UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A RECONNAISSANCE OF THE EFFECTS OF A FOREST FIRE ON WATER QUALITY IN KINGS CANYON NATIONAL PARK CALIFORNIA

OPEN-FILE REPORT 79-497

Prepared in cooperation with the
NATIONAL PARK SERVICE

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A RECONNAISSANCE OF THE EFFECTS OF A FOREST FIRE ON WATER QUALITY IN KINGS CANYON NATIONAL PARK CALIFORNIA

By Ray J. Hoffman and Rodger F. Ferreira

Open-File Report 76-497

Prepared in cooperation with the
National Park Service

6422-06

Menlo Park, California
August 1976

CONTENTS

	Page
Abstract	1
Introduction	2
Description of study area	6
Methods	7
Results of the study	8
Field measurements	8
Major dissolved chemical constituents	8
Selected plant nutrients	9
Nitrogen	9
Phosphorus	12
Plants and animals	13
Periphytic algae	13
Benthic invertebrates	13
Other determinations	15
Trace metals and suspended sediment	15
Total organic carbon	15
Seston	16
Summary and conclusions	16
References cited	17

ILLUSTRATIONS

	Page
Figure 1. Map showing Kings Canyon National Park and Roaring River drainage basin	3
2. Map showing location of South Sentinel and Moraine Creek fires and sampling sites	4
3. Map showing location of the five headwater sampling sites	5
4-7. Graphs showing:	
4. Field measurements in the Roaring River, May-July 1974	9
5. Mean concentration of selected chemical constituents in the Roaring River, May-July 1974	10
6. Mean concentration of selected plant nutrients, total organic carbon, and seston in the Roaring River, May-July 1974	11
7. Diversity indexes calculated for benthic invertebrate samples from the 10 sampling sites in the Roaring River drainage basin	14

TABLES

	Page
Table 1. Description of sampling sites	6

CONVERSION FACTORS

Factors for converting English units to the International System of Units (SI) are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	*Multiply by*	*Metric (SI)*
acre	4.047×10^{-1}	ha (hectares)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
ft (feet)	3.048×10^{-1}	m (meters)
in (inches)	2.540×10	mm (millimeters)
in^2 (square inches)	645.2	mm^2 (square millimeters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.59	km^2 (square kilometers)
ton/d (tons per day)	9.072×10^{-1}	t/d (tonnes per day)
$(ton/mi^2)/d$ (tons per square mile per day)	3.503×10^{-1}	$(t/km^2)/d$ (tonnes per square kilometer per day)

A RECONNAISSANCE OF THE EFFECTS OF A FOREST FIRE ON WATER QUALITY IN KINGS CANYON NATIONAL PARK, CALIFORNIA

By Ray J. Hoffman and Rodger F. Ferreira

ABSTRACT

Following two adjacent forest fires in the Roaring River drainage basin, Kings Canyon National Park, a sampling program was undertaken from May to July 1974 to ascertain water-quality changes resulting from the fires.

Field measurements included alkalinity, pH, specific conductance, temperature, and discharge. Water samples were analyzed in the laboratory for major dissolved chemical constituents, selected plant nutrients, trace metals, suspended sediment, total organic carbon, and seston. Periphytic algae and benthic invertebrate samples were collected.

A noticeable increase in the concentration of nitrogen was found in Roaring River immediately downstream from the Moraine Creek fire. The increase in the concentration of inorganic nitrogen compounds, however, was not great enough to pose a serious threat to the aquatic ecosystem. High total organic nitrogen concentrations may have been due, in part, to factors other than the effect of fire. The results of other water-quality measurements were typical of dilute Sierra Nevada streams and indicate that Roaring River was not adversely affected by the fires.

INTRODUCTION

Forest fires are a common event in North America. Historically, fires have been an important environmental factor in many terrestrial ecosystems (Ahlgren and Ahlgren, 1960). In the past, most forest fires were suppressed as quickly as possible to prevent the widespread destruction of valuable timber. Research has shown that forest fires do not necessarily have a negative effect on the forest ecosystem (Kilgore, 1972, 1973). In 1968, a program was begun by the National Park Service to allow lightning-caused fires in some wilderness areas to burn without suppression (Kilgore and Briggs, 1972).

Areas where fires are allowed to burn are included in a National Fire Management Zone. One such area is in the Roaring River drainge basin in Kings Canyon National Park (fig. 1). As a water resource, Roaring River sustains a diverse wildlife population, is used for recreation by park visitors, and, in addition to other Sierra Nevada streams, is source water for the vast San Joaquin Valley irrigation system. Because the river is remote and visitor access is restricted to hikers and pack animals, disturbance of the Roaring River drainage basin by man is minimal; however, disruptive natural events such as lightning-caused fires are commonplace.

An average of 6.5 fires per year (G. Briggs, oral commun., June 1974) occurs in the Roaring River drainage basin as a result of lightning. In August 1973, two lightning-caused fires occurred in proximity in the basin (fig. 2): The Moraine Creek fire began on August 26, burning an estimated 1,760 acres (712 ha), and the South Sentinel fire began on August 28, burning about 2,490 acres (1,010 ha). No effort was made to control either fire.

The National Park Service is concerned with any events that may affect the quality of water in the remote streams in the Roaring River drainage basin. As uncontrolled fires are natural and frequent events in this area, the National Park Service requested in 1974 that the U.S. Geological Survey conduct a water-quality reconnaissance study related to the August 1973 fires. Fieldwork began in May 1974.

The objective of this study was to determine the effects of fire on selected physical, chemical, and biological variables in Roaring River and selected tributaries (fig. 2). Additional data were collected from five randomly chosen headwater streams (fig. 3) to obtain baseline water-quality information in the event a fire should occur near one of the streams.

Alkalinity, pH, specific conductance, water temperature, and discharge were determined in the field. Water samples were collected at the sites to determine the variability of major dissolved chemical constituents (calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and silica); selected plant nutrients (nitrogen and phosphorus); trace metals (copper, iron, manganese, and zinc); suspended sediment; total organic carbon; and seston. Periphytic algae and benthic invertebrate samples also were collected.

Appreciation is extended to G. S. Briggs and D. J. Parsons of the National Park Service for their valuable assistance during this study.

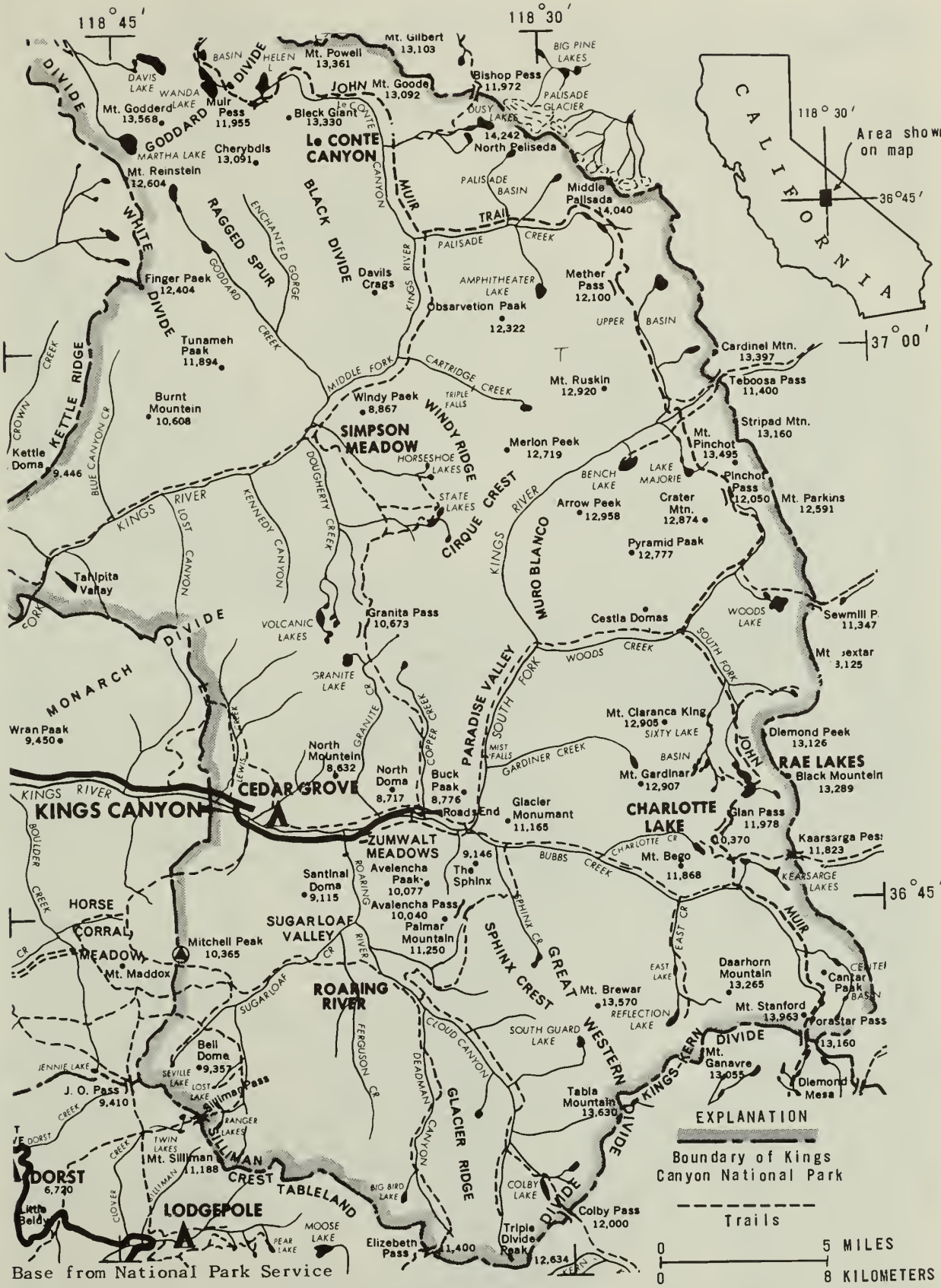

FIGURE 1.—Kings Canyon National Park and Roaring River drainage basin.

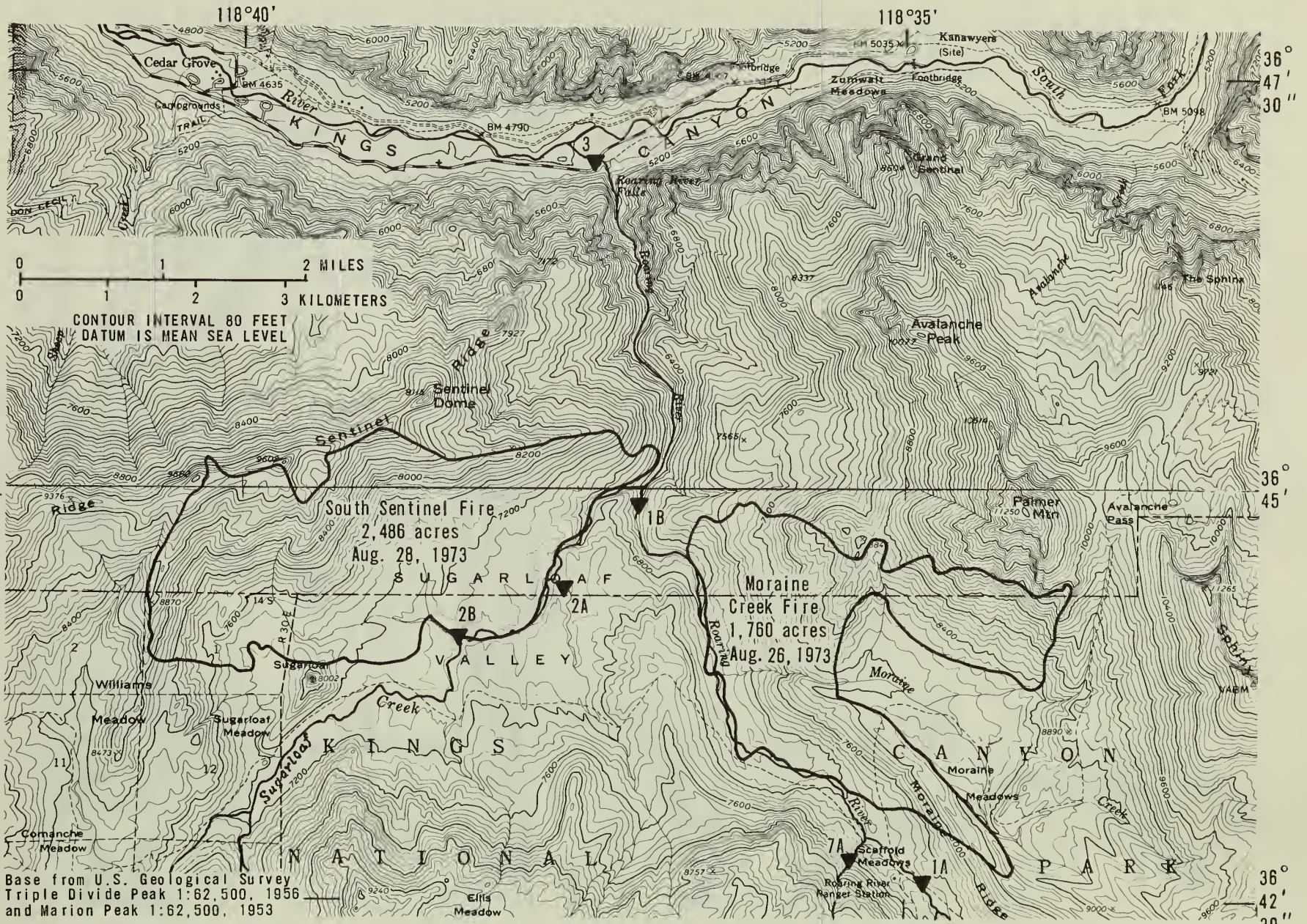

FIGURE 2.—Location of South Sentinel and Moraine Creek fires and sampling sites.

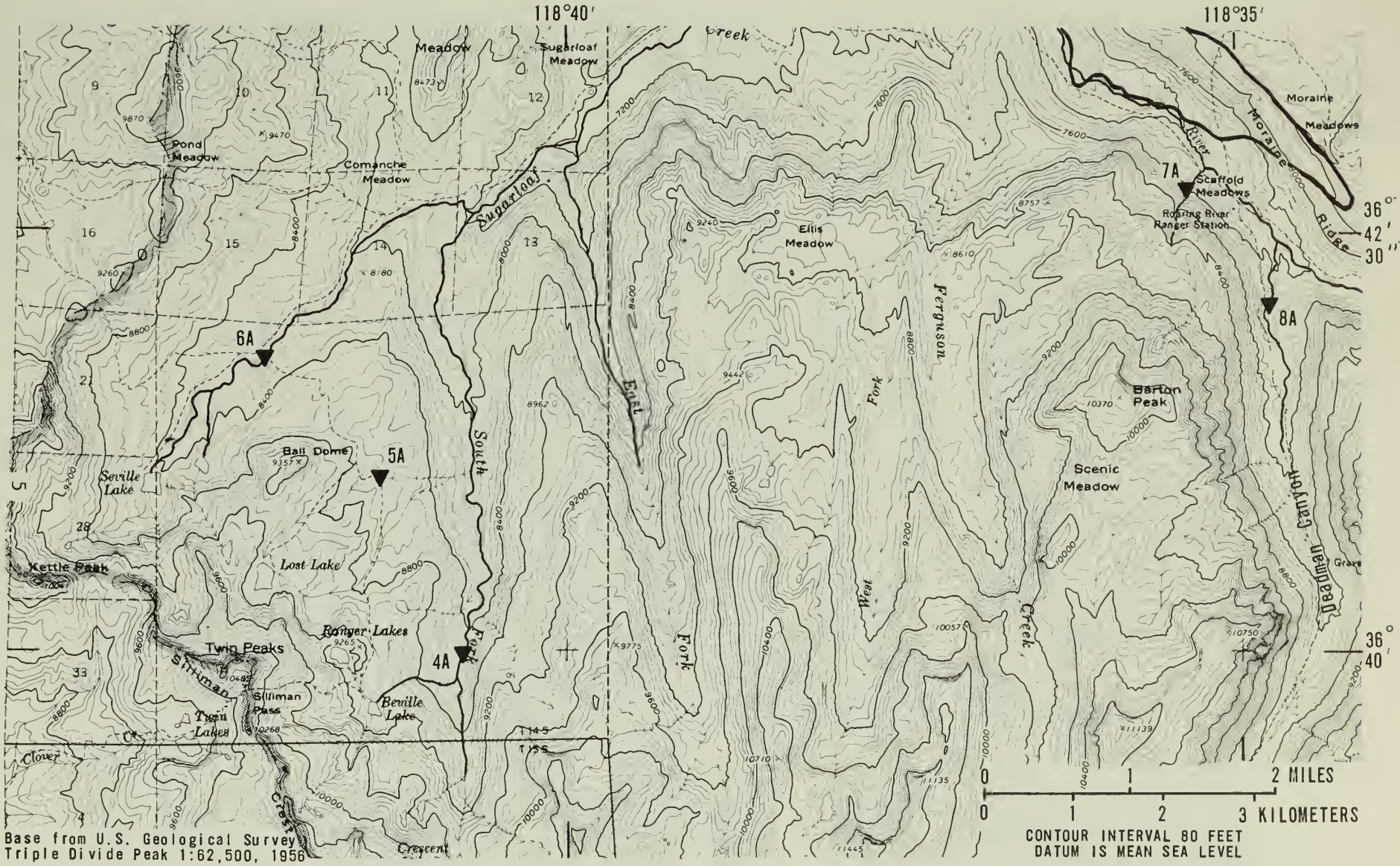

FIGURE 3.—Location of the five headwater sampling sites.

DESCRIPTION OF STUDY AREA

The Roaring River, with a drainage area of 115 mi^2 (298 km^2), begins on the western slope of the central Sierra Nevada and flows northward into the South Fork of the Kings River. The source of the river is primarily snowmelt. During the summer, streamflow originates from many glacial lakes ranging in altitude from 8,000 ft (2,440 m) to 11,000 ft (3,350 m). The climate of the area is dry in the summer and cold and wet in the winter with a snowpack normally from October to May. Precipitation was 49 in (1,240 mm) and 48 in (1,220 mm) in the 1973 and 1974 water years, respectively. The area is underlain by granitic rock of the Sierra Nevada batholith, and is forested with a mixed coniferous overstory and a patchy brush understory. Neither fire was severe enough to completely consume most of the overstory. Although both fires burned slowly and, for the most part, without intense heat, much of the brush understory was destroyed.

A brief description of sampling sites is given in table 1. Site locations are shown in figures 2 and 3.

Table 1.--*Description of sampling sites*

Site Number		Drainage area (mi^2)	Drainage area (km^2)
	Moraine Creek Fire		
1A (unburned)	Roaring River at Ranger Station near Cedar Grove, California	48.5	126
1B (burned)	Roaring River above Sugarloaf Creek near Cedar Grove, California	60.8	157
3 (unburned)	Roaring River at Roaring River Falls near Cedar Grove, California	115	298
	South Sentinel Fire		
2A (unburned)	Ferguson Creek at Mouth near Cedar Grove, California	13.1	33.9
2B (burned)	Sugarloaf Creek tributary at Mouth near Cedar Grove, California	1.59	4.12
	Headwater streams		
4A	South Fork Sugarloaf Creek	3.56	9.22
5A	North Lost Lake Creek	.74	1.92
6A	Upper Sugarloaf Creek	2.63	6.81
7A	Barton Peak Creek	.58	1.50
8A	Deadman Canyon Creek	15.9	41.2

METHODS

Sampling sites near the Moraine Creek and South Sentinel fires were selected to obtain water-quality data upstream and downstream from the two burned areas. Preliminary aerial reconnaissance of the two burned areas revealed that sampling might be conducted in Sugarloaf Creek (draining the South Sentinel fire) and in Roaring River (draining the Moraine Creek fire). Complicated runoff patterns discovered during the first sampling, however, excluded further sampling in Sugarloaf Creek. Instead, a major and a minor tributary to Sugarloaf Creek (sites 2A and 2B in figure 2) were selected for study. Although the two tributaries are not comparable because of material differences in drainage basins, they provided supportive water-quality data throughout the study; consequently, this report will be primarily concerned with the Moraine Creek fire and its effects on water quality in Roaring River.

Discharge measurements of streamflow were made according to the methods of Corbett and others (1943). Stream temperature was obtained using a calibrated hand-held thermometer. Specific conductance and pH were measured using standard meters. Alkalinity was determined immediately after sample collection by titration with 0.01639N sulfuric acid to a pH of 4.5.

Water samples for the determination of suspended-sediment concentrations were collected during sampling visits using a hand-held sediment sampler (DH-49) according to the methods of Guy and Norman (1970), and a single stage suspended-sediment sampler (Guy and Norman, 1970, p. 10, fig. 14) was installed at each sampling site to collect water samples during peak snowmelt runoff in the spring of 1975. The samples were analyzed at the U.S. Geological Survey laboratory in Sacramento, California, according to the methods of Guy (1969).

Water samples for the analysis of chemical constituents, except carbon, were collected in PVC (polyvinyl chloride) bottles. The samples for carbon analyses were collected in acid-rinsed glass bottles. All water samples were pretreated in the field. The samples for dissolved constituents were filtered from 1 to 6 hours after collection. Chemical constituents in water samples were analyzed at the U.S. Geological Survey Central Laboratory, Salt Lake City, Utah, using the methods described by Brown and others (1970). Water samples for seston analyses were collected in PVC bottles, preserved with a dilute solution of mercuric chloride, and analyzed at the U.S. Geological Survey Central Laboratory, Doraville, Ga., using the methods of Slack and others (1973).

Periphytic algae samples were obtained by grab sampling, and by scraping 7.75 in^2 (5,000 mm^2) of surface area from plastic substrates that were submerged in the streams from July 16 to October 11, 1974. The algae were preserved with Lugol's solution and taxonomically identified using the inverted microscope method of Slack and others (1973). Benthic invertebrates were collected using a Surber stream-bottom sampler (Slack and others, 1973, p. 145, fig. 28). A minimum of three samples was collected at each sampling site. The collected organisms were preserved in 70 percent ethyl alcohol (Slack and others, 1973) and taxonomically identified by a commercial laboratory.

RESULTS OF THE STUDY

Field Measurements

Data from field measurements of pH, temperature, total alkalinity (as $CaCO_3$), specific conductance, and discharge of the Roaring River are shown in figure 4. The pH values were similar and often slightly below neutral (<7.0). The slightly acid nature of the water is characteristic of many streams in the Sierra Nevada.

Generally, water temperature increased throughout the summer at all the Roaring River sampling sites. Water temperature at site 1B was usually lower when compared to sites 1A and 3 because at site 1B, and continuing 1 mi (1.6 km) upstream, the river was sheltered from the sun by trees.

Total alkalinity and specific conductance values were low and varied uniformly with time at each sampling site. The values also show the typical downstream increase as the river flowed through the canyon.

Discharge during the study was highest during the spring snowmelt period and lowest in the summer.

Major Dissolved Chemical Constituents

The mean concentrations of the major dissolved chemical constituents found in the Roaring River are shown in figure 5. A slight increase in the concentration of most of these constituents was found in water samples immediately downstream from the Moraine Creek fire at site 1B and further downstream at site 3. The concentrations of dissolved constituents found at site 1B are common to most river reaches not influenced by inflow from an outside source or affected by man-made causes. Under such conditions there is a gradual increase in the concentration of dissolved solids in a downstream direction (Hynes, 1972, p. 44-45). The concentration of dissolved solids (sum of constituents) at site 3 may be due in part to inflow from Sugarloaf Creek. The contribution, however, appears to be slight. No significant changes in the concentrations of the major dissolved chemical constituents that may have been the result of fire were found in Roaring River. Overall, the concentrations found at all sampling sites were low and typical for Sierra Nevada streams (Feth and others, 1964, p. 53).

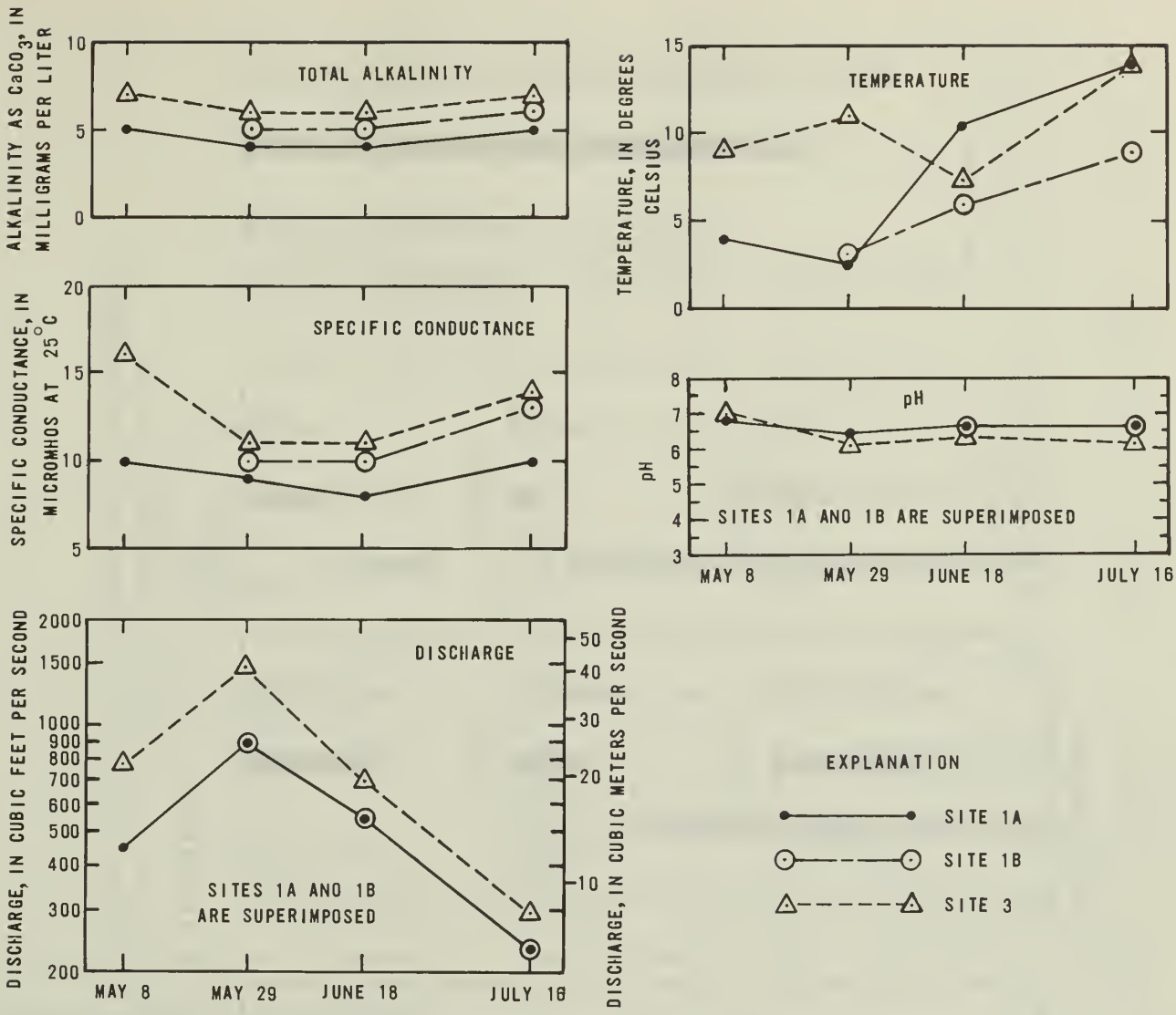

FIGURE 4.—Field measurements in the Roaring River, May–July 1974.

Selected Plant Nutrients

The various compounds of nitrogen and phosphorus are good indicators of the nutritional status of water. These compounds are often considered as the key nutrients limiting algal growth and abundance in most surface water.

Nitrogen

The four forms of nitrogen analyzed in this study (fig. 6) showed increases in concentration at site 1B immediately downstream from the Moraine Creek fire. Inorganic nitrate and ammonium increased slightly, whereas total organic nitrogen and total nitrogen increased substantially.

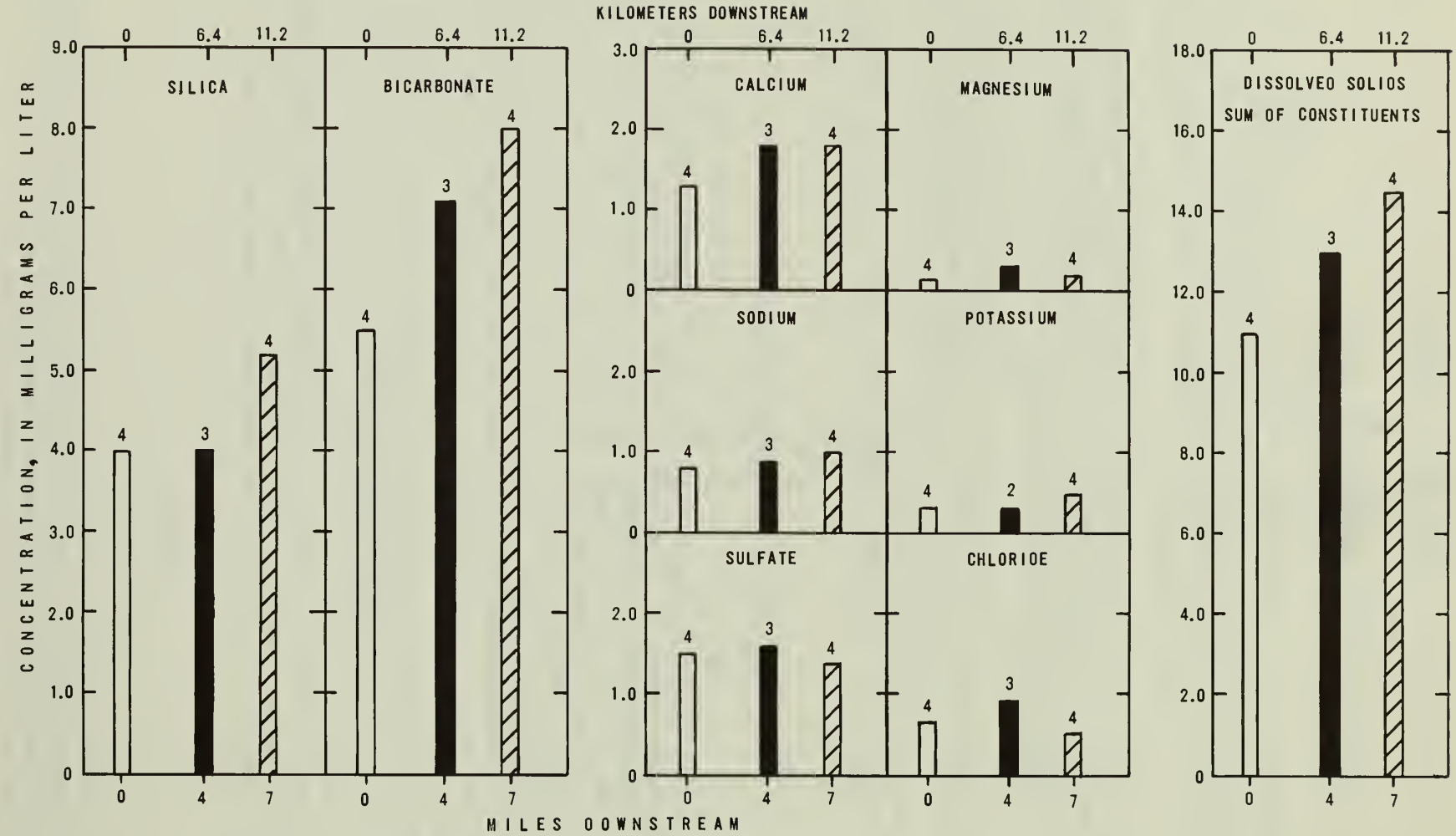

FIGURE 5.—Mean concentration of selected chemical constituents in the Roaring River, May-July 1974. *(See figure 6 for explanation of bar symbols)*

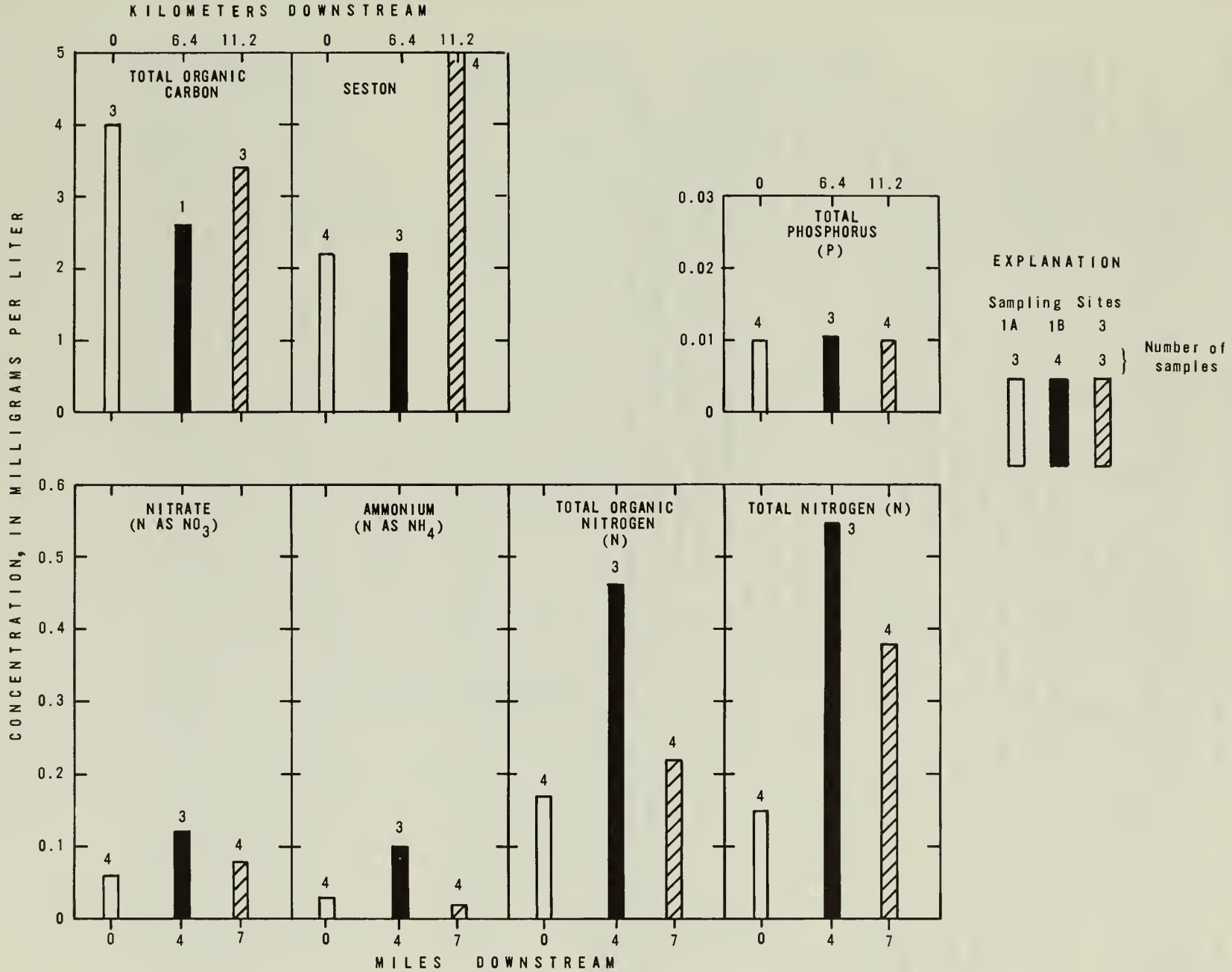

FIGURE 6.—Mean concentration of selected plant nutrients, total organic carbon, and seston in the Roaring River, May-July 1974.

In the literature, the reported nitrogen concentrations in water from drainage basins affected by fire are contradictory. For example, Johnson and Needham (1966) found exceedingly low levels of nitrate. Brown and others (1973) found that the maximum concentrations of nitrate tripled following clear-cut logging and slash burning. Tiedemann (1973) found measurable increases in ammonium and organic nitrogen. Lotspeich and others (1970) found no important nitrogen fluctuations that could be attributed to the effects of fire.

In this study, the higher inorganic nitrogen concentrations found in water at site 1B relative to sites 1A and 3 suggest that the Moraine Creek fire could have caused a detectable imbalance in the nitrogen cycle. The maximum concentrations (0.30 mg/ℓ [milligrams per liter] nitrate and 0.12 mg/ℓ ammonium), however, were not large enough to pose a serious threat to the aquatic ecosystem. The increase in the concentration of total organic nitrogen at site 1B may have been due, in part, to infiltration of nitrogenous organic compounds from Scaffold Meadows (fig. 2), an occasional grazing area for pack animals.

Phosphorus

Phosphorus concentrations (fig. 6) were uniformly low in water samples from the three Roaring River sites. The results indicate that phosphorus was not readily leached into the river, a possible consequence of the nutrient being tightly bound to soil particles. Similarly, McColl and Grigal (1975) found that the concentration of phosphorus in a lake's influent stream did not increase following a large fire.

Plants and Animals

The community of aquatic organisms reflects the quality of water in which they live. Generally, a change in the species composition of aquatic organisms in a stream indicates a change in the water quality of that stream. Although good quantitative methods of biological sampling have yet to be devised, samples of periphytic algae and benthic invertebrates can be easily collected for qualitative analysis. Analyses of the biological data used in this study were obtained from the five headwater streams as well as the five sampling sites in and near the burned areas.

Periphytic Algae

Achnanthes lanceolata, *Cymbella* sp., *Synedra ulna*, *Hannea arcus*, and *Navicula* sp. were the most ubiquitous algae, each being collected from five or more of the sampling sites. These genera belong to the class Bacillariophyceae (diatoms) and constitute only 13 percent of the total number of genera collected from all of the sites. In contrast to taxa found at several sampling sites, each of 22 taxa (55 percent of the total number of genera collected) was found at only one sampling site. There were no observed relationships between the community composition of algae at the sampling sites immediately upstream and downstream from the burned areas.

A similarity index (Odum, 1971) was calculated for each paired combination of algae samples from the 10 sites. Similarity index values can range from 0, when two samples have no taxa in common, to 1 when two samples have the same taxa. Algae samples from sites 2A and 2B near the South Sentinel fire had a similarity index of 0.44, and algae samples from sites 1A and 1B near the Moraine Creek fire had a similarity index of 0.38. The similarity index calculated between pairs of samples from the five headwater streams are essentially the same as those calculated for the two burned areas; hence the similarity index does not reveal any adverse effect of fire on algal growth.

Benthic Invertebrates

The genus *Baetis* sp. was the only taxon collected at each of the 10 sampling sites. *Simulium* sp. and *Acroneuria* sp. were found at six sites, and *Nemoura californica* was found at five sites. In contrast to taxa found at several sampling sites, each of 26 taxa (54 percent of the total number of genera collected) was found at only one sampling site. *Arcynopteryx* was the only genus that was collected at the sampling sites immediately upstream from the burned areas and not downstream. There were no other observed relationships between the community composition of benthic invertebrates upstream and downstream from the burned areas.

Diversity index ($\bar{d}$) (Wilhm and Dorris, 1968) calculated for benthic invertebrate samples collected from the 10 sites ranged from 2.4 to 3.5 (fig. 7). Generally, a larger diversity index indicates a larger variety of organisms. The relationship of diversity index values between the sites upstream and downstream from the burned areas was inconsistent. Because of this inconsistency, which was also observed at all the sampling sites, there was no evidence that the fires had affected the diversity of the benthic invertebrate community.

The similarity index calculated for sites 1A and 1B (0.80) near the Moraine Creek fire also indicated that fire had no effect on the community composition of benthic invertebrates in Roaring River. In contrast, the similarity index for the South Sentinel fire was 0.14. Similarity indexes between paired samples collected in the five headwater streams, however, were just as low, showing that a variety of benthic invertebrates can be found in different areas of the same drainage basin. The similarity index values, therefore, reveal no adverse effect of fire on the benthic invertebrate composition of the streams.

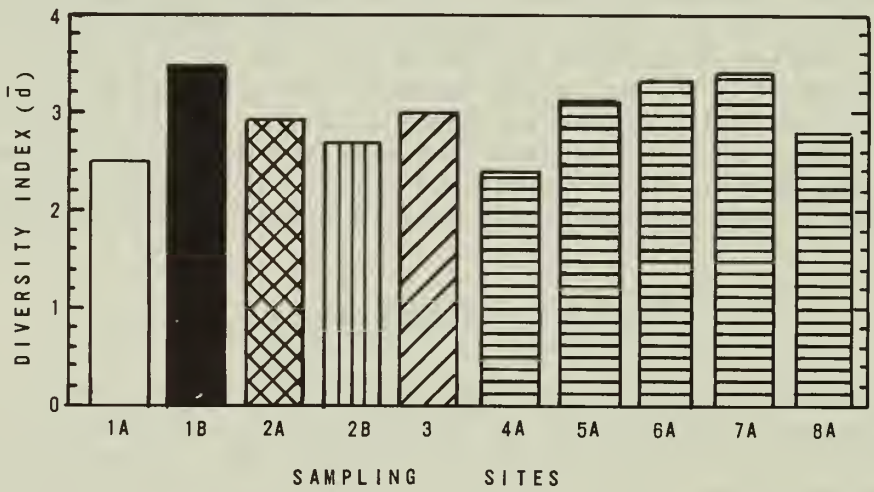

FIGURE 7.—Diversity indexes (Wilhm and Dorris, 1968) calculated for benthic invertebrate samples from the 10 sampling sites in the Roaring River drainage basin. (*See figures 2 and 3 for location of sampling sites*)

Other Determinations

Trace Metals and Suspended Sediment

Trace metal (copper, iron, manganese, and zinc) concentrations were low, ranging from <1 to 70 µg/ℓ (micrograms per liter). No important differences in the concentrations of these metals were noted that could be attributed to the effects of fire. Values of suspended-sediment concentrations for the limited number of samples obtained from Roaring River (shown below) were low, and no major increase in the load of suspended material was found immediately downstream from the Moraine Creek fire (site 1B). The values for site 3, of course, include the contribution of suspended sediment from Sugarloaf Creek.

Sampling site	Date	Streamflow discharge (ft^3/s)	Suspended-sediment concentration (mg/ℓ)	Suspended-sediment discharge	
				ton/d	(ton/mi^2)/d
1A (control)	May 29, 1974	900	14	34	0.70
	July 16, 1974	235	3	1.9	.04
	May 27/28, 1975	2,000	162	870	18
	June 24, 1975	300	8	6.5	.13
1B	May 29, 1974	900	6	15	.25
	July 16, 1974	240	8	5.2	.09
	------	--	--	--	--
	June 24, 1975	300	6	4.9	.08
3	May 28, 1974	1,500	30	120	1.0
	July 16, 1974	300	7	5.7	.05
	May 27/28, 1975	2,500	235	1,590	14
	June 24, 1975	450	8	9.7	.08

Total Organic Carbon

Observed TOC (total organic carbon) concentrations in Roaring River were highly variable (fig. 6). Note that the value for site 1B represents one analysis. At that time, the TOC concentration was 2.9 mg/ℓ at site 1A and 4.4 mg/ℓ at site 3. Because of inconsistent results and the lack of sufficient samples from site 1B, a correlation between the fire and TOC concentrations cannot be made.

Seston

Seston is the total particulate matter suspended in water (Slack and others, 1973). Apart from its effect on the optical properties of water, its organic fraction is a measure of a biotic energy source moving in a stream. The mean concentration of seston in Roaring River (fig. 6) immediately upstream and downstream from the Moraine Creek fire was identical, whereas at site 3 the concentration was nearly twice as great. The difference at site 3 was probably a result of seston input from Sugarloaf Creek draining the area of the South Sentinel fire.

SUMMARY AND CONCLUSIONS

The various physical, chemical, and biological data examined in this study indicate that water quality in a reach of Roaring River was not adversely affected by the Moraine Creek fire. Only nitrogen showed any significant increase in concentration in the river downstream from the burned area. The concentrations of inorganic nitrogen, (nitrate and ammonium) were not great enough to pose a serious threat to water quality. High total organic nitrogen concentrations may have been due, in part, to factors other than the effect of fire.

Because of the lack of an adequate control site, an evaluation of the effects of the South Sentinel fire on water quality, similar to that for the Moraine Creek fire, was not possible. But, judging from the data collected at site 3 representing the combined runoff from both burned areas, the effects appear to be negligible.

A possible deficiency of this study was its duration; a 4-month study is much too short a time to define long-term changes or trends in water quality resulting from fire. In addition, the Moraine Creek fire and South Sentinel fire did not allow advance selection of sampling sites for best evaluation of water-quality changes. The data collected from the five headwater streams (U.S. Geological Survey, 1976) should provide a valuable base for a future water-quality monitoring study in the event a fire should occur near one of these five streams.

REFERENCES CITED

Ahlgren, I. F., and Ahlgren, C. E., 1960, Ecological effects of forest fires: Bot. Rev. 26, p. 483-533.

Brown, Eugene, Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geol. Survey Techniques Water-Resources Inv., book 5, chap. A1, 160 p.

Brown, G. W., Gahler, A. R., and Warston, R. B., 1973, Nutrient losses after clear-cut logging and slash burning in the Oregon Coast Range: Water Resources Research, v. 9 (5), p. 1450-1453.

Corbett, D. M., and others, 1943, Stream-gaging procedure, a manual describing methods and practices of the Geological Survey: U.S. Geol. Survey Water-Supply Paper 888, 245 p.

Feth, J. H., Roberson, C. E., and Polzer, W. L., 1964, Sources of mineral constituents in water from granitic rocks, Sierra Nevada, California and Nevada: U.S. Geol. Survey Water-Supply Paper 1535-I, p. 1-170.

Guy, H. P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geol. Survey Techniques Water-Resources Inv., book 5, chap. C1, 58 p.

Guy, H. P., and Norman, V. W., 1970, Field methods for measurement of fluvial sediment: U.S. Geol. Survey Techniques Water-Resources Inv., book 3, chap. C2, 59 p.

Hynes, H. B. N., 1972, The ecology of running waters: Toronto, Univ. of Toronto Press, 555 p.

Johnson, C. M., and Needham, P. R., 1966, Ionic composition of Sagehen Creek, California, following an adjacent fire: Ecology 47, p. 636-639.

Kilgore, B. M., 1972, Impact of prescribed burning on a sequoia-mixed conifer forest: Proc., Ann. Tall Timbers Fire Ecology Conf. 12, p. 345-375.

_____1973, The ecological role of fire in Sierran conifer forests--its application to National Park Management: Jour. Quart. Research, v. 3 (3), p. 496-513.

Kilgore, B. M., and Briggs, G. S., 1972, Restoring fire to high elevation forests in California: California Jour. Forestry, v.70 (5), p. 266-271.

Lotspeich, F. B., Mueller, E. W., and Frey, P. J., 1970, Effects of large scale fires on water quality in Interior Alaska: [U.S.] Federal Water Pollution Control Adm., 115 p.

McColl, J. G., and Grigal, D. F., 1975, Forest fire: Effects on phosphorus movement to lakes: Sci., v. 188 (4193), p. 1109-1111.

Odum, E. P., 1971, Fundamentals of ecology [3d ed.]: Philadelphia, W. B. Saunders Co., 574 p.

Slack, K. V., Averett, R. C., Greeson, P. E., and Lipscomb, R. G., 1973, Methods for collection and analysis of aquatic biological and microbiological samples: U.S. Geol. Survey Techniques Water-Resources Inv., book 5, chap. A4, 165 p.

Tiedemann, A. R., 1973, Stream chemistry following a forest fire and area fertilization in North-Central Washington: U.S. Dept. Agriculture, Forest Service Research Note PNW-203, 20 p.

U.S. Geological Survey, 1976, Water resources data for California, 1975. Volume 3, Southern Central Valley basins and The Great Basin from Walker River to Truckee River: U.S. Geol. Survey Water-Data Rept. CA-75-3 (in press).

Wilhm, J. L., and Dorris, T. C., 1968, Biological parameters for water-quality criteria: Bioscience, v. 18, p. 477-481.