Mount St. Helens Volcanic-Ash Fall in the Bull Run Watershed, Oregon, March—June 1980

EOLOGICAL SURVEY CIRCULAR 850-A

COVER: North Fork Toutle River, June 30, 1980. Volcanic mud flow breccia and debris from the May 18, 1980 eruption of Mount St. Helens (in upper right) are as much as several hundred feet thick in the reach shown. Photograph by Austin Post, U.S. Geological Survey.

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By Michael V. Shulters and Daphne G. Clifton

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

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FOREWORD

On May 18, 1980, after more than a month of earthquakes and eruptions of steam and gas, 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 flank of the mountain, knocking down trees to distances as great as 12 miles. Within minutes, a giant ash cloud rose to about 60,000 feet. Winds then carried the ash eastward across the United States, with heavy deposition occurring in eastern Washington and parts of Idaho and Montana. Other 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. The explosion caused a massive flow of rock, ice, and mud that devastated the upper reaches of the Toutle River on the north and west slopes of the volcano and deposited debris in the Toutle River valley for a distance of 17 miles. In the upper reaches of the valley the debris deposits are about 600 feet thick. Runoff from the melted glaciers and snow, and possible outflow from Spirit Lake, then caused unprecedented flooding in the Toutle River. The flood transported a massive volume of sediment, shattered and uprooted thousands of trees, destroyed most of the local bridges, and carried an estimated 25,000 acre feet of sediment into the Cowlitz River. A considerable part of this sediment moved through the Lower Cowlitz into the Columbia River and formed a shoal that blocked the shipping channel.

As part of a total Geological Survey effort, Survey hydrologists were speedily on the scene collecting data and interpreting the hydrologic effects of the eruptions. The major initial hydrologic findings are reported in this circular series. This quick assessment was possible only because the Survey has long conducted extensive water-resources investigations in the affected areas of Washingon, Oregon, and Idaho. Hence, there was a well-defined basis for evaluating the types and magnitudes of hydrologic changes.

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

H William Menard

H. William Menard
Director

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Mount St. Helens Volcanic-Ash Fall in the Bull Run Watershed, Oregon, March-June 1980

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Abstract

During several periods of volcanic-ash eruption at Mount St. Helens, Wash., (March 30, May 25–26, May 30–June 2, and June 12–13, 1980) strong winds from the north occurred at high altitudes. As a result, the volcanic ash fell some 50 miles to the south in the Bull Run watershed, the principal water-supply source for the metropolitan area of Portland, Oreg.

Water samples collected from three stream sites within the watershed where compared with samples collected during the same season in previous years. No detectable changes were noted in chemical characteristics.

Precipitation samples collected immediately after the June 12–13 ash fall ranged in specific conductance from 20 to 41 micromhos per centimeter at 25°C and in pH from 4.0 to 4.3 pH units. Stream samples collected during the May-June period ranged in specific conductance from 18 to 28 micromhos per centimeter at 25°C and in pH from 6.7 to 7.5 pH units.

Volcanic-ash samples were collected and analyzed for particles size, chemical composition, and weight. Significant differences in particle size of ash were found in samples from two separate eruptions.

Introduction

On March 27, 1980, Mount St. Helens in southwestern Washington began ejecting gas and volcanic ash for the first time in more than 100 years. Volcanic activity has continued steadily since then. Periodically, gas and ash are ejected from the volcano. Volcanologists have reported that a highly viscous magma is beginning to ooze from the bottom of the mile-deep crater created by an explosive eruption on May 18, 1980 (oral commun., D. R. Crandell, U.S. Geological Survey, June 27, 1980). (See figure 1.)

The 102-square-mile (264-square-kilometer) Bull Run watershed (fig. 2) is south of the Columbia River, approximately 50 miles (80 kilometers) south of Mount St. Helens (fig. 3), and supplies water to more than 600,000 users in the Portland area. Because of the proximity of the watershed to Mount St. Helens, Portland residents were concerned that ash would fall in the Bull Run watershed if a volcanic

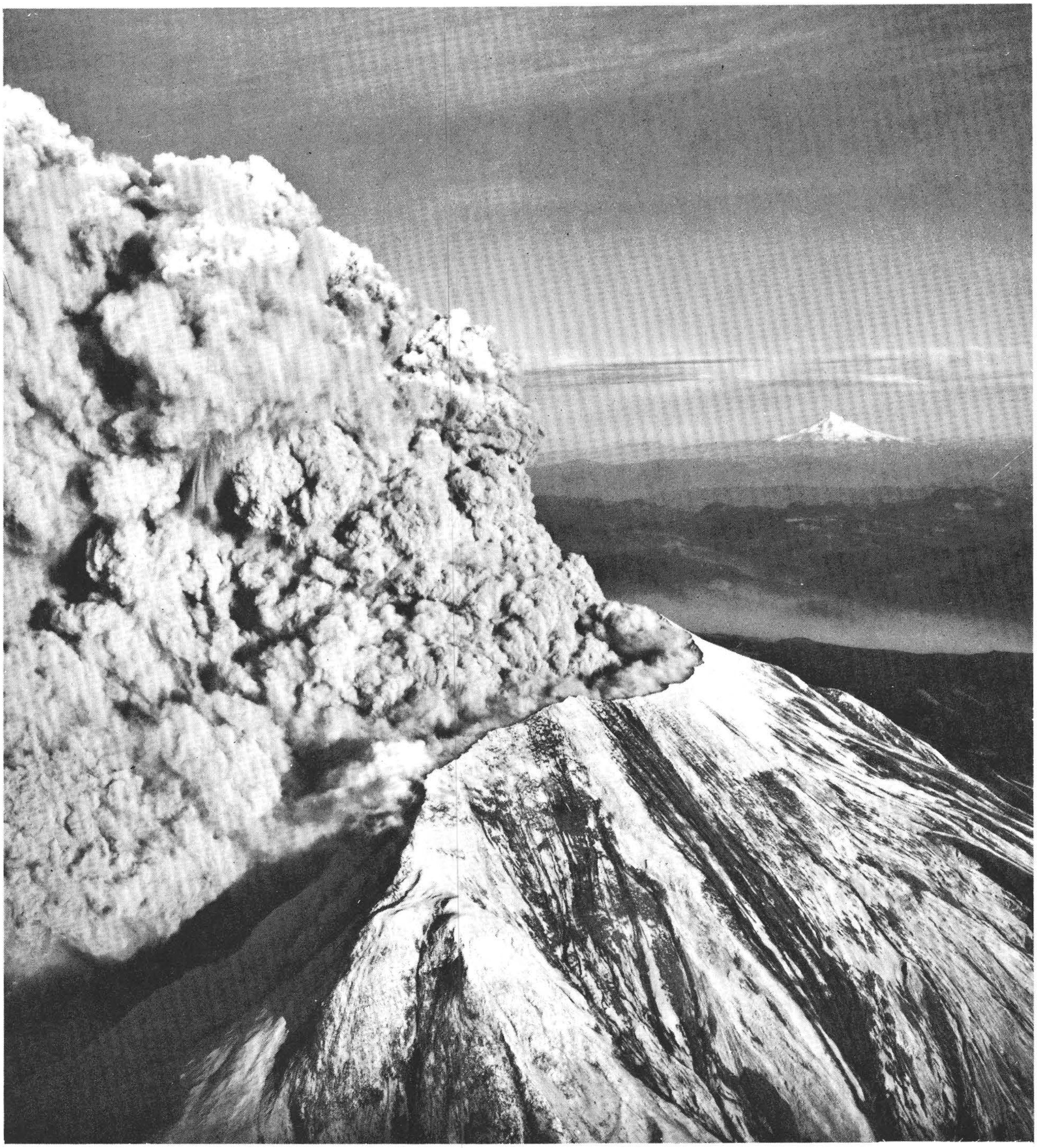


FIGURE 1.—Mount St. Helens, Wash., ejecting ash on May 18, 1980. Ash from this eruption drifted eastward, whereas on March 30 the ash drifted south toward Mount Hood, Oreg., (shown in background) and the Bull Run watershed. (U.S. Geological Survey photograph.)

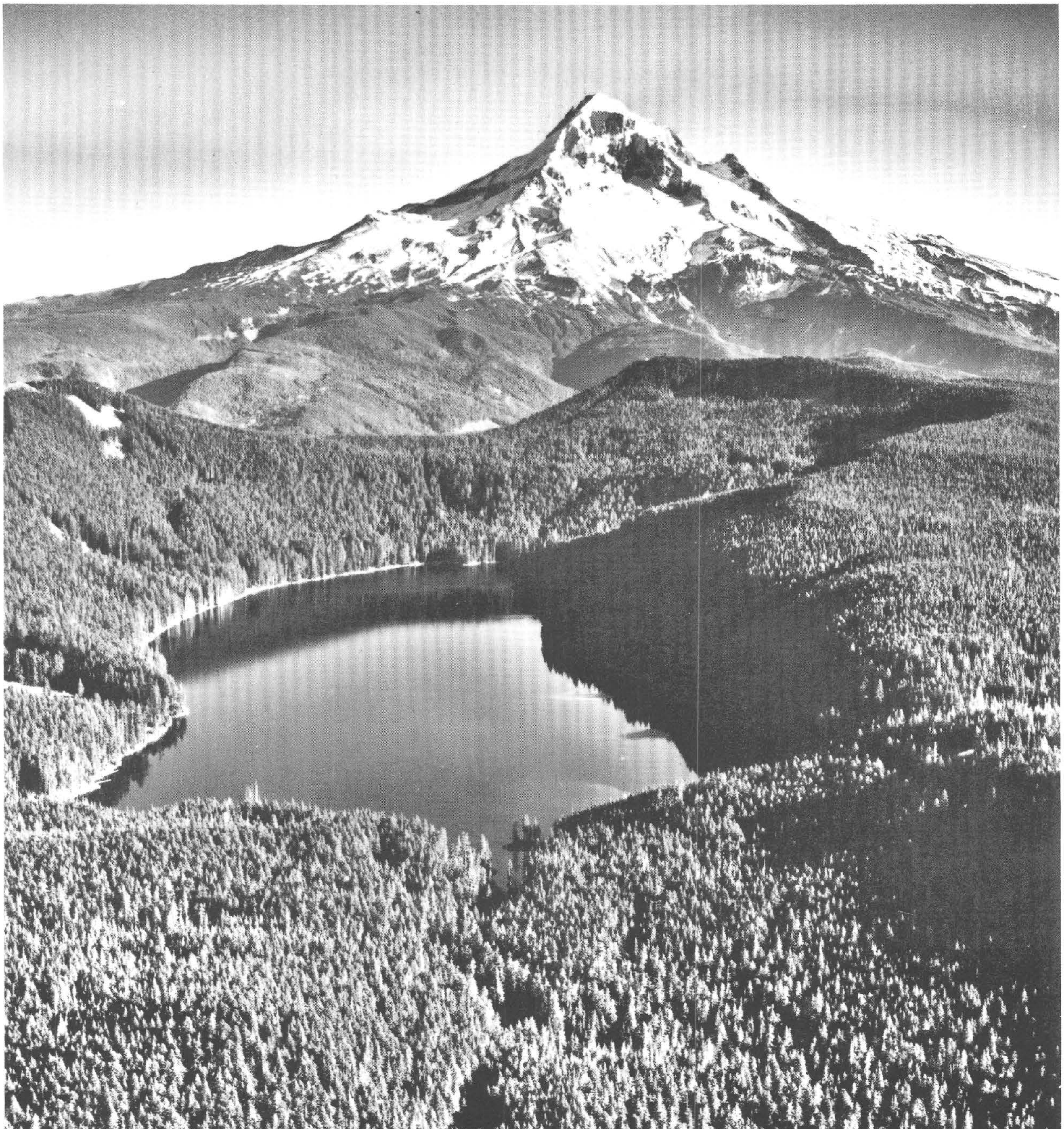


FIGURE 2.—Bull Run watershed, looking east toward Bull Run Lake and Mount Hood. (Photograph courtesy of U.S. Forest Service.)

eruption occurred during a period of northerly windflow. The first such occurrence was on March 30 and resulted in a thin dusting of ash over much of the watershed. On April 2, the Water Resources Division of the U.S. Geological Survey placed precipitation and ash collectors at seven locations in the basin to obtain data on future ash falls (fig. 4). These sites were integrated into a hydrologic-data network established earlier in cooperation with the city of Portland for an ongoing water-quality investigation of the Bull Run watershed.

This report presents the data obtained immediately after the March 30 ash fall in the Bull Run watershed. Data also are presented for the period May 18 through June 15; during this period, ash fall was noted on at least three occasions in the Bull Run watershed. No data were collected between April 21 and the large eruption on May 18. Water analyses include temperature, pH, specific conductance, acidity, alkalinity, hardness, total dissolved solids, and selected major ions.

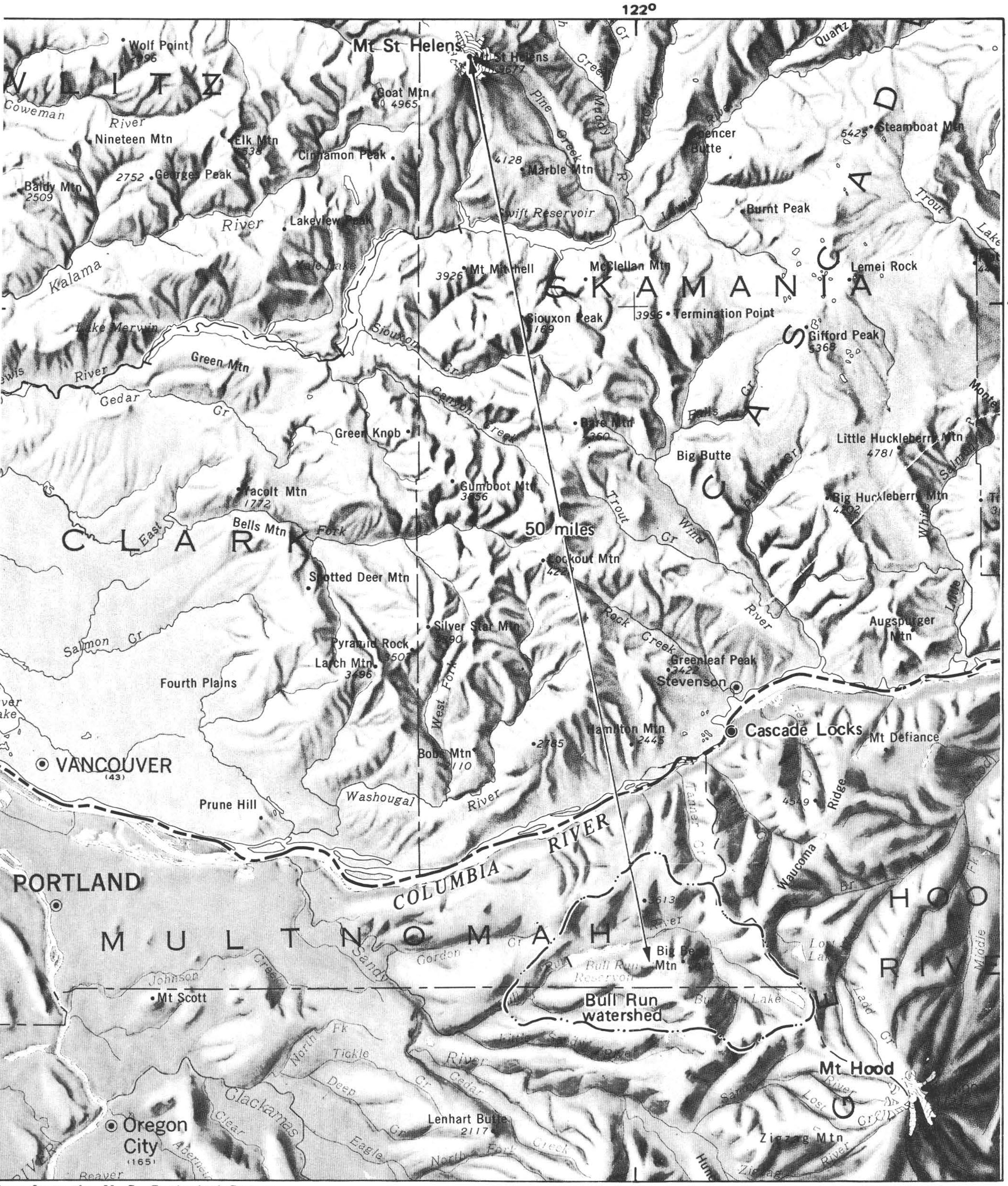
Particle-size analyses, chemical composition, and weight of ash collected at selected sites also are shown.

Volcanic events

On March 30, gray-black ash and steam from Mount St. Helens were ejected to altitudes of 11,000 to 16,000 feet (3,400 to 4,900 meters) above mean sea level during several eruptions (fig. 5). At 4 a.m. and 4 p.m., north-northwesterly winds were recorded gusting to speeds as high as 100 miles per hour (160 kilometers per hour) at altitudes between 10,000 and 20,000 feet (3,000 and 6,000 meters), as shown in figure 5. The high-altitude wind measurements were taken above Salem, Oreg. U.S. Forest Service aerial observers reported at 5:30 a.m. that the plume from a 4:11 a.m. ejection had traveled about 30 miles (50 kilometers) southeast of Mount St. Helens and was drifting toward Mount Hood (figs. 1, 2). At 9:47 a.m., they also noted that the plume from a 7:03 a.m. ejection had drifted nearly to Cascade Locks, Oreg. (U.S. Forest Service, written commun., April 1980).

Beginning on the morning of May 18, a cataclysmic eruption of Mount St. Helens ejected large quantities of ash that covered much of eastern Washington, northern Idaho, and western Montana. Because winds were generally from the west at that time, detectable ash fall in the Bull Run watershed did not occur. A subsequent eruption on May 25, although not as large, was accompanied by high-altitude northerly winds that transported ash into the Bull Run watershed and the Portland metropolitan area (fig. 5). Samples collected in the watershed on June 3 show that ash also was deposited sometime between May 28 and June 2 although that ash fall was not observed in the Portland area. Another ash fall on the Bull Run watershed and the Portland metropolitan area occurred on June 12 and 13, when a large, sustained eruption was accompanied by high-altitude winds from the north.

FIGURE 3.—Location of the Bull Run watershed and its distance from Mount St. ▶ Helens.



Base from the U. S. Geological Survey
Oregon and Washington (Shaded relief)
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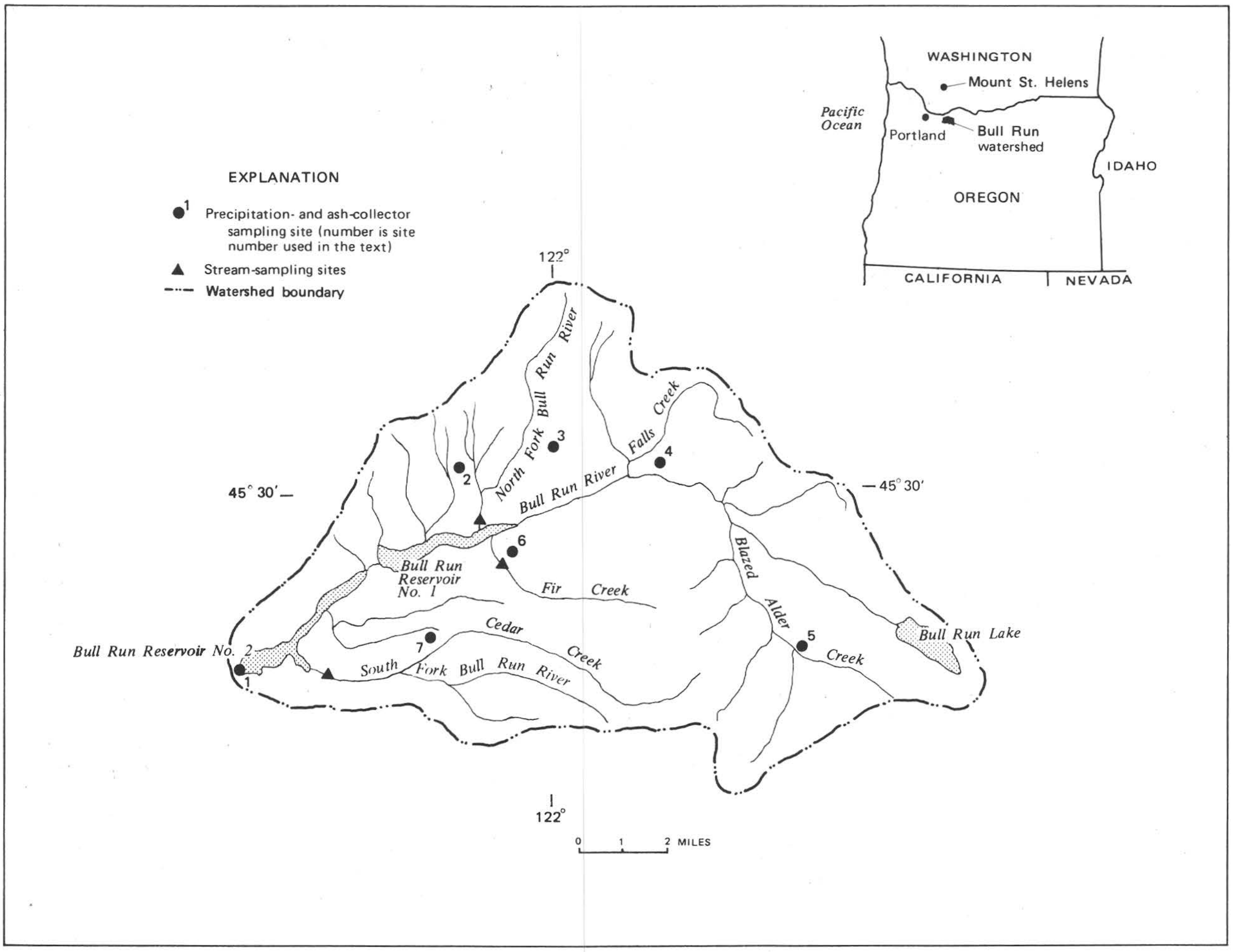


FIGURE 4.—Location of sampling sites in the Bull Run watershed.

Data collection and analysis

On April 2, 1980, precipitation and ash collectors were placed at the locations shown in figure 2. Each precipitation collector is an 8-inch (200-millimeter) plastic funnel mounted on a metal post connected to flexible plastic tubing that conveys the precipitation to a 0.3-gallon (1-liter) sample bottle. Ash collectors are arrays of nine open-top bottles with a total catchment area of 48 square inches (310 square centimeters). Visits to collect samples are made in response to storms and volcanic activity. Ash samples also were collected at the U.S. Geological Survey's district office and in other parts of the Portland area.

All field measurements and laboratory procedures for water analyses were by methods described by Skougstad and others (1979). Water temperatures were determined in the field. Stream and precipitation pH values generally were determined by immersing a glass electrode in an unstirred subsample of water. Stream samples were from a depth-integrated cross-sectional composite. Acidity and specific conductance were determined at the U.S. Geological Survey laboratory in Portland, and all other analyses were made at the Survey's water-quality laboratory in Denver, Colo. The analytical results are listed in table 2.

Ash samples were collected for particle-size analyses at the sites listed in table 1. Analytical procedures were those described by Guy (1969). Figure 6 shows ash particles deposited in Portland on May 25, magnified by a scanning-electron microscope.

Ash from the March 30 eruption was collected at sites 4, 5, and 7 on April 2 and 4 by removing 1-square-foot (0.09-square meter) sections of snow on which the ash had been deposited (table 2). On other dates the ash samples were taken from the ash collectors. Samples from the Bull Run watershed and the Portland metropolitan area were analyzed by the U.S. Geological Survey, Branch of Analytical Laboratories, Menlo Park, Calif., and the results are given in table 3.

Significance of data

Data in this report were collected to document stream and precipitation conditions as quickly as possible following ash-fall occurrences in the Bull Run watershed. The Portland Water Bureau has collected stream data since 1973 in the North Fork Bull Run River, since 1974 in the South Fork Bull Run River, and since 1975 from Fir Creek. Comparison of the new and historical data suggest that no significant changes have occurred in stream water quality. This preliminary finding seems reasonable because of the light ash fall that occurred in the Bull Run watershed. Unfortunately no historical data exist to permit a pre- and post-eruption comparison of the chemical characteristics of precipitation.

In most precipitation samples collected on June 13, the specific-conductance values are higher than in any of the previous samples and are about equal to or greater than stream conductivities on the same day. Nearly all the precipitation collected on this date fell during and immediately following the June 12 ash fall. Precipitation data in table 2 seem to show that pH decreases as specific conductance increases.

Particle-size data are given in table 1. The data show that for a given eruption the particle sizes of the ash samples are similar; however, for eruptions on separate days, the particle sizes differ significantly. For example, ash from the May 25 eruption at both the Bull Run and Portland locations is largely silt (82–89 percent of sample) and ash from the June 12 eruptions at both the Portland and Gaston locations is almost equally divided between sand (44–48 percent of sample) and silt (46–49 percent of sample).

Because ash characteristics can vary with different eruptions, and because larger accumulations of ash within the watershed remain a possibility, hydrologic-data collection is continuing so that any detectable changes that may occur can be documented.

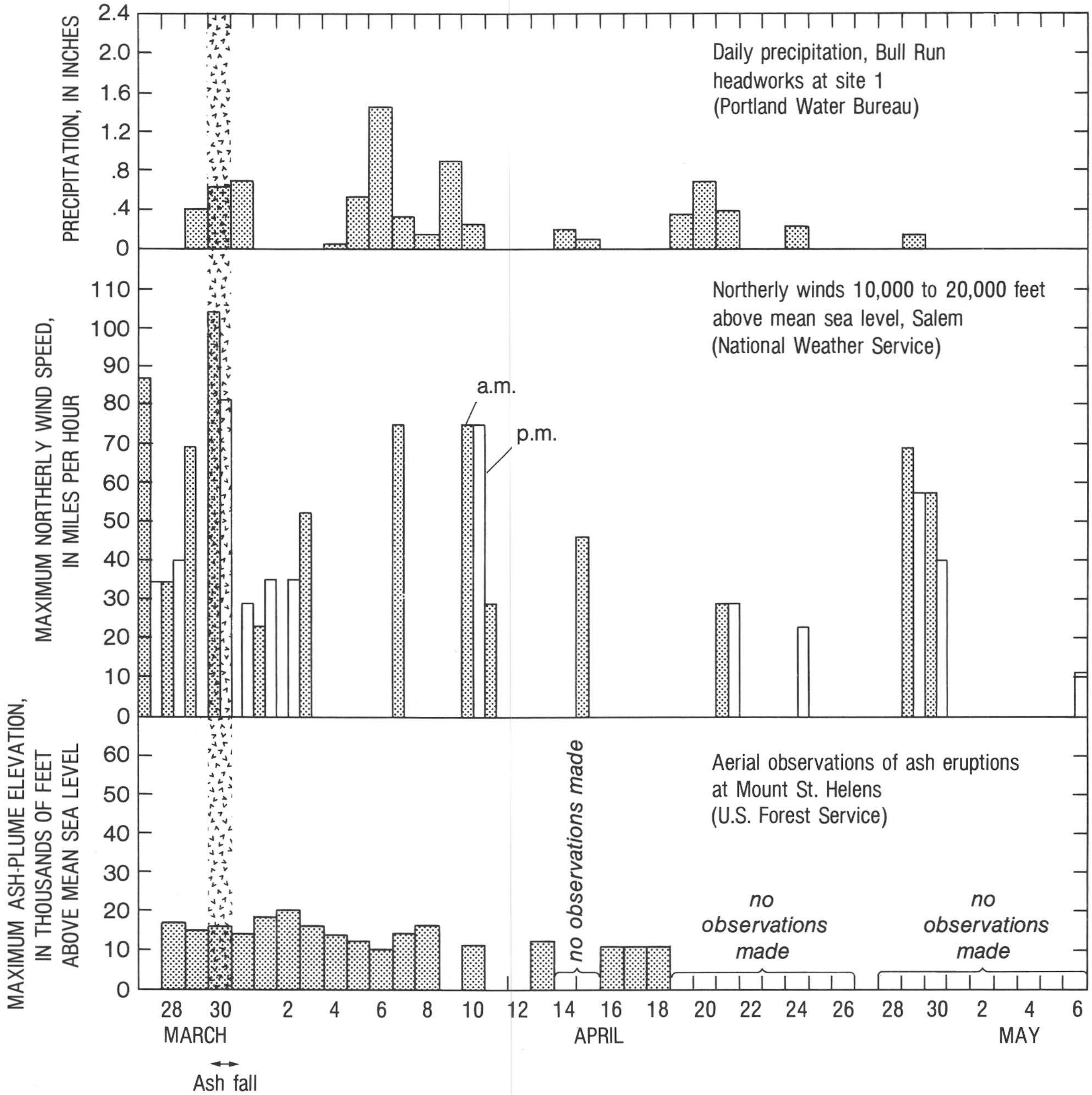
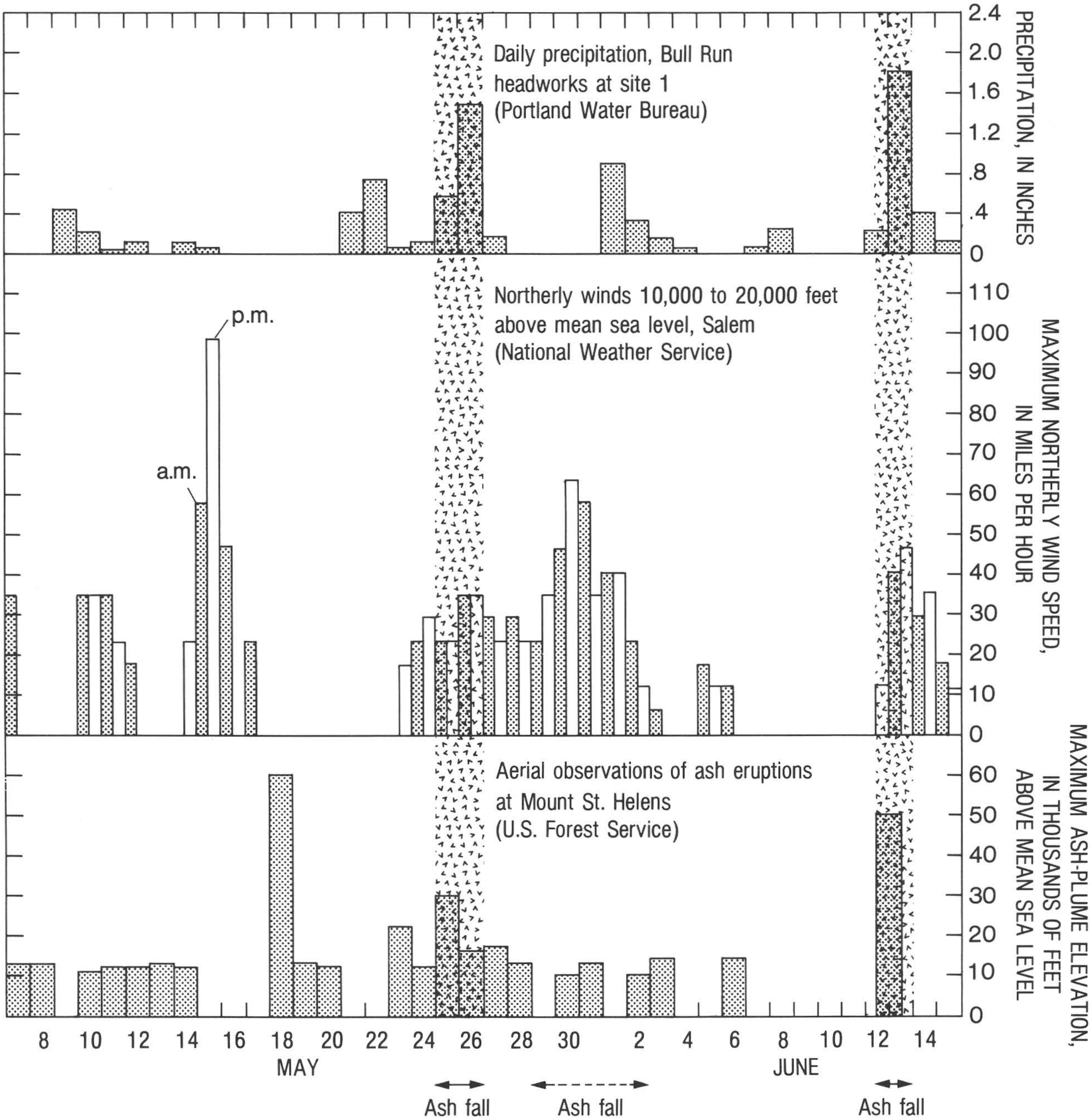


FIGURE 5.—Precipitation, high-altitude northerly wind speeds, and ash-plume elevations, March 28–June 15, 1980. Ash fa
precipitation samples but the date of the ash fall was not determined.



Run watershed are shown for March 30, May 25–26, and June 12–13. Ash was detected in the May 28–June 2

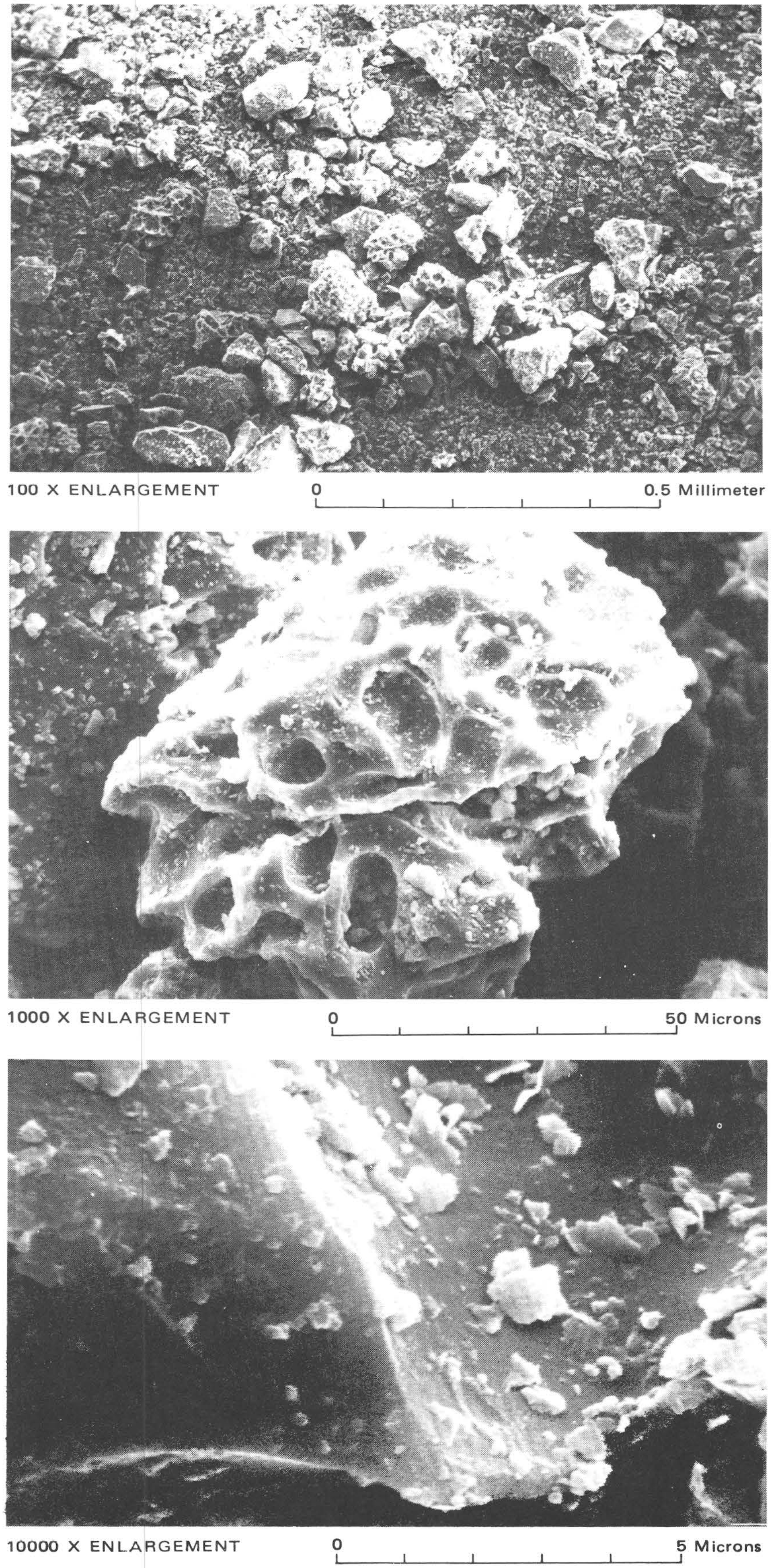


FIGURE 6.—Scanning-electron-microscope photographs showing volcanic ash deposited in Portland, Oreg., on May 25, 1980. (Photographs courtesy of Nancy G. Temple.)

TABLE 1.—*Particle-size analyses of volcanic-ash fall, Oregon*

[Size determinations by settling-velocity method; ash taken from precipitation collectors]

Eruption date and sample identification	Percent of ash finer than indicated size, in millimeters											
	Sand				Silt					Clay		
	0.250	0.175	0.125	0.088	0.062	0.053	0.031	0.016	0.008	0.004	0.002	0.001
May 25, 1980:												
Bull Run watershed (composite sample from collectors at sites 1-7)	100	100	100	99	96	78	38	21	12	7	4	2
Portland (USGS district office)	100	100	100	98	90	83	58	38	17	8	5	2
June 12, 1980:												
Portland (about 1 mile northeast of USGS district office)	100	99	84	61	52	48	34	19	12	6	3	<1
Gaston (about 25 miles southeast of Portland)	100	99	89	67	56	53	40	24	13	7	3	2

TABLE 2.—*Analyses of precipitation, snow, and stream samples from the Bull Run watershed, Oregon*

[All chemical analyses are for dissolved constituents. No data were collected between April 21 and May 18. --- indicates not determined]

Sampling site (see fig. 3 for location)	Sampling date, or period (1980)	Water temperature (°C)	pH (units)	Specific conductance (μmhos/cm @ 25°C)	Milligrams per liter: Sulfate	Nitrite + nitrate (as N)	Chloride	Flouride	Calcium	Magnesium	Potassium	Silica	Acidity[1] (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	Hardness (as $CaCO_3$)	Dissolved solids (residue on evaporation)	Weight of ash in sample (milligrams per square centimeter)
							Precipitation samples										
1	4/2-4/7	7.2	---	8	1.1	0.05	---	---	---	---	---	---	12	---	---	---	([2])
	4/7-9	8.2	---	9	1.0	.06	---	---	---	---	---	---	6	---	---	---	([2])
	4/9-11	5.6	---	21	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	4/11-17	11.3	---	11	---	---	---	---	---	---	---	---	12	---	---	---	([2])
	4/17-21	8.0	---	15	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	5/19-28	17.8	5.5	12	1.1	.12	---	---	---	---	---	---	2	---	---	---	---
	5/28-6/3	12.4	4.9	16	1.3	.17	---	---	---	---	---	---	4	---	---	---	0.38
	6/3-10	17.4	5.0	10	.9	.28	---	---	---	---	---	---	4	---	---	---	([2])
	6/10-13	12.0	4.0	41	1.3	.22	---	---	---	---	---	---	10	---	---	---	.98
2	4/2-7	.7	---	7	1.1	.05	---	---	---	---	---	---	12	---	---	---	([2])
	4/7-11	21.2	---	11	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	4/11-17	14.8	---	7	1.1	.03	0.9	0.0	0.1	0.0	0.2	0.1	10	0	0	6	([2])
	4/17-21	7.2	---	12	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	5/19-28	17.2	5.6	9	.4	.07	---	---	---	---	---	---	4	---	---	---	6.10
	5/28-6/3	12.2	5.0	16	.4	.09	---	---	---	---	---	---	4	---	---	---	.35
	6/3-10	17.4	4.6	13	.3	.37	---	---	---	---	---	---	6	---	---	---	([2])
	6/10-13	12.0	4.1	31	.9	.14	---	---	---	---	---	---	6	---	---	---	.62
3	4/2-7	.6	---	7	1.2	.06	.8	.0	.3	.0	.1	.0	10	0	<1	2	([2])
	4/7-11	21.4	---	8	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	4/11-17	15.4	---	11	1.2	.05	.5	.0	.1	.0	.2	.0	8	0	0	8	([2])
	4/17-21	7.6	---	12	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	5/19-28	16.4	5.2	10	.5	.06	---	---	---	---	---	---	5	---	---	---	---
	5/28-6/3	15.0	4.8	16	.7	.10	---	---	---	---	---	---	5	---	---	---	.39
	6/3-10	20.6	4.8	9	.8	.23	---	---	---	---	---	---	6	---	---	---	([2])
	6/10-13	11.5	4.3	22	.4	.12	---	---	---	---	---	---	5	---	---	---	.63
4	4/2-9	9.0	---	6	1.3	.04	---	---	---	---	---	---	11	---	---	---	([2])
	4/9-11	21.4	---	12	.5	.02	---	---	---	---	---	---	---	---	---	---	([2])
	4/11-17	18.6	---	6	---	---	---	---	---	---	---	---	7	---	---	---	([2])
	4/17-21	6.8	---	12	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	5/19-28	20.0	5.5	7	.5	.07	---	---	---	---	---	---	4	---	---	---	3.20
	5/28-6/3	15.0	4.8	17	.6	.12	---	---	---	---	---	---	4	---	---	---	.31
	6/3-10	21.6	4.1	12	1.2	.33	---	---	---	---	---	---	10	---	---	---	([2])
	6/10-13	11.5	4.3	20	1.0	.12	---	---	---	---	---	---	5	---	---	---	.38
5	5/20-30	---	5.5	6	.1	.01	---	---	---	---	---	---	2	---	---	---	6.74
	5/30-6/3	13.8	5.0	11	.3	.05	---	---	---	---	---	---	4	---	---	---	.22
	6/3-10	18.0	4.1	39	---	---	---	---	---	---	---	---	12	---	---	---	([2])
	6/10-13	13.0	4.3	21	.1	.10	---	---	---	---	---	---	6	---	---	---	.05
6	4/2-9	12.0	---	6	1.5	.04	---	---	---	---	---	---	7	---	---	---	([2])
	4/9-11	19.7	---	13	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	4/11-17	16.3	---	10	.5	.03	---	---	---	---	---	---	10	---	---	---	([2])
	4/17-21	8.1	---	10	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	5/19-27	11.6	5.4	8	1.1	.08	---	---	---	---	---	---	4	---	---	---	---
	5/27-6/4	15.2	4.7	17	1.3	.18	---	---	---	---	---	---	5	---	---	---	.44
	6/4-11	17.0	4.2	17	.7	.22	---	---	---	---	---	---	5	---	---	---	([2])
	6/11-13	12.5	4.1	35	.7	.17	---	---	---	---	---	---	7	---	---	---	.36
7	4/2-9	11.0	---	7	1.8	.05	---	---	---	---	---	---	8	---	---	---	([2])
	4/9-11	20.1	---	16	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	4/11-17	20.0	---	7	.3	.04	---	---	---	---	---	---	8	---	---	---	([2])
	4/17-4/21	8.2	---	10	---	---	---	---	---	---	---	---	---	---	---	---	([2])
	5/19-27	11.8	5.4	9	.7	.07	---	---	---	---	---	---	4	---	---	---	---
	5/27-6/4	17.4	4.8	16	.9	.18	---	---	---	---	---	---	5	---	---	---	.34
	6/4-11	17.4	4.1	33	.8	.28	---	---	---	---	---	---	12	---	---	---	([2])
	6/11-13	13.5	4.1	33	.6	.20	---	---	---	---	---	---	6	---	---	---	.76

TABLE 2.—*Analyses of precipitation, snow, and stream samples from the Bull Run watershed, Oregon*—Continued

Sampling site (see fig. 3 for location)	Sampling date, or period (1980)	Water temperature (°C)	pH (units)	Specific conductance (µmhos/cm @ 25°C)	Milligrams per liter: Sulfate	Nitrite + nitrate (as N)	Chloride	Flouride	Calcium	Magnesium	Potassium	Silica	Acidity[1] (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	Hardness (as $CaCO_3$)	Dissolved solids (residue on evaporation)	Weight of ash in sample (milligrams per square centimeter)
Snow samples, filtrate																	
4	4/4	---	---	3	2.2	.003	---	---	---	---	---	---	7	---	---	---	1.94
5	4/2	---	---	5	3.2	.01	---	---	---	---	---	---	---	---	---	---	1.29
7	4/2	---	---	3	2.0	.002	---	---	---	---	---	---	---	---	---	---	3.12
Stream samples																	
North	4/9	4.0	---	17	1.6	---	1.2	.0	1.3	.4	.2	6.2	7	7	5	23	
Fork	4/11	4.6	---	19	---	---	---	---	---	---	---	---	---	---	---	---	
Bull	4/17	4.8	---	18	.7	.000	1.1	.0	1.4	.5	.2	7.3	5	8	6	22	
Run	4/21	4.7	---	17	---	---	---	---	---	---	---	---	---	---	---	---	
River	5/28	7.8	7.4	22	.3	.002	---	---	---	---	---	---	1	---	---	---	
	6/3	9.0	7.4	23	.7	.000	---	---	---	---	---	---	1	---	---	---	
	6/6	7.7	7.5	26	---	---	---	---	---	---	---	---	5	---	---	---	
	6/10	9.8	7.4	28	.1	.001	---	---	---	---	---	---	1	---	---	---	
	6/13	14.0	7.1	22	1.8	.02	---	---	---	---	---	---	1	---	---	---	
South	4/9	11.0	---	18	1.9	.03	1.3	.0	1.5	.5	.2	6.6	7	7	6	19	
Fork	4/11	5.4	---	20	---	---	---	---	---	---	---	---	---	---	---	---	
Bull	4/17	6.0	---	20	.5	.000	1.1	.0	1.5	.6	.2	7.8	4	10	6	23	
Run	4/21	5.0	---	17	---	---	---	---	---	---	---	---	---	---	---	---	
River	5/27	6.4	7.2	21	.7	.005	---	---	---	---	---	---	2	---	---	---	
	6/4	14.4	7.0	22	2.1	.003	---	---	---	---	---	---	5	---	---	---	
	6/11	10.0	7.3	27	1.3	.01	---	---	---	---	---	---	2	---	---	---	
	6/13	14.0	7.2	25	.6	.02	---	---	---	---	---	---	2	---	---	---	
Fir	4/9	9.0	---	17	1.7	.06	1.6	.0	1.3	.5	.2	6.3	7	4	5	16	
Creek	4/11	4.2	---	20	---	---	---	---	---	---	---	---	---	---	---	---	
	4/17	4.9	---	18	.2	.01	1.8	.0	1.4	.6	.2	7.5	6	3	6	22	
	4/21	4.0	---	19	---	---	---	---	---	---	---	---	---	---	---	---	
	5/27	5.4	7.2	18	1.6	.01	---	---	---	---	---	---	2	---	---	---	
	6/4	9.8	6.8	19	.8	.01	---	---	---	---	---	---	1	---	---	---	
	6/11	8.4	6.7	22	.6	.000	---	---	---	---	---	---	1	---	---	---	
	6/13	14.0	7.2	21	.7	.04	---	---	---	---	---	---	2	---	---	---	

[1] Acidity titrations were carried to an end point pH of 8.3. See American Public Health Association and others (1971) for additional information.
[2] Ash not observed in sample.

TABLE 3.—*Analyses of volcanic ash from the Bull Run watershed and from Portland, Oregon*

[Analyses by P. Klock, C. Heropolus, T. Fries, and S. Neil, Branch of Analytical Laboratories, Menlo Park, Calif., using emission spectroscopy]

Element	Semiquantitative analyses[1]		Quantitative analyses[1]	
	Blazed Alder Creek (site 5) March 30, 1980	Cedar Creek (site 7) March 30, 1980	Bull Run watershed composite sample (sites 1.7) May 25, 1980	Southeast Portland June 12, 1980
	Percentage of sample, by weight			
	(precision is ±50 percent)		(precision is ±15 percent)	
Aluminum (Al)	10	10	9.8	8.6
Calcium (Ca)	5	5	3.9	3.5
Iron (Fe)	3	5	3.9	3.6
Magnesium (Mg)	1.5	1.5	1.1	1.3
Phosphorus (P)	.06	.06	.09	.08
Potassium (K)	1.5	1	1.8	1.6
Silicon (Si)	>10	>10	32	30
Sodium (Na)	3	3	3.6	2.7
Sulfur (S)[2]	.26	.17	.10	.06
Titanium (Ti)	.7	.7	.46	.42
	Parts per million (ppm) of sample, by weight			
	(precision is ±50 percent)		(precision is ±5 percent)	
Arsenic (As)	1.5	1.5	3	2
Barium (Ba)	300	300	410	330
Beryllium (Be)	1.5	1	2.1	1.9
Boron (B)	7	7	17	10
Cadmium (Cd)	.3	.1	1	<.2
Chromium (Cr)	15	15	17	13
Cobalt (Co)	15	20	12	12
Copper (Cu)	30	30	39	38
Gallium (Ga)	20	20	21	18
Lanthanum (La)	20	15	---	---
Lead (Pb)	15	10	20	14
Manganese (Mn)	700	700	570	580
Mercury (Hg)	<1	<1	.05	---
Nickel (Ni)	15	20	20	15
Scandium (Sc)	15	15	11	11
Strontium (Sr)	500	500	530	420
Vanadium (V)	70	100	94	89
Ytterbium (Yb)	1.5	1.5	---	---
Yttrium (Y)	15	15	19	15
Zinc (Zn)	50	50	77	57
Zirconium (Zr)	100	70	250	140

Element having concentration, in all samples, below detection limits

Element	Detection limit (ppm)	Element	Detection limit (ppm)	Element	Detection limit (ppm)	Element	Detection limit (ppm)
Antimony (Sb)	1	Platinum (Pt)	5	Antimony (Sb)	1	Niobium (Nb)	25
Bismuth (Bi)	.2	Rhenium (Re)	7	Bismuth (Bi)	.2	Rhenium (Re)	50
Cerium (Ce)	50	Selenium (Se)	10	Cerium (Ce)	100	Selenium (Se)	5
Germanium (Ge)	7	Silver (Ag)	.2	Gold (Au)	.2	Silver (Ag)	1.0
Gold (Au)	.1	Tantalum (Ta)	50	Lanthanum (La)	20	Tellurium (Te)	50
Hafnium (Hf)	50	Tellurium (Te)	1	Lithium (Li)	50	Tin (Sn)	10
Indium (In)	1.5	Thallium (Tl)	1	Molybdenum (Mo)	10	Wolfram (W)	100
Lithium (Li)	100	Thorium (Th)	150				
Molybdenum (Mo)	.2	Tin (Sn)	2				
Niobium (Nb)	7	Uranium (U)	150				
Palladium (Pd)	1	Wolfram (W)	10				

[1] Quantitative analyses are performed using a direct reader, which provides better precision than the visual methods used in the semiquantitative test.
[2] For sulfur analyses the precision is ±1 percent using wet chemical methods.

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