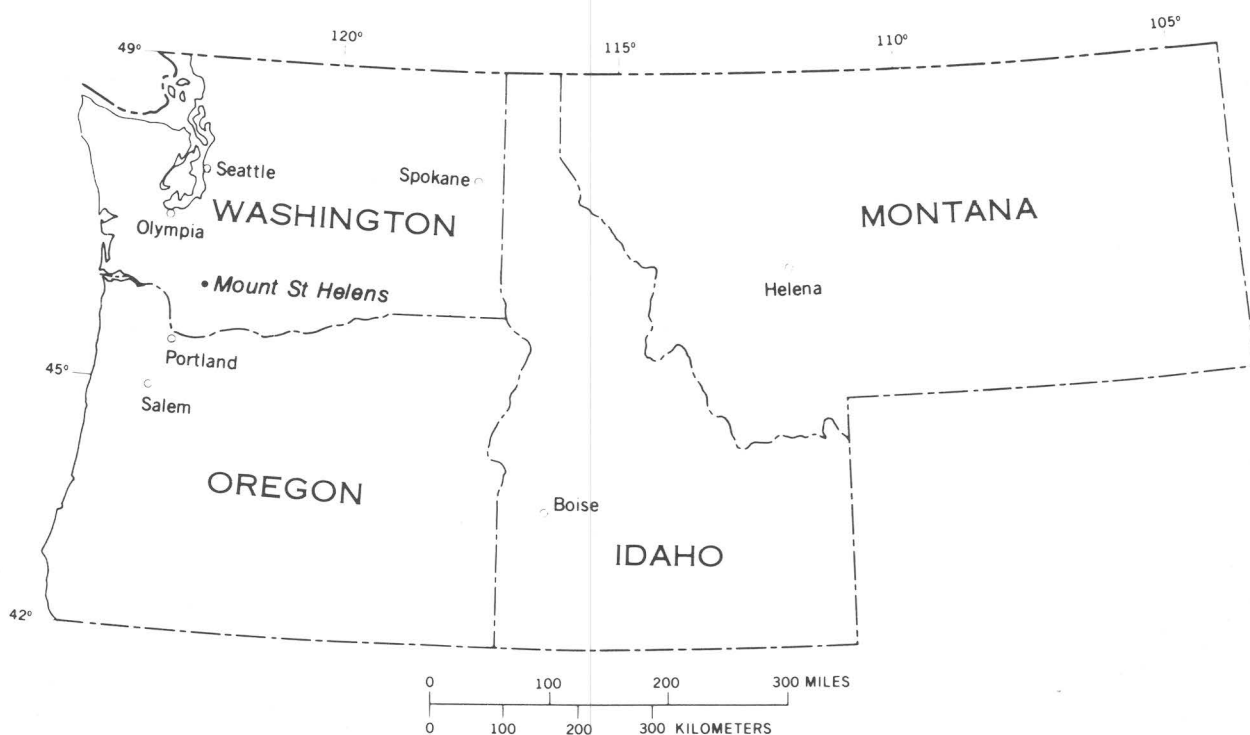


Some Chemical Effects of the Mount St. Helens Eruption on Selected Streams in the State of Washington



METRIC CONVERSION FACTORS

<i>Multiply</i>	<i>By</i>	<i>To obtain</i>
foot (ft)	0.3048	meter (m)
cubic yard (yd ³)	0.7646	cubic meter (m ³)
mile (mi)	1.609	kilometer (km)
square mile (mi ²)	2.590	square kilometer (km ²)
cubic foot per second (ft ³ /sec)	.02832	Cubic meter per second (m ³ /s)



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.

Some Chemical Effects of the Mount St. Helens Eruption on Selected Streams in the State of Washington

By John M. Klein

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

GEOLOGICAL SURVEY CIRCULAR 850-E

United States Department of the Interior

JAMES G. WATT, *Secretary*



Geological Survey

Dallas L. Peck, *Director*

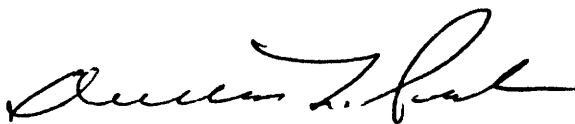
FOREWORD

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 Fork 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 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.



Dallas L. Peck
Director

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HYDROLOGIC EFFECTS OF THE ERUPTIONS OF
MOUNT ST. HELENS, WASHINGTON, 1980

**SOME CHEMICAL EFFECTS OF THE MOUNT ST. HELENS
ERUPTION ON SELECTED STREAMS IN THE
STATE OF WASHINGTON**

By JOHN M. KLEIN

ABSTRACT

The eruption of Mount St. Helens in southwestern Washington had a pronounced effect on the chemistry of water in rivers draining these areas affected by the debris deposits, pyroclastic flows, mudflows, and airborne ash. Comparison of pre-eruption and post-eruption data show that there were marked increases in selected rivers of the levels of sulfate, chloride, turbidity, total nitrogen, total organic nitrogen, and total iron, manganese, and aluminum. In streams affected solely by ash, the changes were shortlived and the intensity of change decreased with distance downwind from Mount St. Helens. Streams in the blast and mudflow-affected areas showed more persistent effects.

INTRODUCTION

After 100 years of dormancy, Mount St. Helens, in southwestern Washington (fig. 1), erupted with moderate intensity on March 27, 1980. Ash and steam were emitted, and a crater opened on the flank of the cone. Eruptions of ash and steam continued for several weeks, the crater enlarged daily, and continual seismic activity was recorded. On April 23, a bulge was detected on the north flank overlooking Spirit Lake. The bulge continued to grow outward at the rate of about 5 feet per day.

On May 18 at 8:32 a.m., Mount St. Helens erupted violently. After an explosive north-trending lateral blast, ash and steam were shot vertically to about 50,000 feet. In the immediate vicinity north of the volcano, a once-productive forest was completely pyrolyzed or burned; with increasing distance from the mountain, trees were uprooted and stripped of bark, branches, and needles

or leaves. Ash was carried easterly by the prevailing winds and deposited to depths of up to 5 inches over much of the agricultural lands of eastern Washington. Watersheds immediately east of the volcano received heavy ash fall, and streams draining to the south, tributary to the Columbia River, received only traces of ash.

At the onset of the eruptive activity, the major part of the north flank of the volcano collapsed, depositing a massive plug of debris, including rock, ash, pumice, and ice in the upper 17 miles of the North Fork Toutle River valley. Following the initial blast, a mudflow quickly developed in the South Fork Toutle River, and several hours later a much larger mudflow originated from the massive debris avalanche deposit in the North Fork Toutle valley. This mudflow caused widespread destruction as it moved downstream through the lower Toutle and Cowlitz Rivers, and a considerable part of the sediment was conveyed through the Cowlitz into the Columbia River.

The massive physical alterations caused by the eruption could be expected to have marked effects on river water quality. This paper describes some of the effects caused by (1) ash deposition in rivers east of the volcano, and (2) the massive debris deposit and mudflows in rivers draining to the west and south.

DATA COLLECTION

Following the initial eruption on March 27, 1980, a program for the collection of water-quality data

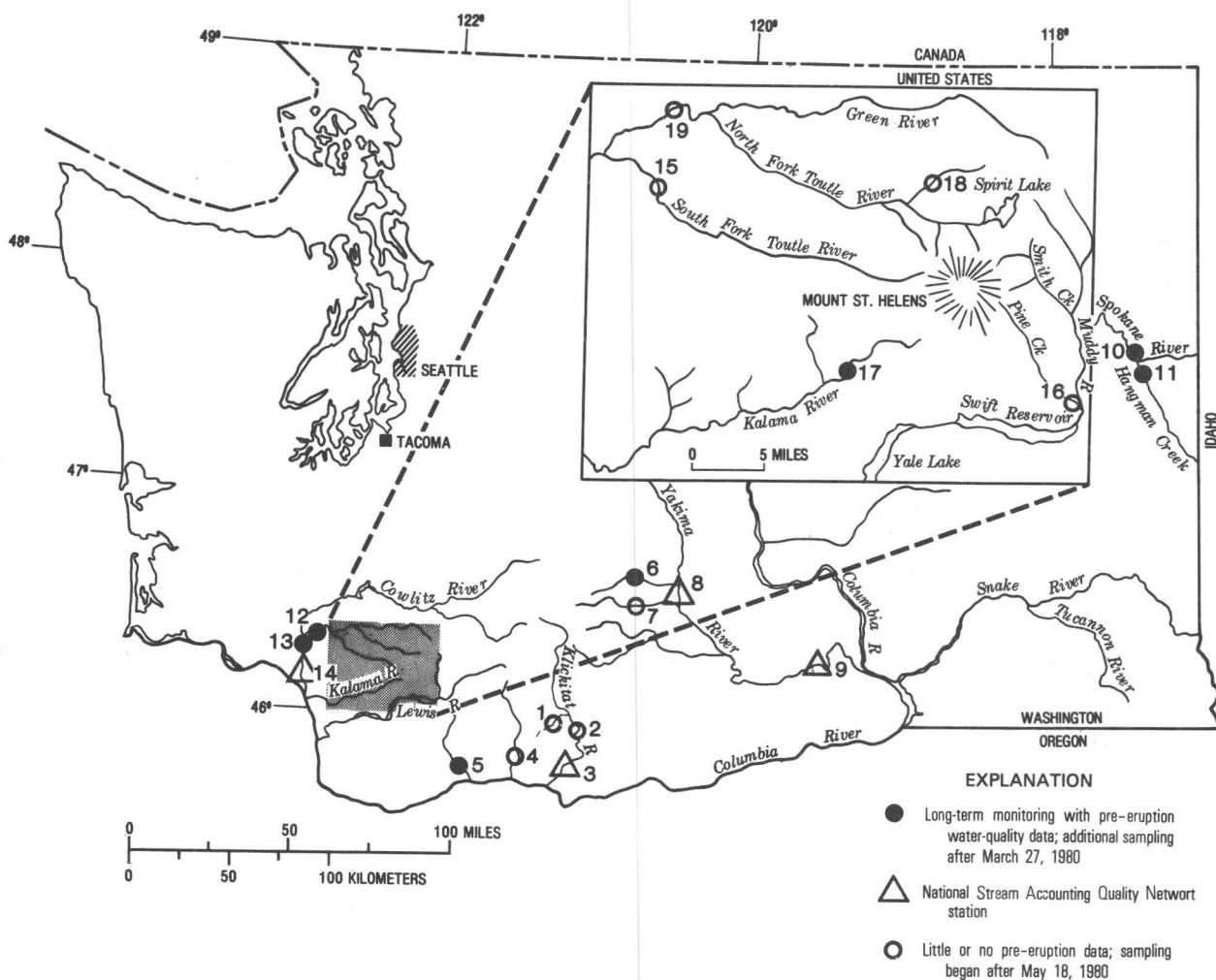


FIGURE 1.—Location of Mount St. Helens in Washington, and location of water-quality sampling sites.

(water chemistry, sediment, and biology) was initiated at selected stream sites surrounding Mount St. Helens (fig. 1) to document the effects of the initial eruption and resultant ash fallout on the physical and chemical character of the water and to collect background data at unaffected sites. These measurements supplement data collected monthly at 3 U.S. Geological Survey National Stream Quality Accounting Network Stations¹ and at 22 other sites sampled periodically in cooperation with the Washington State Department of Ecology, the Tacoma City Light, and the Confederated Tribes and Bands of the Yakima Indian Nation.

Following the May 18 eruption, additional sites

¹The U.S. Geological Survey National Stream Quality Accounting Network is a series of surface-water monitoring sites at which systematic and continuing measurements are made to determine the quality of the nation's streams.

(fig. 1) were chosen for an intensive sampling program. The frequency of collection at these sites decreased with time to daily at some of the heavily impacted but accessible sites until several days after the eruption, then weekly until the end of June, and monthly thereafter.

All samples for chemical analysis were collected along the stream cross section using depth-integrating samplers and methods (Guy and Norman, 1970). These sample-collection techniques assure a sample that is representative of the average chemical conditions in the cross section of the stream at the time of sampling. Water samples for dissolved trace elements and selected major chemical-constituent determinations were filtered through a 0.45- μ m (micrometer) pore-size membrane filter, placed in an acid-washed polyethylene bottle, and acidified with double-distilled, analyti-

TABLE 1.—List of characteristics determined for water from streams and rivers used to document the impact of Mount St. Helens

Alkalinity, total (CaCO ₃)	mg/L	Nitrogen, dissolved (as N)	mg/L
Arsenic, dissolved	µg/L	Nitrogen, suspended	
Arsenic, total	Do.	(NH ₄ + organic as N)	Do.
Barium, dissolved	Do.	Nitrogen, total	
Barium, suspended	Do.	(NO ₂ + NO ₃ as N)	Do.
Barium, total	Do.	Nitrogen, total	
Cadmium, dissolved	Do.	(NH ₄ as N)	Do.
Cadmium, suspended	Do.	Nitrogen, total	
Cadmium, total	Do.	(NH ₄ + organic as N)	Do.
Calcium, dissolved	mg/L	Nitrogen, total (organic as N)	Do.
Carbon, organic dissolved	Do.	Nitrogen, total (as N)	Do.
Carbon, organic suspended	Do.	pH field	
Chloride, dissolved	Do.	pH lab	
Chromium, dissolved	µg/L	Phosphorus, dissolved (as P)	Do.
Chromium, suspended	Do.	Phosphorus, total (as P)	Do.
Chromium, total	Do.	Phosphorus, total (PO ₄)	Do.
Cobalt, dissolved	Do.	Potassium, dissolved	Do.
Cobalt, suspended	Do.	Potassium 40, D.PCI/L	
Cobalt, total	Do.	Residue dis calc sum	Do.
Copper, dissolved	Do.	Residue dis ton/aft	
Copper, suspended	Do.	Residue dis 180°C	Do.
Copper, total	Do.	SAR	
Fluoride, dissolved	mg/L	Selenium, dissolved	µg/L
Hardness, noncarbonate	Do.	Selenium, suspended	Do.
Hardness, total	Do.	Selenium, total	Do.
Iron, dissolved	µg/L	Silica, dissolved	mg/L
Iron, suspended	Do.	Silver, dissolved	µg/L
Iron, total	Do.	Silver, suspended	Do.
Lead, dissolved	Do.	Silver, total	Do.
Lead, suspended	Do.	Sodium + potassium	mg/L
Lead, total	Do.	Sodium, dissolved	Do.
Magnesium, dissolved	mg/L	Sodium, percent	
Manganese, dissolved	µg/L	Specific conductance field	µmho/cm at 25°C
Manganese, suspended	Do.	Specific conductance lab	Do.
Manganese, total	Do.	Sulfate, dissolved	mg/L
Mercury, dissolved	Do.	Turbidity (NTU) EPA	NTU
Mercury, suspended	Do.	Water temperature (degrees C)	°C
Mercury, total	Do.	Zinc, dissolved	µg/L
Nitrogen, dissolved		Zinc, suspended	Do.
(NO ₂ +NO ₃ as N)	mg/L	Zinc, total	Do.
Nitrogen, dissolved		Lithium, dissolved	Do.
(NH ₄ as N)	Do.	Lithium, total	Do.
Nitrogen, dissolved		Aluminum, dissolved	Do.
(NH ₄ + organic as N)	Do.	Aluminum, total	Do.
Nitrogen, dissolved		Boron, dissolved	Do.
(organic as N)	Do.	Boron, total	Do.

cal-grade nitric acid to prevent adsorption and chemical precipitation. Unfiltered samples were analyzed for total element concentrations. Samples for nutrient analysis were chilled at the time of collection and during shipment to the Geological Survey National Water Quality Laboratory, Arvada, Colo. A list of the chemical constituents determined is shown in table 1. Constituents were analyzed by methods outlined by Skougstad and others (1979). The chemical data collected since the March 27 eruption have been released in a data report (Turney and Klein, 1982).

ASH COMPOSITION

Fruchter and others (1980) have reported some general ash composition trends with increasing distance from the volcano. Silica increased with distance, whereas iron, magnesium, calcium, and manganese decreased. Potassium and sodium showed little variability. Taylor and Lichte (1980) have also analyzed volcanic ash samples for major, minor, and trace constituent composition. They also observed a change in chemical composition of the ash as a function of distance from Mount St.

TABLE 2.—Major, minor, and trace soluble constituents in volcanic ash

Constituent*	Tampico, Wash.	Ft. Simpcó, Wash.	Moses Lake, Wash.	Potlach, Idaho
Calcium	89	190	151	190
Magnesium	13	42	27	30
Sodium	87	209	143	164
Potassium	1.7	41	20	23
Ammonium	0.07	0.9	1.2	0.75
Chloride	134	319	178	369
Fluoride	0.81	2.4	1.3	3.7
Sulfate	297	744	534	524
Silica	8.1	16	19	13
Nitrate	1.8	7.0	2.8	1.0
Boron	0.28	0.74	0.58	0.47
Iron	0.013	0.013	0.024	0.013
Manganese	2.0	7.3	2.0	5.8
Zinc	0.024	0.062	0.012	0.240

*Concentrations in microgram per gram of dry ash (from Taylor and Lichte, 1980).

Helens and related these changes to changes in the physical characteristics of the ash. In addition, Taylor and Lichte have reported water-soluble components after column-leaching the ash with known volumes of distilled water. Table 2 is a summary of some of the major, minor, and trace soluble-constituent concentrations of the ash at specified locations.

From these analyses alone, one might expect that a major impact on river water quality would be an increase, from pre-eruption levels, in the concentrations of certain soluble constituents, especially chloride and sulfate. The timing of such compositional and concentration changes in the surface-water chemistry, with respect to the eruption, would depend on whether the ash fell on land or water, and the occurrence and intensity of precipitation on land-deposited ash. If ash did fall directly on water, the soluble constituents would dissolve rapidly and be observed in analyses of samples collected soon after deposition. Heavy precipitation on top of land-deposited ash would wash large quantities of soluble constituents into streams; whereas light precipitation would leach those constituents into the soil, where they would probably react with soil materials. In the latter case, changes in the stream water composition might not be measurable. Moreover, any changes would occur at some later date, after sufficient water had leached through the soil and eventually entered a water course.

Calcium and bicarbonate are normally the pre-dominant dissolved constituents in streams of the

northwest. Variations in concentrations are small, occur slowly, and are correlated with stream discharge. A major geologic event, such as the eruption and subsequent ashfall, might be expected to produce noticeable changes in the chemical composition of waters.

RESULTS AND DISCUSSION

EFFECTS OF ASH ON RIVER WATER QUALITY

As expected, based on the distribution of ashfall (fig. 1), streams to the south of the volcano, tributary to the Columbia River (stas 4 and 5), were unaffected. A small tributary to the Klickitat River (sta 1) was also unaffected.

East of Mount St. Helens, the magnitude of the observed effects of ash deposition was a function of the pattern of ash depths, and the relative volumes of water draining from heavily and slightly affected areas down to the sampled sites. In general, the magnitude of the observed effects ranged from pronounced in streams close to the volcano to slight in streams in eastern Washington. In the following sections, the effects are described for streams located progressively eastward.

KLICKITAT RIVER

Samples from the Klickitat River near Glenwood (sta 2) and near Pitt (sta 3) showed that ash deposition had a pronounced effect on water composition. The changes at the downstream Pitt station were not as pronounced as those near the headwaters Glenwood station owing to dilution

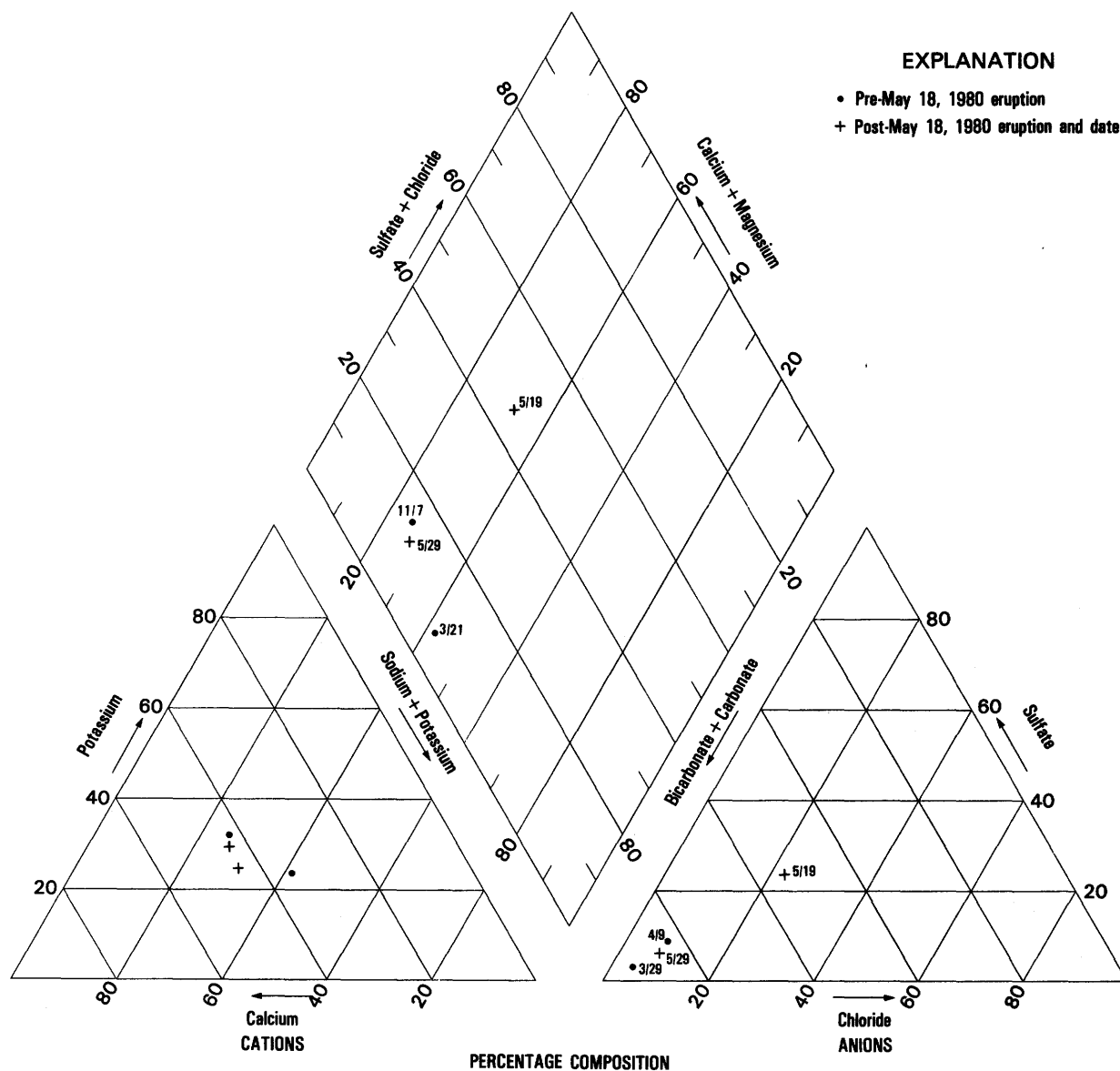


FIGURE 2.—Percentage composition of water in the Klickitat River near Glenwood.

from tributary drainages that received light ashfall.

Variation in chemical composition is shown by both trilinear diagrams (see figs. 2, 3) and in time-series plots (for example, figs. 4–10). Within each triangle and the center quadrangle of the trilinear diagrams, the milliequivalent percentages of the major cations (calcium, magnesium, sodium, and potassium) total 100, as they also do of the major anions (bicarbonate, carbonate, chloride, and sulfate); thus, changes in the relative concentrations of these constituents are shown concisely. In each trilinear diagram, dates are included with the plot-

ted data points for the anions (lower right triangle) and for the center quadrangle portion of the diagram to illustrate the degree and rate of compositional changes. Variation in cation composition (lower left triangle) was relatively minor, precluding the need for accompanying dates. Variation in the concentrations of sulfate, chloride, total nitrogen, total organic nitrogen, and turbidity² are shown in time series plots for selected sites. For each characteristic, the same scale is

²Turbidity, an optical phenomenon, was determined as the nephelometric turbidity unit, NTU, which refers to the amount of light scattered at 90° when the turbidimeter is calibrated with formazin.

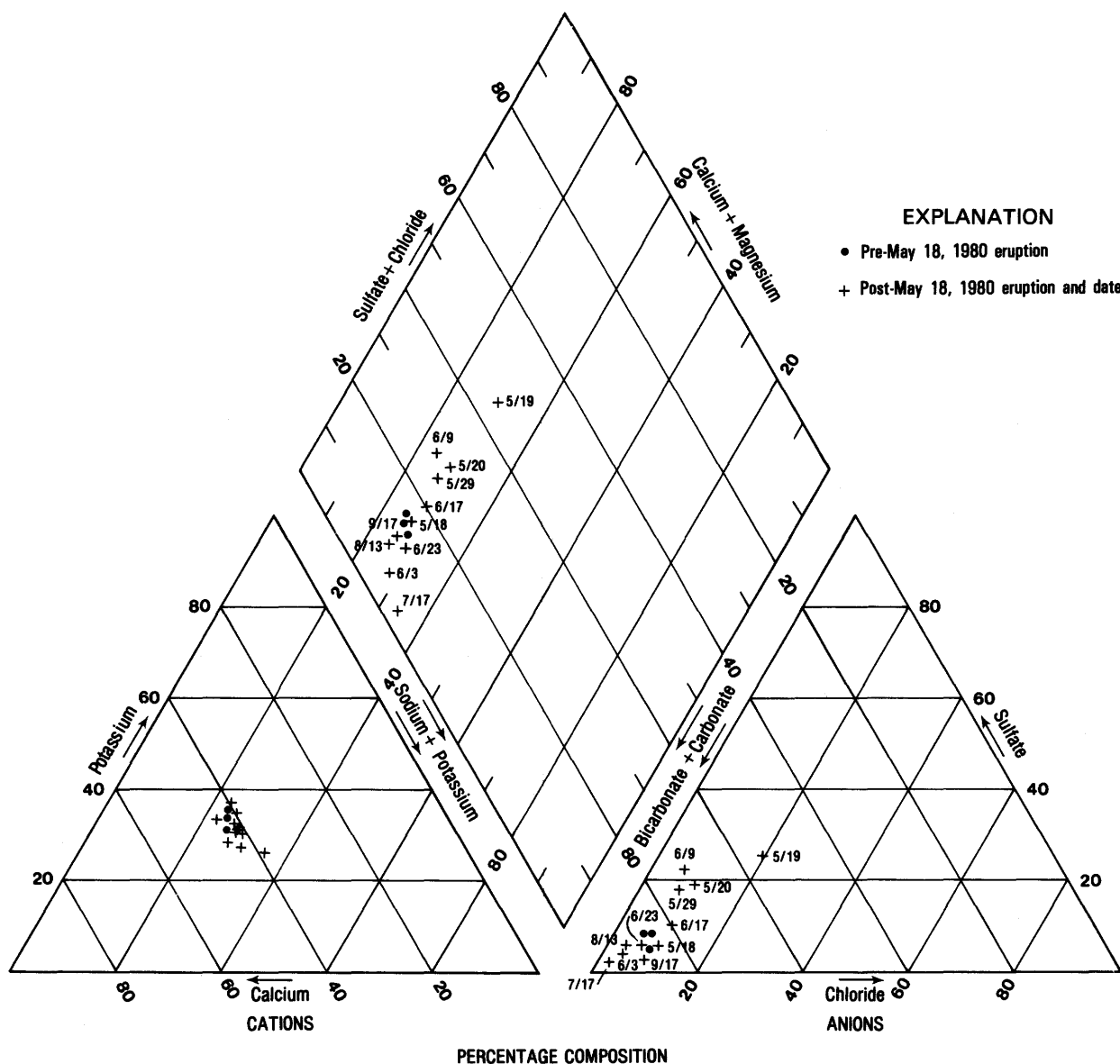


FIGURE 3.—Percentage composition of water in the Klickitat River near Pitt.

used for all sites to permit easy comparison of the relative magnitudes of change.

Figure 2 shows the changes in the relative concentrations for the Klickitat River near Glenwood before and after the eruption. Following the eruption there was change in the composition, particularly noticeable for the anions; however, by May 29, the anion composition had returned to pre-eruption conditions.

A similar shift in chemical composition in the Klickitat River near Pitt from May 19 until several days afterwards is illustrated in another trilinear

diagram (fig. 3). The sample taken on May 18 failed to show any effects of ashfall, but the sample collected the following day showed a strong shift in the anion composition toward higher percentages of chloride and sulfate, suggesting additions of soluble chloride and sulfate compounds from the ash. By May 20, the anion composition had shifted back toward the normal pre-eruption percentages, and subsequent samples confirmed that the composition returned to the normal ranges. The cation composition failed to vary to any measurable extent, probably because the per-

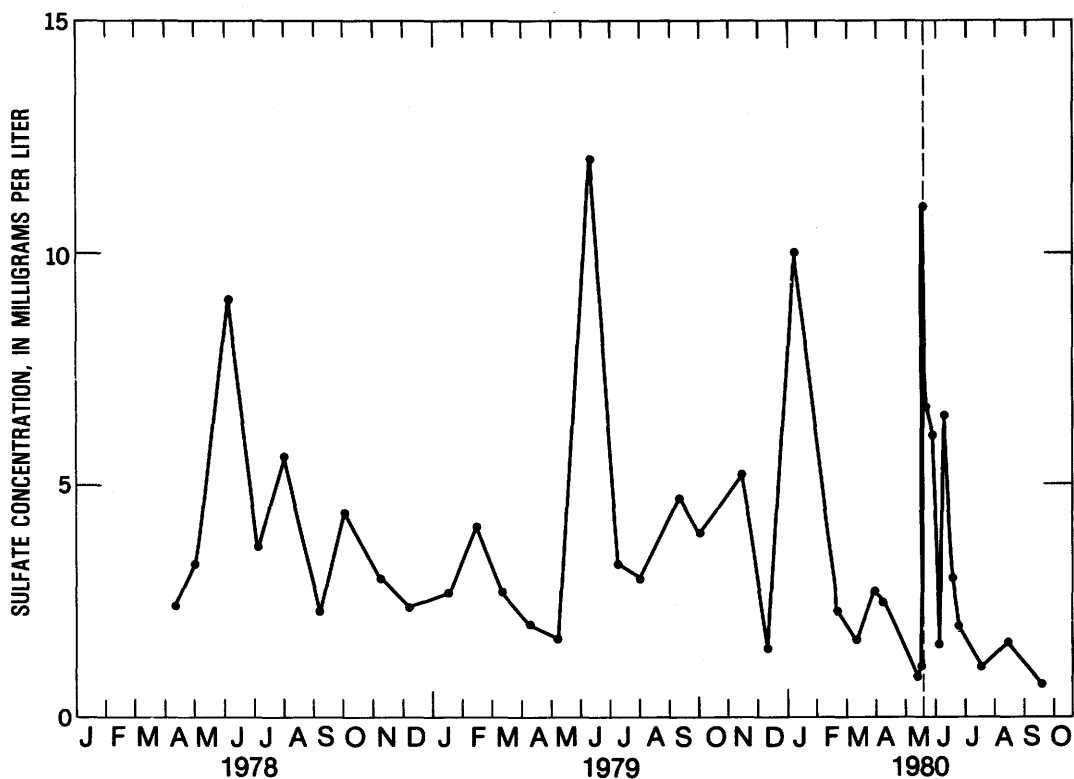


FIGURE 4.—Variation with time of sulfate for water samples from the Klickitat River near Pitt.

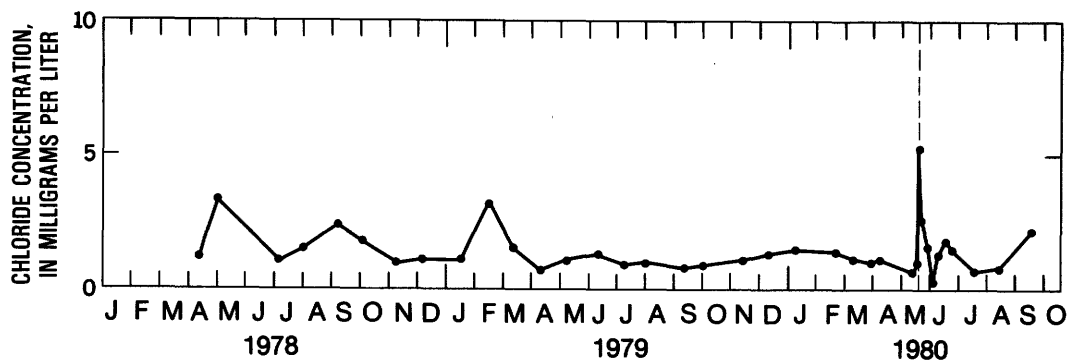


FIGURE 5.—Variation with time of chloride for water samples from the Klickitat River near Pitt.

centage composition of soluble cations in the ash (table 1) was not substantially different from that of the native waters.

Changes in the anion concentrations in the Klickitat River at Pitt were extremely short lived, as illustrated by the time series of sulfate, chloride, and dissolved solids (figs. 4, 5, 6). Samples collected just after May 18 showed increases in the concentration of these constituents. The increase in sulfate, while significant, did not exceed previous high concentrations. The chloride in-

crease noted in the May 19 sample was notably greater than other pre- and post-eruption samples. By the end of June, the concentrations of both sulfate and chloride had returned to within the pre-eruption ranges.

The most dramatic effects of the ashfall on water quality in the Klickitat is illustrated in the time series of total nitrogen, total organic nitrogen, turbidity, and specific conductance (figs. 7, 8, 9). Samples collected just after May 18 contained concentrations of these characteristics well

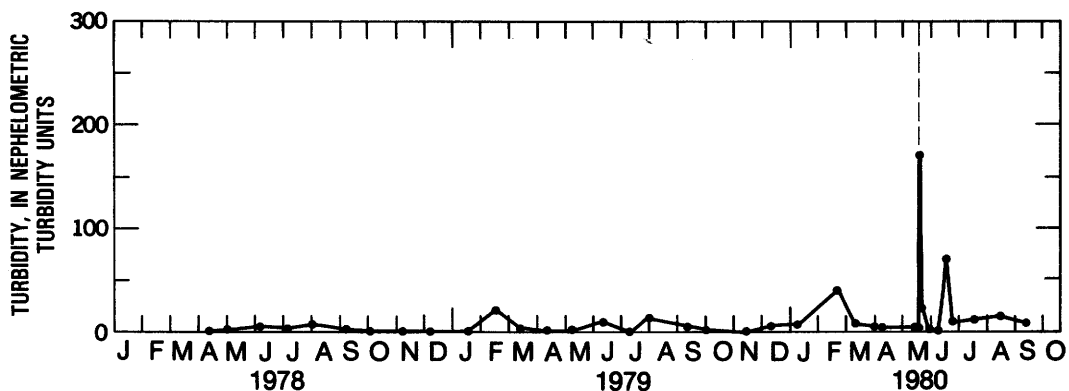


FIGURE 8.—Variation with time of turbidity for water samples from the Klickitat River near Pitt.

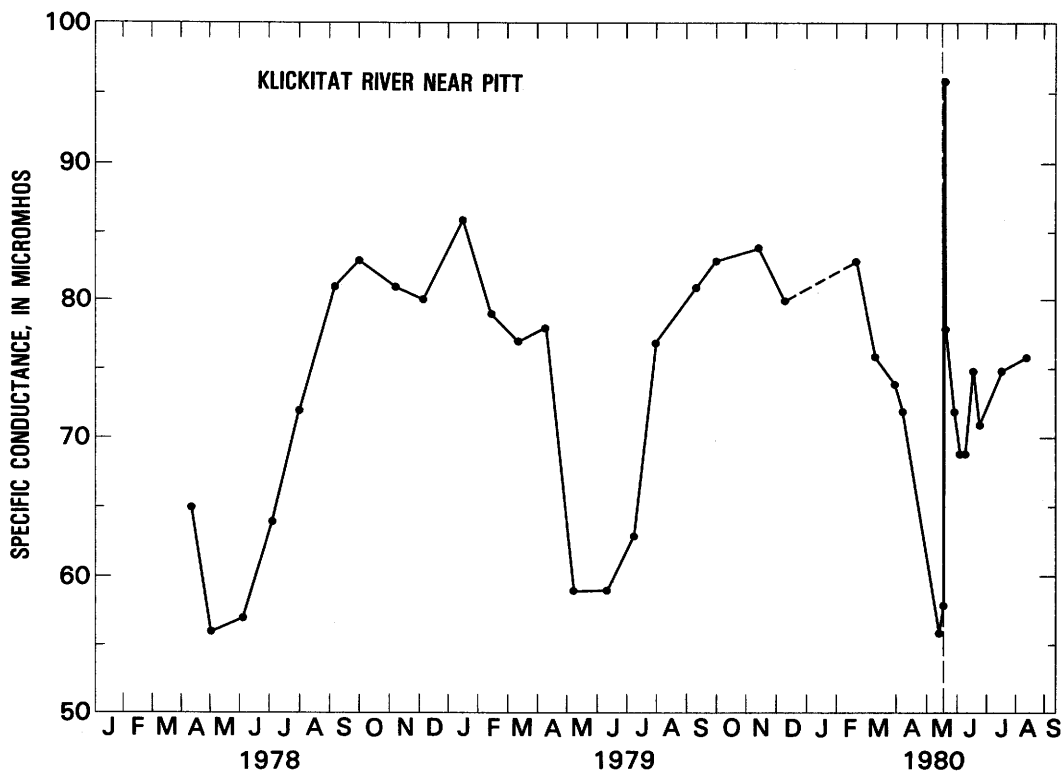


FIGURE 9.—Variation with time of specific conductance for water samples from the Klickitat River near Pitt.

above the highest observed during the previous 2 years. Because the nitrogen analyses were made on unfiltered samples, the correspondence between the peaks in nitrogen and turbidity suggest that the nitrogen was closely associated with the particulate material. The peaks observed in June were probably related to ashfall from the minor eruption of June 12–13.

The high nitrogen concentrations cannot be as easily correlated with the ash as were the high

sulfate and chloride concentrations because, unfortunately, the ash was not analyzed for organic nitrogen. However, the increase in nitrogen corresponding to the time of ash deposition is not surprising. The major blast on May 18 denuded the nearby environment including the lush forest, vegetation, and soils. It is thought that pyrolysis (a major chemical change due to intense heat) of the forest resulted in vaporization of much of the forest organic material, including a large quantity

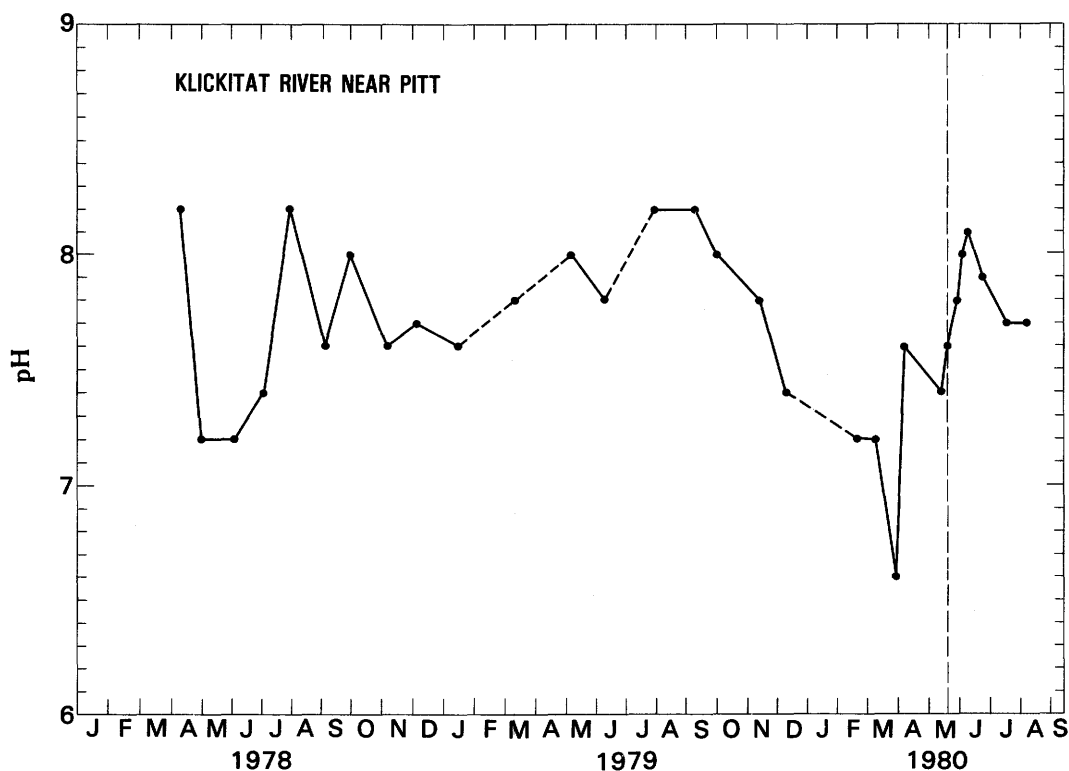


FIGURE 10.—Variation with time of pH for water samples from the Klickitat River near Pitt.

of nitrogen. The vaporized organics probably condensed, attached to the ash particles, and were transported in the ash plume. Organic carbon concentrations in ash samples collected elsewhere tend to confirm this. For the short term, organic nitrogen conveyed by ash into water would stay attached to the ash particles. With time, dissolution, mineralization, and nitrification of this nitrogen would shift the nitrogen species dominance toward dissolved nitrate.

The effects of ashfall on the nitrogen concentrations and turbidity were shortlived. By July, variations had returned to within the normal range. Figure 10 shows variations in pH. Historically, pH has ranged from 6.5 to 8.3 at this site. The 6.5 reading was obtained following the March 27 eruption, when a light dusting of ash occurred in the Klickitat drainage. A peak on June 17 on the graphs of chloride, sulfate, nitrogen, and turbidity probably represents ash deposited by the June 12–13 eruption or eroded into the river by precipitation in the upstream basin.

AHTANUM CREEK

In streams farther east of the volcano, such as the North and South Forks of Ahtanum Creek (stas 6 and 7), variations were similar to those in the Klickitat River. The North Fork Ahtanum Creek site near Tampico (sta 6) is used here to illustrate the similarity (fig. 11).

The shift in anion composition toward higher percentages of sulfate and chloride was observed in the sample taken May 18, the day of the eruption, rather than May 19, when the shift was seen in the Klickitat. The time difference is probably due to closer proximity of Ahtanum Creek to the heaviest ashfall area (fig. 1) and to a shorter time of travel of water from within the watershed to the sampling site. The degree of change in composition over normal values was also greater because the entire drainage received substantial ash. A small shift toward higher percentages of sulfate and chloride can be seen on June 24 and 28, possibly the remnant effect of the ashfall from the minor eruption of June 17.

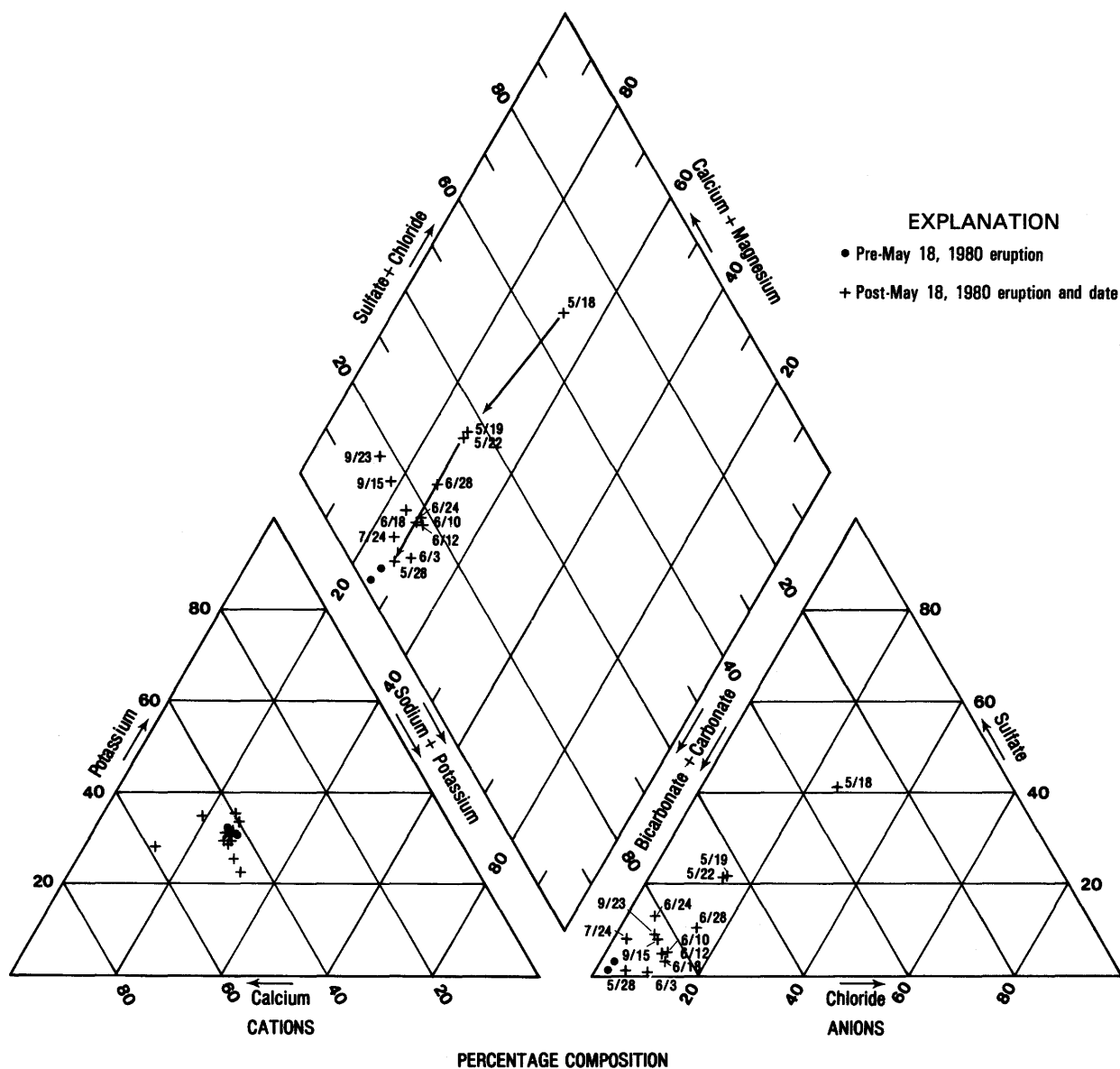


FIGURE 11.—Percentage composition of water from the North Fork of Ahtanum Creek.

YAKIMA RIVER

In streams and rivers still farther east of the volcano, the effects of ashfall on water quality were much less apparent than in the Klickitat River and Ahtanum Creek. The Yakima River is the major river draining central Washington, and much of the land it drains received significant ashfall. Two sites for which historical water-quality data were available, the Yakima River at Union Gap (site 8, fig. 3) and near Kiona (site

9, fig. 3), were chosen for intensive sampling to document water-quality changes caused by volcanic activity. The changes in water chemistry during the May 18 ashfall for the Yakima River at Union Gap were not as dramatic as seen in the North Fork Ahtanum Creek because of dilution by water draining areas unaffected by ash fall. The sulfate, chloride, and dissolved-solids concentrations varied sharply over a short period of time, and the changes were small when compared with seasonal variations; however, they are detectable in figures

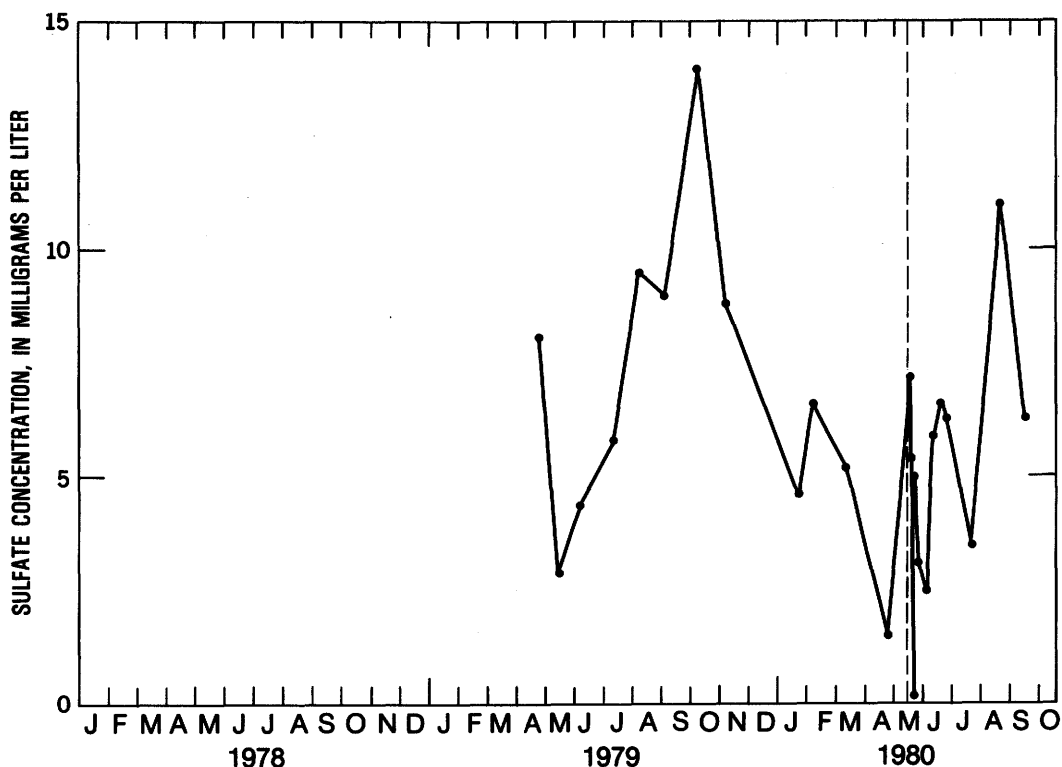


FIGURE 12.—Variation with time of sulfate for water samples from the Yakima River at Union Gap.

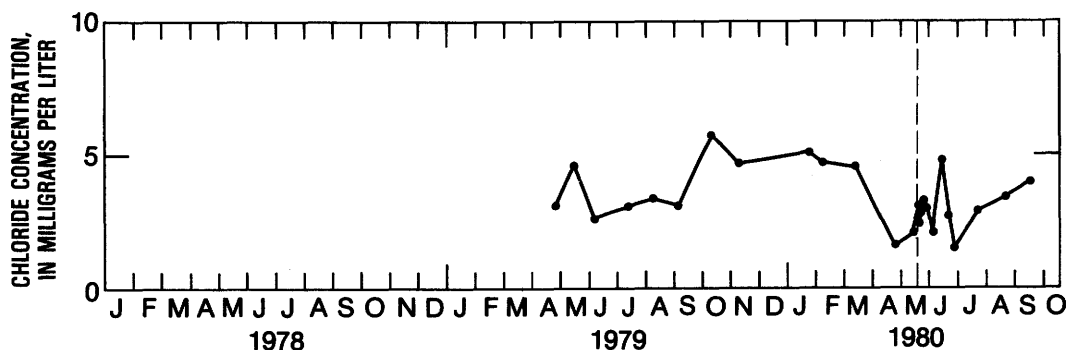


FIGURE 13.—Variation with time of chloride for water samples from the Yakima River at Union Gap.

12–16. The greatly reduced effects in the Yakima River as compared with those in the Klickitat River and Ahtanum Creek probably can be explained by dilution; water from highly ash-affected tributaries is diluted by waters from tributaries that received little or no ash.

By contrast, the total nitrogen and organic nitrogen concentrations and turbidity values (figs. 15, 16) increased dramatically. Of further interest, immediately after the eruption the total nitrogen concentration was primarily organic nitrogen,

which in preceding years had made up only about 50 percent of the total nitrogen concentrations.

Figures 17–21 show the water-chemistry data for the Yakima River at Kiona site from April 1978 to August 1980. At the Kiona site, as with the other sites, changes in the major chemical constituents are apparent, but delayed and of short duration. Total-nitrogen concentration and turbidity changed dramatically, and dissolved chloride concentration increased significantly. Dissolved sulfate and dissolved-solids concentration also in-

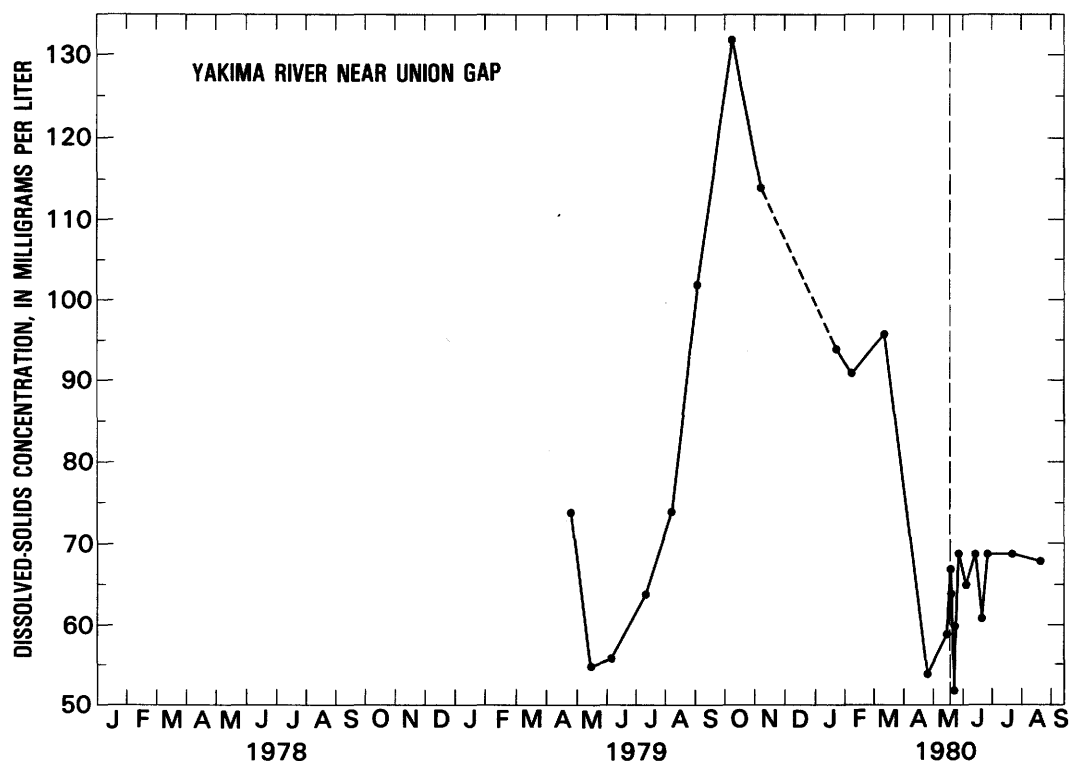


FIGURE 14.—Variation with time of dissolved solids concentration for water samples from the Yakima River at Union Gap.

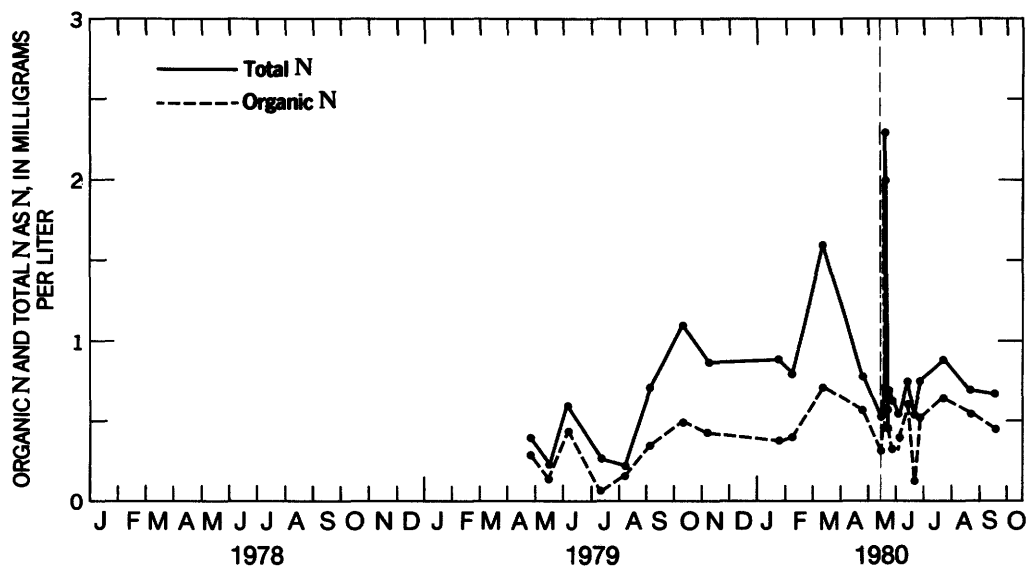


FIGURE 15.—Variation with time of total and organic nitrogen for water samples from the Yakima River at Union Gap.

creased with ash deposition, but the effects were small when compared with the peaks of past periods. Although total nitrogen showed a large increase, the organic nitrogen component was not

as large as at several of the other sites, possibly because of alteration of the organic nitrogen to inorganic forms such as ammonium or nitrate. Additionally, the nitrogen, which began to increase

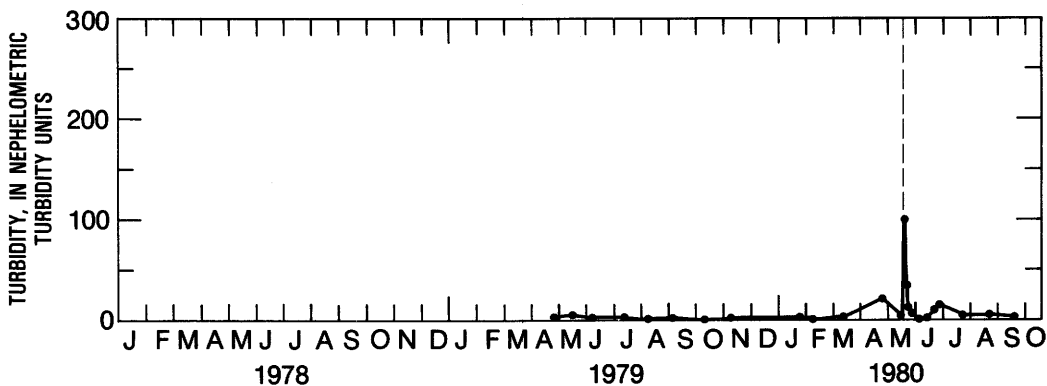


FIGURE 16.—Variation with time of turbidity for water samples from the Yakima River at Union Gap.

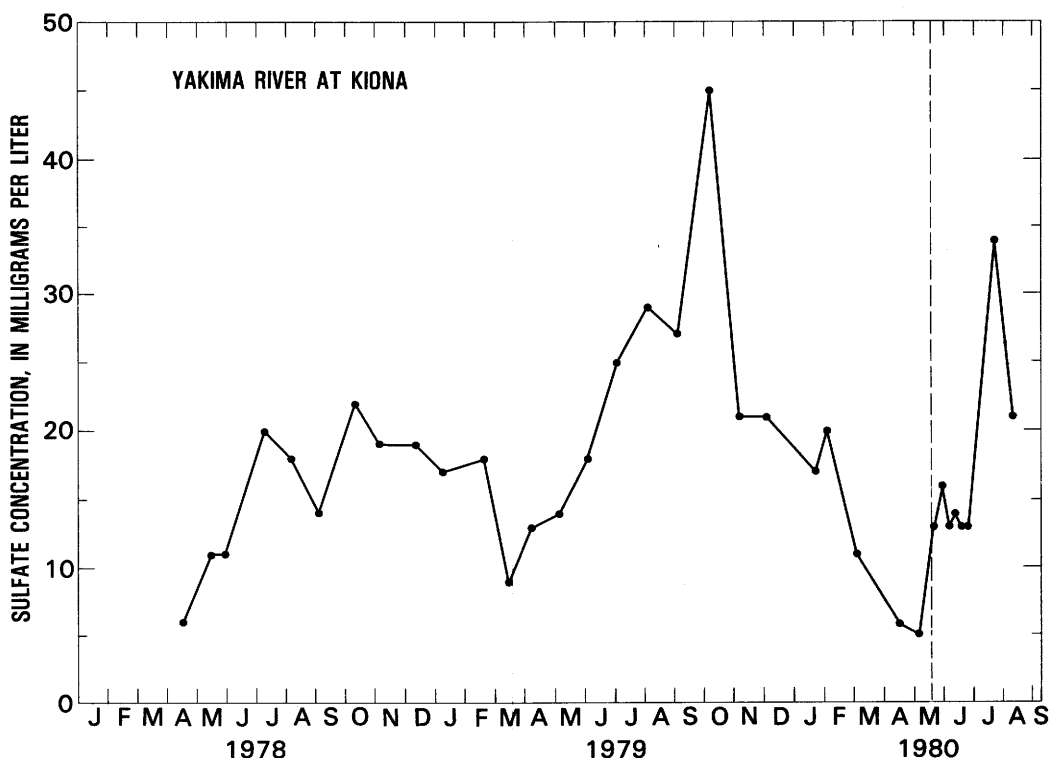


FIGURE 17.—Variation with time of sulfate for water samples from the Yakima River at Kiona.

on May 6, before the May 18 eruption, did not peak until June 25, probably because this component may have a lag time in this river system. The turbidity extreme that occurred on June 19 was also accompanied by a dissolved-solids decrease, indicating the possibility of dilution by precipitation and erosion of ash from the land surface to the river.

SPOKANE RIVER

Farther to the east, the effects of ashfall on water quality were much less apparent than noted

in the previous sections. Samples were collected from the Spokane River near Riverside State Park (site 10, fig. 1) and from Hangman Creek (site 11, fig. 1). The Spokane River drains an area of northwestern Idaho and eastern Washington that received substantial ash and is below the mouth of Hangman Creek, which drains the area south of Spokane. Figures 22–26 show the chemical variations observed in water from the Spokane River site. As with the Yakima River sites, changes in the water chemistry caused by ash fall are similar. The peaks observed in the data in figures 22–26

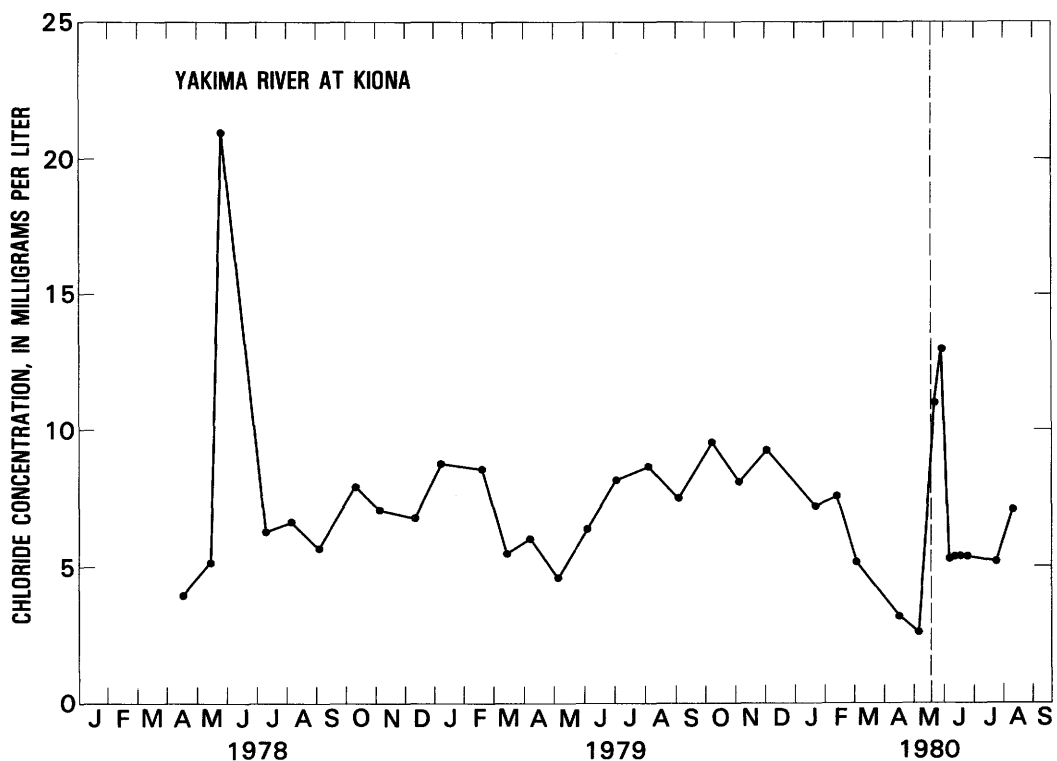


FIGURE 18.—Variation with time of chloride for water samples from the Yakima River at Kiona.

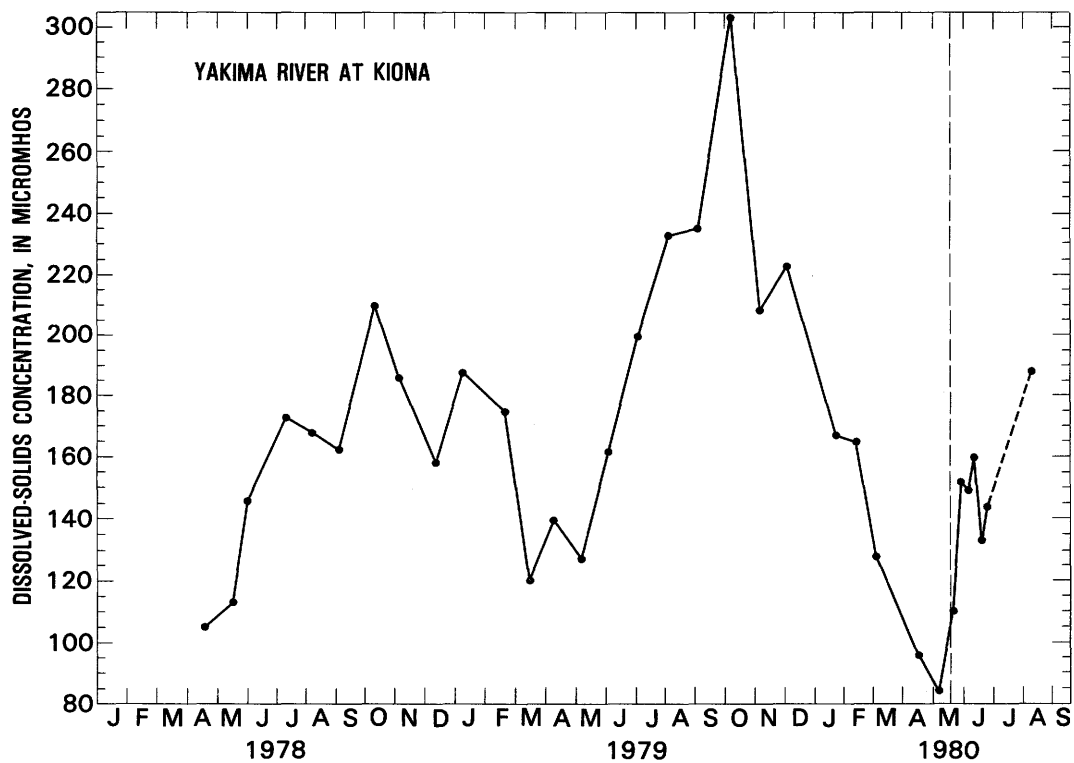


FIGURE 19.—Variation with time of dissolved-solids concentration for water samples from the Yakima River at Kiona.

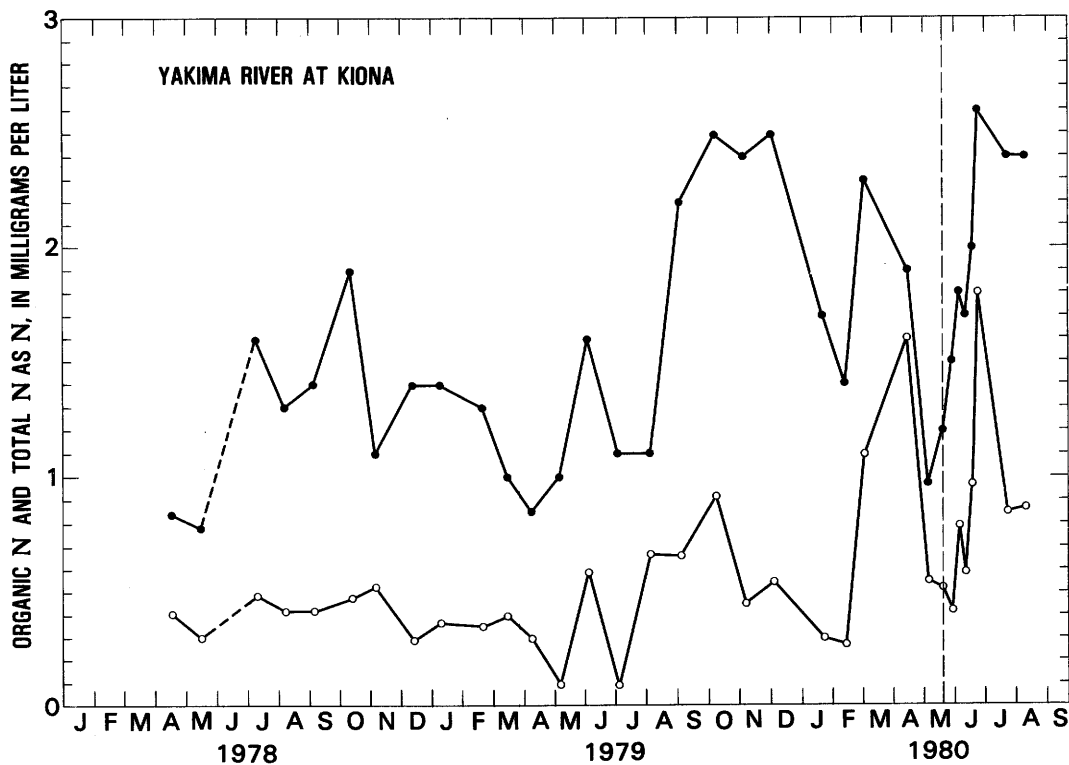


FIGURE 20.—Variation with time of total and organic nitrogen for water samples from the Yakima River at Kiona.

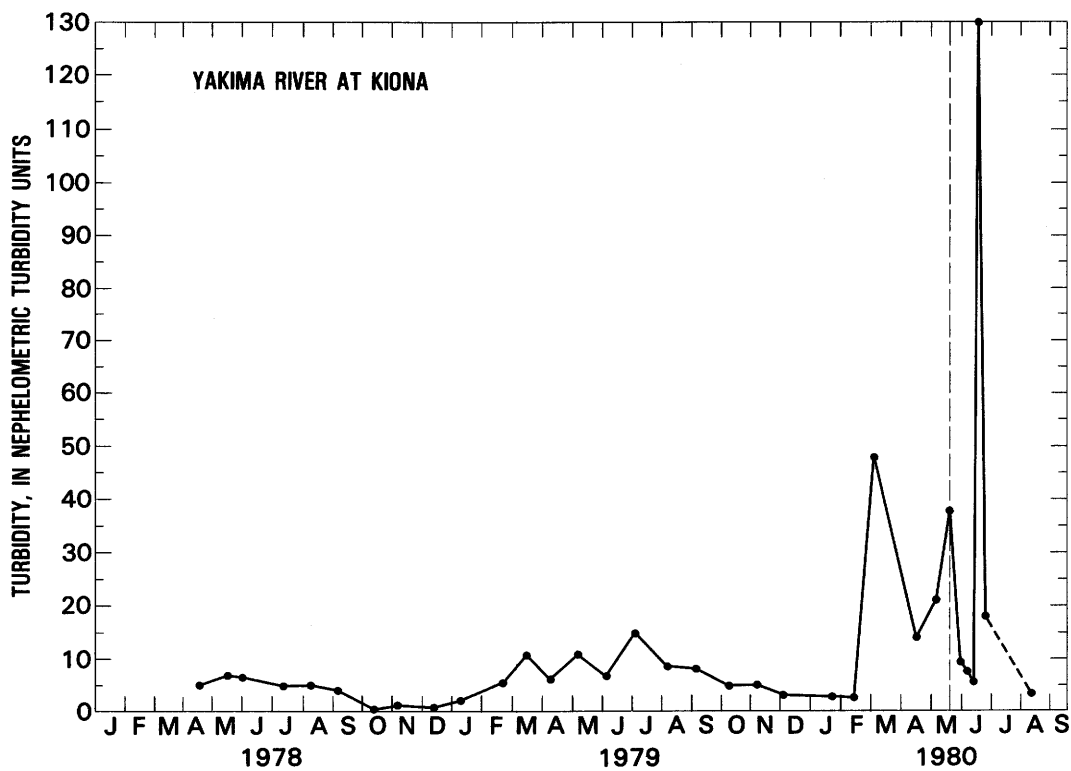


FIGURE 21.—Variation with time of turbidity for water samples from the Yakima River at Kiona.

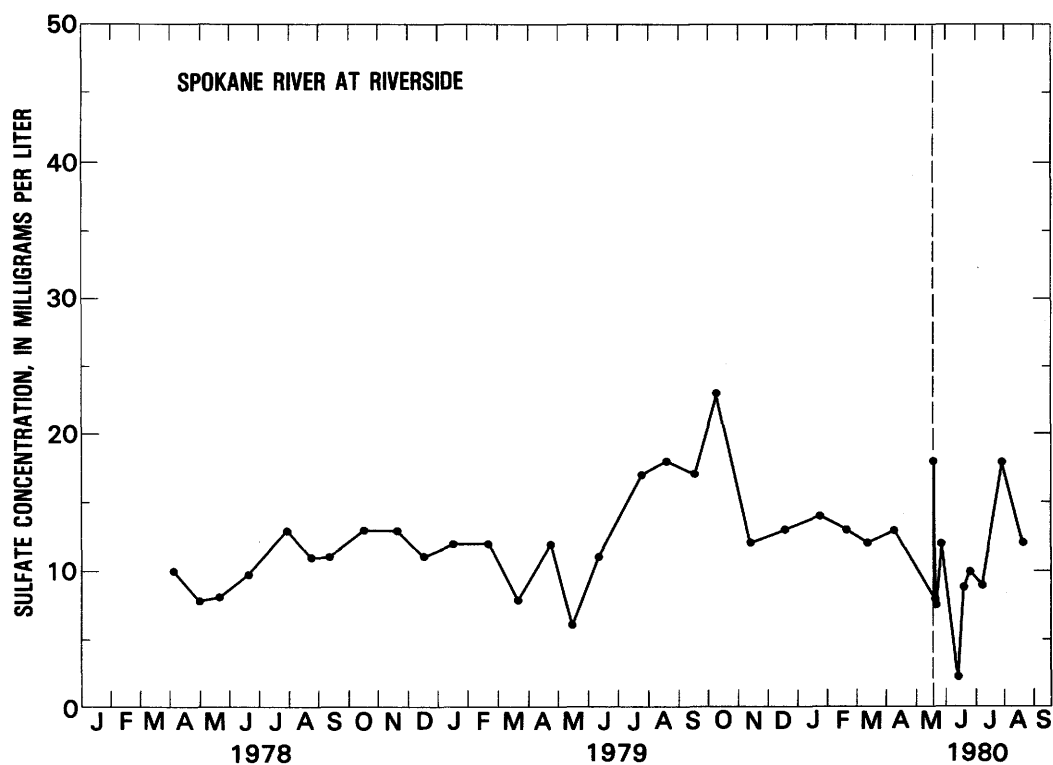


FIGURE 22.—Variation with time of sulfate for water samples from the Spokane River at Riverside State Park.

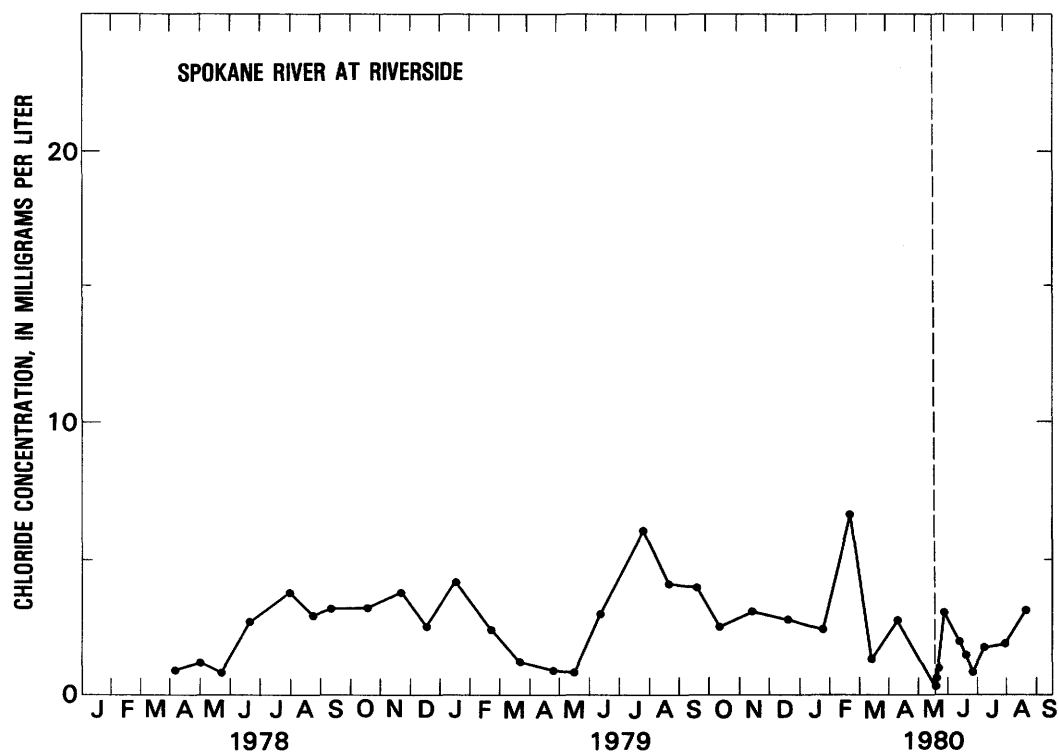


FIGURE 23.—Variation with time of chloride for water samples from the Spokane River at Riverside State Park.

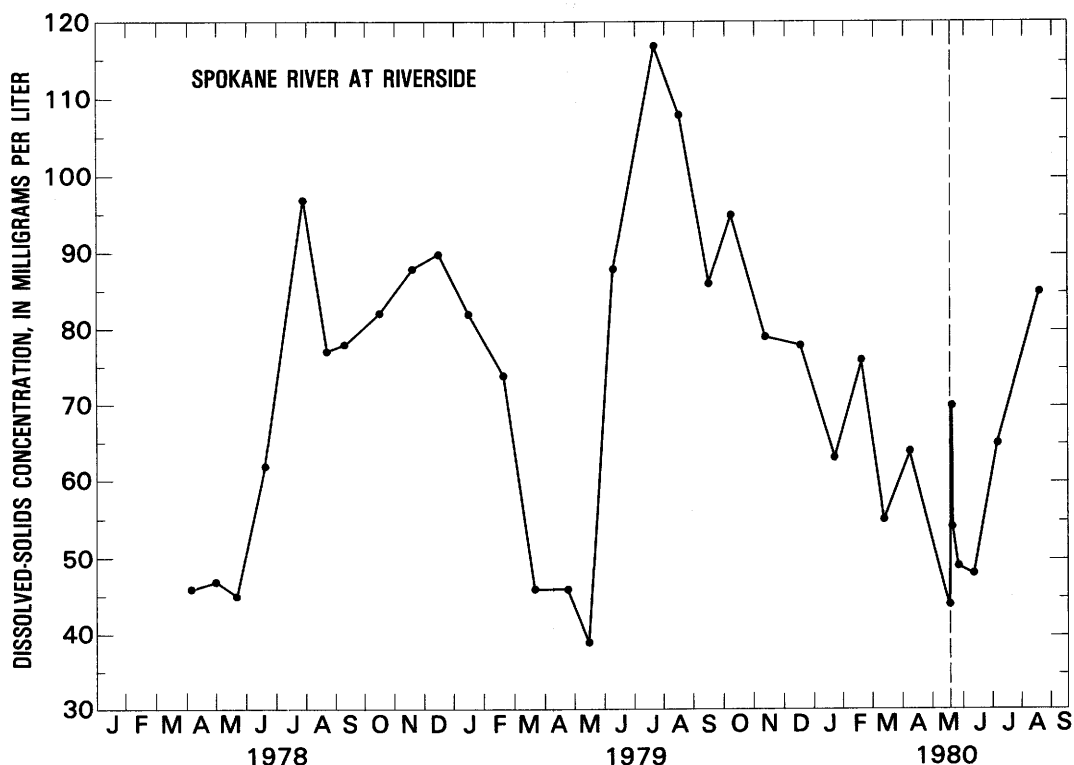


FIGURE 24.—Variation with time of dissolved-solids concentration for water samples from the Spokane River at Riverside State Park.

do not necessarily coincide with the days of maximum ash deposition in the Spokane area. Rather, the peaks for chloride (fig. 23), total and organic nitrogen (fig. 25), and turbidity (fig. 26) are 1 week later (May 27), during and following rains that washed large quantities of ash into the river system. Additionally, large quantities of ash in the Spokane area were reportedly dumped into the Spokane River for disposal.

At the Spokane River sampling site, the organic nitrogen component of the total nitrogen predominated and, on the days preceding the eruption, made up almost the entire total-nitrogen concentration.

EFFECTS OF VOLCANIC DEBRIS AND MUDFLOWS ON RIVER WATER QUALITY

The headwaters of the Toutle River drainage were altered beyond recognition by volcanic debris deposits and pyroclastic flows from the May 18 eruption. The downstream reaches of the Toutle and of the lower Cowlitz below its confluence with the Toutle River were devastated by massive

flooding and mudflows. Water samples from the Toutle and Cowlitz Rivers at sites 12, 13, and 14 (fig. 1) collected on a regular basis since the May 18 eruption show that these events have had a pronounced and persistent effect on the surface-water chemistry.

Water samples collected on March 29, 1980, at the Toutle River near Castle Rock (site 12, fig. 1) before the major eruption indicate that calcium and bicarbonate were the principal dissolved chemical constituents. Water samples collected on May 20 indicate an entirely different chemical composition (fig. 27), with dissolved sulfate and chloride abruptly becoming the dominant anions. The June 24 sample suggested a trend of the river back to its pre-eruption composition; however, the July 22 sample showed another large increase in the chloride concentration, indicating that some upstream activity is continuing to alter the chemistry of the river water, such as dredging and continuing leaching of the ash, debris, and mudflow deposits.

The mudflows that occurred on the evening of May 18 in the Toutle River prohibited collection

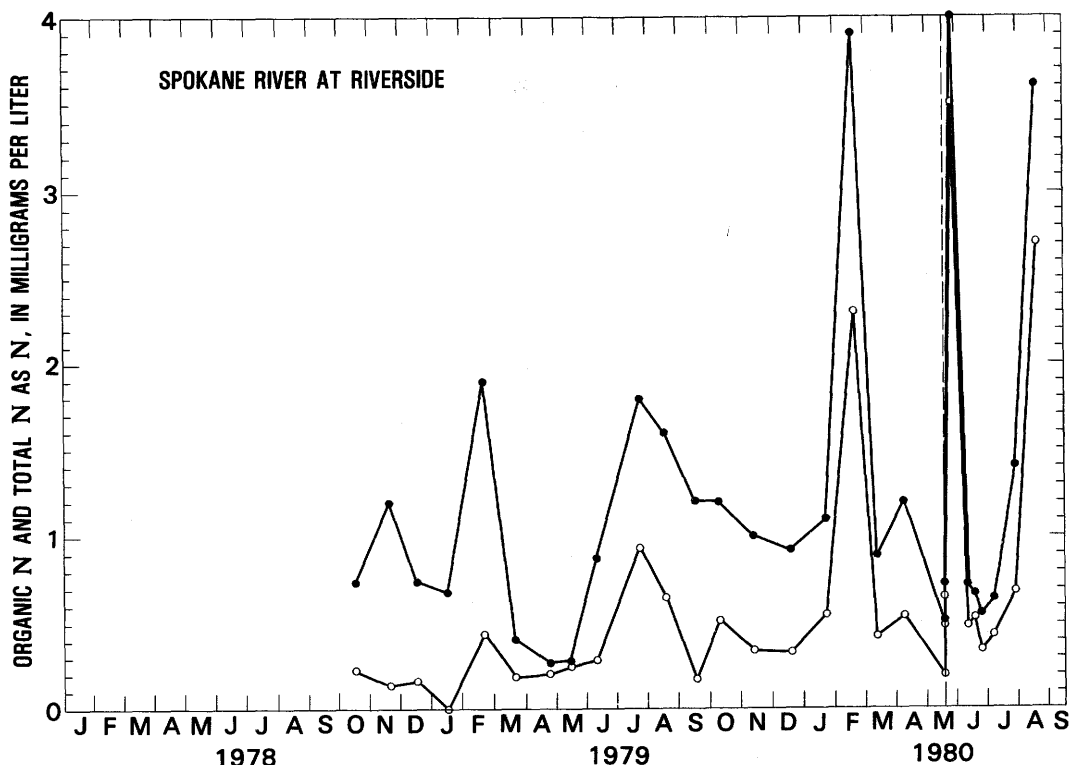


FIGURE 25.—Variation with time of total and organic nitrogen for water samples from the Spokane River at Riverside State Park.

of satisfactory water-quality samples. The specific conductance of the mudflows on May 19 was 1,200 micromhos per centimeter at 25°C, as compared with normal water values of about 90 μ mho, decreasing to 560 μ mho on May 20 when the first water samples could be obtained.

Following the major eruption, the sampling frequency at Cowlitz River at Castle Rock (site 13, fig. 1) was increased to determine the effects caused by inflow from the Toutle drainage. Starting on May 30, 1980, sample intensity was also increased downstream from the Cowlitz River at Kelso (site 14, fig. 1) to monitor changes in chemical composition between the two sites and to document the chemistry of the water flowing into the Columbia River.

The compositional variations in the Cowlitz River at Castle Rock were similar to those observed in the Toutle. The overall effect, however, was reduced because of dilution of the flow in the Cowlitz. The variability of the composition at the Castle Rock site was and is being determined by the nature and magnitude of the effects of flow

from the devastated Toutle system, dredging activities upstream in the Toutle and Cowlitz, and by dilution affects of water from the upper Cowlitz.

Long-term data from the Cowlitz River at Kelso can be examined to determine the degree of impact of volcanic activity on river-water chemistry at this point. Figures 28–32 show data for selected characteristics from April 1978 to the present (August 1980). The largest variations occurred in the concentrations of sulfate, dissolved solids, total and organic nitrogen, and turbidity. High concentrations of sulfate and chloride were observed in late May and June, although maximum values for both ions were below those in samples collected monthly during the previous 2 years. However, the mudflows had a drastic effect on the levels of total organic nitrogen, total nitrogen, and turbidity (figs. 31 and 32). Samples collected in late May and early June showed turbidity values well above the normal values observed at this station, and, as before, these increases were accompanied by major increases in total nitrogen concentration,

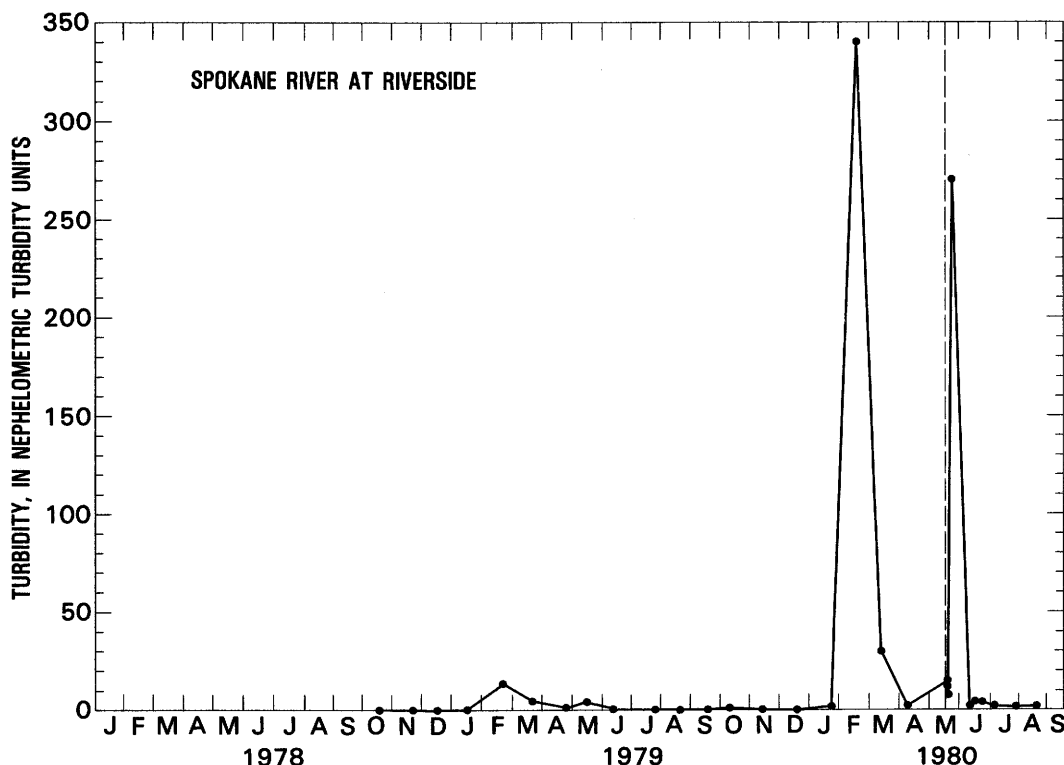


FIGURE 26.—Variation with time of turbidity for water samples from the Spokane River at Riverside State Park.

with most of the increase due to total organic nitrogen.

When and where possible, streams draining the slopes of Mount St. Helens have been sampled to determine the effects of the volcanic eruption on water chemistry and to determine chemical changes with time. The debris pile, covering the North Fork of the Toutle and several pre-existing data sites, the mudflows, and the flooding severely altered the conditions of most of the sites close to Mount St. Helens. Following the May 18 eruption, miscellaneous sampling sites were established at the locations shown in figure 33. Background data were collected at several of these sites beginning on March 28 and 29, and these data can be compared with those collected since the eruption to assess chemical changes.

At the South Fork Toutle River (site 15, fig. 33) there was a major increase in chloride composition and sulfate increases were negligible. Only minor cation changes were observed. Similar changes were observed in Pine Creek at its mouth near Cougar (site 16, fig. 33). Samples collected

before the major eruption indicated that the water was characterized by sodium and bicarbonate, but post-eruption changes resulting from the mudflows in Pine Creek showed a shift toward higher chloride concentration (fig. 33).

The Kalama River at site 17 (fig. 33) was relatively unaffected by the May 18 eruption, but received ash deposits from the May 25 event. Few overall concentration and compositional changes in water chemistry were apparent, except for a minor increase in the sulfate and chloride components.

Post-eruption water-chemistry data from the North Fork (mainstem) of Coldwater Creek (site 18) and the Toutle River near Kid Valley (site 19) showed nearly equal percentages of the major dissolved-chemical constituents (fig. 33). Both stations had uniquely greater percentages of sulfate and chloride in comparison with all other sites, indicating a greater chemical effect of the eruption on streams whose headwaters are within or very near the blast area and the debris avalanche deposit.

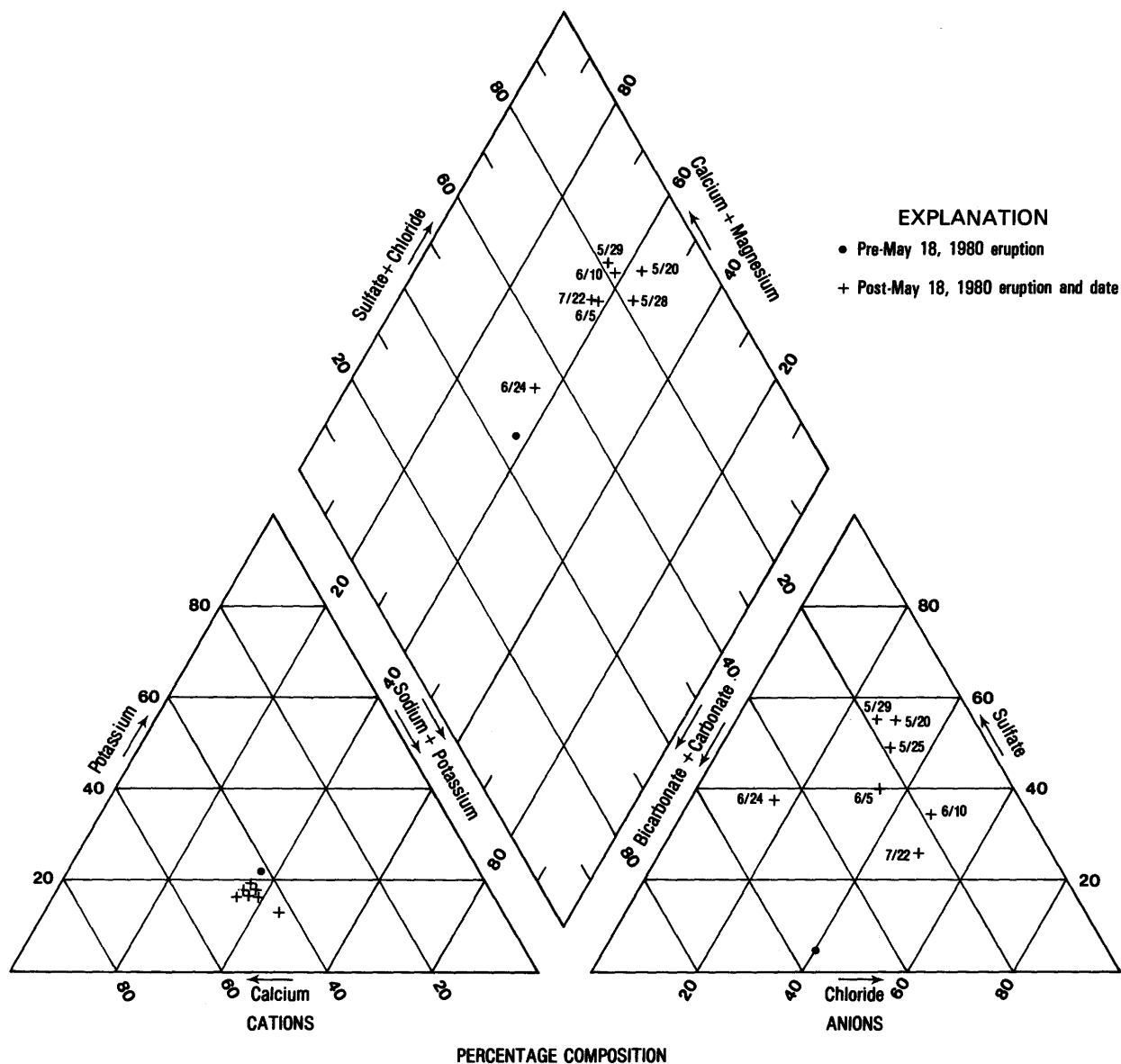


FIGURE 27.—Percentage composition of water from the Toutle River near Castle Rock.

OCCURRENCE OF TRACE METALS

Analysis of the ash (table 2) showed the presence of iron, manganese, and several other metals which, in the investigated streams and rivers, normally occur in very low concentrations. To determine the effects of ashfall on concentrations of these trace metals, both filtered and unfiltered samples were analyzed to measure the dissolved- and total metal concentrations. The difference between the two values represents the concentration in the suspended sediments.

Suspended-sediment concentrations were high in most of the samples, and most of the trace metals determined were associated with these sediments. The dissolved-metal concentrations (table 3) were generally much lower than the suspended-sediment metal concentrations and only slightly elevated above pre-eruption levels in those streams affected solely by ash deposition. In the Toutle and Cowlitz Rivers, post-eruption concentrations of dissolved iron, manganese, and aluminum increased and the increases persisted owing

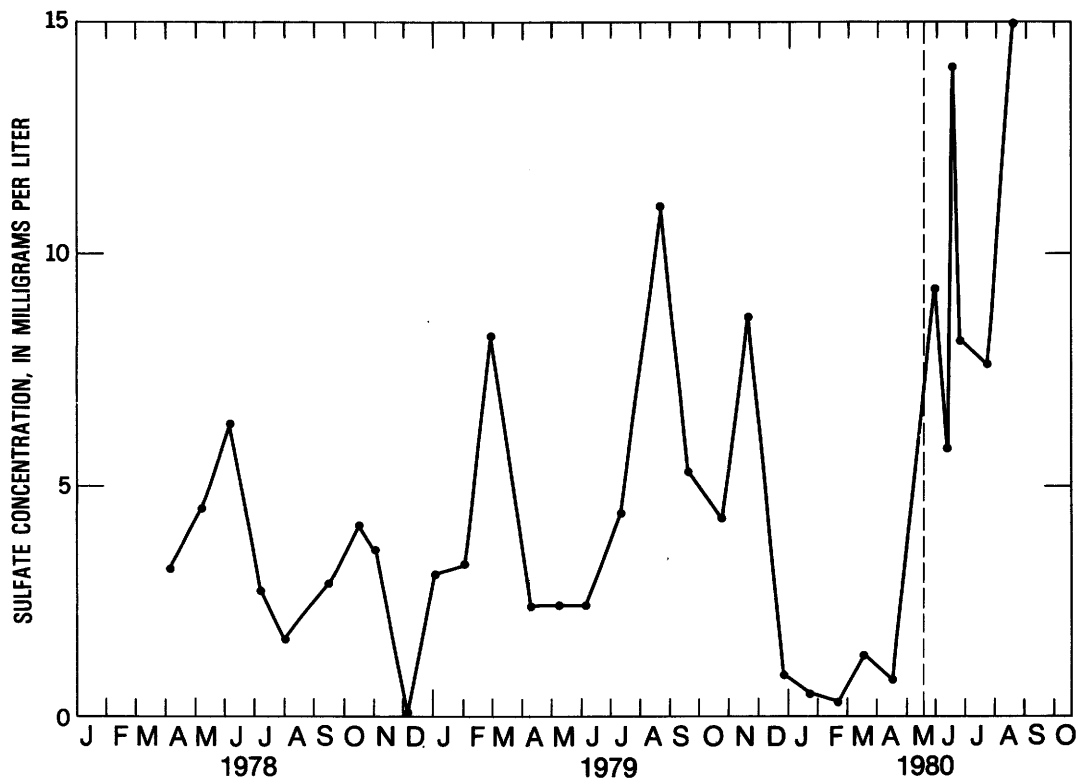


FIGURE 28.—Variation with time of sulfate for water samples from the Cowlitz River at Kelso.

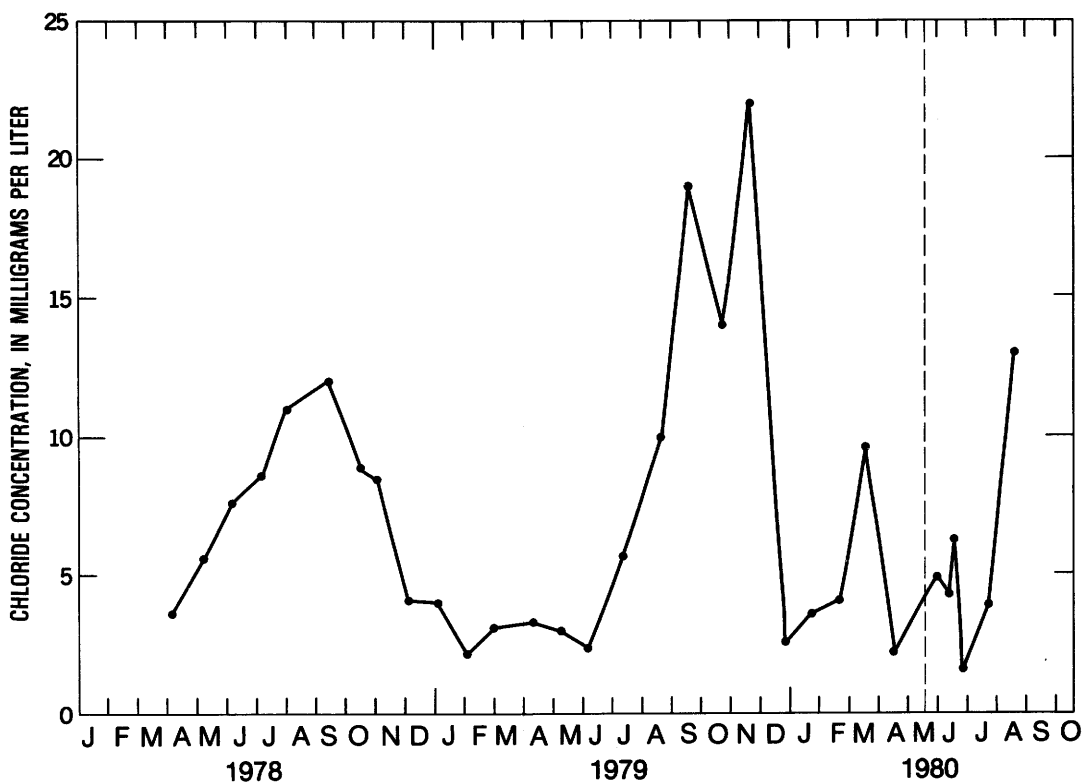


FIGURE 29.—Variation with time of chloride for water samples from the Cowlitz River at Kelso.

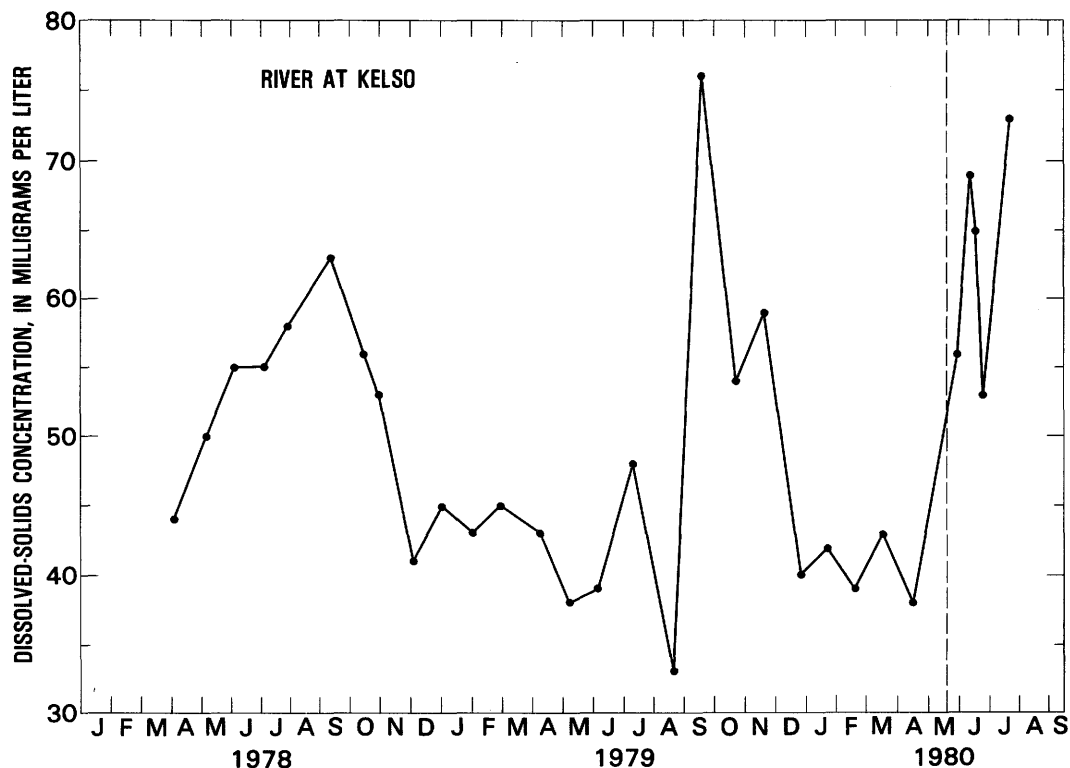


FIGURE 30.—Variation with time of dissolved-solids concentration for water samples from the Cowlitz River at Kelso.

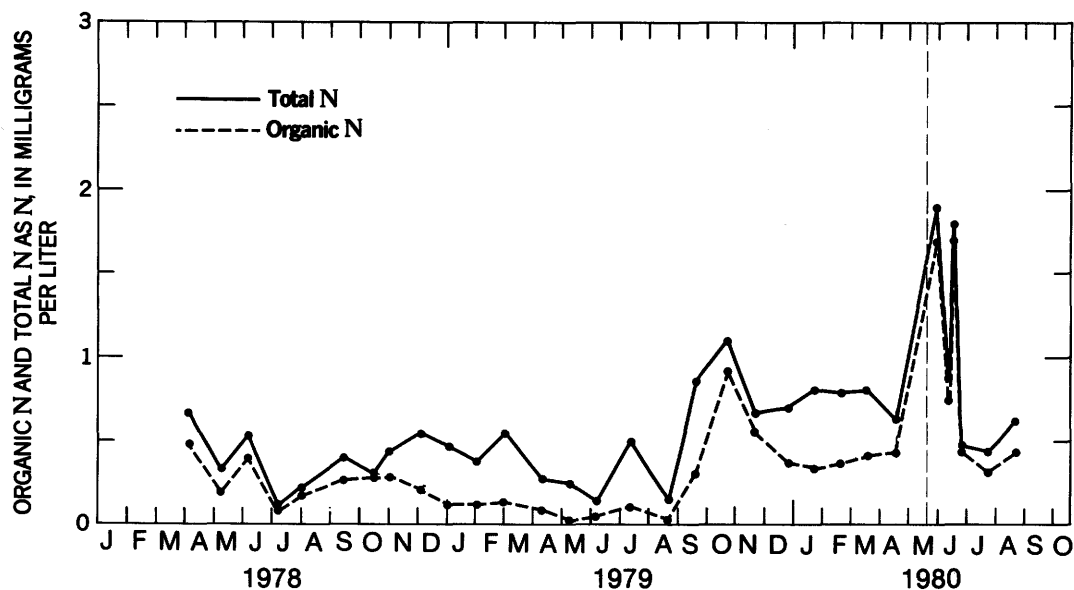


FIGURE 31.—Variation with time of total and organic nitrogen for water samples from the Cowlitz River at Kelso.

to continued leaching from the debris and mudflow deposits.

Total concentrations of iron, manganese, and aluminum increased greatly over pre-eruption

levels (table 3). Total concentrations of these metals at the Toutle and Cowlitz stations increased 100 to 500 times over pre-eruption values, whereas the concentrations increased only about

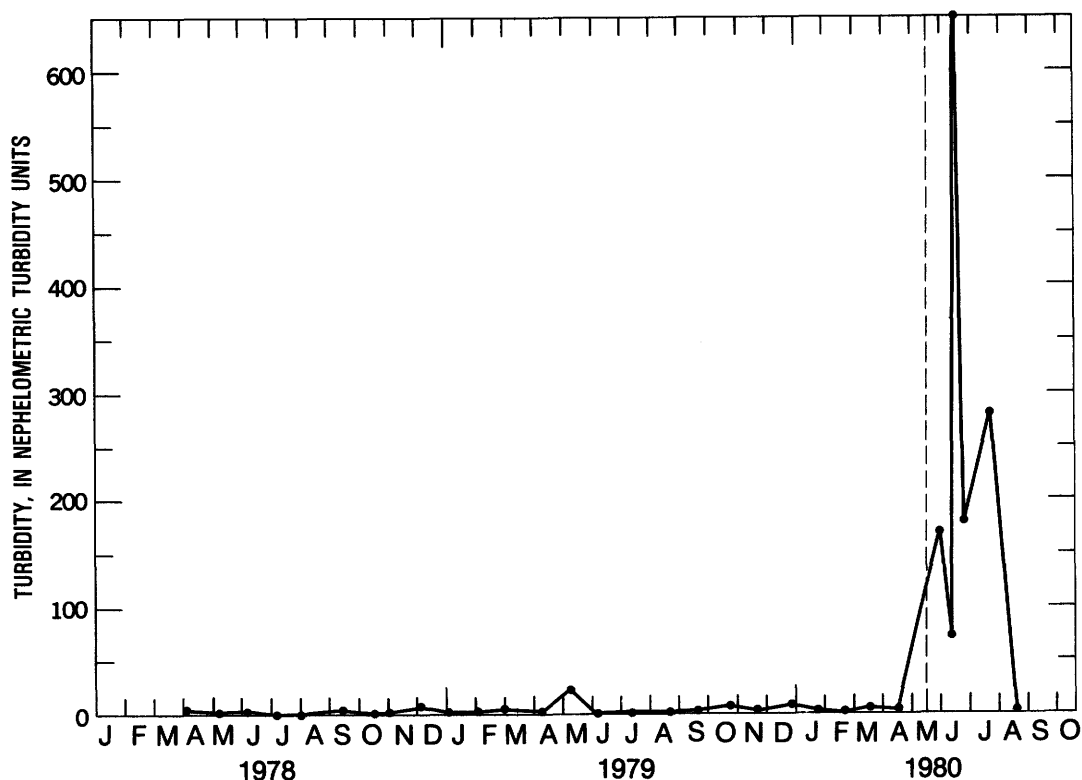


FIGURE 32.—Variation with time of turbidity for water samples from the Cowlitz River at Kelso.

TABLE 3.—Variation in trace elements, in micrograms per liter, at selected stations

Station	Date (1980)	Iron		Manganese		Aluminum	
		Dissolved	Total	Dissolved	Total	Dissolved	Total
Klickitat River near Pitt (station 3)	5/13	60	850	3	20	40	620
	5/18	80	680	20	40	40	500
	5/19	70	4,200	10	90	70	3,100
	5/20	60	1,100	7	30	40	820
	5/29	47	500	3	3	30	640
North Fork	3/30	170	600	7	20	140	470
Ahtanum Creek near Tampico (station 6)	5/18	50	17,000	70	360	60	16,000
	5/19	60	4,600	10	80	110	2,200
	5/28	85	920	10	20	50	400
Toutle River near Castle Rock (station 12)	3/29	70	230	20	20	40	200
	5/20	95	22,000	1,000	1,300	310	20,000
	5/22	21	76,000	1,200	2,200	700	55,000
	5/25	160	50,000	350	1,400	540	33,000
	5/27	110	78,000	490	2,000	250	5,700
	5/29	65	41,000	400	1,300	270	34,000
	6/ 5	110	32,000	380	1,100	110	65,000
	6/10	140	40,000	320	1,100	100	85,000
	6/19	240	33,000	290	290	40	20,000
	6/24	210	19,000	290	680	140	100,000
Cowlitz River at Kelso (station 14)	4/16	50	400	5	10	-	-
	5/30	24	12,000	110	350	120	29,000
	6/12	90	10,000	90	290	80	10,000
	6/17	70	45,000	110	900	20	39,000
	6/25	80	8,000	70	230	60	10,000

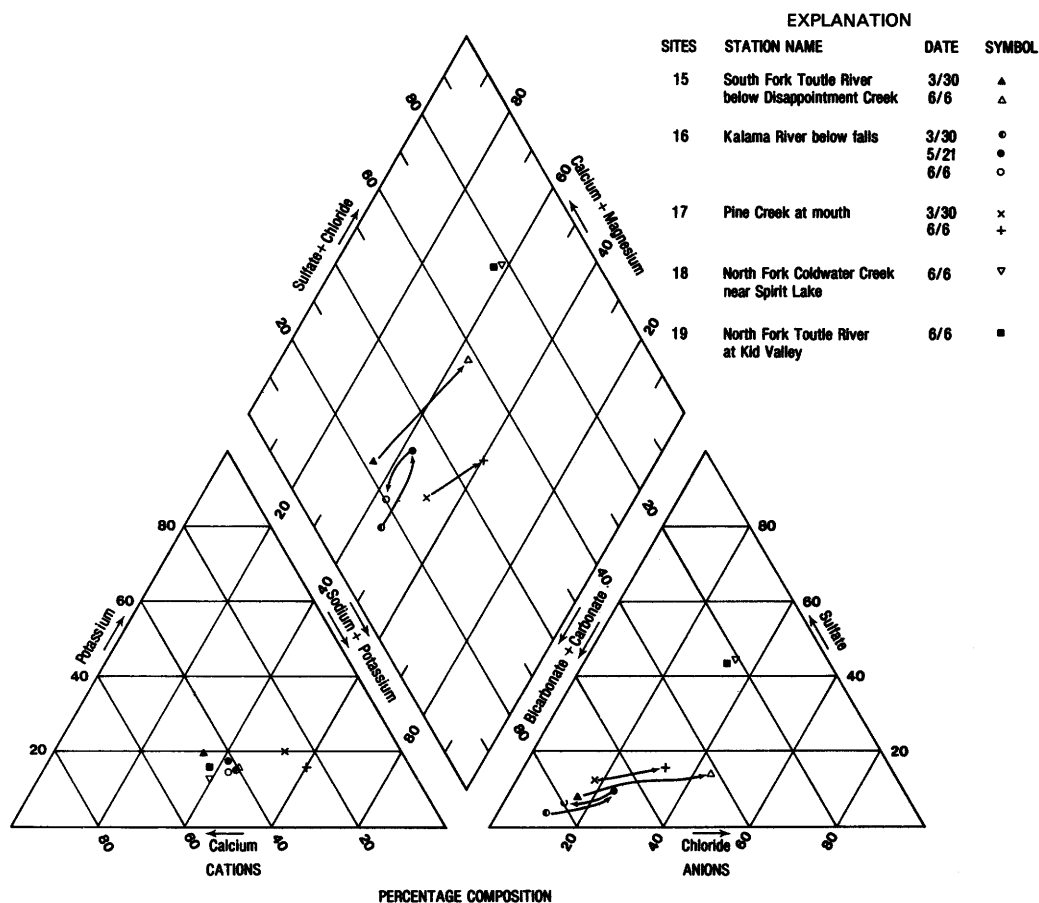


FIGURE 33.—Percentage composition of water from selected sampling sites near Mount St. Helens.

5 to 50 times at the ash-affected stations on the Klickitat River and the North Fork Ahtanum Creek. There was also a marked difference between the mudflow- and ash-affected stations in the duration of total-metal-concentration increases. At the Klickitat and North Fork Ahtanum stations, the increases in total metal concentrations were short lived. In contrast, increases at the Toutle and Cowlitz River stations persisted at least through June, owing to the continuing influx of suspended sediment.

Concentrations of other trace metals of interest—arsenic, cadmium, chromium, and cobalt—were not noticeably elevated over pre-ashfall levels in either the filtered or unfiltered samples.

SUMMARY

The May 18 eruption of Mount St. Helens in southwestern Washington had a pronounced effect on river water quality. The effects were greatest in the Toutle River system, which was devastated by the blast, a massive debris deposit, and

mudflows. The Cowlitz River, into which the Toutle drains, was similarly affected. Relatively smaller but still marked changes in water quality were observed in volcanic-ash-affected drainage basins east of the volcano.

The major changes in water quality associated with the eruptive events included increases in the levels of sulfate, chloride, total nitrogen, total organic nitrogen, turbidity, iron, manganese, and aluminum. In the ash-affected basins east of Mount St. Helens, the observed river quality changes were short lived and, in general, decreased in magnitude with distance from the volcano. Changes in quality in the Toutle and Cowlitz Rivers have tended to persist owing to continuing influxes and leaching of sediment from the devastated headwater areas.

Total concentrations of iron, manganese, and aluminum increased greatly over pre-eruption levels, up to 100 to 500 times in the Toutle and Cowlitz Rivers compared with 5 to 50 times at the reported sites east of the mountain. The ele-

vated total concentrations of these metals have tended to persist in the Toutle and Cowlitz Rivers; whereas, those in the ash-affected streams quickly returned to pre-eruption levels. At all sampled sites, the dissolved-metal concentrations were generally much lower than the suspended-metal concentrations.

High concentrations of total nitrogen and total organic nitrogen were observed in post-eruption water samples. In all cases, the high nitrogen concentrations were associated with high levels of turbidity, and the greater proportion of the nitrogen was organic. The high concentrations of organic nitrogen probably resulted from pyrolysis of the forest within the blast zone. It is envisioned that the vaporized organic products immediately attached to volcanic ash particles and were then transported to points of deposition.

SELECTED REFERENCES

- Fruchter, J. S., and others, 1980, Mount St. Helens ash from the 18 May 1980 eruption: chemical, physical, mineralogical, and biological properties: *Science* v. 209, no. 4461, p. 1116-1125.
- Guy, H. P., and Norman, V. W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chapter C2, 59 p.
- Skougstad, M. W., Fishman, J. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.
- Taylor, H. E., and Lichte, F. G., 1980, Chemical composition of Mount St. Helens volcanic ash: *Geophysical Research Letters* v. 7, no. 11, p. 944-953.
- Turney, G. L., and Klein, J. M., 1982, Surface-water-quality data from selected sites in Washington affected by Mount St. Helens eruptions: March 27- September 30, 1980: U.S. Geological Survey Open-File Report 81-1007, 153 p.