA0033). This location requires particular attention because it may be sensitive to future acid deposition. Given its low buffering capacity, relatively small increases in acid concentrations may impact this location.

Several of the waters in MORA probably have been affected by acid deposition. Seven water bodies showed probable impact by acid deposition. Two stream sites, Ohanapecosh River (MORA0027) and Carbon River (MORA0050), had high nitrate levels (> 6 μeq/L). The nitrate level in the Carbon River may be too high to be from acid deposition alone. Five lake locations, Marsh Lake (MORA0016), Unnamed Lake (16/07-34) (MORA0031), Golden Lake (MORA0036), Mowich Lake (MORA0045), and Chenuis Lake (MORA0049), had low specific conductance, suggesting that these waters may already have been impacted by acid deposition.

Five other locations show probable acid impact from disturbance or land use or from organic acids: Muddy Fork of the Cowlitz River (MORA0021), Nisqually River (MORA0022), Paradise Cold Stream (MORA0025), Withrop Cold Stream (MORA0039), and Inter Fork of the White River (MORA0040). Two other locations may lack the buffering capacity to deal with future acidity: Golden Lake - Southwest (MORA0033), as listed above, and Chenuis Lake - Southern (MORA0048).

The DSS result distribution for extreme water values are largely the same as that for average lake values. Many results contain data from one or two samples. In these cases, the result is 'extreme' values that are the same as the mean values. With so few samples, it is difficult to ascertain if the data assembled is representative of the water body in question.

Data issues that affected this analysis include a general lack of data, infrequent sampling, and old data. Only 52% of water bodies in the report contained data relevant to the DSS. In addition, 37% of sites with data had only one data element used by the DSS. This lack of data left the DSS unable to report with any certainty most stream locations with respect to being impacted by high organic levels, high nitrogen levels, likely due to anthropogenic causes, and not being sensitive to acid due to high buffering capabilities. Such a large degree of uncertainty makes it difficult to make an overall recommendation for the park concerning water quality management decisions.

Data representing present conditions are needed. All but one of the MORA waters were sampled after 1990. The Horizon report is 10 years old. It is likely the condition of these waters has changed during this period. Ongoing monitoring and research can now provide additional data to characterize MORA lakes and streams.

While an overall recommendation for the park cannot be made, the DSS has identified 14 bodies of water that may require attention. Given resource limitations, it is important to prioritize potential and already existing problem areas at specific bodies of water, to collect more samples at these locations, and to run a standardized set of chemical analyses against these samples. The one location that had an ANC value below 50 μeq/L, Golden Lake, tops the priority list. The other waters that were currently or potentially impacted under extreme water chemistry conditions should be monitored for changes.

Chapter 7 - North Cascades National Park

Background

The information in this section was taken from the Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service (Eilers et al. 1994). The complete report is available on the web at the following site:

http://www2.nature.nps.gov/air/pubs/PacificNW.Review/index.html

Description

Created on October 2, 1968 and nicknamed the "American Alps", North Cascades National Park encompasses 271,700 ha of rugged mountain scenery in north-central Washington, about 80 km east of Bellingham. Extending from Canada's Fraser River south beyond Oregon, the Cascades contribute greatly to shaping the Pacific Northwest's climate and vegetation.

The area has extensive topographic relief. Mountain summits rise abruptly 1800-2600 m above the valley floor. This steep topography and orographic climatic influences produce a diverse range of biogeoclimatic zones and ecosystems. The average annual precipitation ranges from 280 cm on the western side, to only 90 cm on the eastern side of the park complex. The heavy precipitation and cold, harsh winters of the area have produced an abundance of alpine lakes, ice caps, and more than 300 glaciers.

The park contains three reservoirs: Ross, Diablo, and Gorge Lakes. These reservoirs are an important recreational element in the park because of their accessibility. In contrast, the 245 natural lakes in the park are in subalpine and alpine settings, and are accessible only on foot. The natural lakes and stream valleys were formed by glacial action which is still evident throughout the park.

The emissions in the three counties adjacent to NOCA and King County to the south indicate that nitrogen dioxide and sulfur dioxide values generally were low in the region and no exceedances occurred for either of these primary standards. However, emissions from areas outside the park, such as Seattle (King County) and Vancouver, British Columbia, have the potential to impact the park.

Deposition

Total annual S and N deposition is difficult to estimate at the more sensitive sites, which tend to be located at higher elevations in remote regions of the parks. Extrapolation of low-elevation deposition monitoring data (e.g., NADP/NTN sites) to these high-elevation sites has been done with some success. Methods combining data from wet deposition, dry deposition, snow cores, bulk deposition, throughfall, and cloudwater chemistry can produce estimates of site-specific total deposition.

NOCA has a NADP/NTN site located at Marblemount immediately to the west of the park at an elevation of 123 m. The site has operated since February 1984. Precipitation-weighted mean annual chemistry at this site shows that the site receives precipitation with slightly elevated levels of SO_4^{2-} and NO_3^-. As a result, pH is slightly less than that experienced at other Pacific Northwest sites such as the Hoh Valley in OLYM. The NADP site at Marblemount probably is representative of deposition in the low elevations on the west side of the park. Precipitation volume increases at higher elevations on the west side of the park and decreases dramatically to the east.

Figure 7-1 shows that sulfate wet deposition has declined since records were first kept in 1984 to 1987, and again after 1990. The first reduction in sulfur dioxide (SO_2) emissions occurred in 1985 when the ASARCO smelter in Tacoma discontinued operation, resulting in a reduction of 143,000 tons SO_2 per year (WDOE 1993).

Figure 7-1: Sulfate deposition at Marblemount NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA19&inpanalyte=SO4-kg&PlotSize=Small)

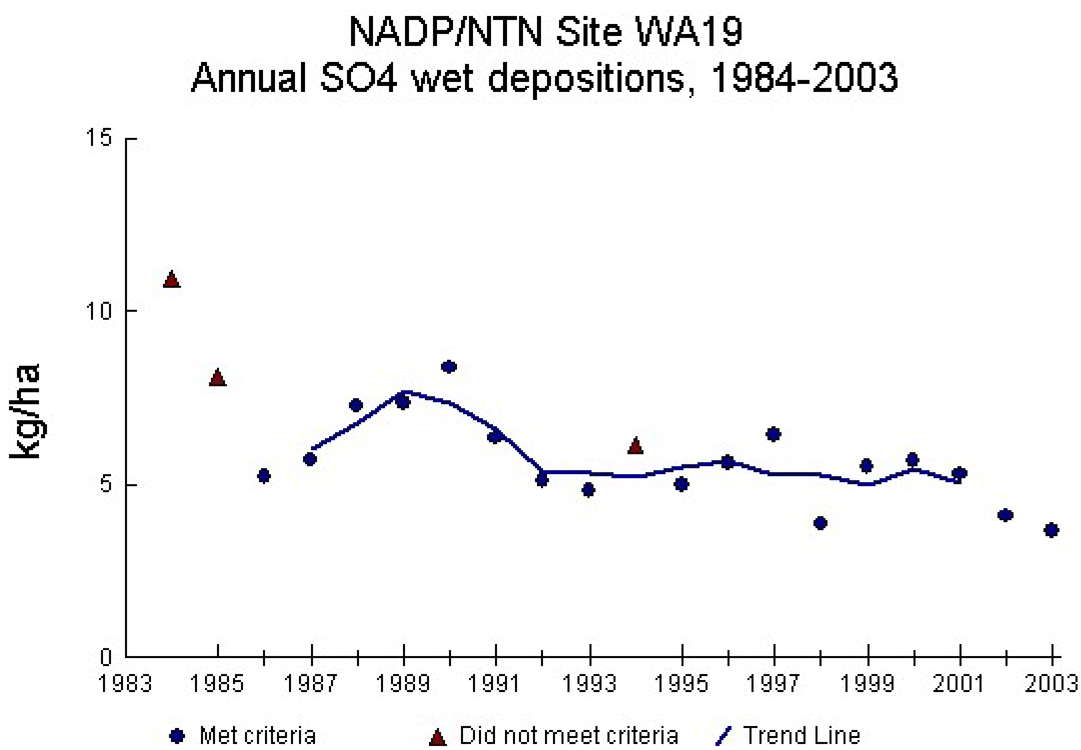
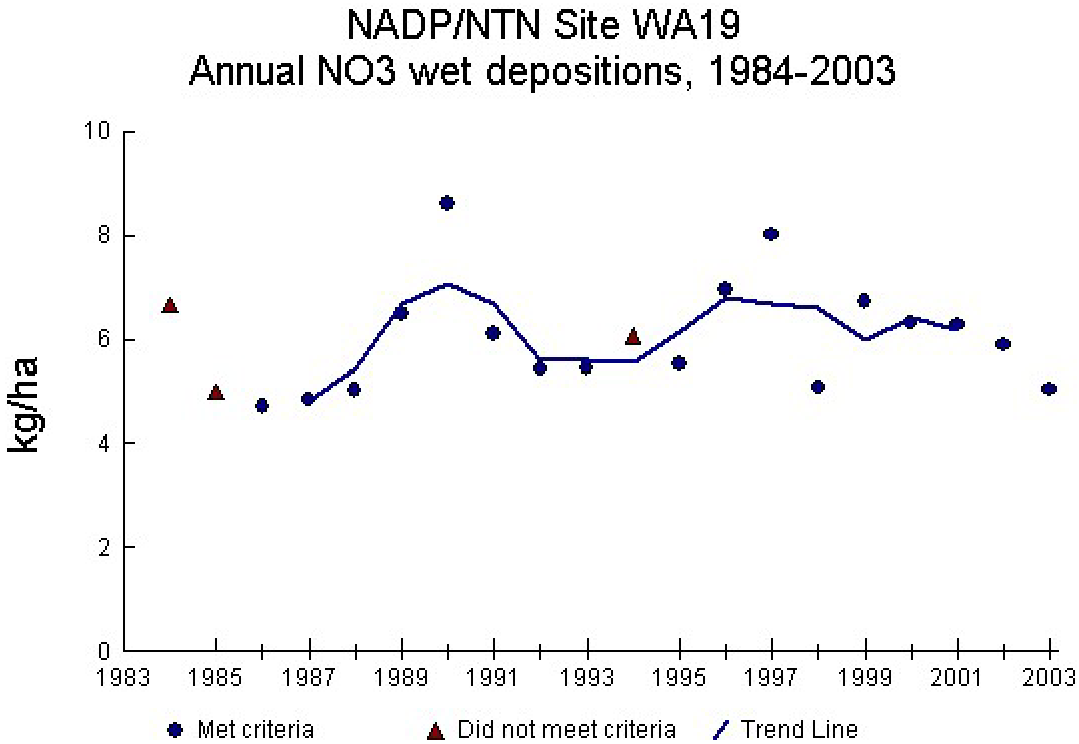


Figure 7-2 shows a cycle of increases and decreases of nitrate wet deposition since 1984. With some exceptions, these values remain between 4-7 kg/ha/yr of nitrate.

Figure 7-2: Nitrate deposition at Marblemount NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA19&inpanalyte=NO3-kg&PlotSize=Small)



Water Quality

Because some parts of the park are extremely difficult to access, considerable monitoring and research work remains to be done, particularly with respect to detailed chemical characterization of the alpine lakes and streams. The complex mineralogy of NOCA, as evidenced in the wide range of the ratio of dissolved Ca:Na in the lakes in the region makes the task of predicting effects of atmospheric deposition very difficult.

For lake data, the major reservoirs in NOCA, creations of the dams impounding Ross, Diablo, and Gorge Lakes, have been studied. Due to their relatively high alkalinity (500 to 800 μeq/L), the studies concluded that the reservoirs are not highly relevant for air-pollution effects. A natural lakes inventory is 'complete' for 115 of 245 natural lakes. However, the inventory does not include complete chemistry data. Major ion chemistry data is available for only approximately 20 lakes.

Data from Brakke (1984) and Liss et al. (1991) illustrate the existence of some low-alkalinity (less than 10 μeq/L) waters in the park that may be very susceptible to acidification. In contrast, Funk et al. (1987) studied baseline water quality in lakes Ross, Diablo, and Chelan and found relatively high alkalinity (500 to 800 μeq/L).

Unlike many other lakes in the West which have moderately high Na^+ concentrations, many NOCA lakes had comparatively high Ca^{2+} concentrations, supporting the results of Drever and Hurcomb (1986) who studied weathering in South Cascade. Excess SO_4^{2-} in one of the lakes was attributed to weathering of pyrite present in the watershed.

Little is known about the seasonal variation of these lakes and streams, and virtually no data have been collected on episodic responses associated with snowmelt. The highest priority for seasonal and episodic response again is on the west side of the park because of the much greater precipitation and likelihood of enhanced deposition of S and N in cloudwater. Lakes and streams receiving meltwater from glaciers may be less sensitive because of the high physical weathering rates associated with glacial action.

Aquatic Chemistry Data and DSS Results

Horizon Report

The Horizon report was completed for North Cascades NP in May 1995. Although the park has approximately 245 lakes and many streams, the report contains information on only 82 water bodies in the park (19 lakes and 63 streams). More water bodies exist, but were not sampled; for example, only 7.8% of lakes in NOCA were listed in the report. Only 52% of water bodies in the report contained data relevant to the DSS. Table 7-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for the sampled lakes is relatively complete in terms of the DSS requirements, while data for the streams is quite sparse.

Table 7-1: Chemistry Component Summary - NOCA

	Total	Lakes	Streams
Number	82	19	63
Conductance	39	14	25
pH	27	14	13
ANC	21	14	7
DOC	12	12	0
Nitrate	25	17	8
Base Cations	20	12	8
Sulfate	20	12	8

In addition, 37% of sites with data had only one data element used by the DSS, leaving two-thirds of all reported sites in North Cascades NP with one element or less, including 79% of streams. In contrast, 63% of the lake sites had all of the data elements required by the DSS. Table 7-2 shows the number of sites that had a given number of data elements required by the DSS.

Table 7-2: Number of Elements Summary - NOCA

# of Elements	Total	Lakes	Streams
0	39	2	37
1	16	3	13
2	3	0	3
3	2	0	2
4	3	2	1
5	2	0	2
6	5	0	5
7	12	12	0

Of the 43 sites that had any data collection, 30 sites were last sampled in the 1970s and 13 in the 1980s. The lake data was newer than the stream data. Sixty-three percent of lakes had their last samples taken during the 1980s, while the latest sampling at 96% of streams occurred in the 1970s. At best, the data in this report is 15 years old and may not indicate current water chemistry conditions. Of the 21 locations that had alkalinity data, sampling occurred once at 62% of them, including 86% of lakes. However, at 86% of streams, sampling took place more than once.

ANC Results

One of the parameters used in the DSS is alkalinity, which is a measure of how well the water body can buffer additions of acid. A standard measure of alkalinity is ANC or acid neutralizing capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body may be sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and characterizes the most sensitive condition for that water body.

Mean ANC

Of the 21 sampling locations which contained data for ANC calculations, 24% of them had mean ANCs below 50 μeq/L. These locations are listed in Table 7-3.

Table 7-3: Locations with mean ANCs below 50 μeq/L - NOCA

Location ID	Location Name	ANC (μeq/L)
NOCA0010	Doubtful Lake	46.6
NOCA0011	Hidden Lake	40.7
NOCA0070	Razorhone Creek Tributary, Point H	40.0
NOCA0080	Tapto Lakes (east)	14.3

NOCA0082	Silver Lake	35.6

Figure 7-3 contains a graph of the frequency distribution of mean ANC values in North Cascades National Park.

Minimum ANC

Of the 21 sampling locations which contained data for ANC calculations, 29% of them had minimum ANCs below 50 μeq/L. These locations are listed in Table 7-4.

Table 7-4: Locations with minimum ANCs below 50 μeq/L - NOCA

Location ID	Location Name	ANC (μeq/L)
NOCA0010	Doubtful Lake	46.6
NOCA0011	Hidden Lake	40.7
NOCA0070	Razorhone Creek Tributary, Point H	40.0
NOCA0075	Galena Creek near Glacier, WA	20.0
NOCA0080	Tapto Lakes (east)	14.3
NOCA0082	Silver Lake	35.6

The mean and minimum values are, for many sites (62%), the same because sampling was conducted only one time. Another 14% of sites were based on 5 or fewer samples; each of these sites has a mean ANC value that is quite different than the minimum value. Figure 7-4 contains a graph of the frequency distribution of minimum ANC values in North Cascades National Park.

Figure 7-3: Frequency Distribution of Mean ANC Values - NOCA

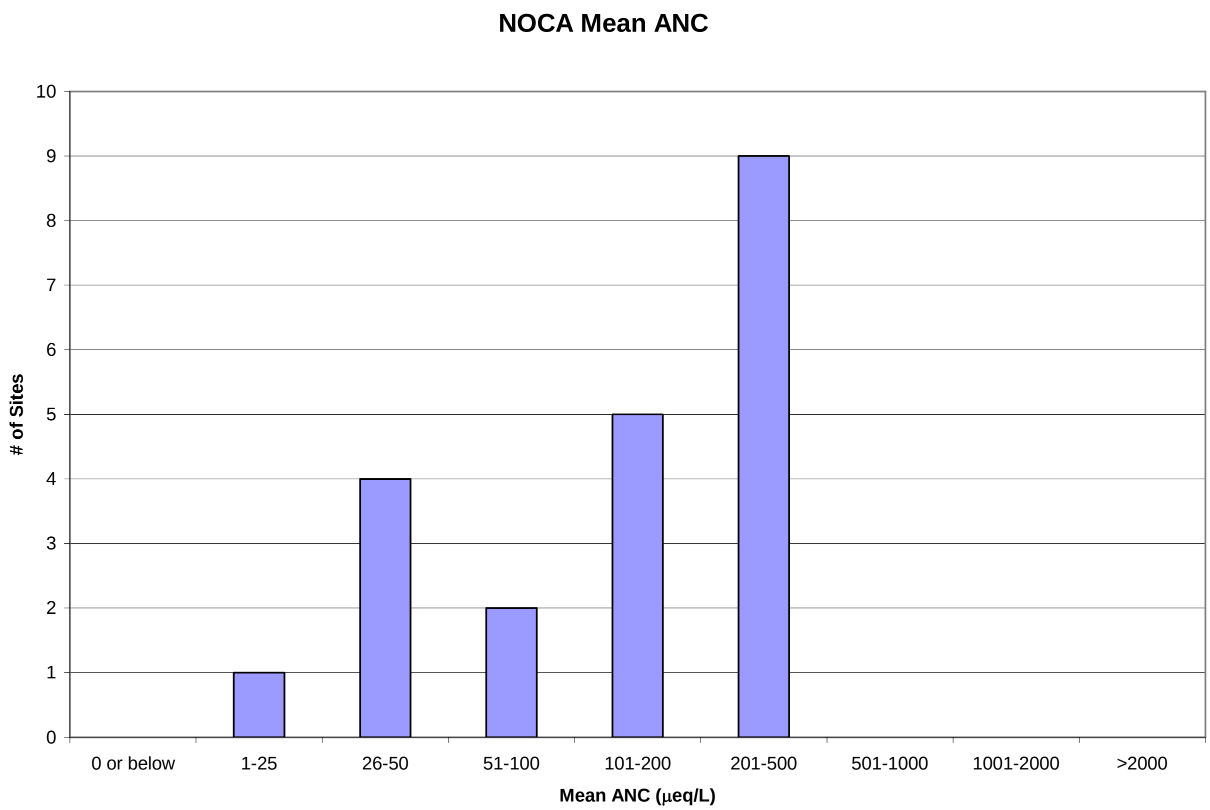
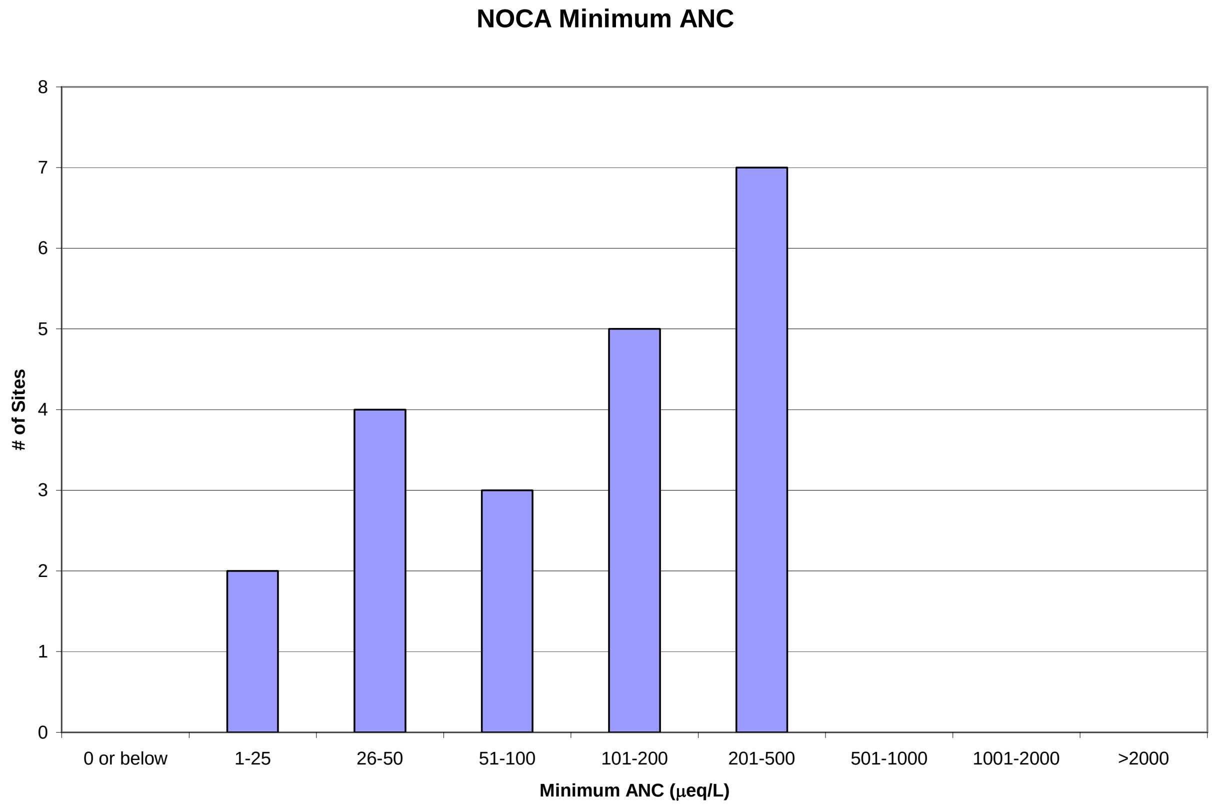


Figure 7-4: Frequency Distribution of Minimum ANC Values - NOCA



Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

Lakes - Average Water Chemistry Values

Table 7-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in North Cascades National Park and Figure 7-5 includes graphical representations of this data.

Three of the lake sites had only one data parameter for the DSS (nitrate concentration). The DSS makes no suggestions for any of the categories for these lakes except for ‘Disturbance or Land Use Impacted’.

Table 7-5: DSS Results for Average Lake Values - NOCA

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	12	13	0	14	4	17	12
-0.59 to -0.20	1	0	0	0	0	0	0
-0.19 to 0.20	3	3	17	3	4	0	2
0.21 to 0.60	0	0	0	0	0	0	0
0.60 to 1.00	*1	*1	0	0	9	0	3

* Hidden Lake

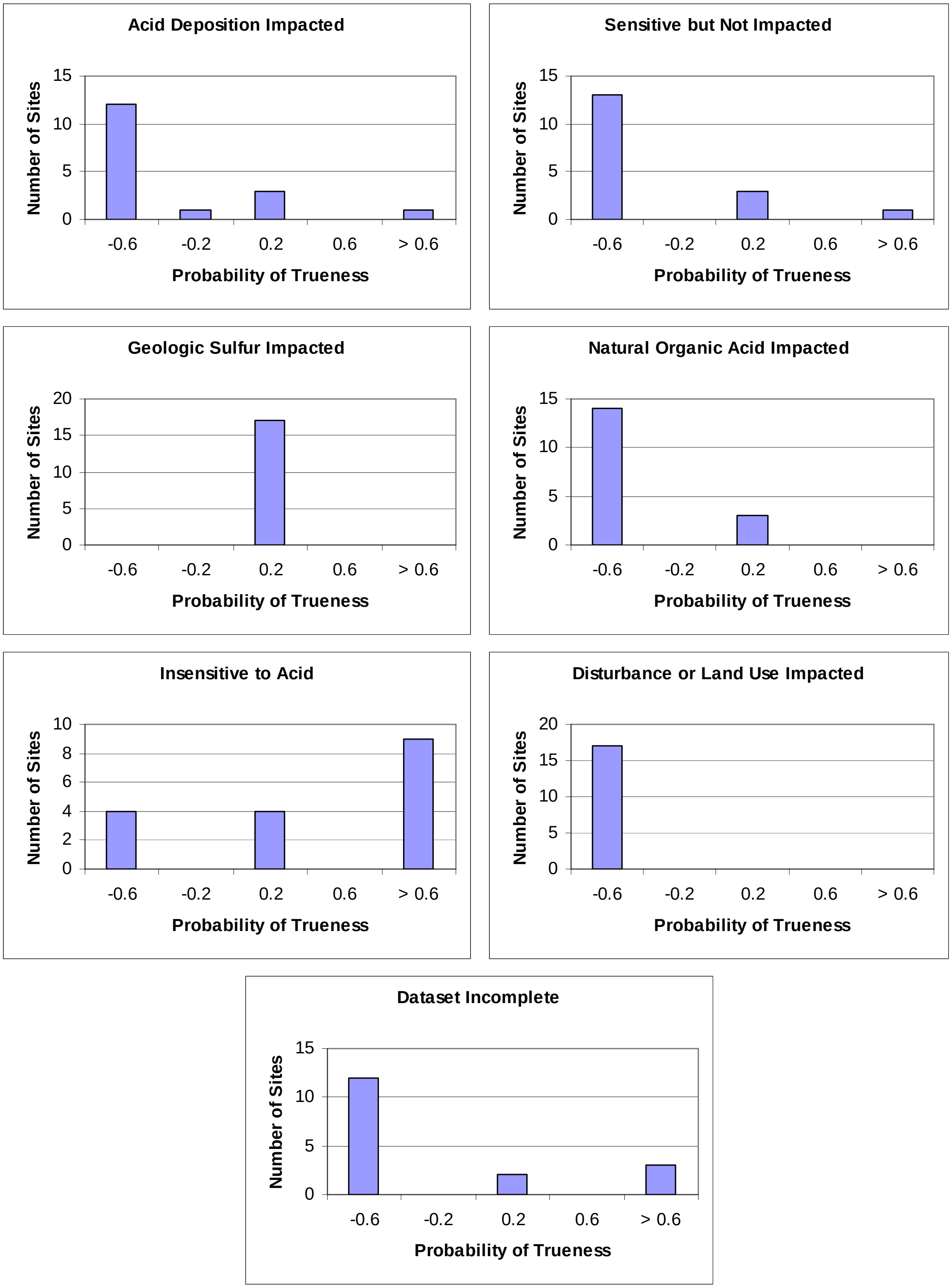
Of the 14 lakes for which the DSS made an assessment about acid deposition, 13 are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category), 12 with a high degree of certainty. These lakes have high ANC and pH values, low nitrate concentrations, and relatively low sulfate concentrations. The lake identified as acid deposition impacted (true in the 'Acid Deposition Impacted category'), Hidden Lake, has an extremely low specific conductance (5 μmhos/cm) in addition to a low ANC (41 μeq/L) and few base cations (26 μeq/L). Low specific conductance suggests that the lake may already have been impacted by acid deposition (Sullivan et al., in review).

The same 13 lakes are also classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes have high ANC values, low nitrate concentrations, and relatively low sulfate concentrations compared to relatively high base cation concentrations. Hidden Lake, with low buffering capacity, as mentioned above was found to be a sensitive but not impacted lake (true in the 'Sensitive but Unimpacted' category).

It seems counterintuitive that a single water body can be both 'Acid Deposition Impacted' and 'Sensitive but not Impacted'. There is a reasonable interpretation of these seemingly conflicting categories. The Hidden Lake results demonstrate that the model allows for some uncertainty in definitely lumping a lake into one category at the exclusion of all others. The potential for it to be sensitive but unimpacted is due to the fact that there still is fairly high ANC and pH; impact, if it exists, would be gauged to be moderate. The potential for it to be acid deposition impacted is due to nitrate and sulfate values that could well be caused by acid deposition and to ANC that is low enough to have suffered some moderate impact.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

Figure 7-5: Charts of Synthesis Results for Average Lake Values - NOCA



All 14 lakes with data were found to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted" category). This is due to the low levels of DOC found in the samples (<1.6 mg/L) and the high ANC values (>100 μeq/L).

Nine lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (>100 μeq/L) and high specific conductance values (≥ 13 μmhos/cm). Four lakes were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category). These locations had ANC values below 50 μeq/L and conductance values under 10 μmhos/cm. The four sensitive lakes are Doubtful Lake (NOCA0010), Hidden Lake (NOCA0011), Tapto Lakes - East (NOCA0080), and Silver Lake (NOCA0082).

No lakes were found to suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In all cases, the nitrate concentration was ≤ 5 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The twelve locations containing all seven inputs have complete datasets. Five of the locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

Lakes – Extreme Water Chemistry Values

Table 7-6 lists the results of the DSS for extreme values of water chemistry parameters in lakes in North Cascades National Park. Figure 7-6 graphically represents these results.

Table 7-6: DSS Results for Extreme Lake Values - NOCA

DSS Score	Acid Deposition Impacted	Sensitive but Not Impacted	Geologic Sulfur Impacted	Natural Organic Acid Impacted	Insensitive to Acid	Disturbance or Land Use Impacted	Dataset Incomplete
-1.00 to -0.60	12	13	0	14	4	17	12
-0.59 to -0.20	1	0	0	0	0	0	0
-0.19 to 0.20	3	3	17	3	4	0	2
0.21 to 0.60	0	0	0	0	0	0	0
0.60 to 1.00	1	1	0	0	9	0	3

Figure 7-6: Charts of Synthesis Results for Extreme Lake Values - NOCA

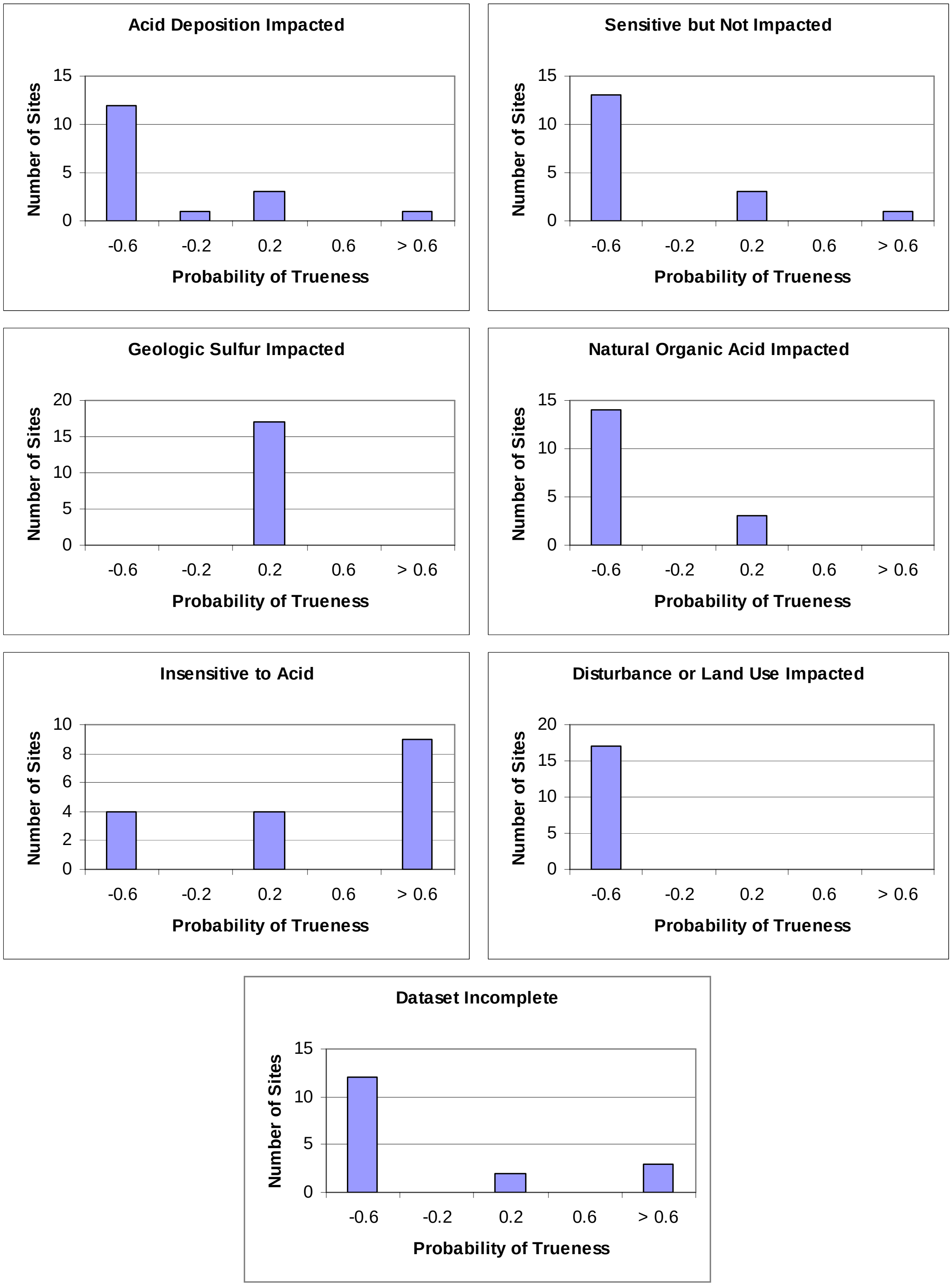


Figure 7-7: Charts of Synthesis Results for Average Stream Values - NOCA