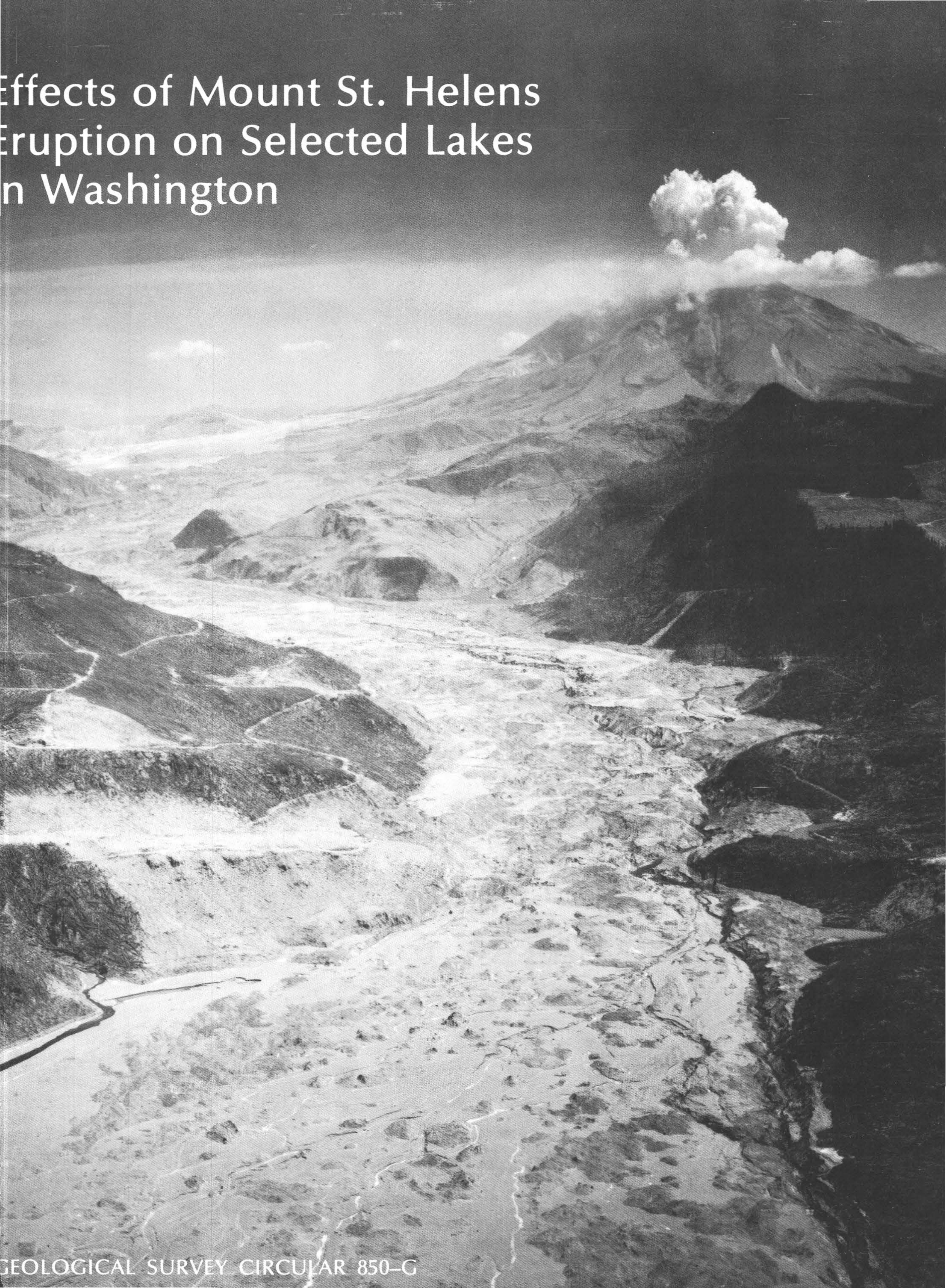
Effects of Mount St. Helens Eruption on Selected Lakes in Washington



GEOLOGICAL SURVEY CIRCULAR 850-G

EFFECTS OF MOUNT ST. HELENS
ERUPTION ON SELECTED LAKES
IN WASHINGTON

Aerial view of Mount Saint Helens, Spirit Lake, and Saint Helens Lake after the eruption.

Effects of Mount St. Helens Eruption on Selected Lakes in Washington

By N. P. Dion and S. S. Embrey

Hydrologic Effects of the Eruptions of Mount St. Helens, Washington, 1980

GEOLOGICAL SURVEY CIRCULAR 850-G

1981

United States Department of the Interior

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Doyle G. Frederick, *Acting Director*

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FOREWORD

On May 18, 1980, after more than a month of earthquakes and eruptions, Mount St. Helens, in southwestern Washington, exploded in a volcanic eruption more violent than any in the conterminous United States during the 20th century. A lateral blast of hot gas and rock particles devastated an area of about 150 square miles on the northern side of the mountain knocking down trees to a distance of 15 miles. Several minutes later, a giant ash cloud rose to about 60,000 feet. Winds then carried the ash cloud across the United States, with heavy fallout and deposition in eastern Washington and parts of Idaho and Montana. Earlier, smaller eruptions deposited ash in western Washington and parts of Oregon and Canada.

The hydrologic effects of the May 18 eruption have been both widespread and intense. During the eruption, a massive debris avalanche moved down the north flank of the volcano depositing about 3 billion cubic yards of rock, ice, and other materials in the upper 17 miles of the North Folk Toutle River valley. The debris deposits are about 600 feet thick in the upper reaches of the valley. Following the avalanche, runoff from the melted glaciers and snow, and possible outflow from Spirit Lake, caused an extraordinary mudflow in the North Fork Toutle River. The mudflow shattered and uprooted thousands of trees, destroyed most of the local bridges, and deposited an estimated 25,000 acre-feet of sediment in the Cowlitz River channel. A considerable amount of additional sediment was conveyed through the lower Cowlitz into the Columbia River where it was deposited and formed a shoal that blocked the shipping channel. Mudflows also occurred in the South Fork Toutle River and in tributaries on the east flank of Mount St. Helens which enter Swift Reservoir.

As part of a concerted Geological Survey effort to study the volcanic event and to identify potential hazards, Survey hydrologists have mounted an intensive program to document the hydrologic effects of the eruptions. The major initial hydrologic findings are reported in this circular series. Quick, useful assessment was made possible only because the Survey has long conducted extensive water-resources investigations in the affected areas of Washington, Oregon, and Idaho. Hence, there was a well-defined basis for identification and documentation of the types and magnitudes of hydrologic changes.

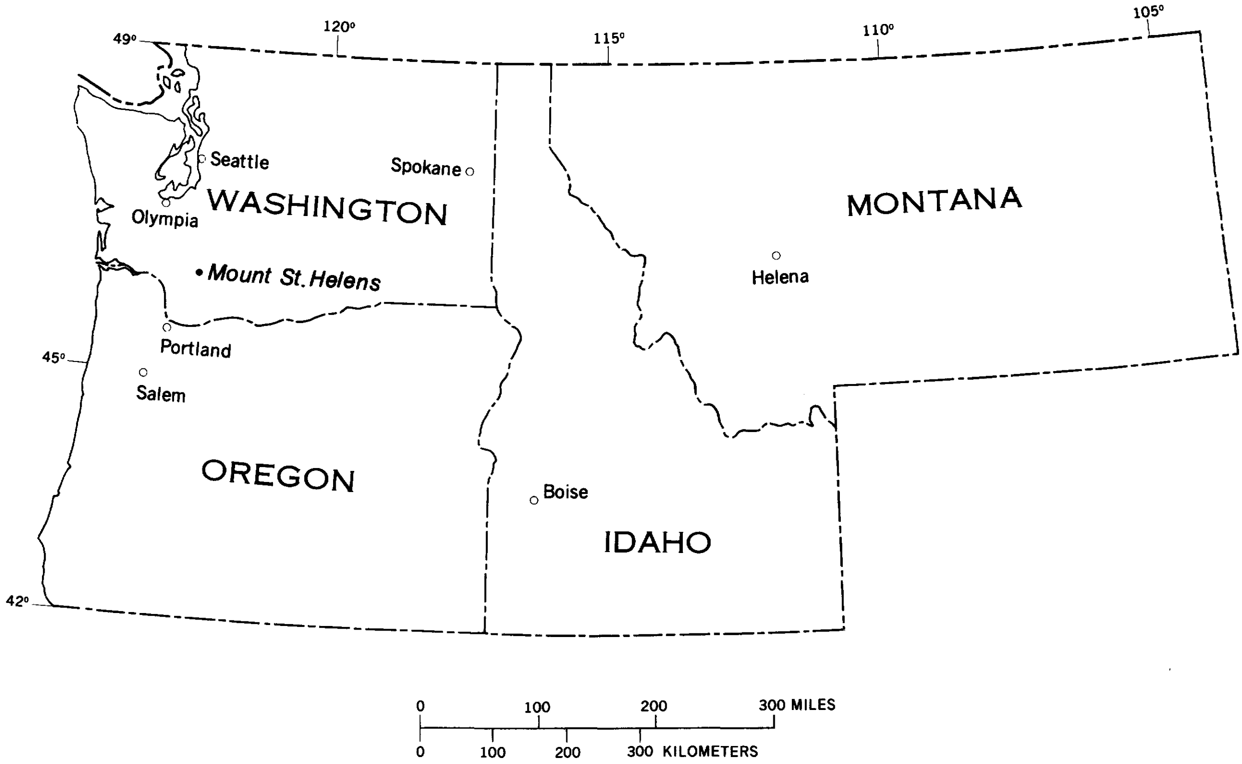
The Geological Survey Circular 850, "Hydrologic Effects of the Eruptions of Mount St. Helens, Washington, 1980," consists of individually published short chapters that emphasize data collection activities, field observations, and initial comparisons of pre- and post-eruption conditions. The series will cover hydrologic events occurring on May 18 in the Toutle and Cowlitz River; physical alteration of the Toutle River system; the chemical and physical quality of precipitation, streams, and lakes affected by volcanic ash fall; ash-leaching studies; and Mount St. Helens glaciers.

Doyle G. Frederick

Doyle G. Frederick
Acting Director

METRIC CONVERSION FACTORS

Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4,047.0	square meter



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By N. P. DION and S. S. EMBREY

ABSTRACT

The cataclysmic eruption of Mount St. Helens May 18, 1980, altered the physical, chemical, and biological characteristics of numerous Washington lakes. As would be expected, those lakes closest to the volcano were the ones affected most by the eruption. Spirit Lake can now be considered a completely different lake because of its higher altitude, larger area, shallower depth, and changed hydrology, biology, and water chemistry.

Water-quality changes were observed only in the lakes situated in the blast zone of the volcano. The changes included increases in most chemical constituents and reductions in transparency. Productivity levels in these lakes, as estimated by chlorophyll *a* concentrations, probably increased. No chemical or biological changes were observed in lakes that received only ash fall.

INTRODUCTION

The major eruption of Mount St. Helens on May 18, 1980, dumped tons of ash, mud, logs, and debris into more than 30 near-pristine lakes in the immediate vicinity of the volcano. Even lakes in parts of eastern Washington received deposits of windblown ash that locally measured up to 7.6 centimeters thick (Sarna-Wojicki and others, 1980).

The objective of this report is to describe the preliminary findings of a long-term study that was designed to (1) describe the present physical, chemical, and biological conditions in selected Washington lakes affected by volcanic activity; (2) compare present conditions in the lakes to pre-eruption conditions; and (3) document the recovery of the lakes. This report summarizes the first 5 months of a 3-year investigation that began in June 1980.

The study lakes, whose locations are shown in figure 1, were selected on the basis of the following criteria:

1. All the lakes received significant amounts of ash as a result of the May 18 eruption;
2. Most of the lakes had been studied previously by the U.S. Geological Survey, and some background data are available for comparison;
3. The lakes in the immediate vicinity of the volcano were sufficiently close to be impacted by the deposition of pyroclastic material, ash, ice, mud, or timber; and
4. The lakes distant from the volcano (that is, in eastern Washington) were at least moderately productive of aquatic plants and animals and showed a distinct seasonal succession of the algal community.

General descriptions of the locations and physical features of the eight lakes selected for study are summarized in table 1. Background data for most of the lakes are contained in Washington Department of Ecology Bulletins 42 (parts 2, 4, 5, and 6) and 43 (vol. 4); the detailed references are given at the end of this report. St. Helens Lake had not been studied by the U.S. Geological Survey prior to this investigation; consequently, no background data exist for that lake.

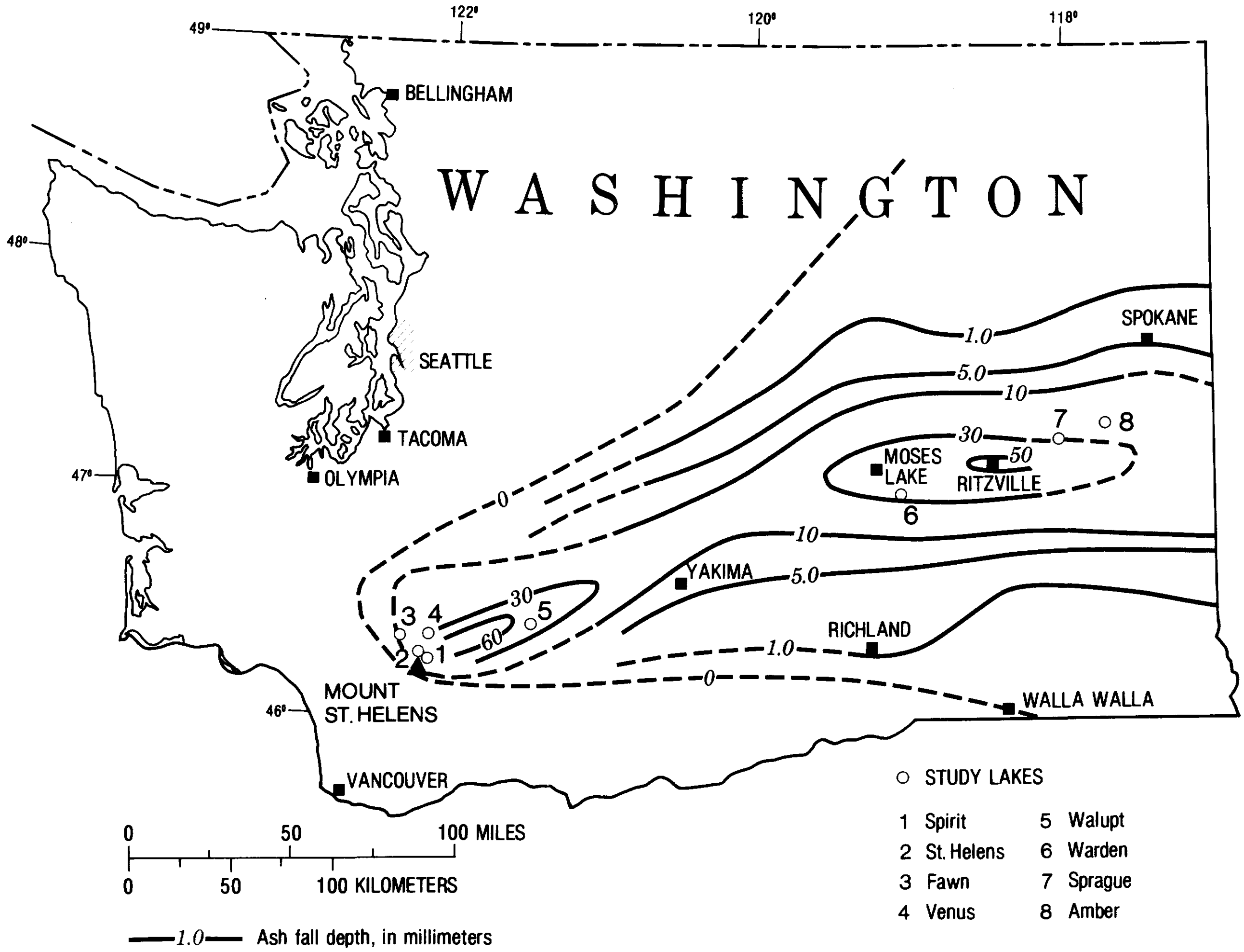

FIGURE 1.—Map showing distribution of volcanic ash and locations of lakes studied.

TABLE 1.—*Locations and physical features of study lakes*

Lake	County	Township, Range, and Section	Altitude (ft)	Area (acres)	Volume (acre-ft)	Maximum depth (ft)	Mean depth (ft)
Spirit [1]	Skamania	9N-5E-15	3,198	1,300	160,000	190	130
St. Helens	Skamania	9N-5E-3	4,567	79	--	--	--
Venus	Skamania	10N-5E-14	4,920	20	930	140	47
Fawn	Cowlitz	10N-4E-25	3,700	20	430	54	22
Walupt	Lewis	11N-11E-20	3,926	354	62,300	295	176
Warden	Grant	17N-29E-15	1,076	200	5,300	71	27
Sprague	Adams	20N-37E-12	1,878	1,800	19,000	20	11
Amber	Spokane	21N-40E-2	2,160	120	2,000	40	17

[1] Prior to May 18, 1980, eruption.

EFFECTS OF VOLCANIC ERUPTION

PHYSICAL

The four study lakes in the blast zone of Mount St. Helens (Spirit, St. Helens, Fawn, and Venus Lakes) received varying amounts of pyroclastic material, mud, ice, ash, and downed timber. The blast zone, as used in this report, is defined as the area immediately north of the volcano that was affected by the violent outburst, or explosion, that marked the beginning of the eruption. A detailed description of conditions in the blast zone at the time of the eruption was given by Korosec and others (1980).

Because of its proximity to the volcano, Spirit Lake was the most affected of the four lakes. A comparison of aerial photographs taken before (fig. 3) and after (fig. 4) the eruption shows that the lake increased in size and rose in altitude. The surface area of the lake increased from 1,300 acres to about 2,200 acres. Soundings of the east bay of the lake on October 16, 1980, indicated that the depth at the midpoint of the east bay, originally 190 ft (fig. 2), was less than 50 ft. Because of an extensive cover of logs on the surface of Spirit Lake, a post-eruption bathymetric map could not be constructed. The rise in lake level, estimated to be about 240 ft, is due to the blockage of the North Fork Toutle River, floods from melting snow on the volcano, and partial filling of the lake with debris (Youd and Wilson, 1980). Because of the blockage of the original outlet, surface outflow to North Fork Toutle River will not occur until the lake rises from its present altitude of about 3,440 ft to about 3,600 ft. The pre-eruption altitude of the lake was 3,198 ft.

St. Helens Lake is immediately north of the volcano and was in the direct line of the initial blast. Unlike Spirit Lake, St. Helens Lake did not receive a direct flow of volcanic material, so it was affected differently from Spirit Lake. Aerial photographs taken before (fig. 5) and after (fig. 6) the eruption depict the devastation resulting from the volcanic blast. As shown in figure 6, much of the surface of the lake is covered by logs, and much volcanic material undoubtedly fell into the lake or slid into it from the steep slopes that surround the lake. The outlet of the lake, which allows water to flow across a bedrock lip and into Spirit Lake, appears to have been unaffected. Water was observed flowing out of the lake when the area was visited in July and August 1980. Because bathymetric maps are not available for St. Helens Lake, the effects of the eruption on the depth of the lake cannot be accurately determined. Sporadic soundings of the lake with a handline suggest that the post-eruption lake is more than 250 ft deep.

Fawn Lake, about 9 miles north-northwest of the volcano, and Venus Lake, about 10 miles north-northeast of the volcano, were also impacted by the eruption; but, because they are farther from the volcano, they were less impacted than Spirit and St. Helens Lakes. Both Fawn and Venus Lakes received heavy deposits of ash, and most nearby trees were uprooted, blown down, or completely stripped of their bark, branches, and leaves (figs. 7 to 10). The stages of the lakes have not changed significantly because of the eruption, and when they were visted in August 1980, water was draining from both lakes. Comparisons of pre- and post-eruption bathymetric maps (not shown in report) indicate that the basins of Fawn and Venus Lakes have not changed significantly, despite the deposition of ash in the lakes.

The configurations of the basins of other study lakes also were unchanged. For this reason, photographs and bathymetric maps of these lakes have not been included in this report. Readers desiring that information are referred to reports by Bortleson and others (1974, 1976), Dion and others (1976, 1980), and McConnell and others (1976).

CHEMICAL

The May 18, 1980, eruption introduced huge quantities of volcanic debris into nearby lakes and varying quantities of ash into all lakes beneath the ash plume depicted in figure 1. Chemical analyses of the leachate of volcanic ash collected near Moses Lake (Taylor and Lichte, 1980) indicate that the ash contains the following, and possibly other, soluble constituents:

Constituent	Concentration (micrograms per gram dry ash)
Calcium	151
Chlorine	178
Magnesium	27
Manganese	2.0
Potassium	20
Sodium	143
Sulfate	534

Constituent	Concentration (nanograms per gram dry ash)
Arsenic	2
Barium	51
Beryllium	0.5
Cadmium	5
Copper	24
Iron	24
Lead	5
Mercury	0.1
Selenium	3
Zinc	12

The leachate also contained high concentrations of ammonia, nitrate, phosphate, and up to 225 mg/L (milligrams per liter) of dissolved organic carbon. Taylor and Lichte theorized that the source of the organic material in the ash was the atmospheric condensation of the products formed by the burning of vegetation surrounding the volcano.

In order to determine the effects of the debris and ash on the chemical characteristics of lake water, comparisons were made of chemical conditions in the study lakes before and after the eruption. Those conditions are summarized in tables 2–9, at the end of the report. Post-eruption vertical profiles of water temperatures and dissolved-oxygen concentrations were completed for most of the lakes studied and were compared with pre-eruption profiles, if available. These comparisons indicated that, except for Spirit Lake, no significant changes had occurred in the temperatures and dissolved-oxygen concentrations of the lakes; therefore, the profiles have not been included in this report. Because of the lack of either pre- or post-eruption data, however, this comparison was not made for St. Helens Lake.

Most of the water samples were collected over the deepest part of each lake; however, for logistical reasons, some of the samples from lakes in the blast area of the volcano were collected from the littoral (nearshore) zone of the lake. The amount of pre-eruption chemical data available for Fawn and Venus Lakes is limited to that collected as part of a reconnaissance investigation of Washington lakes.

SPIRIT LAKE

In addition to the logs covering its surface, Spirit Lake contains large amounts of organic debris that impart an unpleasant odor to the water and give it a dark color. In fact, the water looks and smells very much like the effluent liquor from a pulp mill. The lake is rich in organic compounds (H. E. Taylor and J. M. Klein, U.S. Geological Survey, oral commun., November 4, 1970), especially gases (R. A. Rasmussen, Oregon Graduate Center, oral commun., October 10, 1980), as a result of the thermal, chemical, and biological alteration of organic matter introduced at the time of eruption. When visited on September 4, 1980, the surface of the lake was emitting large quantities of gas, some of it in "boils" 2 to 3 ft in diameter and some of it in almost continuous "streamers" of gas bubbles. On the October 1980 visit, the gas activity of Spirit Lake was considerably less. According to Rasmussen, more than 50 gases have been identified, including H_2S (hydrogen sulfide), CS_2 (carbon disulfide), and COS (carbonyl sulfide). Many of the gases identified are toxic, and some are flammable. The concentrations of the gases within the lake, however, are unknown. Rasmussen also reported that there is a large amount of chlorine gas present.

FIGURE 2.—Bathymetric map of Spirit Lake before the eruption.

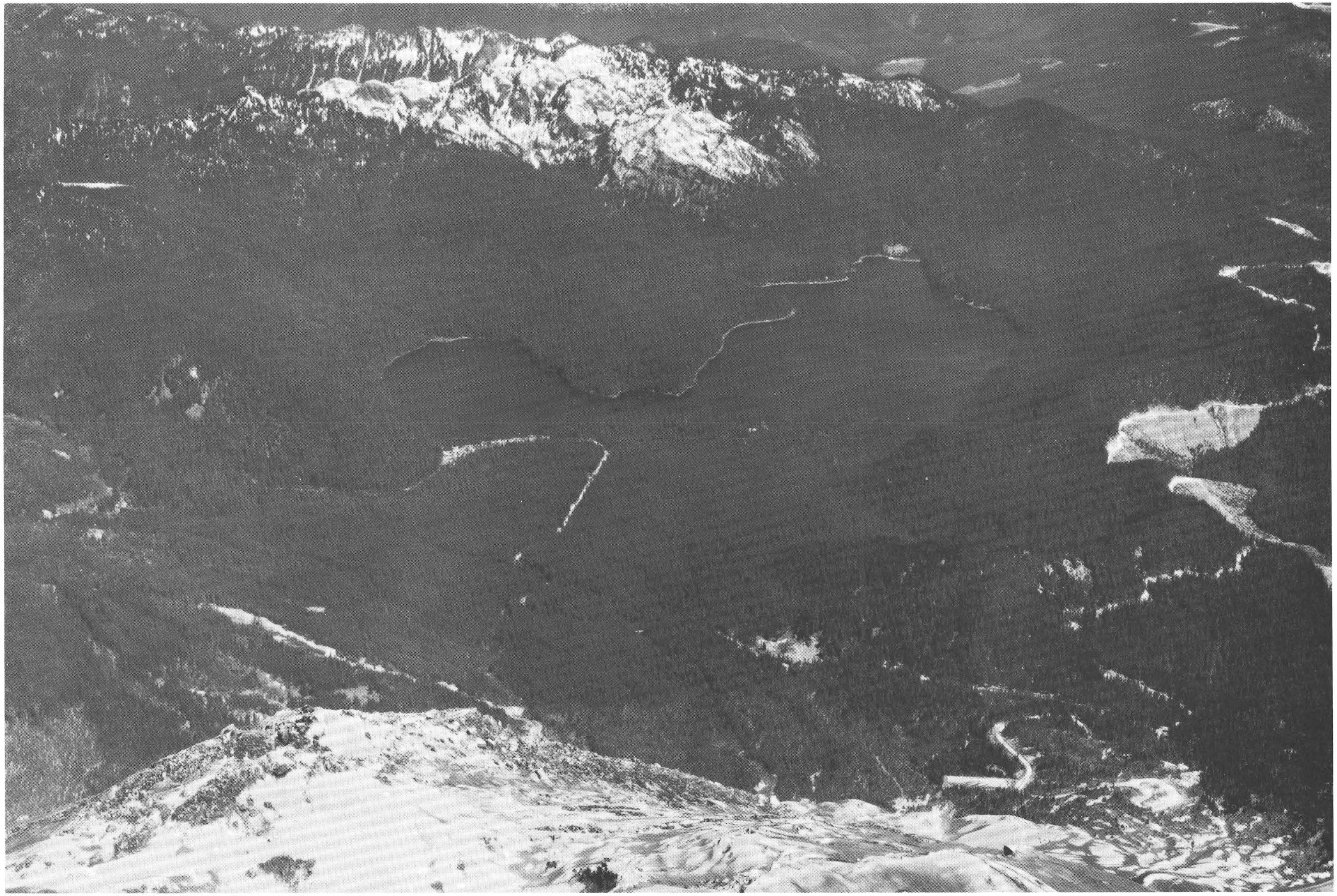

FIGURE 3.—Spirit Lake before the eruption. Top of Mount St. Helens in foreground. View is to the northeast.

Figure 4.—Spirit Lake after the eruption. View is to the northeast.

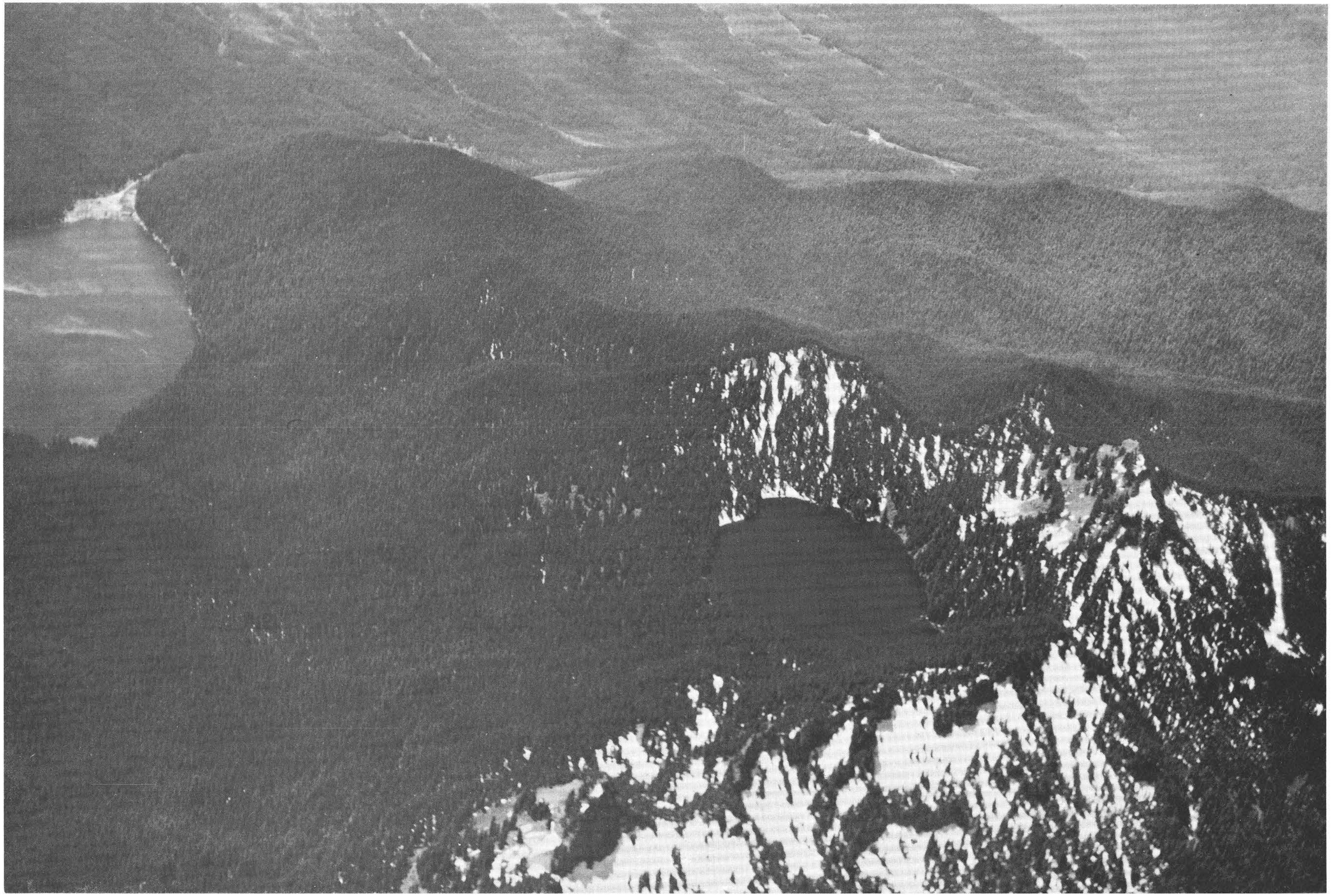

FIGURE 5.—St. Helens Lake before the eruption. View is to the south. Photograph from the Washington Game Department.

FIGURE 6.—St. Helens Lake after the eruption. View is to the south.

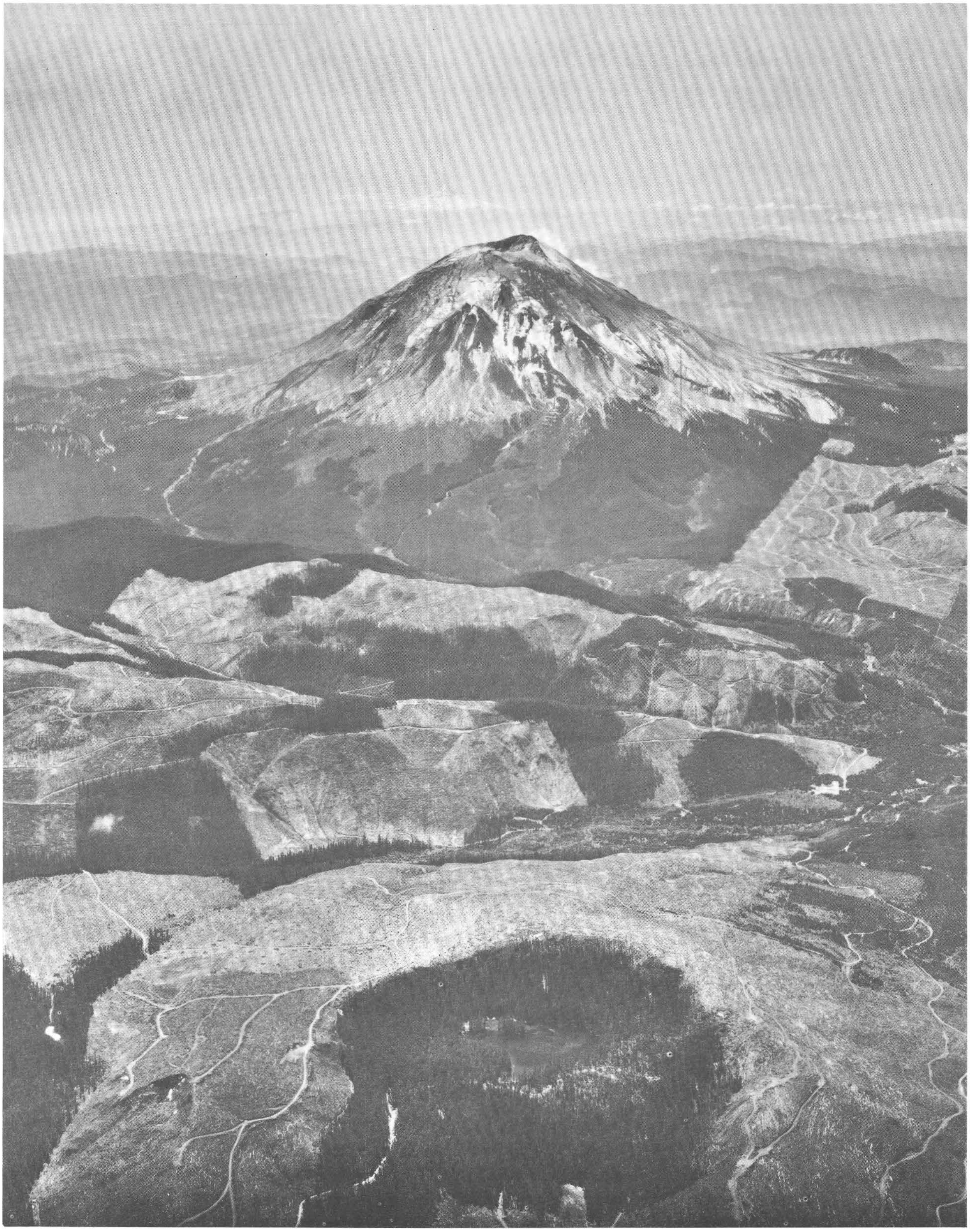

FIGURE 7.—Fawn Lake before the eruption. View is to the southeast.

FIGURE 8.—Fawn Lake after the eruption. View is to the southeast.

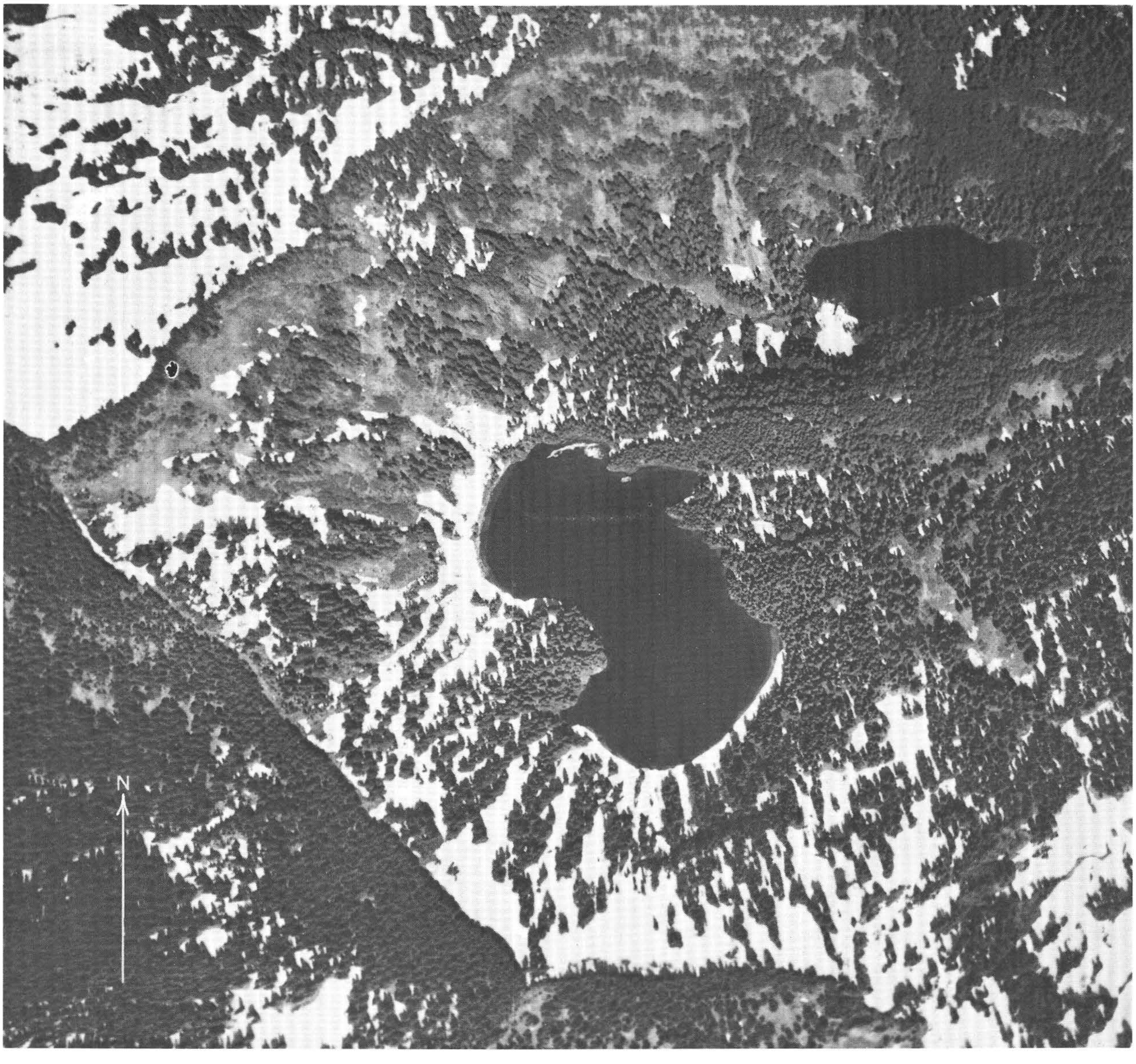

FIGURE 9.—Venus Lake before the eruption. Photograph from the Washington Game Department.

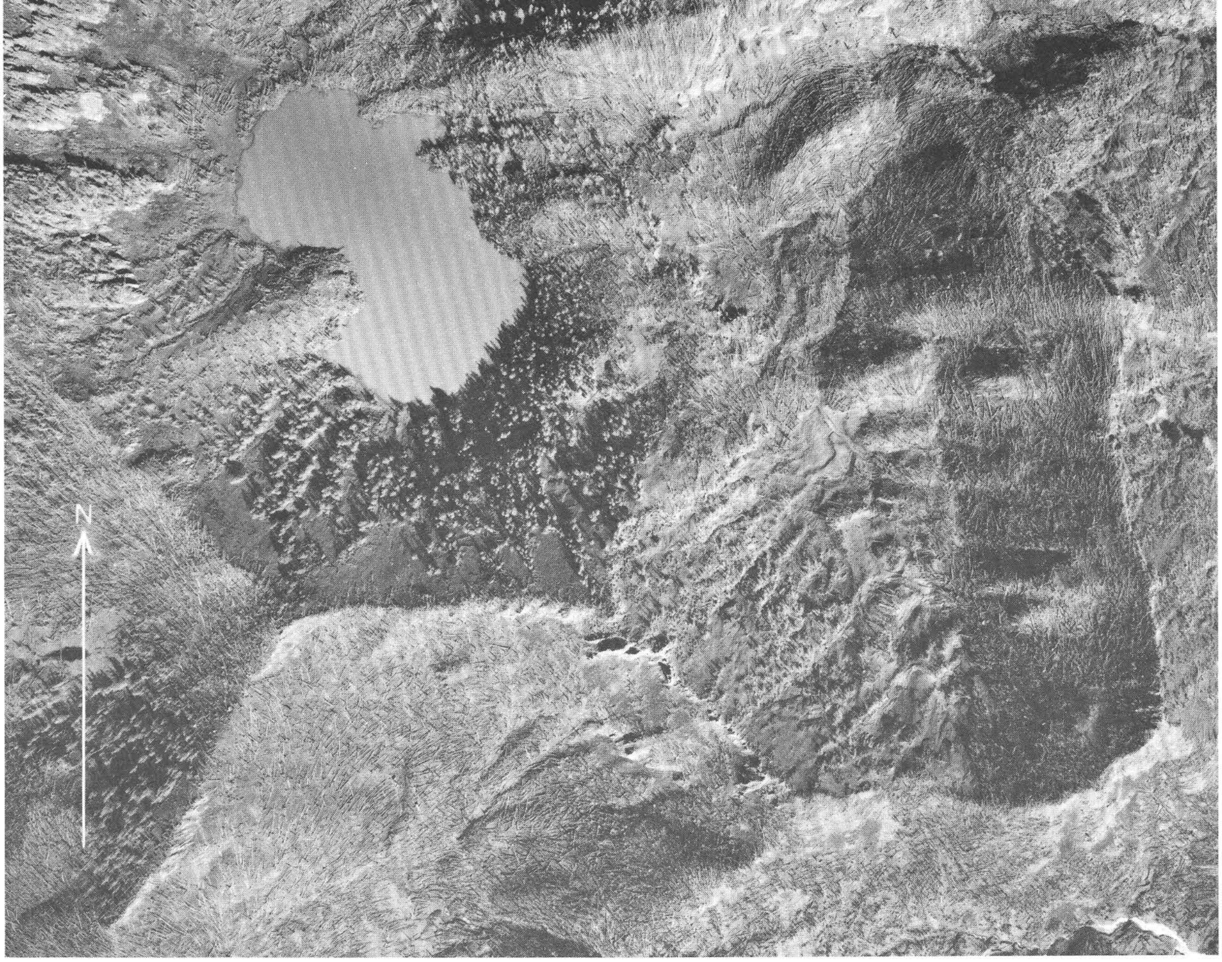

FIGURE 10.—Venus Lake after the eruption.

On May 19, 1980, one day after the eruption and the subsequent influx of hot volcanic material into Spirit Lake, the temperature at the water surface (fig. 11) was 32.7°C (T. J. Casadevall, U.S. Geological Survey, written commun., October 8, 1980). By October 16, 1980, the temperature at the water surface had decreased to 12.7°C and was only slightly higher than on October 9, 1974. The maximum temperature observed in 1974 was 16.1°C, in August.

The heating of Spirit Lake and the introduction of organic matter have contributed to the depletion of the DO (dissolved-oxygen) concentration of the water. On October 16, 1980, the DO concentration in the epilimnion (top water layer) of Spirit Lake was only 0.8 mg/L; on October 9, 1974, before the eruption, the DO concentration in the epilimnion was 9.2 mg/L.

The chemical data in table 2 indicate that, as a result of the eruption, there were significant increases in the dissolved-solids concentration, specific conductance, hardness, and alkalinity of the water in Spirit Lake. The concentrations of dissolved iron and manganese also greatly increased, although the iron concentration had decreased by June 8, 1980. Significant increases were also noted in the concentrations of metals (calcium, magnesium, sodium, and potassium), nutrients (nitrogen and phosphorus), sulfate, chloride, and silica.

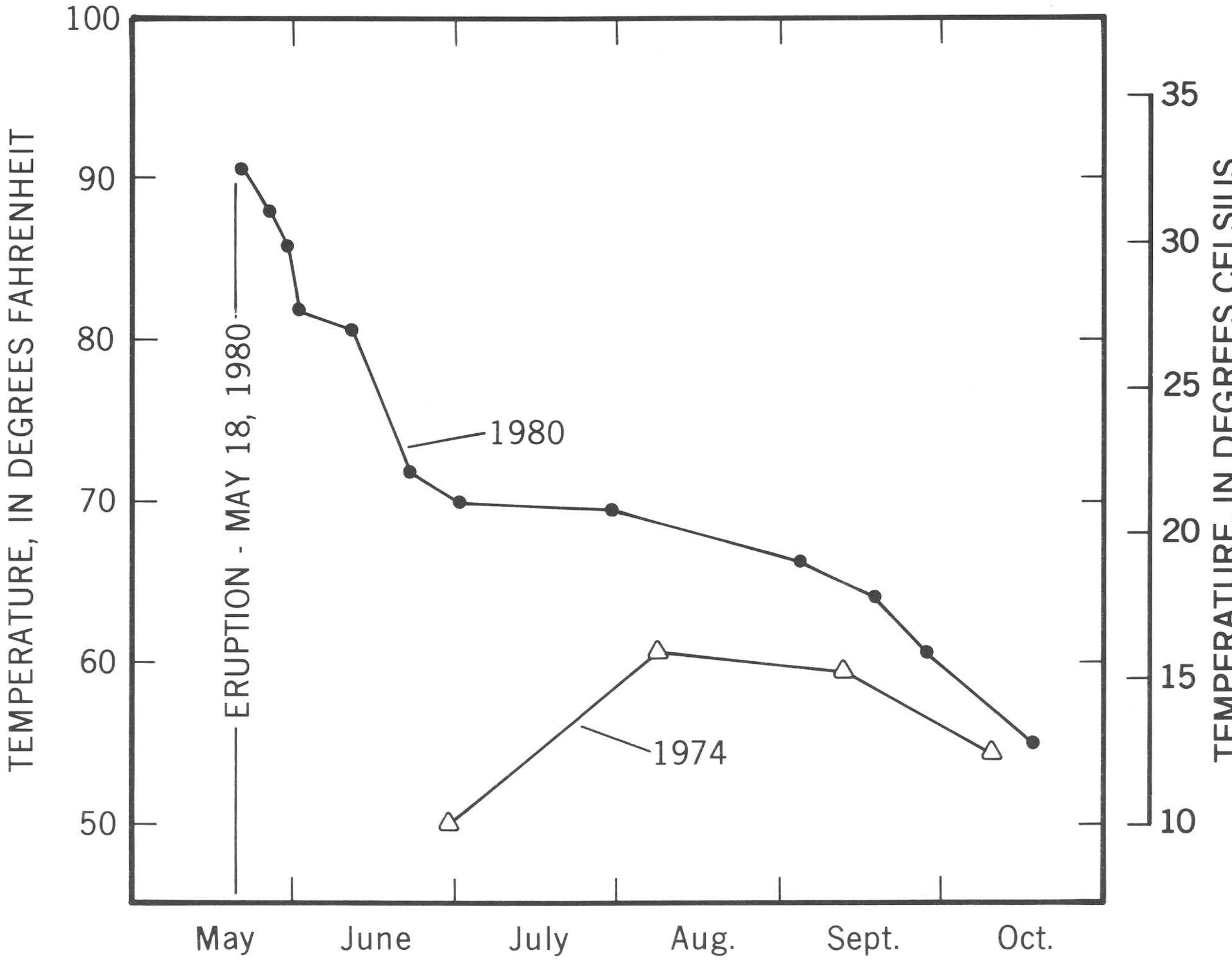

FIGURE 11.—Surface-water temperatures of Spirit Lake before (1974) and after (1980) the eruption of Mount St. Helens. (Based in part on data from T. J. Casadevall, U.S. Geological Survey, written commun., October 8, 1980.)

TABLE 2.—*Water-quality data for Spirit Lake*

[In milligrams per liter unless otherwise indicated]

	Pre-May 18, 1980, eruption									Post-May 18, 1980, eruption		
Date of collection (mo/day/yr)	6/27/74		8/7/74		9/11/74		10/9/74		3/28/80	6/6/80	6/8/80	7/28/80
Sample depth (ft)	3	171	3	171	3	164	3	164	Outlet	Littoral	Littoral	Littoral
Specific conductance (micromhos at 25°C)	27	35	25	35	26	33	19	20	30	844	828	860
pH (units)	6.9	6.4	8.3	8.2	6.6	6.2	7.2	7.2	7.1	6.4	6.0	6.8
Temperature (degrees Celsius)	10.0	4.0	16.0	4.0	15.0	3.0	12.3	3.5	2.6	26.0	26.0	20.6
Transparency, Secchi-disk (ft)	23		36		46		41		--	--	--	--
Dissolved oxygen (DO)	10.4	--	9.0	1.9	8.9	2.8	9.2	3.2	--	--	--	--
Hardness, as $CaCO_3$ (Ca,Mg)	--	--	--	--	--	--	12	17	9	240	230	240
Noncarbonate hardness	--	--	--	--	--	--	0	0	1	130	110	54
Calcium, dissolved (Ca)	--	--	--	--	--	--	5.0	3.5	2.8	74	74	76
Magnesium, dissolved (Mg)	--	--	--	--	--	--	.0	1.9	.6	13	12	13
Sodium, dissolved (Na)	--	--	--	--	--	--	1.8	2.1	2.0	68	68	78
Potassium, dissolved (K)	--	--	--	--	--	--	.4	.4	.6	15	15	15
Bicarbonate (HCO_3)	14	20	14	21	14	20	16	20	--	--	--	--
Alkalinity, total, as $CaCO_3$	11	16	11	17	11	16	13	16	8	110	120	190
Carbon dioxide (CO_2)	2.8	13	.1	.2	5.6	20	1.6	2.0	1.2	85	--	--
Sulfate, dissolved (SO_4)	--	--	--	--	--	--	1.3	1.3	.0	190	160	150
Chloride, dissolved (Cl)	--	--	--	--	--	--	1.3	1.5	1.5	86	86	83
Silica, dissolved (SiO_2)	12	15	11	16	11	15	12	15	12	46	46	50
Dissolved solids, calculated, sum of constituents	--	--	--	--	--	--	30	36	25	574	543	--
Nitrate plus nitrite, total as N	.00	.17	.00	.20	.00	.19	.02	.16	.06	.07	--	.00
Nitrogen, ammonia, total as N	.01	.01	.01	.01	.01	.02	.02	.02	.14	.19	--	.00
Nitrogen, total organic, as N	.03	.04	.09	.05	.04	.01	.13	.04	.80	1.5	--	1.2
Nitrogen, total, as N	.04	.22	.10	.26	.05	.22	.17	.22	1.0	1.8	--	1.2
Phosphorus, total, as P	.01	.02	.00	.01	.00	.01	.01	.01	.03	1.8	.40	.34
Phosphate, ortho, dissolved (PO_4)	.00	.03	.00	.03	.00	.00	.00	.00	--	--	--	--
Iron, dissolved, as Fe ($\mu g/L$)	20	230	50	180	80	180	50	50	10	8,800	2,100	420
Manganese, dissolved,, as Mn ($\mu g/L$)	0	260	10	70	0	40	0	0	6	5,000	4,900	4,800
Carbon, organic, total, as C	2.7	--	1.7	--	--	--	1.4	--	--	--	--	40
Chlorophyll *a* ($\mu g/L$)	0.7		0.3		0.6		1.3		--	--	--	--

ST. HELENS LAKE

Because no pre-eruption data were available for this lake, it was assumed that the quality of the water prior to the eruption was similar to that of Spirit Lake. Previous studies (Dethier and others, 1979) have shown that most alpine lakes without significant cultural development have similar chemical and biological characteristics. A comparison of pre-eruption water-quality conditions in Spirit Lake (table 2) with post-eruption conditions in St. Helens Lake (table 3) suggests that the changes brought about by the volcano were similar to those observed in Spirit Lake, but not as great. This generalization holds true for such characteristics as dissolved solids, specific conductance, hardness, metals, phosphorus, sulfate, and chloride. The concentrations of silica and DO in the epilimnion may have decreased, whereas the nitrogen, iron, and manganese may have increased. Assuming that the transparency of pre-eruption St. Helens Lake was as great as that of Spirit Lake, the transparency of St. Helens Lake, as measured by Secchi disc, was substantially decreased because of the suspended mud and ash. On August 28, 1980, the water was grayish brown and transparency was only 1 ft. No significant change in the water temperature has been observed.

FAWN LAKE

The pre-eruption water-quality data for this lake are sparse, making comparisons difficult. The small amount of available information (table 4) suggests that the specific conductance, hardness, and concentrations of metals, sulfate, chloride, dissolved solids, organic nitrogen, iron, manganese, and chlorophyll *a* increased while the transparency and concentration of dissolved silica decreased as a result of the

TABLE 3.—*Water-quality data for St. Helens Lake*

[In milligrams per liter unless otherwise indicated]

	Post-eruption			
Date of collection (mo/day/yr)	6/6/80	7/28/80	8/28/80	
Sample depth (ft)	Littoral	Littoral	3	240
Specific conductance (micromhos at 25°C)	150	161	154	164
pH (units)	7.1	6.4	6.6	6.6
Temperature (degrees Celsius)	5.4	17.0	11.0	5.3
Transparency, Secchi-disk (ft)	--	--	1.0	
Dissolved oxygen (DO)	7.2	--	7.0	2.6
Hardness, as $CaCO_3$ (Ca,Mg)	40	42	44	43
Noncarbonate hardness	31	30	35	36
Calcium, dissolved (Ca)	14	14	15	15
Magnesium, dissolved (Mg)	1.3	1.6	1.5	1.4
Sodium, dissolved (Na)	8.9	8.8	9.2	9.3
Potassium, dissolved (K)	2.5	2.8	2.4	2.2
Bicarbonate (HCO_3)	0	--	--	--
Alkalinity, total as $CaCO_3$	9	12	9	9
Carbon dioxide (CO_2)	1.4	--	--	--
Sulfate, dissolved (SO_4)	36	43	38	44
Chloride, dissolved (Cl)	16	12	12	14
Silica, dissolved (SiO_2)	7.6	8.7	5.8	5.7
Dissolved solids, calculated, sum of constituents	93	99	90	98
Nitrate, plus nitrite, total as N	.01	.09	.00	.05
Nitrogen, ammonia, total as N	.09	.02	.02	.02
Nitrogen, total organic as N	.13	.88	.56	.58
Nitrogen, total as N	.23	.99	.58	.65
Phosphorus, total as P	.17	.11	.05	.16
Phosphate, ortho, dissolved (PO_4)	.52	.34	.06	.06
Iron, dissolved as Fe (μg/L)	75	140	150	50
Manganese, dissolved as Mn (μg/L)	320	330	330	360
Carbon, organic, total as C	--	--	5.5	--
Chlorophyll *a* (μg/L)	--	--	3.1	

TABLE 4.—*Water-quality data for Fawn Lake*

[In milligrams per liter unless otherwise indicated]

	Pre-eruption		Post-eruption	
Date of collection (mo/day/yr)	9/14/74		8/27/80	
Sample depth (ft)	3	72	3	50
Specific conductance (micromhos at 25°C)	30	46	666	760
pH (units)	--	--	6.5	6.5
Temperature (degrees Celsius)	14.8	3.7	15.7	9.9
Transparency, Secchi-disk (ft)	21		7	
Dissolved oxygen (DO)	8.8	1.0	9.2	.6
Hardness, as $CaCO_3$ (Ca,Mg)	--	--	200	210
Noncarbonate hardness	--	--	180	190
Calcium, dissolved (Ca)	--	--	68	74
Magnesium, dissolved (Mg)	--	--	6.2	6.8
Sodium, dissolved (Na)	--	--	46	47
Potassium, dissolved (K)	--	--	10	11
Bicarbonate (HCO_3)	--	--	--	--
Alkalinity, total as $CaCO_3$	--	--	19	25
Carbon dioxide (CO_2)	--	--	--	--
Sulfate, dissolved (SO_4)	--	--	170	180
Chloride, dissolved (Cl)	--	--	71	76
Silica, dissolved (SiO_2)	--	--	8.1	9.5
Dissolved solids, calculated, sum of constituents	--	--	392	414
Nitrate, plus nitrite, total as N	.02	.01	.00	.00
Nitrogen, ammonia, total as N	.06	.27	.02	.21
Nitrogen, total organic as N	.05	.02	.56	.79
Nitrogen, total as N	.13	.30	.58	1.0
Phosphorus, total as P	.00	.05	.02	.06
Phosphate, ortho, dissolved (PO_4)	.00	.02	.03	.03
Iron, dissolved as Fe (μg/L)	--	--	--	--
Manganese, dissolved as Mn (μg/L)	--	--	--	--
Carbon, organic, total as C	--	--	1.9	--
Chlorophyll *a* (μg/L)	--		3.6	

eruption. The decrease in silica concentration may have been the result of changes in the algal diatom population and not a direct result of the eruption. The water transparency observed on August 27, 1980, was 7 ft, but it had increased to 12 ft by October 28, 1980.

VENUS LAKE

The paucity of chemical data available for this lake prevents a complete discussion of the effects of the eruption. However, the observed increase in the specific-conductance value, from 9 to 233 micromhos (table 5), suggests that the lake water has undergone some type of alteration because of the eruption.

WALUPT LAKE

On the basis of available chemical data, the eruption had no effect on the water quality of Walupt Lake, about 37 miles northeast of the volcano. The relatively low transparency observed on June 23, 1980 (3.5 ft—table 6), occurred at a time of high runoff and inflow, and the exact source of the inorganic suspended sediment that caused the low transparency is not known. The source of the sediment may have been ash that was deposited either directly in the lake or on snow in the drainage basin of the lake. The sediment may also have been the result of normal spring runoff, although the minimum transparency value observed prior to the eruption was 20 ft (in 1971).

WARDEN, SPRAGUE, AND AMBER LAKES

For the most part, on the basis of chemical and physical characteristics documented in this report, the study lakes in eastern Washington appear to have been unaffected by the volcanic eruption, despite the deposition of up to 3 inches of ash in some areas. The chemical data

TABLE 5.—*Water-quality data for Venus Lake*

[In milligrams per liter unless otherwise indicated]

	Pre-eruption		Post-eruption
Date of collection (mo/day/yr)	9/14/74		7/28/80
Sample depth (ft)	3	125	Littoral
Specific conductance (micromhos at 25°C)	9	12	233
pH (units)	--	--	6.3
Temperature (degrees Celsius)	9.4	3.8	17.8
Transparency, Secchi-disk (ft)	66		--
Dissolved oxygen (DO)	9.5	7.2	--
Hardness, as $CaCO_3$ (Ca,Mg)	--	--	60
Noncarbonate hardness	--	--	58
Calcium, dissolved (Ca)	--	--	20
Magnesium, dissolved (Mg)	--	--	2.4
Sodium, dissolved (Na)	--	--	13
Potassium, dissolved (K)	--	--	2.7
Bicarbonate (HCO_3)	--	--	--
Alkalinity, total as $CaCO_3$	--	--	2
Carbon dioxide (CO_2)	--	--	--
Sulfate, dissolved (SO_4)	--	--	61
Chloride, dissolved (Cl)	--	--	19
Silica, dissolved (SiO_2)	--	--	8.2
Dissolved solids, calculated, sum of constituents	--	--	--
Nitrate, plus nitrite, total as N	.01	.02	.00
Nitrogen, ammonia, total as N	.04	.03	.00
Nitrogen, total organic as N	.10	.08	.74
Nitrogen, total as N	.15	.13	.74
Phosphorus, total as P	.00	.01	.16
Phosphate, ortho, dissolved (PO_4)	.00	.00	--
Iron, dissolved as Fe ($\mu g/L$)	--	--	51
Manganese, dissolved as Mn ($\mu g/L$)	--	--	370
Carbon, organic, total as C	--	--	3.1
Chlorophyll *a* ($\mu g/L$)	--		--

(tables 7–9) suggest that the dissolved-iron concentration in the hypolimnion (bottom water layer) of Amber Lake and the dissolved-manganese concentration in the hypolimnion of both Warden and Amber Lakes have increased. However, the data for Sprague Lake suggest that the iron and manganese concentrations in that lake have decreased. Given this set of seemingly contradictory data, it is difficult to ascribe changes in the water chemistry of the lakes to the eruption with any degree of certainty.

BIOLOGICAL

Very little pre-eruption biological information is available for lakes in the blast zone of Mount St. Helens, and, therefore, the biological effects of the eruption can only be surmised. Qualitative and quantitative data pertaining to populations of phytoplankton and zooplankton are available for the post-eruption period, but, because corresponding pre-eruption data are not available, the post-eruption data have not been included in this preliminary report. Productivity levels can be approximated, however, by the concentration of chlorophyll *a* in the water. Chlorophyll *a* is a green photosynthetic pigment present in all groups of algae.

Chlorophyll *a* concentrations in Spirit Lake in 1974 ranged from 0.3 to 1.3 $\mu g/L$ (micrograms per liter). If the assumption can be made that pre-eruption concentrations in other alpine study lakes (St. Helens, Fawn, Venus, and Walupt Lakes) were similar to that in Spirit Lake, it appears that the productivities of all lakes mentioned were increased as a result of the eruption. The possibility exists, however, that the very fine suspended sediment in the water samples interfered with the optical technique of determining chlorophyll *a*

TABLE 6.—*Water-quality data for Walupt Lake*

[In milligrams per liter unless otherwise indicated]

	Pre-eruption					Post-eruption			
Date of collection (mo/day/yr)	7/8/71	8/18/71		10/5/71		6/23/80		8/11/80	
Sample depth (ft)	50	3	200	3	285	3	240	3	240
Specific conductance (micromhos at 25°C)	25	27	28	--	--	38	32	38	34
pH (units)	7.2	7.9	7.9	--	--	6.4	6.1	6.9	7.1
Temperature (degrees Celsius)	6.0	17.5	4.0	10.5	4.0	11.2	4.4	16.7	4.0
Transparency, Secchi-disk (ft)	20	26		32		3.5		24	
Dissolved oxygen (DO)	11.2	8.8	9.2	9.8	3.8	10.0	10.6	8.6	9.7
Hardness, as $CaCO_3$ (Ca,Mg)	12	--	--	--	--	11	9	14	10
Noncarbonate hardness	0	--	--	--	--	0	0	6	0
Calcium, dissolved (Ca)	4.3	--	--	--	--	3.6	3.1	4.0	3.0
Magnesium, dissolved (Mg)	.4	--	--	--	--	.5	.4	1.0	.6
Sodium, dissolved (Na)	1.7	--	--	--	--	2.0	1.8	2.2	2.1
Potassium, dissolved (K)	.3	--	--	--	--	.4	.4	.5	.5
Bicarbonate (HCO_3)	17	--	--	--	--	--	--	--	--
Alkalinity, total as CaCo3	14	--	--	--	--	12	13	8	15
Carbon dioxide (CO_2)	--	--	--	--	--	--	--	--	--
Sulfate, dissolved (SO_4)	.0	--	--	--	--	3.0	3.4	1.5	1.9
Chloride, dissolved (Cl)	.3	--	--	--	--	1.4	1.1	2.3	1.7
Silica, dissolved (SiO_2)	8.0	--	--	--	--	8.6	8.4	6.4	6.4
Dissolved solids, calculated, sum of constituents	23	--	--	--	--	30	34	23	25
Nitrate, plus nitrite, total as N	--	--	--	--	--	.00	.00	.00	.00
Nitrogen, ammonia, total as N	.06	.05	.02	.01	.01	.00	.00	.00	.00
Nitrogen, total organic as N	--	.12	.11	.07	.07	.19	.25	.21	.22
Nitrogen, total as N	--	--	--	--	--	.19	.25	.21	.22
Phosphorus, total as P	.00	.01	.01	.01	.01	.02	.02	.01	.01
Phosphate, ortho, dissolved (PO_4)	.00	.00	.00	.01	.01	.00	.00	.00	.00
Iron, dissolved as Fe ($\mu g/L$)	10	--	--	--	--	<10	<10	20	0
Manganese, dissolved as Mn ($\mu g/L$)	0	--	--	--	--	10	20	0	0
Carbon, organic, total as C	--	--	--	--	--	--	--	--	--
Chlorophyll *a* ($\mu g/L$)	--	--		--		0.74		2.5	

TABLE 7.—*Water-quality data for Warden Lake*

[In milligrams per liter unless otherwise indicated]

	Pre-eruption								Post-eruption			
Date of collection (mo/day/yr)	4/21/75		5/27/75		8/18/75		9/15/75		6/24/80		8/12/80	
Sample depth (ft)	3	66	3	66	3	62	3	60	3	65	3	65
Specific conductance (micromhos at 25°C)	592	578	630	660	531	584	532	580	550	630	548	632
ph (units)	9.2	9.2	8.8	7.9	9.4	7.4	9.0	7.2	9.5	7.8	9.3	7.6
Temperature (degrees Celsius)	10.7	6.8	14.9	7.7	21.4	9.0	19.9	9.1	21.8	9.3	22.7	8.7
Transparency, Secchi-disk (ft)	8.0		9.5		2.7		3.5		4.5		10	
Dissolved oxygen (DO)	11.0	8.0	10.8	.3	11.9	0	13.4	0	15.8	.2	10.0	.0
Hardness, as $CaCO_3$ (Ca,Mg)	180	--	--	--	--	--	160	--	140	160	140	180
Noncarbonate hardness	0	--	--	--	--	--	0	--	0	0	0	0
Calcium, dissolved (Ca)	26	--	--	--	--	--	19	--	17	25	16	30
Magnesium, dissolved (Mg)	27	--	--	--	--	--	27	--	23	24	24	25
Sodium, dissolved (Na)	71	--	--	--	--	--	74	--	72	69	73	70
Potassium, dissolved (K)	8.7	--	--	--	--	--	10	--	8.1	8.8	9.1	9.0
Bicarbonate (HCO_3)	253	200	256	280	164	297	256	307	--	--	--	--
Alkalinity, total, as $CaCO_3$	222	164	220	230	206	244	210	252	210	240	200	250
Carbon dioxide (CO_2)	.3	.2	.7	5.6	.2	19	.4	31	--	--	--	--
Sulfate, dissolved (SO_4)	71	--	--	--	—	—	77	--	60	57	59	53
Chloride, dissolved (Cl)	22	--	--	--	--	--	22	--	20	15	18	17
Silica, dissolved (SiO_2)	29	29	26	30	26	31	27	31	21	32	15	24
Dissolved solids, calculated, sum of constituents	389	--	--	--	--	--	382	--	348	376	335	379
Nitrate plus nitrite, total as N	.20	.15	.95	.25	.01	.01	.01	.00	.11	.00	.35	.00
Nitrogen, ammonia, total as N	.06	.23	.08	.80	.09	2.4	.11	2.9	.06	1.7	.01	3.7
Nitrogen, total organic, as N	.55	.69	.57	.50	1.0	.60	.71	.90	.78	.60	.62	.70
Nitrogen, total, as N	.81	1.1	1.6	1.6	1.1	3.0	.83	3.8	.95	2.3	.98	4.4
Phosphorus, total, as P	.02	.03	.02	.02	.04	.16	.03	.21	.02	.11	.01	.25
Phosphate, ortho, dissolved (PO_4)	.00	.00	.00	.00	.00	.43	.00	.55	.00	.06	.00	.43
Iron, dissolved, as Fe ($\mu g/L$)	20	30	30	40	30	20	20	40	<10	<10	20	20
Manganese, dissolved,, as Mn ($\mu g/L$)	4	70	20	260	20	290	20	270	4	440	10	400
Carbon, organic, total, as C	--	--	7.9	--	11	--	12	--	--	--	--	--
Chlorophyll *a* ($\mu g/L$)	6.8		4.2		19		7.9		8.2		8.2	

TABLE 8.—*Water-quality data for Sprague Lake*

[In milligrams per liter unless otherwise indicated]

	Pre-eruption								Post-eruption			
Date of collection (mo/day/yr)	4/16/75		5/19/75		8/13/75		9/30/75		6/25/80		8/13/80	
Sample depth (ft)	3	16	3	16	3	14	3	13	3	15	3	15
Specific conductance (micromhos at 25°C)	308	309	326	326	304	341	338	337	384	383	379	388
pH (units)	8.9	9.1	8.6	8.6	9.1	8.4	8.2	8.1	8.5	8.5	8.8	8.6
Temperature (degrees Celsius)	8.1	8.1	13.1	12.6	22.0	20.0	15.1	14.7	19.4	19.4	20.8	19.8
Transparency, Secchi-disk (ft)	3.5		2.8		1.9		1.8		1.5		1.5	
Dissolved oxygen (DO)	12.2	12.0	9.4	8.6	14.4	3.8	8.9	8.7	7.9	7.3	9.7	7.6
Hardness, as $CaCO_3$ (Ca,Mg)	130	--	--	--	--	--	150	--	130	130	140	150
Noncarbonate hardness	0	--	--	--	--	--	0	--	0	0	0	0
Calcium, dissolved (Ca)	29	--	--	--	--	--	34	--	28	28	27	30
Magnesium, dissolved (Mg)	14	--	--	--	--	--	15	--	15	15	17	17
Sodium, dissolved (Na)	19	--	--	--	--	--	22	--	24	24	28	28
Potassium, dissolved (K)	6.9	--	--	--	--	--	8.8	--	8.5	8.6	9.5	9.8
Bicarbonate (HCO_3)	189	189	195	196	202	215	224	223	--	--	--	--
Alkalinity, total, as $CaCO_3$	155	155	160	161	166	176	184	183	160	160	160	160
Carbon dioxide (CO_2)	.4	.2	.8	.8	.3	1.4	2.3	2.8	--	--	--	--
Sulfate, dissolved (SO_4)	13	--	--	--	--	--	12	--	30	29	16	16
Chloride, dissolved (Cl)	4.8	--	--	--	--	--	5.2	--	6.3	6.8	9.4	9.6
Silica, dissolved (SiO_2)	13	14	3.3	3.3	.4	5.6	2.5	2.9	1.0	1.1	7.4	7.3
Dissolved solids, calculated, sum of constituents	193	--	--	--	--	--	210	--	209	209	211	214
Nitrate plus nitrite, total as N	.08	.07	.00	.00	.01	.01	.02	.03	.00	.00	.02	.00
Nitrogen, ammonia, total as N	.15	.13	.10	.13	.29	.32	.07	.08	.08	.09	.23	.16
Nitrogen, total organic, as N	.75	.73	.80	.82	1.7	.78	1.1	1.1	1.4	.85	1.3	1.1
Nitrogen, total, as N	.98	.93	.90	.95	2.0	1.1	2.0	1.2	1.5	.94	1.5	1.3
Phosphorus, total, as P	.06	.07	.09	.10	.10	.12	.08	.08	.05	.05	.07	.07
Phosphate, ortho, dissolved (PO_4)	.00	.00	.00	.00	.03	.06	.03	.03	.00	.00	.00	.00
Iron, dissolved, as Fe ($\mu g/L$)	80	90	250	310	130	340	260	290	<10	<10	20	20
Manganese, dissolved,, as Mn ($\mu g/L$)	30	30	30	40	30	50	30	40	<3	0	10	10
Carbon, organic, total, as C	8.5	--	7.9	--	22	--	28	--	--	--	--	--
Chlorophyll *a* ($\mu g/L$)	35		23		29		15		11		133	

TABLE 9.—*Water-quality data for Amber Lake*

[In milligrams per liter unless otherwise indicated]

	Pre-eruption								Post-eruption			
Date of collection (mo/day/yr)	4/4/73		5/22/73		7/10/73		10/2/73		6/26/80		8/14/80	
Sample depth (ft)	3	34	3	34	3	32	3	30	3	36	3	36
Specific conductance (micromhos at 25°C)	250	240	267	264	260	272	249	255	274	290	266	292
pH (units)	6.9	7.2	8.2	7.6	8.8	7.4	9.4	8.9	9.0	7.5	9.0	7.7
Temperature (degrees Celsius)	8.0	7.0	16.3	12.3	21.0	14.7	14.0	13.8	19.6	10.5	21.4	10.4
Transparency, Secchi-disk (ft)	9.8		16		18		9.8		12		17	
Dissolved oxygen (DO)	10.5	9.6	9.6	4.1	9.0	.1	7.0	6.6	9.6	.2	9.4	.2
Hardness, as $CaCO_3$ (Ca,Mg)	100	--	--	--	--	--	96	--	95	100	97	110
Noncarbonate hardness	--	--	--	--	--	--	0	--	0	0	0	0
Calcium, dissolved (Ca)	22	--	--	--	--	--	17	--	20	22	19	24
Magnesium, dissolved (Mg)	12	--	--	--	--	--	13	--	11	12	12	12
Sodium, dissolved (Na)	16	--	--	--	--	--	18	--	15	15	16	15
Potassium, dissolved (K)	8.3	--	--	--	--	--	8.4	--	8.0	7.9	8.1	8.4
Bicarbonate (HCO_3)	158	160	162	161	147	166	163	163	--	--	--	--
Alkalinity, total, as $CaCO_3$	130	131	133	132	132	136	134	134	130	130	110	140
Carbon dioxide (CO_2)	--	--	--	--	--	--	--	--	--	--	--	--
Sulfate, dissolved (SO_4)	6.1	--	--	--	--	--	4.7	--	11	13	5.7	2.1
Chloride, dissolved (Cl)	5.1	--	--	--	--	--	4.9	--	2.9	2.6	6.6	5.8
Silica, dissolved (SiO_2)	1.2	1.3	2.0	4.0	2.6	9.6	8.6	9.1	.1	4.1	.4	3.9
Dissolved solids, calculated, sum of constituents	--	--	--	--	--	--	155	--	146	156	134	158
Nitrate plus nitrite, total as N	.02	.02	.04	.02	.02	.02	.02	.02	.00	.00	.00	.00
Nitrogen, ammonia, total as N	.09	.11	.05	.14	.10	.11	.16	.18	.00	.33	.00	1.2
Nitrogen, total organic, as N	.22	.22	.66	.57	3.9	.10	.74	.78	.78	.87	1.0	.80
Nitrogen, total, as N	.33	.35	.75	.73	4.0	.23	.92	.98	.78	1.2	1.0	2.0
Phosphorus, total, as P	.03	.03	.02	.06	.03	.05	.04	.04	.04	.05	.02	.12
Phosphate, ortho, dissolved (PO_4)	.01	.00	.01	.01	.01	.06	.04	.03	.00	.03	.03	.18
Iron, dissolved, as Fe (μg/L)	40	50	40	60	30	150	60	70	<10	190	30	980
Manganese, dissolved,, as Mn (μg/L)	10	30	10	60	20	340	60	50	<3	660	0	1,200
Carbon, organic, total, as C	8.0	--	8.0	--	11	--	9.5	--	--	--	--	--
Chlorophyll *a* (μg/L)	2.0		1.3		7.9		6.6		2.8		8.2	

concentrations and caused falsely high readings. Sedell and others (1980) reported that the biological productivity of Spirit Lake has never been higher, but that it has thus far been limited primarily to greatly expanded populations of bacteria. No biological data are available for Venus Lake.

The high temperatures and low DO concentrations observed in Spirit Lake after the eruption most likely killed all fish in the lake. Fish conditions in other blast-zone lakes have been described by B. A. Crawford of the Washington Department of Game (oral commun., November 24, 1980). In September 1980, according to Crawford, gill nets were set in three blast zone lakes not studied as part of this investigation. Live fish were found in all three lakes. The fish were fat and in good condition, but most had been feeding on terrestrial, as opposed to aquatic, insects. Crawford believes the long-term implications of this diet are significant. The fish will most likely survive the winter season by becoming semidormant beneath the ice cover of the lake and by utilizing stored fat reserves. However, the spring season will be especially critical for the fish, until such time as the terrestrial and (or) aquatic insect populations become large enough to support the fishery. Crawford thinks all fish in St. Helens Lake were killed by the high turbidity, although gill nets have not been set in that lake.

The study lakes of eastern Washington (Warden, Sprague, and Amber) are considerably more alkaline and productive than the lakes discussed above. A comparison of chlorophyll *a* concentrations before and after the eruption indicated that the concentrations generally have not changed. An algal bloom observed in Sprague Lake on August 13, 1980, resulted in a chlorophyll *a* concentration of 133 μg/L. Sprague Lake has a history of summer blooms, and there is no evidence to indicate that the bloom observed on that particular date was a result of ash deposited in the lake.

The speed and extent of biological recovery of lakes in the blast zone of the volcano will depend in large measure on the specific biological effects of the physical and chemical changes observed in this study. It is likely that the lakes will not recover to their exact preeruption biological levels, but rather to new levels of productivity that are determined by prevailing physical and chemical conditions. Because algae are at the base of the aquatic food chain, and because they produce organic tissue from inorganic substances dissolved in water, the recovery and well-being of the algal population is of prime concern in discussions of lake recovery in general.

A prediction of the likely biological effects of the observed changes is difficult; not all the changes affect algal growth in the same manner. Some of the changes, such as increased concentrations of nutrients, dissolved solids, silica, alkalinity, and hardness, would tend to encourage algal growth. Other changes, such as reduced transparency and the presence of potentially toxic trace metals (cadmium, copper, and zinc) might discourage growth. The effects of still other changes, such as increased temperature and increased concentrations of organic substances, iron, manganese, sulfate, and chloride, are more difficult to assess. Further complications arise from the fact that some elements, such as copper, are considered vital for algal growth, yet the same elements in excessive concentrations act as deterrents to growth.

Recent experiments by D. M. McKnight, G. L. Feder, and E. A. Stiles (U.S. Geological Survey, written commun., September 20, 1980) investigated the possible toxicity of leachate from volcanic ash collected in eastern Washington. The investigators determined that, although the leachate from ash collected near Richland was toxic to cultures of the blue-green alga *Anabaena flos-aquae* in dilutions up to 1 to 250, the leachate from ash collected near Moses Lake had no effects, either stimulatory or inhibitory, on the same organism. The investigators concluded that the toxic substance is an organic compound that is not uniformly distributed in the ash fall, and that the ash fall had no effect on the chemistry or biology of four lakes studied, which included Walupt and Warden Lakes.

SUMMARY AND CONCLUSIONS

The preliminary findings of a study designed to determine the effects of the Mount St. Helens eruption of May 18, 1980, on the physical, chemical, and biological characteristics of selected lakes in Washington indicate that the lakes closest to the volcano were the most

TABLE 10.—*Generalized water-quality conditions in lakes at various distances from the volcano*

[Milligrams per liter unless otherwise indicated]

Lake	Spirit		Fawn		Walupt	
Distance (miles) and direction from volcano	4(NE)		9(NNW)		37(NE)	
	Before	After	Before	After	Before	After
Specific conductance (μmhos at 25°C)	27	844	30	666	27	38
Temperature (°C)	10	26.1	15	15.6	17.8	16.7
Transparency (ft)	23	2.5	21	7.0	26	24
Dissolved oxygen, top water	10.4	0.8	8.8	9.2	8.8	8.6
Hardness	12	240	--	200	12	14
Alkalinity	11	110	--	19	14	8
Silica	12	46	--	8.1	8.0	6.4
Dissolved solids	30	574	--	392	23	23
Total nitrogen	.04	1.8	.13	.58	--	.19
Total phosphorus	.01	1.8	.00	.02	.00	.02
Dissolved iron (μg/L)	20	8,800	--	40	10	20
Dissolved manganese (μg/L)	0	5,000	--	1,000	0	0
Chlorophyll *a* (μg/L)	.7	--	--	3.6	--	2.5

affected. These findings are supported by the data in table 10, which summarizes water-quality conditions in lakes at various distances from the volcano.

Spirit Lake, at the base of the volcano, was affected to the extent that it must now be considered a completely different lake. It has increased in area, decreased in depth, and risen about 240 ft in altitude as a result of the eruption. The surface of the lake is covered with logs, and the outlet to the North Fork Toutle River has been blocked.

The water of Spirit Lake is dark in color, contains large quantities of dissolved organic material, and emits foul-smelling gases. The water temperature rose to at least 32.8°C immediately following the eruption, and most of the dissolved oxygen was depleted. The concentrations of several chemical constituents, including iron and maganese, increased sharply.

The biological productivity of Spirit Lake is high but, so far, has been limited to bacteria. The fish population, once composed chiefly of cold-water species, has undoubtedly been decimated or destroyed.

Other lakes in the blast zone were similarly affected, but not to such an extent. Chemical constituents in St. Helens, Fawn, and Venus Lakes have probably increased, and water transparency has decreased. Biological conditions in these lakes are largely unknown, and the speed of biological recovery cannot be predicted with certainty at this time.

Lakes outside the blast zone of the volcano appear to have been unaffected by the eruption, despite the deposition of up to 3 inches of ash in some lakes.

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