UNITED STATES
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GEOLOGICAL SURVEY

WATER QUALITY OF SELECTED LAKES IN MOUNT RAINIER NATIONAL PARK, WASHINGTON WITH RESPECT TO LAKE ACIDIFICATION

By G. L. Turney, N. P. Dion, and S. S. Sumioka

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

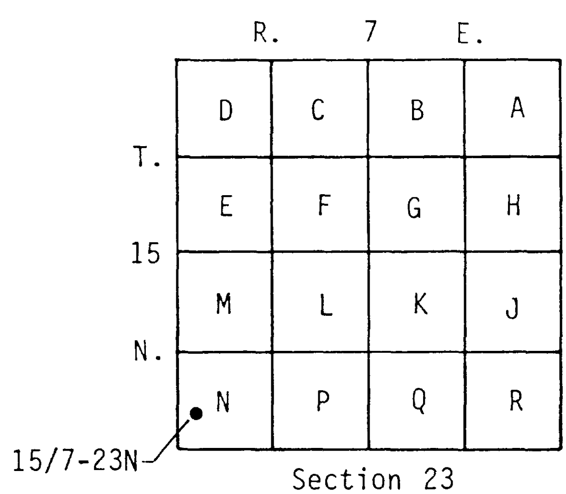
Multiply	By	To obtain
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare (ha)
	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F = 1.8 °C + 32

National Geodetic Vertical Datum of 1929 (NGVD of 1929). A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

LAKE LOCATION NUMBERING SYSTEM

Lake location is determined by the position of the lake outlet (or the southernmost shoreline point of the lake if there is no outlet) on U.S. Geological Survey topographic maps. The location numbering system used by the U.S. Geological Survey in the State of Washington is based on the rectangular subdivision of public land which indicates township, range, section and 40-acre tract within the section. For example, in site number 15/7E-23N, the part preceding the hyphen indicates the township and range (T. 15 N., R. 7 E.) north and east of the Willamette base line and meridian, respectively. Since all locations in Washington are north of the base line, the "N" designation of the township is omitted. The number following the hyphen (23) indicates the section, and the letter (N) gives the 40-acre tract within that section. A diagram of the location numbering system follows:



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ABSTRACT

Thirteen lakes in Mount Rainier National Park were evaluated for general chemical characteristics, sensitivity to acidification by acidic precipitation, and degree of existing acidification. They were found to be pristine for the most part. The lakes studied were Allen, one of the Chenuis group, Crescent, Crystal, Eleanor, Fan, one of the Golden group, Marsh, Mowich, Mystic, Shriner, and two unnamed lakes. The lakes were sampled in August 1983.

Specific-conductance values were generally 21 uS/cm (microsiemens per centimeter at 25°C) or less, and dissolved-solids concentrations were generally 20 milligrams per liter (mg/L) or less. The major cations were calcium and sodium, and the major anion was bicarbonate (or alkalinity). Alkalinity concentrations ranged from 2.1 to 9.0 mg/L in 12 of the lakes. Allen Lake was the exception, having an alkalinity concentration of 27 mg/L. The pH values for all of the lakes ranged from 5.8 to 6.5. In most of the lakes vertical profiles of temperature, dissolved oxygen, pH, and specific conductance were relatively uniform. In the deeper lakes, temperature decreased with depth and dissolved-oxygen concentrations increased to about 20 feet, remained constant to 80 feet, then decreased with increasing depth.

Exceptions to general water quality patterns were observed in three lakes. Allen Lake had a specific conductance value of 58 uS/cm and an alkalinity concentration of 27 mg/L. The lake of the Golden group was anaerobic at the bottom and had relatively high concentrations of dissolved organic carbon and dissolved metals. It also had a lower light transmission than the other lakes studied. One of the unnamed lakes had relatively high concentrations of phytoplankton and dissolved organic carbon and relatively low levels of light transmission.

Comparisons of lake data to acid-sensitivity thresholds for specific conductance and alkalinity indicated that all of the lakes except Allen would be sensitive to acidic precipitation. The small sizes of the lakes, and their locations in basins of high precipitation and weathering-resistant rock types, enhance their sensitivity.

None of the lakes in this study appeared to be presently acidified. pH values were above the levels generally accepted as indicative of acidification (pH = 5.5), and nitrate, sulfate and metals concentrations were low. Plots based on pH and calcium (which represented "original" alkalinity) suggested that most of the lakes are not being acidified.

INTRODUCTION

The acidification of lakes by acidic precipitation is well documented in the northeastern United States, southeastern Canada, Scandinavia, and parts of western Europe (Oden, 1976; Cowling, 1982). Recent work suggests that other areas also may be affected to various degrees. One of these is the Cascade Range in Washington, where many pristine, high-altitude lakes are located. Precipitation on these lake basins carries pollutants that largely originate from the Willamette-Puget Sound Trough. This precipitation has been shown to be acidic in some cases (Logan and others, 1982; Vong and Waggoner, 1983) as have some of the lakes (Dethier, 1979; Welch and Chamberlain, 1981).

Purpose and Scope

The National Park Service (NPS) is concerned about the potential acidification of lakes in Mount Rainier National Park, located in the Cascade Range. Like many other lakes in the Cascades, these lakes were thought to be susceptible to the effects of acidic precipitation because most are located in basins of weathering-resistant bedrock and thin soil cover. As a result, their waters are usually dilute with little buffering capacity (resistance to pH changes). The park lakes are also in areas of heavy precipitation and as such their chemical composition is dependent upon the composition of the precipitation as well as the basin geology.

The U.S. Geological Survey, in cooperation with the NPS, undertook this study to determine the general chemical characteristics of 13 selected lakes in Mount Rainier National Park. Using these data, an evaluation of the sensitivity of the lakes to acidification was made, along with an assessment of the acidification of the lakes. The data also will be useful in future studies to determine long-term changes in lake acidity.

Description of Study Area

Mount Rainier National Park is approximately 35 miles southeast of Tacoma and 40 miles northwest of Yakima. The park covers an area of 378 square miles in Pierce and Lewis Counties (fig. 1). Volcanic Mount Rainier is in the center of the park, although its foothills extend well beyond the park boundaries. Many lakes are located around the mountain, either in the foothills or on the flanks of the mountain itself.

Climatological data for 1982 are shown in table 1 (National Oceanic and Atmospheric Administration, 1982). Subfreezing air temperatures prevail in the park during the winter months, but temperatures routinely exceed $50^{o}F$ in August. Annual precipitation is high, exceeding 60 inches per year throughout the park (U.S. Department of Agriculture, 1965). Precipitation is varied; amounts of 100 inches per year are common near the mountain, and the summit receives up to 140 inches per year. Most precipitation occurs as snow during the winter months.

Because of its climate and high altitude (14,410 feet), Mount Rainier is extensively glaciated. On its flanks reside 1.1 cubic miles of snow and ice covering 36 square miles (Driedger and Kennard, 1984). The climate also results in snow and ice cover on many lakes persisting well into summer (Larson, 1973).

Other Studies

Few limnological studies in Mount Rainier National Park have been published. A general limnological study of Mowich Lake was completed by Larson (1973). Similar but unpublished studies were completed on Fan Lake by Richard Perry (National Park Service, written commun., 1979) and Shadow Lake by Timothy Hall (National Park Service, written commun., 1973). Many lakes in the park have been included as part of larger studies, such as that by Wolcott (1973). These studies were usually an evaluation of the lakes in terms of physical dimensions, chemical constituents, or biological populations. Only Welch and Chamberlain (1981) have studied lakes in the park in terms of potential acidification. None of the lakes sampled by Welch and Chamberlain, however, were sampled in this study.

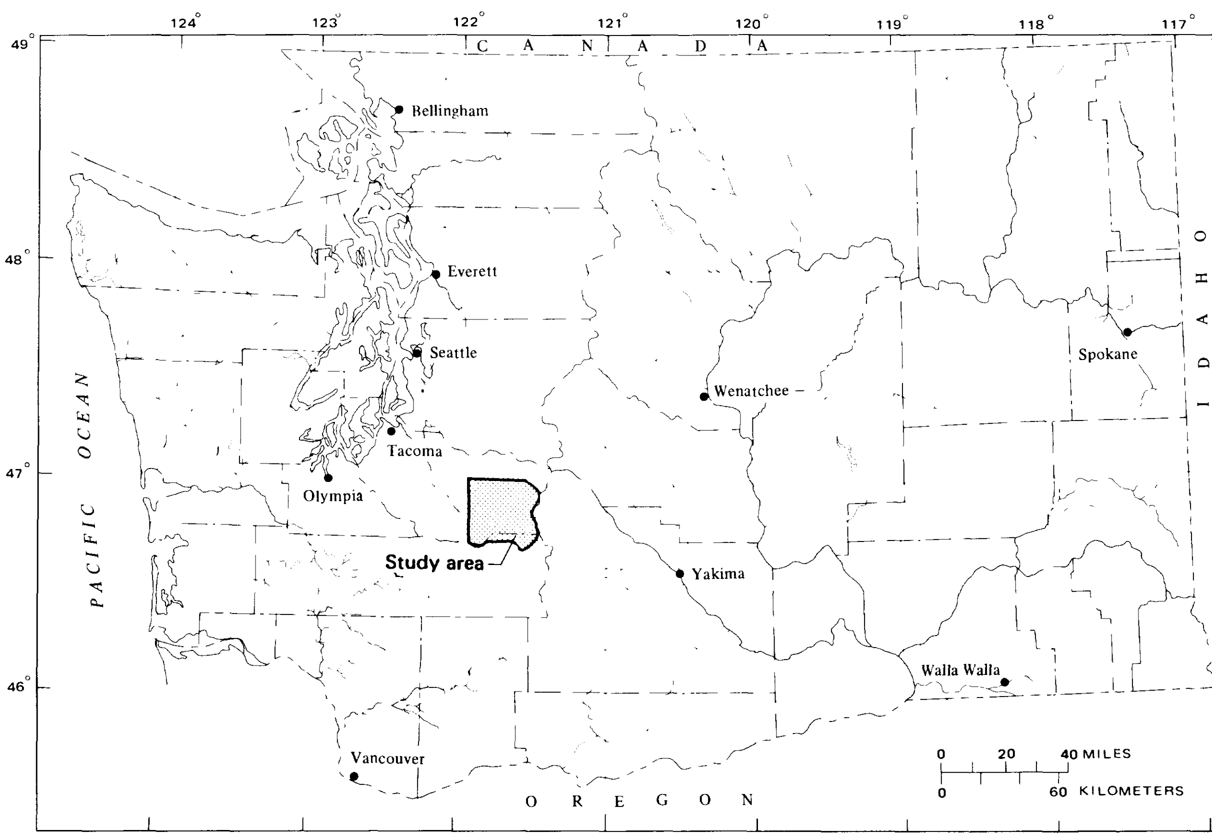

FIGURE 1.--Location of study area.

TABLE 1.--Climatological data[1] for Mt Rainier National Park in 1982

	Elevation (in feet)	Mean air temperature (°F)			Precipitation (in inches)		
		Jan	Aug	Annual	Jan	Aug	Annual
Longmire	2762	28.9	59.2	43.2	18.42	.90	88.45
Paradise	5427	21.2	51.4	35.5	23.64	1.37	120.89

[1]From National Oceanic and Atmospheric Administration, 1982.

METHODS OF STUDY

Lake Selection

Several characteristics were considered in selecting lakes to be sampled. Only lakes with surface areas of two acres or more were sampled. Lakes at high altitude were chosen because they receive the most precipitation and are more susceptible to acidification than lower altitude lakes (Logan and others, 1982; Turk and Adams, 1983). Lakes with drainage basins underlain by relatively uniform geological formations were preferred. However, not all of the drainage basins were of the same rock type. Lakes on all sides of Mount Rainier were chosen to observe any effects that the mountain may have on altering precipitation chemistry.

The locations of the 13 lakes sampled are shown in figure 2. They are Allen, one of the Chenuis group, Crescent, Crystal, Eleanor, Fan, one of the Golden group, Marsh, Mowich, Mystic, Shriner, and two unnamed lakes. To avoid confusion, lake location (as described on page v) is used to differentiate lakes that have the same name or are unnamed. The Chenuis Lake sampled is located in 17/8E-10K and is the southernmost of the Chenuis Lakes. The Golden Lake sampled is located in 16/7E-10A and is the largest of the Golden Lakes. One of the unnamed lakes is located in 16/7E-34J, between the north and south forks of the Puyallup River on the west side of the park. The other unnamed lake is in 17/10E-17L, the Bear Park area of the National Park, and is sometimes referred to as Bear Park Lake. For purposes of this report, Chenuis (17/8E-10K) and Golden (16/7E-10A) Lakes are referred to simply as Chenuis and Golden Lakes. The unnamed lakes, requiring differentiation, are referred to as Unnamed (A) Lake (16/7E-34J) and Unnamed (B) Lake (17/10E-17L).

Sampling and Analysis

The lakes were sampled during the week of August 15-19, 1983. A float-equipped helicopter was used to reach all of the lakes except Mowich, which was accessible by rowboat. While approaching a lake, photographs were taken (see appendix A) and the presence or absence of inflows and outflows was noted. The helicopter landed on the deepest part of the lake (generally near the center), which was determined either visually or from a bathymetric map. All water samples for the lake were collected from the water column at that point. Lake depth soundings and Secchi-disc measurements were made first. Temperature and dissolved-oxygen concentrations were then measured throughout the entire depth of the lake. A Yellow Springs Instruments (YSI) Model 57[a] temperature/dissolved-oxygen meter with a 300-foot lead was used. Vertical light transmission was measured at various depths and the extent of the photic zone determined using a Photomatic Underwater Photometer. Samples for determinations of pH and specific conductance were taken from depths

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[a]The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

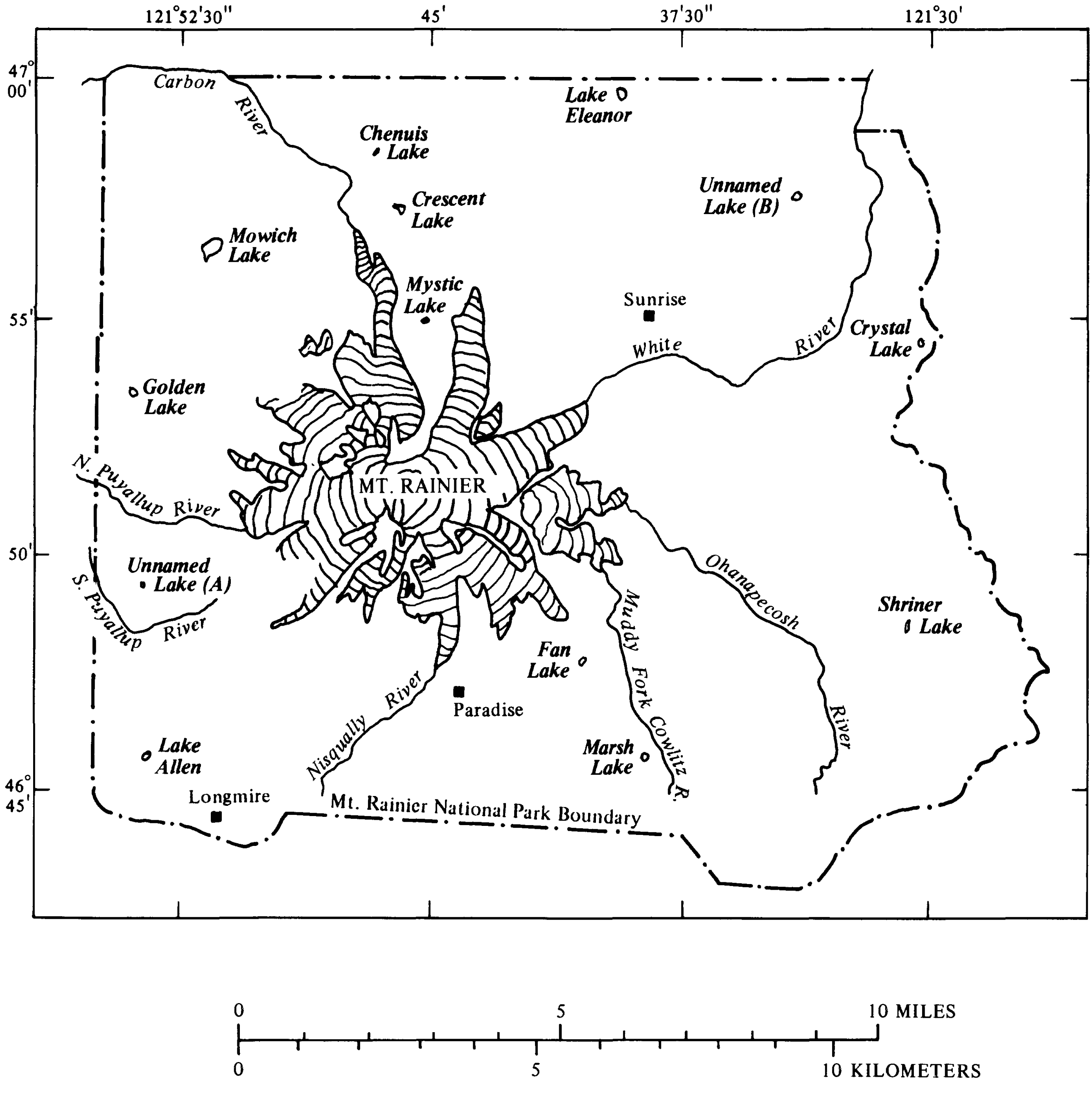

FIGURE 2.--Location of lakes sampled in Mount Rainier National Park.

representing the thermal zones of the lake. (In cases where a particular thermal zone was large, more than one sample was collected for pH and specific conductance.) Samples for phytoplankton analysis were collected from two to six different depths in the photic zone (depending upon the zone's depth) composited into one sample, and preserved on site with formalin. A sample from the 3-foot depth was taken to be analyzed for major water-quality constituents. Finally, any inflows observed were sampled for determinations of pH and specific conductance. All samples were tightly sealed, chilled, and stored in the dark until analyzed.

After two or three lakes were sampled, the samples were transported to a mobile laboratory stationed near the southwest corner of the park. Here pH and specific-conductance samples were analyzed using an Orion Model 407 A/F pH meter with a Model 91-62 low-ionic-strength probe, and a Lectromho Mark IV conductance meter. All pH and specific-conductance measurements were made within 3 hours of collection. Part of the water sample collected at the 3-foot depth was titrated for alkalinity in the mobile laboratory using a microburet, graduated in 0.01 milliliter divisions; alkalinity was calculated using Gran's plots (Gran, 1952). The remainder of the sample was apportioned and preserved for later analysis of major ions, metals, nutrients, and dissolved organic carbon. The samples for major ion and nutrient analyses were filtered using a 0.45 micrometer filter. Metal samples were filtered using a 0.10 micrometer filter. The smaller pore size is preferable for metals because a significant fraction of the suspended metals in dilute waters may pass through a 0.45 micrometer filter. Samples for dissolved organic carbon analysis were filtered through a 0.45 micrometer silver filter. All other preservation methodology followed standard Geological Survey procedures (U.S. Geological Survey, 1977, Skougstad and others, 1979).

Analyses for major ions, nutrients, dissolved organic carbon, and metals were done at the Geological Survey Water Quality Laboratory in Arvada, Colorado, using standard Survey procedures (U.S. Geological Survey, 1977, Skougstad and others, 1979). The taxonomic identifications of phytoplankton were made by Applied Biology Incorporated of Atlanta, Georgia.

Data evaluation

The sensitivity of the study lakes to acidic precipitation was evaluated using a set of threshold values proposed by the Ontario Ministry of the Environment (1979). That report suggests that a pH of 6.0, a specific conductance of 35 uS/cm, and an alkalinity of 15 mg/L (milligrams per liter) be used as levels below which a lake is considered sensitive to acidification.

The degree of lake acidification was evaluated primarily by pH. Other factors were considered, though, such as metals, nitrate, and sulfate concentrations. A method by Henricksen (1979) utilizing calcium concentrations and pH values was also used to assess acidification. All of these acidification evaluation methods are discussed in more detail with the results.

RESULTS

Geographical and Physical Characteristics

The geographical and physical characteristics of the lakes and contributing drainage basins are shown in table 2. The lake surface areas ranged from 2 to 17 acres, except for Mowich Lake, which was 112 acres. Maximum depths varied from 9 to 186 feet, but only three lakes were more than 30 feet deep (Golden, 57 feet; Crescent, 94 feet; and Mowich, 186 feet). The lakes ranged in altitude from 3,946 to 5,828 feet above mean sea level. Annual precipitation varied from 65 to 115 inches per year. Drainage basin areas ranged from 13 acres for Unnamed (A) Lake to 348 acres for Mowich Lake and were generally not proportional to lake area.

Relative vegetation density, which is indicative of soil cover, also is given in table 2. These densities are based on a comparison with each other; overall, even the thickest soils at Mount Rainier are thin when compared to lowland geology.

Geology of Drainage Basins

The percentages of major rock types present in the drainage basin of each lake are shown in table 2. The rock types considered are extrusive igneous, intrusive igneous, and unconsolidated. The percentages were estimated from a visual examination of a geological map of Mount Rainier National Park by Fiske and others (1964).

Extrusive igneous rocks erupted or flowed from the earth's surface in a molten state, solidifying quickly into relatively fine-grained rock above ground. Typical extrusive igneous rocks include andesite, basalt, and rhyolite, and these rock types make up 90 percent or more of the drainage basins of Allen, Crescent, Crystal, Fan, Golden, Marsh, Mowich, Shriner, and Unnamed (A) lakes.

Intrusive igneous rocks were originally molten also, but they solidified slowly into relatively coarse-grained rock prior to reaching land surface. Typical intrusive igneous rocks include granite, diorite, and quartz monzonite, and these rock types make up 80 percent or more of the drainage basins of Chenuis and Unnamed (B) lakes.

Unconsolidated rocks are created from erosional processes acting on extrusive and intrusive igneous rocks, and consist of alluvium and glacial deposits. Significant percentages of unconsolidated rock were found in the drainage basins of Eleanor and Mystic lakes.

All of the rocks described above are resistant to weathering and mineral dissolution. A discussion of weathering as it affects lake water chemistry and sensitivity to acidification is presented later in this report.

TABLE 2.--Geographical, physical and geological characteristics of study lakes

Lake	Location	County	Altitude, in feet above sea level	Drainage basin[1] area (acres)	Surface area (acres)	Maximum depth (feet)	Inflows[2] present	Outflows[2] present	Annual precipitation (inches)	Drainage basin geology, (in percent) Unconsolidated	Extrusive igneous	Intrusive igneous	Relative vegetation density
Allen	15/7E-23N	Pierce	4577	45	4	23	None	None	90	---	100	---	Thick
Chenuis	17/8E-10K	Pierce	4956	32	2	15	None	None	100	---	---	100	Thick
Crescent	17/8E-14N	Pierce	5565	125	17	94	None	1-NW	100	---	90	10	Thin
Crystal	16/10E-2D	Pierce	5828	146	8	22	1-NW	1-E	80	---	90	10	Thin
Eleanor	17/9E-3F	Pierce	4985	66	17	26	None	None	80	50	50	---	Thin
Fan	15/9E-15D	Pierce	5423	44	3	10	1-N	1-E	105	---	100	---	Mod.
Golden	16/7E-10A	Pierce	4490	187	15	57	None[3]	None	105	---	100	---	Thick
Marsh	15/9E-26G	Lewis	3946	87	5	9	None	None	100	---	100	---	Thick
Mowich	17/7E-25B	Pierce	4929	348	112	186	2-E	1-S	105	---	100	---	Mod.
Mystic	17/8E-35J	Pierce	5700	120	7	11	1-W	1-E	115	70	---	30	Mod.
Shriner	15/10E-11G	Pierce	4883	89	4	9	1-NE	1-S	90	---	90	10	Mod.
Unnamed (A)	16/7E-34J	Pierce	4525	13	2	12	None	None	110	---	100	---	Thick
Unnamed (B)	17/10E-17L	Pierce	5396	103	2	10	None	1-S	65	---	20	80	Thick

[1] Does not include lake surface area.

[2] Inflows and outflows are indicated by the number of each observed, followed by an abbreviation of the compass point of the side of the lake on which they were found.

[3] Inflow could be heard but not seen.

Field Measurements

The results of field measurements are shown in table 3. Temperature, dissolved oxygen, and light transmission data are shown in the table for representative depths only.

Surface-water temperatures of the lakes ranged from 12.8°C to 21.1°C. In the more shallow lakes (less than 30 feet deep), a decline was noted of up to four degrees from lake surface to bottom. None of the shallow lakes had temperatures below 10°C at any depth. The three deep lakes, Crescent, Golden, and Mowich, all had temperatures below 10°C at 40 feet and were about 4°C at the bottom. Profiles of temperature as a function of depth are shown in figure 3 for the three deep lakes. These lakes exhibited well-developed thermal stratification and distinct epilimnia, metalimnia, and hypolimnia. The rest of the lakes were more thoroughly mixed and had no thermal stratification due to their relative shallowness. The shallow lakes may be considered as consisting entirely of an epilimnion. (A more detailed discussion of temperature and thermal stratification may be found in appendix B of this report and in Primer on Lakes in Washington, Dion, 1978.)

Dissolved-oxygen concentrations ranged from 7.0 to 8.7 mg/L at the surfaces of the lakes. Concentrations in the shallow lakes were relatively consistent from top to bottom, but some increased up to 2 mg/L. The dissolved-oxygen profiles of the deep lakes showed considerable variation with depth, as is evident in figure 3. Crescent Lake and Mowich Lake showed slight increases in dissolved-oxygen concentration at about 10 feet, fairly uniform concentrations to 80 feet, and a relatively uniform decrease below that depth. In contrast, dissolved-oxygen concentrations in Golden Lake also increased at 10 feet, but quickly dropped to 2.2 mg/L at 40 feet and were completely depleted at the bottom (57 feet). The profiles of Crescent and Mowich Lakes are typical of deep alpine lakes. The initial increase in dissolved oxygen was most likely due to phytoplankton production. The decreasing dissolved oxygen below 80 feet in Mowich Lake was probably due to the oxidation of organic matter in the hypolimnion and the lack of subsequent oxygen replenishment because of thermal stratification. The dissolved-oxygen profile of Golden Lake is atypical and suggests that the lower part of the lake is receiving an unusual load of matter that is placing a heavy oxygen demand on that zone. The oxygen depleting process is probably biological in nature, although chemical oxidation-reduction reactions may cause some oxygen demand.

The pH values for all lakes ranged from 5.8 to 6.5 and were relatively constant with depth. Only Crescent and Unnamed (A) Lakes had pH values less than 6.0. Inflows were observed entering Fan, Mowich, and Mystic Lakes, and the pH values of the inflows were essentially the same as those of the lakes they fed.

Specific-conductance values were generally low, ranging from 4.1 to 21 uS/cm, with only two exceptions. Allen Lake had a specific conductance of 58 to 60 uS/cm throughout its vertical profile, and the bottom sample of Golden Lake had a specific conductance of 72 uS/cm, seven times the specific conductance of the surface sample. With the exception of Golden Lake, specific conductance of all of the lakes was uniform with depth. As with pH, specific conductance of inflows observed were similar to the receiving lakes.

TABLE 3.--Field measurements

Lake	Date	Sampling depth (feet)	Temper-ature (°C)	Dis-solved oxygen (mg/L)	pH	Specific conduc-tance (uS/cm)	Light trans-mission (pct)	Secchi-disk depth (feet)
Allen	8/15/83	3	15.0	8.6	6.4	58	87	> 23
	--do---	11	13.0	10.2	6.4	60	46	--
	--do---	21	12.1	10.2	6.4	60	23	--
Chenuis								
	8/15/83	3	16.5	8.2	6.1	9.2	45	>15
		7	16.1	8.2	6.2	9.0	23	--
		12	15.7	8.3	6.3	9.1	15	--
Crescent	8/15/83	3	12.8	8.7	5.8	6.5	31	57
	--do---	20	6.8	9.9	5.9	6.8	29	--
	--do---	40	5.3	9.8	5.9	7.0	15	--
	--do---	60	4.8	9.6	5.9	7.0	8.7	--
	--do---	90	4.3	9.2	6.1	6.9	2.4	--
Crystal	8/17/83	3	14.2	8.4	6.4	16	34	>22
	--do---	7	14.1	8.4	6.5	15	24	--
	--do---	11	13.5	8.8	6.5	16	21	--
	--do---	15	12.2	9.8	6.5	18	16	--
	--do---	19	11.9	10.1	6.5	19	14	--
Eleanor	8/17/83	3	15.7	8.0	6.5	20	44	> 26
	--do---	8	15.5	8.0	6.5	20	25	--
	--do---	13	15.2	8.3	6.5	20	25	--
	--do---	18	13.0	9.4	6.5	21	17	--
	--do---	23	11.5	9.2	6.5	21	17	
Fan	8/16/83	3	16.8	8.0	6.2	4.1	39	>10
	--do---	8	16.3	8.0	6.1	4.2	27	--
	--do---	Inflow	--	--	6.2	5.9	--	--
Golden	8/16/83	3	16.4	7.9	6.5	9.9	24	23
	--do---	13	8.2	8.2	6.3	13	13	--
	--do---	25	4.9	6.1	6.2	14	1.0	--
	--do---	40	3.9	2.2	6.1	17	--	--
	--do---	55	3.8	0.0	6.2	72	--	--
Marsh	8/16/83	3	21.1	7.8	6.4	11	32	> 9
	--do---	7	21.0	7.8	6.3	11	19	--
Mowich	8/19/83	3	14.8	8.6	6.4	12	32	56
	--do---	20	10.1	9.9	6.3	12	18	--
	--do---	40	6.4	9.8	6.4	12	8.2	--
	--do---	60	5.3	9.5	6.4	13	4.5	--
	--do---	80	4.6	9.4	6.5	13	3.3	--
	--do---	100	4.3	8.5	6.5	13	1.5	--
	--do---	125	4.1	7.7	6.4	14	--	--
	--do---	150	3.9	6.4	6.4	14	--	--
	--do---	180	3.8	5.5	6.4	14	--	--
	--do---	Inflow 1	--	--	6.4	13	--	--
	--do---	Inflow 2	--	--	6.5	14	--	--
Mystic	8/15/83	3	15.4	8.7	6.4	14	48	>11
	--do---	6	13.2	9.6	6.4	14	38	--
	--do---	9	12.8	9.8	6.3	13	37	--
	--do---	Inflow	--	--	6.3	12	--	--
Shriner	8/16/83	3	19.5	7.4	6.3	20	44	> 9
	--do---	7	19.2	7.3	6.3	20	31	--
Unnamed (A)	8/16/83	3	16.6	7.0	5.8	7.3	29	>12
	--do---	7	16.2	7.1	5.8	7.2	11	--
	--do---	11	13.3	8.4	5.9	7.4	4.2	--
Unnamed (B)	8/17/83	3	15.6	7.8	6.3	13	40	>10
	--do---	8	15.6	7.7	6.3	13	24	--

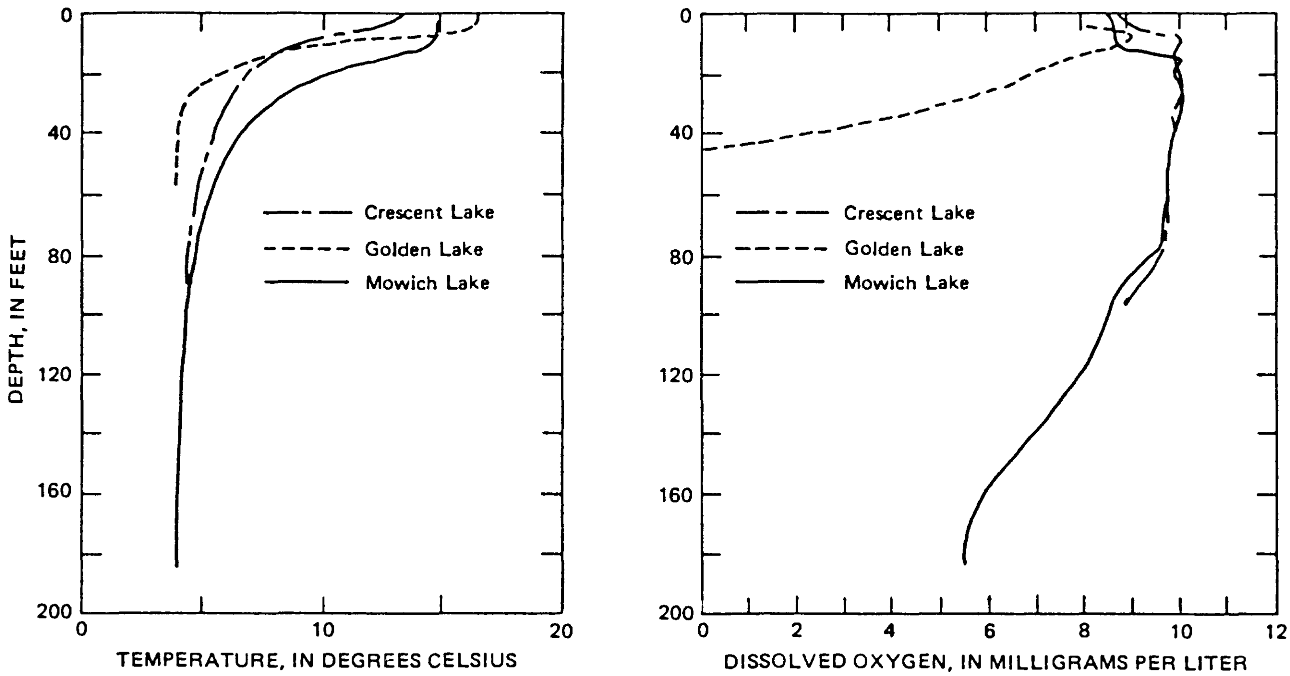

FIGURE 3.--Vertical profiles of temperature and dissolved-oxygen concentration for selected lakes.

The higher conductance values throughout Allen Lake are difficult to explain. The increased conductance in the bottom few feet of Golden Lake in conjunction with an absence of dissolved oxygen suggests that some chemical or biological process is increasing dissolved minerals in that zone.

Light transmission data indicate that the 1-percent transmission depth exceeded the depths of the shallow lakes and Crescent Lake, which is 94 feet deep. The photic zone, therefore, extends to the bottoms of these lakes. The 1-percent depth was 25 feet in Golden Lake and 100 feet in Mowich Lake. Profiles of vertical light transmission as a function of depth for Crescent, Golden, and Mowich Lakes are shown in figure 4. Light transmission values were lower in Golden and Unnamed (A) Lakes than in all the other lakes, indicating a higher turbidity in these two lakes. This turbidity may be due to either organic or inorganic matter.

Secchi-disk depths exceeded maximum lake depths in all lakes except the three deepest. Golden Lake had a value of 23 feet, and Crescent and Mowich Lakes had values of 57 and 56 feet, respectively. This emphasizes the fact that Golden Lake is more turbid than the other two deep lakes.

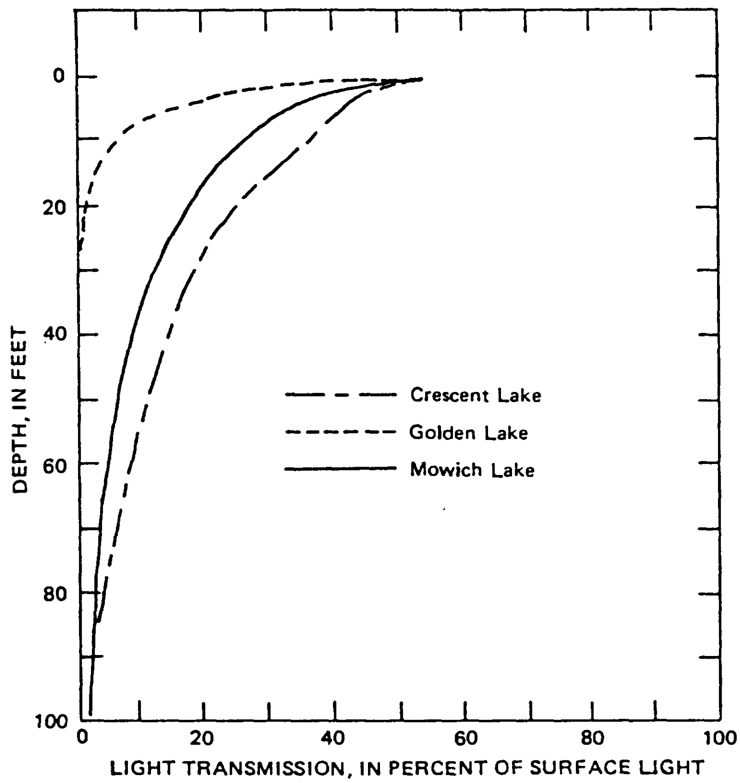

FIGURE 4.--Vertical profiles of light transmission for selected lakes.

Water Chemistry

Concentrations of the major cations and anions, silica, dissolved solids, and metals for all of the lakes are shown in table 4. In general, the concentrations of major cations and anions in the lakes were very low. One exception was Allen Lake, where most of the cation and anion concentrations were substantially higher than in all of the other lakes. This indicates that a relatively higher rate of mineral dissolution is occurring in Allen Lake, and is consistent with the specific-conductance values. The predominant cation in all of the lakes was calcium, although in some cases the percentage of sodium was almost as high, and the predominant anion was bicarbonate (or alkalinity). Alkalinity concentrations ranged from 2.1 to 9.0 mg/L in twelve lakes. The highest alkalinity concentration, 27 mg/L, was found in Allen Lake.

Silica concentrations were low, ranging from 1.6 to 12 mg/L and there appears to be little relation of silica to other constituents measured. The highest silica concentrations occurred in Mystic Lakes, where the drainage basin is predominantly unconsolidated rock. The silica concentrations in the other lakes appear to have little relation to geology.

TABLE 4.--Major cations and anions, silica, dissolved solids, and metals

[Expressed as milligrams per liter except where noted]

		Major cations				Major anions					Dissolved	Metals (ug/L)		
Lake	Date	Calcium	Magnesium	Sodium	Potassium	Alkalinity (as $CaCO_3$)	Sulfate	Chloride	Fluoride	Silica	solids (calculated)	Aluminum	Iron	Manganese
Allen	8/15/83	8.5	0.9	1.1	0.1	27	5.1	1.1	<0.1	5.1	38	<10	<10	10
Chenuis	8/15/83	.9	.2	.6	.1	4.6	.8	.5	< .1	1.6	7	<10	10	<10
Crescent	8/15/83	.5	.1	.5	.1	3.0	.4	.3	< .1	2.8	6	<10	<10	<10
Crystal	8/17/83	2.4	.2	.6	.2	7.7	.2	.2	< .1	4.1	13	<10	10	10
Eleanor	8/17/83	2.4	.5	.8	.1	8.4	1.9	.5	< .1	5.0	16	<10	10	<10
Fan	8/16/83	.3	.1	.3	.1	2.1	.3	.3	< .1	2.9	6	<10	10	<10
Golden	8/16/83	.8	.2	.7	.2	3.6	.6	.6	< .1	5.0	10	40	20	<10
Marsh	8/16/83	1.1	.2	.7	.1	4.3	.6	.3	< .1	3.9	9	10	10	10
Mowich	8/19/83	1.5	.3	.6	.1	5.2	.6	.5	< .1	2.8	10	10	10	<10
Mystic	8/15/83	1.3	.2	1.1	.4	7.4	.2	.3	< .1	12	20	<10	<10	<10
Shriner	8/16/83	2.5	.3	.7	.1	9.0	1.5	.3	< .1	3.5	14	20	10	<10
Unnamed (A)	8/16/83	.5	.2	.6	.2	2.2	.6	.8	< .1	2.6	7	30	20	10
Unnamed (B)	8/17/83	1.4	.3	.8	.2	6.2	.3	.4	< .1	5.3	12	<10	10	<10

Dissolved-solids concentrations ranged from 6 to 20 mg/L in 12 lakes, but Allen Lake had a concentration of 38 mg/L, reflecting the higher mineral concentration in Allen Lake than in the other study lakes.

Aluminum concentrations were 10 ug/L (micrograms per liter) or less in all lakes except Golden, Shriner, and Unnamed (A) Lakes. The highest of these was Golden Lake with an aluminum concentration of 40 ug/L. Iron concentrations were 10 ug/L or less in all lakes except for Golden and Unnamed (A), both of which had iron concentrations of 20 ug/L. Manganese concentrations in all lakes were 10 ug/L or less. The higher metals concentrations in Golden Lake may be related to biological or chemical activity in the lake, as suggested by the dissolved oxygen and specific-conductance data.

Concentrations of dissolved nutrients and dissolved organic carbon for all lakes are given in table 5. Ammonia concentrations ranged from 0.020 mg/L in Fan Lake to 0.054 mg/L in Mowich Lake. Nitrate concentrations were less than 0.01 mg/L in all lakes except Crescent and Unnamed (A) Lakes, where nitrate concentrations were 0.02 mg/L. Phosphate concentrations were less than 0.002 mg/L in all lakes sampled. The dissolved organic carbon concentrations ranged from 0.7 mg/L in Allen and Crescent Lakes to 2.5 mg/L in Unnamed (A) Lake. Golden Lake had the second highest dissolved organic carbon concentration. These data indicate that biological activity that produces organic carbon may be higher in Golden and Unnamed (A) Lakes than in other lakes, but nutrients in those two lakes were not correspondingly higher to support that activity. It must be considered also, that dissolved organic carbon in the lakes may not necessarily be produced in the lakes themselves, but may be a part of the runoff into them.

Plant Biology

Macrophytes, or larger plants, were minimal or non-existent in all of the study lakes. Consequently, they were not considered to be a major factor in affecting the chemistry of those lakes.

Phytoplankton were more abundant in some of the lakes than in others, as shown in table 6. Concentrations ranged from 45 cells/mL in Mystic Lake to 3,600 cells/mL in Unnamed (A) Lake. The high concentration of phytoplankton in Unnamed (A) Lake suggests that its low light transmission and high turbidity may be due to biological activity. However, Golden Lake also had a low light transmission, but phytoplankton concentrations were no higher than in some of the clearer lakes.

The percentage compositions of the phytoplankton collected are also given in table 6. Green and blue-green algae were the predominant types in most lakes. However, it should be noted that dominance in phytoplankton can change from day to day and little interpretation can be made from a one-time sampling. The phytoplankton samples were integrated over several depths in the lakes, resulting in a dilution of cell concentrations from depths with higher phytoplankton activity.

TABLE 5.--Nutrients and dissolved organic carbon

[Expressed as milligrams per liter]

Lake	Date	Ammonia (as N)	Nitrate (as N)	Phosphate (as P)	Dissolved organic carbon (as C)
Allen	8/15/83	0.033	<0.01	<0.002	0.7
Chenuis	8/15/83	.039	< .01	< .002	1.5
Crescent	8/15/83	.034	.02	< .002	.7
Crystal	8/17/83	.030	< .01	< .002	.8
Eleanor	8/17/83	.037	< .01	< .002	.8
Fan	8/16/83	.020	< .01	< .002	.9
Golden	8/16/83	.033	< .01	< .002	2.3
Marsh	8/16/83	.035	< .01	< .002	1.8
Mowich	8/19/83	.054	< .01	< .002	1.0
Mystic	8/15/83	.027	< .01	< .002	1.1
Shriner	8/16/83	.025	< .01	< .002	.9
Unnamed (A)	8/16/83	.041	.02	< .002	2.5
Unnamed (B)	8/17/83	.034	< .01	< .002	1.1

TABLE 6.--Phytoplankton concentrations and compositions

Lake	Date	Sampling depths[1] (feet)	Composition (total cells/mL)	Percent composition Green algae	Blue-green algae	Diatoms	Others[2]
Allen	8/15/83	3,11,21	700	25	45	0	30
Chenuis	8/15/83	3,7,12	2500	63	33	0	4
Crescent	8/15/83	3,20,40 60,90	1200	16	83	1	0
Crystal	8/17/83	3,7,11 15,19	1400	38	8	54	0
Eleanor	8/17/83	3,8,13 18,23	520	55	8	37	0
Fan	8/16/83	3,8	460	34	55	11	0
Golden	8/16/83	3,13,25 40,55	1100	82	16	0	2
Marsh	8/16/83	3,7	2000	14	85	1	0
Mowich	8/19/83	3,20,40 60,80,100	180	44	13	0	43
Mystic	8/15/83	3,6,9	45	24	22	36	18
Shriner	8/16/83	3,7	840	48	48	3	1
Unnamed (A)	8/16/83	3,7,11	3600	98	2	0	0
Unnamed (B)	8/17/83	3,8	2500	17	83	0	0

[1]Equal volumes composited into one sample.
[2]Consists of all other phytoplankton, including phytoflagellates.

Sensitivity of Lakes to Acidic Precipitation

As taken from the Ontario Ministry of the Environment (1979), a pH of 6.0, a specific conductance of 35 uS/cm, and an alkalinity of 15 mg/L were used as threshold levels below which a lake was considered sensitive to acidic precipitation. Table 7 shows that only two lakes, Crescent and Unnamed (A), had pH values below the threshold level; however, all the lakes except Allen had specific conductance and alkalinity values well below threshold levels. This indicates that the dissolved ions and the buffering capacities of all of the lakes except Allen are low and that the lakes are sensitive to acidification.

Many factors contribute to this sensitivity. The drainage basins are generally underlain by weathering-resistant rock and have a thin soil cover. The ratios of lake area to drainage basin area are high; that is, drainage basins are relatively small. Any precipitation in the drainage basin either falls directly on the lakes or travels only short distances in limited contact with surface rocks on its way to the lakes. In addition, all the study lakes are located in areas of high precipitation. The result of all this is that little dissolution of the surrounding minerals occurs and the chemistry of the lakes is highly influenced by the chemistry of the precipitation in the basin. Therefore, a constantly acidic precipitation could result in the eventual acidification of the lakes.

Present Degree of Lake Acidification

Even though the lakes are sensitive to acidification, they are not necessarily acidified. The primary indicator of acidification is pH, but the pH level at which acidification occurs is highly variable. For this study, lakes with a pH of 5.5 or lower were considered acidified. This figure is based on the fact that natural carbon dioxide dissolution in precipitation can result in a pH value as low as 5.6 (Galloway and others, 1976); that is, a pH of 5.6 or higher may be attributed solely to natural causes. As mentioned previously, the pH values of the lakes sampled ranged from 5.8 to 6.5, suggesting that the lakes are not acidified at this time. pH values in this range are considered low when compared to many natural waters, but may in fact be common in high altitude, pristine lakes (Welch and Chamberlain, 1981).

Since acidic precipitation neutralizes the alkalinity in a lake, alkalinity concentrations that are low, or which are known to have decreased with time, may be indicative of acidification. A temporal decrease of alkalinity often occurs before a substantial decline in pH is observed. This decrease is difficult to observe, however, in lakes where alkalinity concentrations are very low naturally, or where no historical data exist.

Henricksen (1979) proposed a method that considers these problems. If one assumes that the original alkalinity of a lake water is proportional to the original calcium concentration, and that the calcium concentration is not affected by acidification, then the calcium currently present in a lake sample is a reasonable measure of the lake's original alkalinity. Although acidification of the lake will reduce the alkalinity, the calcium

TABLE 7.--Comparison of pH, specific conductance, and alkalinity of study lakes to sensitivity thresholds

	pH	Specific conductance (uS/cm)	Alkalinity (mg/L)
Sensitivity threshold[1]	6.0	35	15
Allen	6.4	58	27
Chenuis	6.1	9.2	4.6
Crescent	5.8	6.5	3.0
Crystal	6.4	16	7.7
Eleanor	6.5	20	8.4
Fan	6.2	4	2.1
Golden	6.5	10	3.6
Marsh	6.4	11	4.3
Mowich	6.4	12	5.2455
Mystic	6.4	14	7.4
Shriner	6.3	20	9.0
Unnamed (A)	5.8	7	2.2
Unnamed (B)	6.3	13	6.2

[1]From Ontario Ministry of the Environment, 1979.

concentration should remain essentially constant. This reasoning also assumes that calcium bicarbonate is the only source of calcium and that any calcium sources or sinks affect alkalinity proportionally. Henricksen plotted pH against calcium concentration (which can be thought of as 'original' alkalinity) for numerous lakes in Norway. Using these data and a knowledge of which lakes were acidified and which were not, he constructed the empirical curve duplicated in figure 5. The plots of acidified lakes fall above the dashed curve. As can be seen from the plot of data generated by this study, Allen and Shriner Lakes plot slightly above the curve, indicating a possible acidification of those two lakes. The rest of the lakes in the study fall below the line and may be considered unacidified. It should be emphasized that this evaluation technique is based on the assumption that the curve applies to lakes in the Washington Cascades as well as to those in Norway.

Other indicators of acidification were considered also. Acidified lakes, because of their lower pH, often have substantially increased concentrations of dissolved metals (Cronan and Schofield, 1979). Also, because acidification usually involves sulfur or nitrogen species (Budiansky, 1980; Galloway and others, 1976), proportionally higher concentrations of sulfate and nitrate usually are observed in acidified lakes. The chemical data in tables 4 and 5, however, show that concentrations of dissolved metals, sulfur, and nitrogen species are low in the study lakes indicating no evidence of acidification.

It must be noted that the conditions in this study represent the lakes at one time of the year only and that variations of any or all constituents can occur seasonally. A good example is the runoff that occurs with spring snowmelt. It is thought that, at this time of year, the constituent loads are usually highest and pH is lowest. However, in this study, lakes were considered acidified only if the acidified conditions persisted into summer.

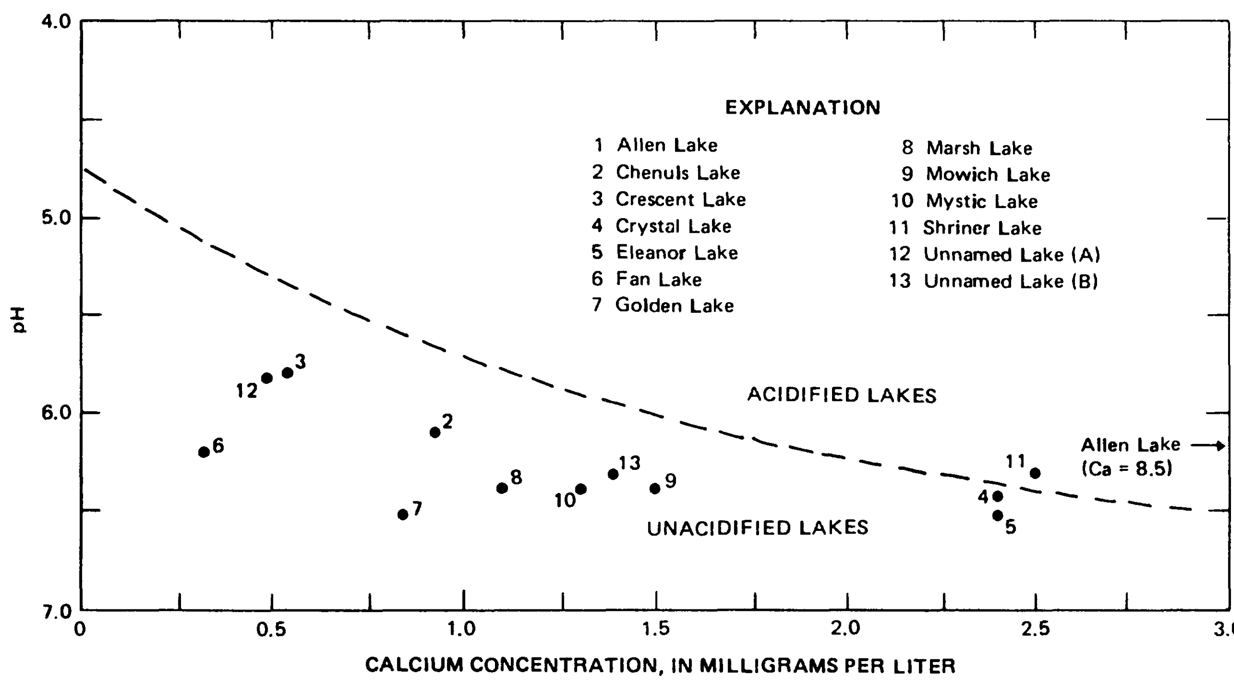

FIGURE 5.--pH versus calcium concentration as an indicator of acidification. (modified from Henriksen, 1979)

SUMMARY AND CONCLUSIONS

For the most part, the lakes sampled in Mount Rainier National Park were pristine. Specific conductance values were generally 21 uS/cm or less and dissolved-solids concentrations were generally 20 mg/L or less. The major cations were calcium and sodium, and the major anion was bicarbonate. Alkalinity concentrations ranged from 2.1 to 9.0 mg/L in twelve of the study lakes. The pH values were between 5.8 and 6.5. Aluminum, iron, and manganese concentrations were generally 10 ug/L or less.

Ten of the lakes were less than 30 feet deep. In these lakes, temperature, dissolved oxygen, pH, and specific conductance varied little with depth, and light penetrated to the bottom. Two of the deeper lakes, Crescent and Mowich, showed decreases in temperature with depth, corresponding variations in dissolved-oxygen concentrations and constant pH and specific conductances with depth. The third deep lake, Golden, was different from the other two in that the dissolved-oxygen concentrations decreased rapidly with depth and the specific-conductance values increased by a factor of seven from surface to bottom.

Notable chemical anomalies were observed in Allen, Golden, and Unnamed (A) Lakes. Allen Lake had a specific conductance of 58 uS/cm, a dissolved-solids concentration of 38 mg/L, and an alkalinity of 27 mg/L, all of which were substantially higher than in the other lakes. Although other major ion concentrations were correspondingly higher, they occurred in proportions similar to those in the rest of the lakes. No reason for this was evident in the data.

Golden Lake had a specific conductance value of 72 uS/cm at a depth of 55 feet, compared to only 10 uS at the 3-foot depth. Dissolved oxygen concentrations decreased with depth, becoming completely depleted at the lake bottom. Light transmission diminished more rapidly with depth than in most other lakes, indicating a higher turbidity. Concentrations of aluminum, iron, and dissolved organic carbon were higher than in most of the other lakes. It is evident from the dissolved-oxygen concentrations that anaerobic conditions exist on the lake bottom, creating a reducing environment that dissolves more minerals and metals than would an aerobic condition. This may account for the high specific conductance observed near the bottom of Golden Lake. The lake was thermally stratified at the time of sampling, indicating that mixing of the hypolimnion with other layers in the lake was minimal. These conditions would tend to keep the higher concentrations of dissolved minerals and lower concentrations of dissolved oxygen near the lake bottom.

Unnamed (A) Lake had the highest concentrations of phytoplankton (3,600 cells/mL) and dissolved organic carbon (28 mg/L) of all of the lakes sampled. Vertical light transmission was also lower at given depths than in most other lakes, indicating higher turbidity. Because this lake is only 12 feet deep, some light penetrates to the bottom and mixing is highly probable. This mixing would encourage algal activity and help to aerate the lake, preventing the development of an anaerobic situation similar to that observed in Golden Lake.

Twelve of the study lakes are sensitive to acidification. When lake data were compared to threshold levels of specific conductance and alkalinity, all of the lakes except Allen were classified in the sensitive range. This sensitivity is related to numerous physical, geological, meteorological, and hydrological characteristics of the lakes.

Although sensitive, none of the lakes appeared to be acidified at this time and cannot be classified as acidic. All pH values were above 5.5, the level used to indicate acidification. Concentrations of dissolved metals were low in all lakes, and the proportions of nitrate and sulfate to alkalinity did not suggest acidification. Comparisons of pH and calcium (which represented "original alkalinity") indicated that all lakes except Allen and Shriner were not acidic. The results from these comparisons are tenuous, however, because of the assumptions that must be made in using them and the general lack of long-term supporting data.

These sensitive lakes could remain unacidified only in the absence of acidic precipitation, suggesting that Mount Rainier National Park presently receives little or no acidic precipitation. This may be the case, since there are no major sources of acidic rain directly upwind of the park (Vong and Waggoner, 1983). However, this study represents only a small percentage of lakes in the park, at only one time of the year. Meteorological conditions near the park can vary considerably throughout the year. New sources of acidic precipitation could be added to the atmosphere upwind of the park at any time. Given their sensitivity, such changes could affect the rate and degree of acidification of lakes in the park in a relatively short time.

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APPENDIX A. Photographs of Lakes Sampled

page 27 follows

Allen Lake, August 15, 1983.

Chenuis Lake, August 15, 1983.

Crescent Lake, August 15, 1983.

Crystal Lake, August 17, 1983.

Eleanor Lake, August 17, 1983.

Fan Lake, August 16, 1983.

Golden Lake, August 16, 1983.

Marsh Lake, August 16, 1983.

Mowich Lake, August 19, 1983.

Mystic Lake, August 15, 1983.

Shriner Lake, August 16, 1983.

Unnamed (A) Lake, August 16, 1983.

Unnamed (B) Lake, August 17, 1983.

page 41 follows

APPENDIX B. Definition of Terms

APPENDIX B. DEFINITION OF TERMS

Definitions and brief explanations of most of the measurements made and constituents analyzed are given below. This information is presented in the same order that the data are arranged in tables 1 through 5.

Lake name--Lake name is as it appears on Geological Survey topographic maps. Lakes that are not named on the topographic maps are referred to as "unnamed," followed by the location designation or other identification scheme. In this report the proper name is used, followed by the term "lake." In common usage, however, "lake" may either precede or follow the proper name. The data are presented alphabetically by proper lake name.

County--The county in which the lake in situated. All lakes in this study are in Pierce County, except Marsh Lake, which is in Lewis County.

Altitude--The altitude of the lake surface, in feet above sea level, as taken from topographic maps. If altitude was not specifically shown on the map, it was estimated from the nearest contour lines. The actual altitude of the lakes varies seasonally.

Drainage basin area--The surface drainage area that contributes water to the lake. These areas were delineated on topographic maps and measured by digital planimeter. The lake area is not included in the drainage basin area.

Surface Area--The total surface area of the lake, as obtained from topographic maps using a digital planimeter. Actual surface area may vary seasonally.

Maximum Depth--Maximum depth for each lake, as obtained with a sounding weight. Like altitude and surface area, depth may vary seasonally. Deeper areas may exist in the lake, but were not detected during sounding.

Inflow--Surface-water inflows observed in the field. The number of inflows and their relative compass positions on the lakeshore are given. Some lakes had no visible inflow and water gain is from direct precipitation, inflowing ground water, and (or) sheet runoff during heavy precipitation that does not flow in defined channels.

Outflow--Surface-water outflows observed in the field. The number of outflows and their relative compass positions on the lakeshore are given. Some lakes had no surface-water outflow, and water loss is through evaporation and (or) outflowing ground water only.

Annual precipitation--Taken from a map of mean annual precipitation for the State of Washington (U.S. Department of Agriculture, 1965), which is based on the period 1930 to 1957.

Drainage basin geology--The predominant geology of the drainage basin, indicated as a percentage of three major rock types: unconsolidated deposits, extrusive igneous rocks, and intrusive igneous rocks. The percentages used were based on visual estimates from a geological map by Fiske and others (1964).

Relative vegetation density--A visual, qualitative estimate of plant cover in the drainage basin. The estimate was made from both aerial photographs and inspection in the field. Vegetation density is related to soil thickness and can be used to indicate basins where soil is thicker than in others. Thicker vegetation suggests a thicker supporting soil.

Sampling depth--The depth in feet, below the surface of the lake where measurements were made or samples were collected. Measurements of temperature, dissolved oxygen, and light transmission were taken at more frequent depth intervals than shown, but the data presented in the tables are considered adequate to describe conditions in each lake.

Temperature--Water temperature, in degrees Celsius (^{o}C). Temperature varies in most lakes with depth and time of year. It is also an important factor in controlling life processes and chemical-reaction rates, as well as many physical events that occur in the aquatic environment. Temperature profiles as a function of depth generally follow one of two patterns during the summer. In shallow lakes, the temperature is fairly uniform from top to bottom, implying well-mixed waters. In deeper lakes, three thermal layers usually are found: (1) an upper zone (epilimnion) of warmer uniform temperature; (2) an intermediate zone (metalimnion) in which temperature rapidly decreases with depth; and (3) a lower zone (hypolimnion) of colder water in which temperature is relatively uniform. In the winter, if freezing temperatures are reached, ice cover may be present and all lakes will have a fairly uniform increase in temperature with depth, up to about $4^{o}C$. The deeper lakes will have "turned over" in the fall and will do so again in the spring (Dion, 1978).

Dissolved oxygen--The gaseous oxygen that is in solution in the water. The concentration of dissolved oxygen in a lake varies with time of year and depth. It is a function of many factors, including water temperature and atmospheric pressure. Dissolved oxygen is also affected by various life processes, such as photosynthesis and respiration.

pH--The negative logarithm of the effective hydrogen-ion concentration, expressed as a number from 0 to 14. A pH of 7 is considered neutral. Decreasing pH indicates increasing acidity and increasing pH indicates increasing basicity.

Specific conductance--The ability of a substance to conduct an electrical current. In water, specific conductance is directly related to the number and chemical type of ions in solution and is expressed as uS/cm (microsiemens per centimeter) at $25^{o}C$.

Light transmission--The percentage of incident surface light penetrating to a given depth. Readings were taken from the lake surface to either the lake bottom (in shallow lakes) or to a depth where the penetrating light was 1 percent of the incident surface light (in deep lakes). The profiles generated by vertical light-transmission measurements (photometry) are an indication of water turbidity or, conversely, water clarity. The "1-percent depth" usually indicates the bottom of the "photic" zone, the zone in which primary production occurs. The 1-percent depth is also referred to as the compensation level.

Secchi-disk depth--The depth at which a standard disk disappears from view when lowered into the water. The disk, referred to as a "Secchi disk," is 8 inches in diameter with alternate black-and-white colored quarter sections. Like light transmission, Secchi-disk depth is a measure of water turbidity or clarity. Because changes in biological production can cause changes in the turbidity of a lake, Secchi-disk depth is often used as an approximate measure of the quantity of plankton in the water. In shallow lakes, the disk may still be visible while resting on the lake bottom. In such cases, the Secchi-disk depth is expressed as greater than (>) the maximum known lake depth.

Major cations and anions--The primary dissolved constituents that determine the chemical characteristics of a water. The major cations (positive ions) are calcium, magnesium, sodium, and potassium; the major anions (negative ions) are alkalinity (carbonate and bicarbonate), sulfate, chloride, and fluoride. Aluminum, iron, nitrate, and phosphate also may be important as major ions in instances where their concentrations are very high.

Alkalinity--Generally defined as the capacity of a solution to neutralize acid. Although many ions may contribute to alkalinity, the primary components are usually bicarbonate and carbonate. In the lakes sampled, carbonate is negligible and bicarbonate is the only major component of alkalinity. Alkalinity is, by definition, important in determining the buffering capacity of a water.

Silica--Expressed as silicon dioxide, this is a major dissolved constituent in most waters. Silica concentrations are usually related to drainage basin rock type and water temperature.

Dissolved solids--The minerals in solution in a water, primarily the major cations, anions, and silica. Upon evaporation of the water, the minerals leave a residue. In this study, dissolved-solids concentrations were calculated from the summation of the concentrations of the major contributing chemical constituents.

Metals--The specific metals selected for analysis were dissolved aluminum, iron, and manganese. These metals were chosen because they are quite common in most of the rocks in the study area and tend to dissolve readily under acidic conditions. Excessive aluminum concentrations also may be highly toxic to fish under low pH conditions (Driscoll and others, 1980).

Nutrients--Constituents that are required by an organism for the continuation of basic life processes. Although many elements and chemical species act as nutrients, various forms of nitrogen and phosphorus are usually the major nutrients for aquatic plants. The nutrients analyzed in this study were dissolved nitrate, ammonia, and orthophosphate.

Dissolved organic carbon--Carbon, usually of biological origin, that is dissolved in water. The amount of organic carbon present in a lake water is often directly proportional to the primary productivity of the lake. It may also be derived from the bottom sediments or from outside sources.

Phytoplankton--Phytoplankton are generally considered to be free-floating algae. They usually cannot be seen individually without magnification. Phytoplankton account for the majority of the primary productivity in a lake. Concentrations are expressed as cells per milliliter, and the community composition is expressed as percentages of four principal groups (green algae, blue-green algae, diatoms, and "others").

Further discussions dealing specifically with these and other lake characteristics and chemical constituents may be found in reports by Dion (1978), Dion and others (1980), and Hem (1978).