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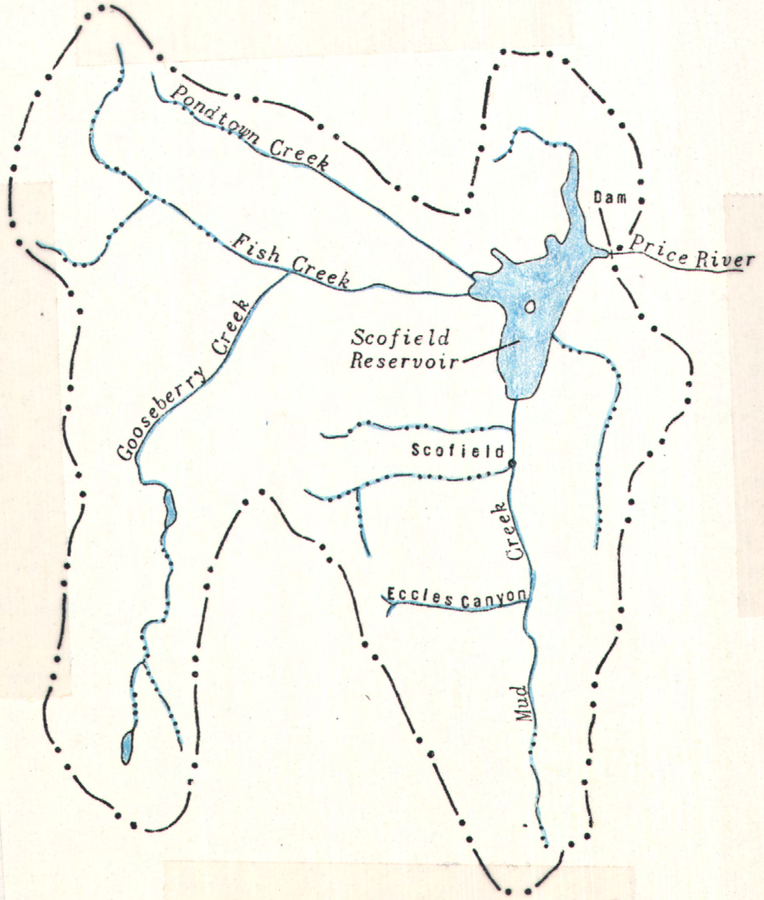
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Dam
Price River
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Scofield Reservoir
Gooseberry Creek
Scofield
Creek
Eccles Canyon
Mud

COVER PAGE

CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER AND SEDIMENT IN SCOFIELD RESERVOIR, CARBON COUNTY, UTAH

U.S. GEOLOGICAL SURVEY

Open-File Report 83-252

Prepared in cooperation with

U.S. BUREAU OF LAND MANAGEMENT

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By K. M. Waddell, D. W. Darby, and S. M. Theobald

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UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

ILLUSTRATIONS-Continued

TABLES

CONVERSION FACTORS AND RELATED INFORMATION

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
acre	0.4047	square hectometer
acre-foot	0.001233 1233	cubic hectometer cubic meter
acre-foot per square mile per year	476	cubic meter per square kilometer per year
cubic foot	0.02832	cubic meter
cubic foot per day per foot	0.0929	cubic meter per day per meter
cubic foot per second per mile	0.01760	cubic meter per second per kilometer
cubic foot per second per square mile	0.01093	cubic meter per second per square kilometer
foot	0.3048	meter
inch	25.40 2.540	millimeter centimeter
mile	1.609	kilometer
pound	454	gram
square mile	2.590	square kilometer
ton	0.9072	metric ton
ton per square mile per year	0.3502	ton per square kilometer per year

Chemical concentration and water temperature are given only in metric units. Chemical concentration is given in milligrams per liter or micrograms per liter. Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter of water). One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million.

Chemical concentration in terms of ionic interacting values is given in milliequivalents per liter. Milliequivalents per liter is numerically equal to equivalents per million.

Water temperature is given in degrees Celsius ($^{\circ}C$), which can be converted to degrees Fahrenheit ($^{\circ}F$) by the following equation:

$$^{\circ}F = 1.8(^{\circ}C) + 32$$

CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER AND SEDIMENT IN SCOFIELD RESERVOIR, CARBON COUNTY, UTAH

By K. M. Waddell, D. W. Darby, and S. M. Theobald

ABSTRACT

Evaluations based on the nutrient content of the inflow, outflow, water in storage, and the dissolved-oxygen depletion during the summer indicate that the trophic state of Scofield Reservoir is borderline between mesotrophic and eutrophic and may become highly eutrophic unless corrective measures are taken to limit nutrient inflow.

Sediment deposition in Scofield Reservoir during 1943-79 is estimated to be 3,000 acre-feet, and has decreased the original storage capacity of the reservoir by 4 percent. The sediment contains some coal, and age dating of those sediments (based on the radioisotope lead-210) indicates that most of the coal was deposited prior to about 1950.

Scofield Reservoir is dimictic with turnovers occurring in the spring and autumn, and water in the reservoir circulates completely to the bottom during turnovers. The concentration of dissolved oxygen decreases with depth except during parts of the turnover periods. Below an altitude of about 7,590 feet where 20 percent of the water is stored, the concentration of dissolved oxygen was less than 2 milligrams per liter during most of the year. During the summer stratification period, the depletion of dissolved oxygen in the deeper layers is coincident with supersaturated conditions in the shallow layers; this is attributed to plant photosynthesis and bacterial respiration in the reservoir.

During October 1, 1979-August 31, 1980, the discharge-weighted average concentrations of dissolved solids was 195 milligrams per liter in the combined inflow from Fish, Pondtown, and Mud Creeks, and was 175 milligrams per liter in the outflow (and to the Price River). The smaller concentration in the outflow was due primarily to precipitation of calcium carbonate in the reservoir--about 80 percent of the decrease can be accounted for through loss as calcium carbonate.

The estimated discharge-weighted average concentration of total nitrogen (dissolved plus suspended) in the combined inflow of Fish, Pondtown, and Mud Creeks was 1.1 milligrams per liter as nitrogen. The load of total nitrogen contributed by each stream was about proportional to the quantity of water contributed by the respective stream.

For the combined inflow of Fish, Pondtown, and Mud Creeks, the discharge-weighted average concentration of total phosphorus was 0.06 milligram per liter as phosphorus. Percentages of the total phosphorus load contributed by Mud and Pondtown Creeks are significantly larger than their percentages of the total inflow. During October 1, 1979-August 31, 1980, Fish Creek contributed 72 percent of the inflowing water but only 60 percent of the total phosphorus load; Mud Creek contributed 16 percent of the total inflow but 24 percent of the total phosphorus load, and Pondtown Creek contributed 6 percent of the total inflow and 16 percent of the load of total phosphorus.

Eccles Canyon is a major contributor of nutrients to Mud Creek, and most of the nutrient load occurs in the form of suspended organic material. During the snowmelt period, concentrations of total nitrogen and phosphorus were as much as 21 and 4.3 milligrams per liter at the gaging station in Eccles Canyon. The unusually large concentrations of nitrogen and phosphorus probably have resulted from flushing of residual debris from the canyon--about 27.3 acres of forested land were cleared during 1979 for fire protection around new mine portals and for road right-of-ways.

The concentrations of trace metals in the sediments near the inflow of Mud Creek are not greatly different from those in the middle of the reservoir, which suggests that sediments related to coal mining either have not affected the trace-metal concentrations in the sediments or that, particularly the fine-grained sediments, have been uniformly distributed over the reservoir bottom. The concentration of total extractable mercury in the sediments ranged from 0.08 to 0.20 part per million near the inflow of Mud Creek and from 0.08 to 0.46 part per million at a site near the middle of the reservoir. Virtually all the mercury is silica bound, which is the least soluble fraction. The maximum concentration of mercury in the nondetrital and easily soluble fraction was 0.02 part per million at both sites.

INTRODUCTION

Location and Physical Characteristics of Reservoir

Scofield Dam is located on the Price River downstream from the confluence of Fish and Mud Creeks; it is about 5 miles north of the town of Scofield and 22 miles northwest of Price city in east-central Utah (fig. 1). The dam is formed by earth and rockfill, and is rock faced; it is 800 feet downstream from an older dam, which was in use from May 1926 to November 8, 1945. The present dam impounds water for public supply and irrigation in the Price city area 20 to 30 miles southeast of the dam; it also provides for flood protection and recreation. The present reservoir inundates the downstream channels of Fish, Mud, and Pondtown Creeks--the principal sources of reservoir inflow--and all the storage is released to the Price River. The pool altitude at maximum storage is 7,617.5 feet[1] and the usable storage capacity between the altitudes of 7,617.5 and 7,586.0 feet is 63,400 acre-feet. The pool altitude of dead storage is 7,586.0 feet and the quantity of water in dead storage is 6,000 acre-feet. The deepest part of the reservoir at maximum pool altitude is 47 feet.

Figure 1 (caption on next page) near here

Purpose and Objectives of Study

Underground coal mining has expanded in the Mud Creek drainage during the past few years and is expected to begin in the Pondtown Creek drainage during the next few years. The expanded mining activities may affect the quality of water entering and leaving Scofield Reservoir, as well as that stored in the reservoir. The effects may include: (1) Increased fluvial sediment resulting from clearing of forest land; and (2) water-quality deterioration casued by increased consumptive use of water, mine drainage, and local contamination from inadequate sewage-treatment facilities.

The U.S. Geological Survey in cooperation with the U.S. Bureau of Land Management conducted a study from September 1979 to August 1980 to assess the chemical and physical characteristics of water and sediment in Scofield Reservoir. The primary objectives of the study were to determine: (1) If anaerobic conditions occurred seasonally in the reservoir; (2) quantity and source of nutrient loading; (3) concentration and distribution of trace metals in the water and sediment; (4) quantity of sediment deposition prior to 1979 and average sediment accumulation rates; (5) accurate bathymetric profiles that can be used to assess future rates of sediment deposition; and (6) need for additional study or monitoring or both.

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[1] The National Geodetic Vertical Datum of 1929 (NGVD of 1929) is a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada. It was formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

Figure 1.--Location of the Scofield Reservoir drainage basin and gaging stations and water-quality sampling sites on streams.

Methods of Investigation

Water-quality data were collected during the 1980 water year for inflowing streams, for the reservoir, and for the outflow from the reservoir (fig. 2). The data collected during this study are presented either in this report or in Waddell and others (1982). For inflowing streams, the data collection was concentrated during periods of high and low flows so that total loads could be estimated for selected constituents, including nutrients and major ions. For the reservoir, chemical and physical data were collected during September and October 1979 and August 1980, so that the change in storage of major ions and of nitrogen and phosphorus could be computed for the 11 months, October 1, 1979 to August 31, 1980. Collection of chemical and physical data for water in the reservoir included: (1) In situ measurements of temperature, dissolved oxygen, pH, and specific conductance at 18 sites; and (2) chemical analyses to determine concentrations of major inorganic ions, trace metals, and nutrients at 9 sites. Chemical and physical data for bottom sediments were collected during September and October 1979 and August 1980, and included: (1) Distribution of selected metals in the silicate, nonsilicate, and nondetrital sediment phases; (2) bathymetric profiles to determine net sediment deposition since 1943; and (3) determination of the age of sediments by use of lead-210. More detailed explanation of the data collection and analytical methods are given in subsequent sections of the report, where appropriate to the subject.

Figure 2 (caption on next page) near here

A portable water-quality instrument (Martek, Model II[1]) was used to make in situ measurements of temperature, dissolved oxygen, specific conductance, and pH. A fathometer was used to make the bathymetric profiles. Core samples of bottom sediments were collected in 2-inch diameter PVC tubes. The samples were collected by placing the tubes in weighted collars, which were secured to a cable issuing from a reel mounted on a boat. The tubing and weighted collar assembly was lowered to within 5 to 10 feet of the lake bottom and released. The core samples ranged from 30 to 41 centimeters in length.

Acknowledgments

The cooperation and assistance of the U.S. Bureau of Reclamation, which provided bathymetric maps prepared during 1943, and the Utah Division of Wildlife Resources, which provided docking facilities for boats as well as accommodations at camping facilities, are appreciated.

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[1] The use of the brand names used in this report are for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Figure 2.--Location of water-quality sampling sites, water-quality and core sampling sites, and bathymetric profiles.

INFLOW TO RESERVOIR

During the first 11 months of the 1980 water year, Fish Creek contributed 72 percent, Pondtown Creek 6 percent, and Mud Creek 16 percent of the inflow to Scofield Reservoir (table 1). Precipitation on the reservoir, inflow from other small tributaries (unmeasured) and ground-water seepage contributed the remaining 6 percent of the inflow. Records of discharge for Fish Creek upstream from the reservoir (site S2, fig. 2) and the Price River downstream from the reservoir (site S37) during the 1938-70 water years indicate that the flow of Fish Creek averages about 75 percent of the total inflow to the reservoir. Thus, the percent of inflow contributed by Fish Creek during the 11 months of the 1980 water year was approximately the same as the long-term average.

Table 1 (next page) near here

The flow of Fish, Pondtown, and Mud Creeks fluctuates seasonally and usually is largest during snowmelt runoff. During the 1938-81 water years, 80 percent of the flow of Fish Creek, at site S2, occurred during April, May, and June (fig. 3), the period of snowmelt runoff.

Figure 3 (caption on next page) near here

Total inflow to the reservoir during the 1980 water year was greater than average. During the 1938-81 water years, the average flow of Fish Creek (site S2, fig. 2) was 34,200 acre-feet per year. During the 1980 water year, the flow of Fish Creek was 61,700 acre-feet or about 180 percent of average. Because the percent of inflow contributed by Fish Creek during the 1980 water year was near that of the long-term average, it was concluded that inflow from other streams to Scofield Reservoir during the 1980 water year (and study period) was about 180 percent of average.

CHEMICAL CHARACTERISTICS OF RESERVOIR INFLOW AND OUTFLOW

The chemical characteristics of the inflow and outflow of Scofield Reservoir were evaluated from October 1, 1979, to August 31, 1980. The chemical characteristics included in the evaluation were: (1) Dissolved major ions, (2) dissolved and suspended nitrogen and phosphorus, and (3) dissolved trace metals.

Dissolved Major Ions

For inflow from Fish, Pondtown, and Mud Creeks, the predominant dissolved ions were calcium and bicarbonate (fig. 4). Most of the water from these streams is at or near saturation with respect to the minerals calcite and aragonite.

Figure 4 (caption on next page) near here

Table 1.--Stream inflow and reservoir outflow (Price River) of nitrogen, phosphorus, and dissolved solids, October 1, 1979—August 31, 1980

[Site: See figure 1 for location]

Site		Volume (acre-feet)	Percent of inflow	Nitrogen (tons)			Percent of inflow of total nitrogen	Phosphorus (tons)			Percent of inflow of total phosphorus	Dissolved solids (tons)	Percent of inflow of dissolved solids
				Dissolved	Suspended	Total		Dissolved	Suspended	Total			
							Inflow						
S2	Fish Creek	60,760	72	63	24	87	73	0.9	3.5	4.4	60	15,600	75
S4	Pondtown Creek	5,280	6	8.0	3.0	11	9	.2	1.0	1.2	16	1,400	7
S36	Mud Creek	13,110	16	17	5	22	18	.5	1.3	1.8	24	3,900	18
—	Precipitation and unmeasured inflow.	4,900	6	—	—	—	—	—	—	—	—	—	—
	Total	84,050	100	88	32	120	100	1.6	5.8	7.4	100	20,900	100
							Outflow						
S37	Price River	67,500	—	66	34	100	—	1.0	1.7	2.7	—	16,200	—

Figure 3.--Monthly distribution of average annual flow at site S2 on Fish Creek, 1938-81.

Figure 4.--Variation of dissolved solids, water discharge, and chemical composition of stream inflow and reservoir outflow (Price River), October 1979-August 1980.

The concentration of dissolved solids, which varies directly in response to the variation in concentrations of the predominant dissolved ions, calcium and bicarbonate, is largest during the late fall and winter when streamflow is low and is smallest during the snowmelt period in late spring and early summer when streamflow is high (fig. 4). The largest variation in the concentration of dissolved solids occurred in Mud and Pondtown Creeks; in Mud Creek the concentration ranged from about 190 to 390 milligrams per liter, and in Pondtown Creek the concentration ranged from 175 to 345 milligrams per liter. In Fish Creek, the concentration ranged from only about 180 to 240 milligrams per liter (fig. 4). The discharge-weighted average concentration of dissolved solids in the combined inflow of the streams during October 1, 1979, to August 31, 1980, was 195 milligrams per liter. The discharge-weighted average concentration represents the concentration that would occur if all the water was stored and mixed during the indicated period and there were no chemical changes or loss of water by evaporation. Fish Creek contributed about 75 percent of the dissolved-solids load, while Mud Creek contributed 18 percent and Pondtown Creek 7 percent (table 1).

The predominant ions in the outflow from Scofield Reservoir to Price River were calcium and bicarbonate (fig. 4). The concentration of dissolved solids in the outflow from the reservoir (site S37) is much less variable than that of the inflow; this is due to mixing in the reservoir. The minimum concentration of dissolved solids was about 160 milligrams per liter and occurred during the fall and the maximum concentration was about 185 milligrams per liter and occurred during the winter and spring (fig. 4). The discharge-weighted average concentration in the outflow during October 1, 1979, to August 31, 1980, was 175 milligrams per liter, which is about 20 milligrams per liter less than that of the inflow. The lesser concentration of dissolved solids in the outflow is due primarily to the loss of dissolved calcium and bicarbonate ions resulting from the chemical precipitation of calcium carbonate from water stored in the reservoir. (See section "Chemical and physical characteristics of water in the reservoir.")

Dissolved and Suspended Nitrogen and Phosphorus

Maximum or near maximum concentrations and most of the loads of dissolved and suspended phases of nitrogen and phosphorus in the water of inflowing streams occurred during snowmelt runoff, April-June 1980 (fig. 5).

Figure 5 (caption on next page) near here

Data in table 1 indicate that most of the load of total nitrogen (dissolved plus suspended) during October 1, 1979, to August 31, 1980, was contributed by Fish Creek. This occurred because the concentration of nitrogen in Fish Creek was about that of the other streams but the flow of Fish Creek was much greater than that of the other streams.

Figure 5.--Variation of total nitrogen and water discharge in stream inflow and reservoir outflow (Price River) and in runoff from Eccles Canyon, November 1979-August 1980.

The estimated discharge-weighted average concentration of dissolved nitrogen (as N) during October 1, 1979, to August 31, 1980, was 0.8 milligram per liter for Fish Creek, 1.1 milligrams per liter for Pondtown Creek, and 1.0 milligram per liter for Mud Creek. The weighted average concentration of dissolved nitrogen in the combined inflow was 0.8 milligram per liter; and the average concentration of suspended nitrogen was 0.3 milligram per liter.

The concentration of total phosphorus in Mud and Pondtown Creeks is larger than that of Fish Creek. However, the load of total phosphorus contributed by Fish Creek is much greater than of Mud and Pondtown Creeks because of its greater flow (table 1).

The discharge-weighted average concentration of dissolved phosphorus was 0.01 milligram per liter for Fish Creek and 0.03 milligram per liter for Pondtown and Mud Creeks, and 0.01 milligram per liter in combined inflow. Suspended phosphorus is the largest portion of the load of total phosphorus in the inflowing streams. In the combined inflow, suspended phosphorus constitutes nearly 80 percent of the load of total phosphorus. The weighted average concentration of suspended phosphorus in the combined inflow was 0.05 milligram per liter, which is five times the weighted concentration of dissolved phosphorus.

Eccles Canyon, a tributary of Mud Creek, contributed relatively large concentrations of nitrogen and phosphorus to Mud Creek during October 1, 1979, to August 31, 1980. Most of the nitrogen and phosphorus load occurred during snowmelt runoff. For example, on May 22, 1980, the concentration of total nitrogen (suspended plus dissolved) was 21 milligrams per liter (fig. 5) and the concentration of total phosphorus was 4.3 milligrams per liter. Most of the nitrogen and phosphorus was in the suspended form. The unusually large concentrations of nitrogen and phosphorus probably resulted from flushing of residual debris that were left in the canyon during land clearing (fig. 6).

Figure 6 (caption on next page) near here

According to Allen Owen, Coastal States Energy Co. (written commun., February 1981), about 27.3 acres of forested land was cleared in the canyon during 1979 for fire protection around new mine portals and for road right-of-ways.

Figure 6.--View of upper part of Eccles Canyon showing area being cleared for fire protection and road right-of-ways. (Photograph by Jeanette E. Dodge, 1979.)

Estimates of the dissolved and suspended quantities of nitrogen and phosphorus were compiled for site S29 near the mouth of Eccles Canyon, and are compared to similar data for site S36 in Mud Creek in the following tabulation:

Site (See fig. 1 for location)	Volume (acre-feet)	Nitrogen						Phosphorus					
		Dissolved		Suspended		Total		Dissolved		Suspended		Total	
		Load (tons)	Concentration[1]	Load (tons)	Concentration[1]	Load (tons)	Concentration[1]	Load (tons)	Concentration[1]	Load (tons)	Concentration[1]	Load (tons)	Concentration[1]
S29 Eccles Canyon	2,810	8	2.1	34	8.9	42	11	0.1	0.03	8.5	2.2	8.6	2.2
S36 Mud Creek	13,110	17	1.0	5	.3	22	1.3	.5	.03	1.3	.07	1.8	.1
Ratio of volume and load in Eccles Canyon to that in Mud Creek.	.2	.5		7		2		.2		7		5	

[1] Milligrams per liter.

The data indicate that, while Eccles Canyon contributed only about 20 percent of the water to Mud Creek, the suspended loads of nitrogen and phosphorus discharged from Eccles Canyon were seven times greater than at site S36 on Mud Creek. The discharge-weighted average concentrations of suspended nitrogen and phosphorus at site S29 in Eccles Canyon were 8.9 and 2.2 milligrams per liter, whereas at site S36 on Mud Creek the concentrations were only 0.3 and 0.07 milligram per liter. Thus, much of the suspended material (including nitrogen and phosphorus) must have settled or been filtered from the water in the reach of Mud Creek between the inflow of Eccles Canyon and site S36. This probably is due chiefly to numerous beaver dams as well as to slower stream velocities in the meandering downstream reach of Mud Creek.

At the outflow site for Scofield Reservoir (site S37 on the Price River), the maximum concentration of total nitrogen occurred during February 1980 (fig. 5), and the maximum concentration of total phosphorus occurred during July 1980. During October 1, 1979, to August 31, 1980, the discharge-weighted average concentration of dissolved nitrogen was 0.6 milligram per liter; suspended nitrogen, 0.3 milligram per liter; dissolved phosphorus, 0.01 milligram per liter; and suspended phosphorus, 0.02 milligram per liter. Comparison of discharge-weighted average concentrations of total nitrogen and total phosphorus in the combined inflow with that of the outflow indicates that there is only a small change in concentrations of nitrogen, but a significant decrease in the concentration of phosphorus in the outflow. Decreased suspended phosphorus accounted for most of the decrease of total phosphorus in the outflow. This decrease is due in part to settling of the suspended matter and use by photosynthetic processes in the reservoir.

The variation of nitrogen in the outflow is related to seasonal changes in the photosynthetic activity in the reservoir. A more detailed discussion pertaining to the relationship between the different phases of dissolved and suspended organic and inorganic nitrogen is given in the section "Effects of storage, inflow-outflow, chemical precipitation, and leaching of minerals."

Dissolved Trace Metals and Other Minor Elements

Ranges of dissolved trace metals and other minor elements in samples from Scofield Reservoir inflows and outflow and from Eccles Canyon runoff are shown in table 2. Many of these elements are found in coal wastes; therefore, the analyses were made to determine possible increases in their concentrations due to mine discharge. Excessive concentrations of dissolved trace metals and other minor elements may have adverse effects on aquatic life and on the suitability of the water for public supply. Because of the small number of samples collected from streams and mine discharge in the area, the effects of coal mining cannot be assessed quantitatively; however, the concentrations of most metals--such as arsenic, lead, and mercury--did not exceed the maximum contaminant levels or secondary maximum contaminant levels set by the U.S. Environmental Protection Agency (1976, p. 14-245) for public-water systems, or for freshwater aquatic life.

Table 2 (next page) near here

Waddell and others (1981, p. 33) reported that the concentrations of total metals in water from the Utah No. 2 Mine (fig. 1) were several times greater than those of the dissolved metals, and they indicated the danger of accumulation of suspended metals in anaerobic zones such as in the bottom of Scofield Reservoir. In this study, total metals were not determined in samples from streams, but they were determined for the bottom sediment in Scofield Reservoir. (See section "Chemical and physical characteristics of sediments in the reservoir.")

CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER IN THE RESERVOIR

Some of the processes that affect the chemical and physical properties of water impounded in a reservoir are: (1) The relationship between inflow-outflow and storage in the reservoir; (2) precipitation of minerals from water in the reservoir; (3) leaching of minerals from rocks and soils inundated by the reservoir; (4) the relationship between the chemical equilibria of water and sediments; (5) photosynthesis and respiration; and (6) chemical and physical characteristics of the sediments.

Table 2.—Range of concentration of dissolved trace metals and other minor elements for selected streams, October 1, 1979-August 31, 1980

[Site: See figure 1 for location. All concentrations in micrograms per liter.]

Site	Stream		Arsenic	Boron	Copper	Iron	Lead	Mercury	Selenium	Zinc
S2	Fish Creek	Maximum	<1	30	<10	160	13	<0.1	<1	10
		Minimum	<1	5	<1	10	<1	<.1	<1	<3
		Number of measurements	6	6	6	5	6	5	7	7
S4	Pondtown Creek	Maximum	<1	40	<10	450	21	<.1	<1	440
		Minimum	<1	6	<1	10	<1	<.1	<1	<3
		Number of measurements	8	8	7	7	7	6	8	8
S29	Eccles Canyon	Maximum	<1	40	9	50	5	<.1	<1	180
		Minimum	<1	<5	<1	10	<1	<.1	<1	<3
		Number of measurements	9	9	5	9	8	6	9	9
S36	Mud Creek	Maximum	2	60	<10	30	28	<.1	<1	10
		Minimum	<1	10	<1	10	<1	<.1	<1	<3
		Number of measurements	9	9	6	8	9	4	9	9
S37	Price River	Maximum	1	30	<10	20	19	<.1	<1	20
		Minimum	<1	4	<1	<10	<1	<.1	<1	<3
		Number of measurements	6	6	6	5	6	4	6	6
			Recommended maximim limits							
			Domestic water supply[1]							
			50	–	1,000	300	50	2.0	10	5,000
			Freshwater aquatic life[2]							
			50	–	(3)	1,000	(3)	.05	(3)	(3)

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[1] U.S. Environmental Protection Agency, 1976, p. 5.

[2] U.S. Environmental Protection Agency, 1978, p. 14-245.

[3] Limit is dependent on type of aquatic species as well as other chemical constituents and physical properties of the water (U.S. Environmental Protection Agency, 1976, p. 54-245).

Effects of Storage, Inflow-Outflow, Chemical Precipitation, and Leaching of Minerals

The large ratio of annual inflow to storage has a flushing effect that is beneficial to the chemical quality of water in Scofield Reservoir. The maximum storage in the reservoir is 69,400 acre-feet and the estimated average annual inflow is about 46,000 acre-feet. Thus the ratio of average inflow to maximum storage is 0.66 or average inflow is about 66 percent of maximum storage. Because the actual storage usually is less than maximum, inflow commonly is larger than 66 percent. During October 1, 1979, to August 31, 1980, inflow was about 120 percent of maximum storage capacity. It was, however, as much as 170 percent of actual storage at the beginning of the period because inflow was greater than average and actual storage was less than maximum.

The chemical composition of water in the reservoir throughout the year is similar to that of streamflows that occur during April, May, and June. This is because about 80 percent of the average annual inflow occurs during these 3 months.

A comparison of the weighted average chemical composition of the major inflowing streams during October 1, 1979, to August 31, 1980, and the average composition of the reservoir during August 1980 is shown in figure 7. Except for the smaller concentrations of calcium and bicarbonate in the reservoir, the chemical composition (based on major ions) of the inflow was very similar. The smaller concentrations of calcium and bicarbonate in the reservoir probably result from chemical precipitation of calcium carbonate.

Figure 7 (caption on next page) near here

The combined effect of chemical precipitation, leaching, inflow and outflow on dissolved major ions in the reservoir from October 1, 1979, to August 31, 1980, are given in table 3 by comparing theoretical loads of ions (in tons) with measured loads. The theoretical load represents the load in the reservoir exclusive of chemical changes. The most significant difference between the theoretical and measured dissolved-ion load during October 1, 1979, to August 31, 1980, was an apparent loss of 1,300 tons of calcium and 3,100 tons of bicarbonate (table 3, column 6). The tonnage of bicarbonate includes carbonates converted to an equivalent tonnage of bicarbonate.

Table 3 (next page) near here

Figure 7.--Comparison of chemical composition of major inflowing streams during October 1, 1979-August 31, 1980, to average composition of Scofield Reservoir during August 1980.

Table 3.--Effect of chemical precipitation, inflow and outflow on loads (in tons) of dissolved ions in Scofield Reservoir, October 1, 1979-August 31, 1980

Dissolved ion	(1) Calculated reservoir load Sept. 1979	(2) Inflow load	(3) Outflow load	(4) Theoretical reservoir load Aug. 1980 (1 + 2 - 3)	(5) Calculated reservoir load Aug. 1980	(6) Increase(+) or decrease(-) in ion load (5 - 4)
Calcium (Ca)	2,400	6,300	4,200	4,500	3,200	-1,300
Magnesium (Mg)	820	1,100	1,100	820	820	0
Sodium (Na)	210	260	280	190	210	+20
Bicarbonate (HCO_3) plus Carbonate (CO_3)[1]	11,500	22,200	17,100	16,600	13,500	-3,100
Sulfate (SO_4)	890	1,200	1,300	790	970	+180
Chloride (Cl)	260	320	390	190	300	+110

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[1] Carbonate (CO_3) has been converted to an equivalent quantity of bicarbonate (HCO_3) and added to the quantity of bicarbonate (HCO_3).

Most of the loss of calcium and bicarbonate probably occurred by precipitation as calcium carbonate. Such precipitation in a reservoir is not unusual. Most of the streams entering Scofield Reservoir as well as water in the reservoir are saturated with respect to several carbonate minerals, including calcite and aragonite. In the reservoir, changes in the concentration of carbon dioxide (CO_2) affect the solubility of calcium carbonate.

The equilibria of calcium, bicarbonate, carbonate, and free carbon dioxide in water can be represented by the following equilibria equation:

$$\underset{\text{Calcium bicarbonate}}{Ca(HCO_3)_2} \quad \rightleftarrows \quad \underset{\text{Calcium carbonate}}{CaCO_3\downarrow} \quad + \quad \underset{\text{Water}}{H_2O} \quad + \quad \underset{\text{Carbon dioxide}}{CO_2}$$

If the concentration of CO_2 required to keep a given concentration of $CaCO_3$ in solution at equilibrium with $Ca(HCO_3)_2$ is decreased, $CaCO_3$ will precipitate (as indicated by the vertical arrow in the equilibria equation). If the concentration of free CO_2 is increased additional $CaCO_3$ will dissolve (Wetzel, 1975, p. 170). A major reason for loss of CO_2 in reservoirs is photosynthetic processes (which use CO_2) of algae and aquatic vegetation primarily during the summer months. (See section "Photosynthesis and respiration.")

By converting the loss of calcium to the equivalent combining weight of bicarbonate, about 1,000 tons of calcium or 80 percent of the total loss can be accounted for by precipitation as $CaCO_3$. This leaves about 300 tons of calcium that cannot be accounted for as loss by chemical precipitation. However, some of the differences between the theoretical and measured dissolved loads are due to the errors associated with measurements of the inflow, outflow, and storage loads as well as use by the biota. The differences between the theoretical and measured dissolved-ion loads for the other constituents are less than 200 tons and are within measurement error.

The errors associated with computation of the budget of inflow and outflow of major ions were evaluated by comparison of independently computed dissolved-solids loads. The net load of dissolved solids was computed on the basis of dissolved solids for the inflow, outflow, and water in storage (table 4). The net decrease for October 1, 1979, to August 31, 1980, was

Table 4 (next page) near here

2,800 tons. A similar computation was made using the sum of the loads of major ions listed in table 3 [neglecting silica (SiO_2) and other constituents], and the net decrease during October 1, 1979, to August 31, 1980, was 2,500 tons. The agreement between the independently computed dissolved-solids loads seems reasonable considering that the difference is only 300 tons. It must be noted, however, that the discharges used in the computations of the loads also have measurement errors, and the same discharges were used to make both load computations.

Table 4.--Water, dissolved solids, nitrogen, and phosphorus budget for Scofield Reservoir, October 1, 1979-August 31, 1980

Water (acre-feet)	
Storage	
August 31, 1980	55,000
October 1, 1979	46,500
Change in storage	+8,500
Inflow to reservoir	
Streams	79,150
Precipitation	2,900
Total	82,050
Outflow from reservoir	
Price River	67,500
Evaporation	8,000
Total	75,500
Unmeasured inflow (rounded) = (Outflow + change in storage) - inflow	2,000
Dissolved solids (tons)	
Storage load, October 1, 1979	10,500
Inflow load	20,900
Storage load, August 31, 1980	12,400
Outflow load	16,200
Net load change	-2,800
Total nitrogen (tons)	
Storage load, October 1, 1979	80
Inflow load	120
Storage load, August 31, 1980	68
Outflow load	100
Net load change	-32
Total phosphorus (tons)	
Storage load, October 1, 1979	2.2
Inflow load	7.4
Storage load, August 31, 1980	3.2
Outflow load	2.7
Net load change	-3.7

Leaching of minerals from rocks and soils inundated by the reservoir is not believed to be appreciable for the following reasons:

1. There was a net loss of dissolved ions computed from October 1, 1979, to August 31, 1980 (table 3, column 6).

2. The predominate minerals in the rocks and soils inundated by the reservoir are limestones and dolomites. These minerals would not be conducive to leaching because of limited solubility and the fact that water entering the reservoir is already near or at saturation with respect to calcite and aragonite.

3. Most of the readily soluble minerals were dissolved and "flushed" from the area of inundation during the early years of inundation and it is not likely that significant quantities of those minerals would still be dissolving after 36 years of inundation.

Plant Photosynthesis and Bacterial Respiration

The balance between plant photosynthesis and bacterial respiration probably is the most important factor controlling the chemistry of productive lakes and reservoirs. The following equation expresses the equilibrium between the reactants and products involved with photosynthesis and respiration (Stumm and Baccini, 1978, p. 98):

$$106CO_2 + 16NO_3^{-} + HPO_4^{-}2 + 122H_2O + 18H^{+} + \text{(trace elements, energy)} \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} \underset{\text{(Algal protoplasma)}}{C_{106}H_{263}O_{110}N_{16}P} + 138O_2 \qquad (1)$$

The equilibria of the equation may be shifted in either direction depending upon the availability of the reactants and products, and the energy (light). If conditions are suitable for producing algae such as in the shallow, trophogenic zone of a lake or a reservoir during the summer, the equation may be shifted to the right. In this situation, dissolved oxygen (O_2) is produced together with the algae. The algae protoplasma contains nitrogen, phosphorus, and carbon (and other nutrients not included in equation 1). The water may become supersaturated by the dissolved oxygen produced in the reaction and the environment becomes very oxidizing. Also, carbon dioxide (CO_2) is depleted and pH increases (use of hydrogen ions). In the oxidizing environment, dissolved inorganic nitrogen will occur primarily in the form of nitrate (NO_3). As the algae die or descend into the deeper zones where there is less light, or energy available for photosynthesis, bacterial decomposition and respiration become the dominant processes. In this situation, there is a shift of the equilibria of equation 1 to the left, causing a depletion of dissolved oxygen but increasing the concentration of carbon dioxide (CO_2), nitrogen, and phosphorus. The increased concentration of CO_2 causes a decrease of the pH. The environment may become reducing, and if so, inorganic nitrogen will occur primarily in the form of ammonia (NH_4).

Limnologic Cycle

The limnologic cycle is a series of related events within the regime of a lake or reservoir that occur during the year that describe: (1) The circulation patterns or lack of circulation (stratification) patterns in lakes and reservoirs, and (2) the thermal and chemical processes that are associated with circulation or lack of circulation in the reservoir (Bolke and Waddell, 1975).

Circulation of Water

The circulation pattern of Scofield Reservoir is typical of a high altitude, temporal region lake. The changes in seasonal circulation are the result of variations in solar radiation and ambient air temperatures. In the reservoir, the water will stratify as differences in density associated with temperature changes occur. At a certain time during the spring the lake becomes homothermous at 3.9° Celsius, the maximum density of water. Winds easily generate currents which circulate the water, mixing the oxygen from the surface, the nutrients from the bottom, and the suspended plankton. This is known as spring turnover and lasts only a few days. When the temperature of water becomes greater than 4° Celsius the density of the water decreases.

The thermal gradient established in lakes or reservoirs is sometimes destroyed by wind action, especially in shallow reservoirs such as Scofield Reservoir where a nearly uniform temperature prevails throughout the water body. In the autumn, a cooling of the uppermost water causes it to become more dense than the water immediately below. The denser water displaces the water below and that too is then cooled creating convection currents, that eventually mix the reservoir until it again reaches a uniform temperature. This is the autumn turnover which lasts somewhat longer than the spring turnover. The reservoir becomes inversely stratified during the winter months when a layer of ice forms on the surface. Near-freezing water (near 0° Celsius) close to the ice layer overlies the warmer (near 3.9° Celsius) but more dense water. The limnologic cycle is complete when the ice melts and the upper layers again become warmed. (See Wetzel, 1975, p. 66-75.)

Thermal and Chemical Stratification

Data collected by the Utah State Department of Health during 1980-81, and by the U.S. Geological Survey during 1980, were used to show seasonal trends of temperature, dissolved oxygen, and dissolved solids near the outlet of Scofield Reservoir (fig. 2, site M5), which is the deepest part of the reservoir. Although the data were not collected continuously at site M5 for a given year, they were sufficient for illustrating seasonal changes as affected by circulation and stratification.

Variations of dissolved oxygen, temperature, and dissolved solids, with depth are shown in figure 8. Profiles A, C, and E show the variations prior to and following the spring turnover of 1981; profiles B, D, and F show them prior to and following the autumn turnover of 1980. Using the same data shown in figure 8, depth-time trends of temperature and dissolved oxygen were prepared (fig. 9) to further illustrate the seasonal variation and emphasize the turnover periods.

Figure 8 (caption on next page) near here

Figure 9 (caption on next page) near here

The graphs of temperature for January, February, and April 1981, are almost identical (fig. 8C). Surface temperatures immediately below the ice cover ranged from 1.5° to 2.5°Celsius (±0.5° Celsius) and deeper in the reservoir (below an altitude of about 7,600 feet) temperatures ranged from about 3.5° to 4.5° Celsius. The maximum density of water occurs at 3.9° Celsius, which is within the range of temperatures measured in the water below an altitude of about 7,600 feet. In this situation, where colder water is overlying warmer water, thermally the reservoir is considered to be inversely stratified. This type of stratification is weak because the difference in density between the warmer and colder water is very small. Because of the weak stratification, winds can easily create turbulence and mixing. However, during the ice-cover period, the water is conducive to stratification because the ice cover protects the water from wind, thereby preventing turbulence and mixing.

The graphs for dissolved oxygen and dissolved solids show that the reservoir was chemically stratified during January-April (fig. 8A, E). The concentration of dissolved oxygen at the surface (altitude 7,612 feet) ranged from 6 to 7.5 milligrams per liter and was less than 1.0 milligram per liter near the bottom (below an altitude of 7,580 feet). The vertical profiles of dissolved-solids concentrations also suggest little or no mixing as the gradients of the profiles progressively increase from January to April. During January, the concentration of dissolved solids ranged from about 190 milligrams per liter at the surface to 200 milligrams per liter near the bottom, whereas in April the concentration ranged from about 190 milligrams per liter at the surface to nearly 230 milligrams per liter near the bottom. The concentration of dissolved solids in the reservoir at any time of the year is largely a mixture of base flows and high flows that have occurred during the prior months. Thus, during periods of base flow (such as January-March) the inflow contains larger concentrations of dissolved solids than the reservoir. Therefore, without mixing of waters in the reservoir, conditions are conducive to the development of differences of concentrations of constituents in the reservoir.

Figure 8.--Vertical profiles of concentration of dissolved oxygen, water temperature, and concentration of dissolved solids at site M5, near dam, 1980-81.

Figure 9.--Depth-time diagram of dissolved oxygen and temperature, showing periods of ice cover, thermal stratification and turnover at site M5, January-May 1981 and June-September 1980.

During April 2-May 13, 1981, the ice cover on Scofield Reservoir melted and the water temperatures increased from surface to bottom. On May 13, the temperature was 11° Celsius at the surface and 9.5° Celsius at the bottom (fig. 8C). The surface water was now warmer than the underlying water as opposed to April when the surface layer was colder than the underlying water. Thus at some time between April 2 and May 13, the temperature became uniform from surface to bottom, and in the absence of the ice cover, the water became susceptible to mixing and spring turnover occurred (fig. 9).

On May 13, 1981, the absence of the anaerobic zone and vertical homogeneity of dissolved oxygen and dissolved solids also indicated that the reservoir had mixed. The concentration of dissolved oxygen was about 6.5 milligrams per liter from the surface to the bottom and the concentrations of dissolved solids ranged from 205 milligrams per liter at the surface to 200 milligrams per liter near the bottom.

The changes in the thermal and chemical characteristics also denote the late summer and autumn turnover. The temperature profile during June 1980, was similar to that of May 1981, but the water was warmer, with temperatures ranging from about 15° Celsius at the surface to 10° Celsius at the bottom (fig. 8D). On July 29, 1980, the maximum measured water temperatures and thermal gradient occurred, with temperatures ranging from 21° Celsius at the surface to 13° Celsius at the bottom. Also on July 29, the maximum depletion of dissolved oxygen occurred (fig. 8B) and the concentration of dissolved solids reached its maximum gradient (fig. 8F) since prior to the spring turnover.

On August 27, the first indication of mixing occurred since the spring turnover. The temperature gradient had almost disappeared, as temperatures ranged from 17° Celsius at the surface to 15° Celsius at the bottom (fig. 8D). Dissolved oxygen had now been replenished in a zone where it was previously depleted. For example, on July 29, the dissolved-oxygen concentration was near 0 milligram per liter in the bottom 15 feet, whereas on August 27, the dissolved-oxygen concentration was almost 0 milligram per liter in the bottom 5 feet. Likewise, the concentration of dissolved solids showed the effects of mixing, as the concentrations were homogeneous to a greater depth on August 27 than on July 29 (fig. 8F).

Comparison of dissolved-oxygen and dissolved-solids profiles on August 27 and September 18 (fig. 8F) indicate that additional mixing occurred within this period. On September 18, oxygen was no longer greatly depleted at the bottom of the reservoir, as the concentration ranged from 5.5 milligrams per liter near the bottom to about 8 milligrams per liter at the surface. Also, the concentration of dissolved solids was nearly the same--about 185 milligrams per liter from surface to bottom (fig. 8F). The gradient of water temperatures did not change from August 27 to September 18, but the temperature cooled about 2° Celsius from the surface to the bottom during that period.

Scofield Reservoir, although being dimictic with turnovers in the spring and autumn, did not develop a well-defined epilimnion and hypolimnion during 1980. Thermal stratification in Scofield Reservoir is undoubtedly affected by the inflow-outflow relationship--a large inflow of water relative to the volume of water in storage can alter the thermal gradient. Also, in shallow reservoirs such as Scofield Reservoir, especially if not protected from the wind, depth may not be sufficient to maintain a typical epilimnion and hypolimnion. During the summer stratification period of 1980, there was only about 1 month when an epilimnion could be distinguished.

Dissolved Oxygen

Dissolved oxygen in water is fundamental for the propagation of aquatic life. It is derived chiefly from air in contact with water, but is also a byproduct of photosynthesis by aquatic vegetation. Dissolved oxygen may be depleted from the water by respiration of vegetation and other aquatic life, including micro-organisms that decompose organic matter in water. (See section "Photosynthesis and respiration.") The solubility of dissolved oxygen is directly proportional to atmospheric pressures and inversely proportional to water temperatures.

Data collected by the U.S. Geological Survey during September and October 1979 and August 1980 were used to describe the variation of dissolved oxygen with depth throughout the reservoir. During September and October 1979, the concentration of dissolved oxygen ranged from less than 8 to about 10 milligrams per liter (fig. 10), and the homogeneity of dissolved oxygen throughout the reservoir was a result of mixing during the autumn turnover. During August 1980, the concentration of dissolved oxygen was about 8 milligrams per liter in the upper few feet of the reservoir but decreased with depth and became almost depleted just above the water-sediment interface. Wetzel (1975) described this as a clinograde profile. The clinograde profile is a pattern where stratification during the summer prevents circulation and an anaerobic condition exists at the sediment-water interface due to oxygen use by bacterial respiration during the decomposition of organic matter. The depletion of dissolved oxygen is greatest near the sediment-water interface because that is where organic matter accumulates and bacterial metabolism is most intense. Depletion decreases upward within the reservoir as oxygen diffuses from the more enriched zones toward the depleted zones.

Figure 10 (caption on next page) near here

The depth-time trend of dissolved oxygen for site M5 shows that oxygen is depleted in the deeper layers of water except during periods of turnover (fig. 11). Below an altitude of about 7,590 feet where 20 percent of the water is stored, the concentration of dissolved oxygen was less than 2 milligrams per liter, which is less than about 30 percent of saturation.

Figure 11 (caption on next page) near here

Figure 10.--Profiles of dissolved-oxygen concentration during September and October 1979 and August 1980.

Figure 11.--Depth-time diagram of percent saturation of dissolved oxygen at site M5, January-May 1981 and June-September 1980.

The concentration of dissolved oxygen, which was depleted during January-April 1981, was replenished during the spring turnover. Depletion quickly developed again near the bottom in the latter part of May and continued to develop until the autumn turnover, when oxygen was again replenished to the bottom of the reservoir. During the summer stratification period, which began after the spring turnover, the depletion of dissolved oxygen in the deeper layers was paralleled by supersaturated concentrations in the near-surface layer. This condition commonly occurs in reservoirs or lakes when seasonal photosynthesis is significant in the shallow layers--much of the oxygen that is produced as a result of photosynthesis (shift of equilibria of equation 1 to the right) causes the near-surface waters to become supersaturated. Part of the oxygen produced in this manner escapes to the atmosphere and does not become available to the deeper layers. As the algae and other plants sink into the deeper layers where there is less light (and energy) for photosynthesis, decomposition and bacterial respiration consume oxygen (shift of equilibria of equation 1 to the left) and the concentration of dissolved oxygen becomes depleted. The greatest percentage of supersaturation at site M5 occurred on July 29, 1980, when the concentration of dissolved oxygen was 142 percent of saturation near the surface. Also, on July 29, 1980, oxygen depletion in the lower layers was at a maximum, and thermal and chemical stratification was more developed than during the other sampling periods (figs. 8 and 11).

Dissolved Trace Metals and Other Minor Elements

During the September-October 1979 and August 1980 sampling periods, the concentration of dissolved arsenic, chromium, lead, and selenium did not exceed the maximum contaminant levels set by the U.S. Environmental Protection Agency, Environmental Studies Board (1976, p. 5) for public water systems. Reducing conditions in the anaerobic zone, however, were conducive to increased concentrations of iron and manganese. During August 1980, in the anaerobic zone at site M5, the concentration of iron was 60 micrograms per liter and that of manganese was 750 micrograms per liter. At other sampled sites and depths, however, the concentration of dissolved iron was less than about 30 micrograms per liter and dissolved manganese was less than about 100 micrograms per liter.

Dissolved and Suspended Nitrogen and Phosphorus

Dissolved and suspended forms of nitrogen and phosphorus were determined for 23 samples collected from the reservoir during September and October 1979, and August 1980. Dissolved and suspended nitrogen were separated into the inorganic and organic phases. The inorganic phases included nitrite, nitrate, and ammonia. Only the dissolved phase of phosphorus was determined separately from total phosphorus, which includes both dissolved and suspended or particulate matter.

Most of the dissolved nitrogen was in the organic form. The concentration of dissolved organic nitrogen ranged from 0.38 to 0.81 milligram per liter and averaged 0.55 milligram per liter during 1979 and 1980 (table 5). The maximum concentration occurred in 1979 at the 1-foot depth zone at site M5. The maximum concentration of dissolved inorganic nitrogen during September-October 1979 was 0.12 milligram per liter and during August 1980 the maximum was 0.47 milligram per liter. Most of the dissolved inorganic nitrogen was in the form of ammonia (NH_4^+) and occurred in the deeper part of the reservoir where anaerobic conditions existed.

Table 5 (next page) near here

Suspended inorganic nitrogen ranged from 0.12 to 1.44 milligrams per liter during September and October 1979 but was less than 0.01 milligram per liter during August 1980. Most of the suspended inorganic nitrogen was in the form of ammonia and the largest concentration was at a depth of 1 foot at site M20. Suspended organic nitrogen varied from less than 0.01 to 3.62 milligrams per liter and the largest concentration was at a depth of 1 foot at site M65, which is near the inflow of Mud Creek. The concentrations of total nitrogen which includes both dissolved and suspended forms of organic and inorganic nitrogen, ranged from 0.53 to 4.00 milligrams per liter and averaged 1.26 and 0.91 milligrams per liter respectively, during 1979 and 1980.

Dissolved phosphorus, which includes the organic and inorganic phases, ranged from 0.00 to 0.12 and averaged 0.01 milligram per liter during 1979. An average was not determined for 1980 because of the large range for such a relatively small number of samples. Total phosphorus which includes both the dissolved and suspended forms of organic and inorganic phosphorus, ranged from 0.01 to 0.18 and averaged 0.03 and 0.04 milligram per liter respectively, during 1979 and 1980 (table 5).

Because of the large ratio of inflow and outflow to storage, the quality of water discharging from the reservoir reflects, to a large extent, the seasonal changes that are occurring in the upper layers of the reservoir. For this reason, total nitrogen was separated into the dissolved and suspended forms of organic and inorganic nitrogen so that changes of nitrogen that are related to changes in photosynthesis in the reservoir could be distinguished (fig. 12). Dissolved nitrogen (inorganic plus organic) is greatest during the winter months when productivity, and thus, the demand for nitrogen is least. The concentration of dissolved nitrogen then decreases rapidly during the summer months as the growth of algae (and aquatic vegetation) is consuming large quantities of dissolved nitrogen. The suspended or particulate nitrogen is virtually nil during the fall, winter, and spring when algae production is negligible, but increases and reaches a peak during the summer when algae production is large--indicating that most of the suspended organic nitrogen probably is contributed by the algae.

Figure 12 (caption on next page) near here

Table 5.—Statistical summary of dissolved and suspended forms of nitrogen and of dissolved and total phosphorus for Scofield Reservoir, September-October 1979 and August 1980

Date		Milligrams per liter						
		Nitrogen (as N)					Phosphorus (as P)	
		Dissolved		Suspended		Total	Dissolved	Total
		Inorganic	Organic	Inorganic	Organic			
September-October 1979	Minimum	0.01	0.42	0.12	< 0.01	0.86	0.00	0.01
	Maximum	.12	.81	1.44	1.37	2.10	.01	.06
	Average[1]	—	.55	—	—	1.26	.01	.03
August 1980	Minimum	0.05	0.38	<0.01	0.01	0.53	0.00	0.03
	Maximum	.47	.63	<.01	3.62	4.00	.12	.18
	Average[1]	—	.55	—	—	.91	—	.04

[1] Average concentration for the reservoir was determined by drawing lines of equal concentration for a cross section of the reservoir and then weighting by the respective increments of volume.

Figure 12.--Variation of dissolved and suspended forms of nitrogen in reservoir outflow (Price River), November 1, 1979-August 31, 1980.

Trophic State

Waters that are enriched in nutrients are very susceptible to excessive production of algae and aquatic vegetation. A rapid rate of productivity affects the overall metabolism in the water, which causes deterioration of the water quality. As a means of classifying the state of productivity of lakes, the concepts of oligotrophy and eutrophy were introduced by limnologists during the early part of this century. Oligotrophic lakes contain small amounts of planktonic algae and eutrophic lakes contain large amounts of planktonic algae. Recent investigators such as Vollenweider (1971) and Wetzel (1975) have related the productivity of lakes to the nutrient quantity in the water.

The most important nutrients in determining the productivity of lakes generally are regarded to be nitrogen and phosphorus. Vallentyne (1974) showed that the typical tissue of algae and aquatic vegetation contains phosphorus, nitrogen, and carbon in approximately the ratios: 1P:7N:40C per 500 grams of net wet weight. Typically, phosphorus is regarded as the limiting nutrient in most lakes and reservoirs. Therefore, if nitrogen and carbon are present in quantities near the above ratios (along with certain trace elements), 1 gram of phosphorus can potentially generate 500 grams of algal biomass. Wetzel (1975, p. 640) states: "Oligotrophic lakes often are limited by phosphorus and contain an excess of nitrogen. As the lakes become more productive, the primary effecting agent is increased loading of phosphorus."

Attempts by many investigators to relate the various fractions of phosphorus to metabolism of phosphorus have been unsuccessful. Wetzel (1975, p. 216) states: "The most important quantity, in view of the metabolic characteristics within a lake, is the total phosphorus content of unfiltered water, which consists of the phosphorus in suspension in particulate matter, and the phosphorus in 'dissolved' form* * *."

The different forms of nitrogen cannot be used to the same extent by the different groups of plants. Vollenweider (1971, p. 27) presented a table which shows the forms of nitrogen used by different groups of plants (table 6). The significant aspect of these data is that all groups of plants use organic nitrogen, including blue-green algae, which is the most objectionable form of algae. (It should be noted that there is some controversy among biologists whether blue-green blooms are actually algae.) Bacterial decomposition is required before many plants can use organic nitrogen; however, in a reservoir or lake there is usually an excess of active bacteria to cause decomposition.

Table 6 (next page) near here

Table 6.--Use of different forms of nitrogen (from Vollenweider, 1971)

	Organic N	$N(NH_3)$	$N(NO_3)$	N_2
Some bacteria and eumycetes, some species of Euglena	x			
Some bacteria and Eumycetes	x	x		
Most bacteria, Eumycetes, algae and higher plants	x	x	x	
Some bacteria and blue-green algae	x	x	x	x

The trophic state of Scofield Reservoir was evaluated on the basis of the nutrient content of the inflow, of water in storage, and of the outflow, and on the basis of dissolved-oxygen depletion during the summer stratification period. Most of the evidence indicates that the trophic state is intermediate between mesotrophic and eutrophic and that the reservoir may be becoming eutrophic unless corrective measures are taken to limit nutrient inflow.

The general degree of lake productivity as related to the concentrations of nitrogen and phosphorus is shown in table 7. The average concentration of dissolved organic nitrogen in the reservoir was 0.55 milligram per liter during 1979 and 1980 and according to table 7 the lake would be classified as mesotrophic. The average concentration of total phosphorus was 0.03 and 0.04 milligram per liter, respectively, during 1979 and 1980 and would classify the reservoir as eutrophic. The average concentration of dissolved inorganic nitrogen was not computed because of the large variability for such small number of samples. However, the weighted average concentration of dissolved inorganic nitrogen in the outflow from the reservoir during October 1, 1979 to August 31, 1980 was 0.4 milligram per liter and provides a suitable estimate of the average concentration in the reservoir. Therefore, for an average concentration of 0.4 milligram per liter, table 7 indicates that during October 1, 1979, to August 31, 1980 the lake would have been classified as mesotrophic.

Table 7 (next page) near here

The concentration and forms of nitrogen and phosphorus change seasonally in Scofield Reservoir due to inflow, outflow, change in equilibria between photosynthesis and respiration, denitrification, and sedimentation as well as other factors. Thus, the average concentrations that were computed during September-October 1979 and August 1980 and the classification of trophic state may not represent average conditions existing through the productive period.

Vollenweider (1971) presented another method to evaluate the trophic state of a reservoir which is based on the inflow load of nutrients and the mean depth of the reservoir. The classification, based on total phosphorus, is shown in figure 13. According to figure 13, Scofield Reservoir would be considered borderline between mesotrophic and eutrophic. Vollenweider (1971, fig. 18) also prepared an illustration similar to figure 13 that was based on total nitrogen. When the concentration of total nitrogen in the inflow to Scofield Reservoir was computed and compared with this illustration, the plot indicated that Scofield Reservoir was borderline between mesotrophic and eutrophic.

Figure 13 (caption on next page) near here

Table 7.--General relationship of lake productivity to average concentrations of epilimnetic nitrogen and phosphorus (modified from Vollenweider, 1971)

General degree of lake productivity	Approximate average (milligrams per liter)		
	Inorganic nitrogen	Organic nitrogen	Total phosphorus
Ultra-oligotrophic	<0.20	<0.20	<0.005
Oligo-mesotrophic	.20-.40	.20-.40	.005-.010
Mesotrophic	.30-.65	.40-.70	.010-.030
Eutrophic	.50-1.5	.70-1.2	.030-.100
Hypereutrophic	>1.5	>1.2	>.100

Figure 13.--Relationship between inflow loads of total phosphorus, mean depth, and trophic state of selected reservoirs and lakes. (Modified from Stumm and Baccini, 1978, fig. 15; published with permission.)

Probably the most important aspect or consideration regardless of the productivity classification based on the nutrients, is the undesirable effects of excessive plant production on critical water-quality constituents such as dissolved oxygen. Depletion of dissolved oxygen occurs in very productive lakes and can directly affect living organisms, especially fish and benthic invertebrates.

During the summer of 1980, dissolved-oxygen depletion occurred within a few weeks of "spring turnover," and anaerobic conditions existed throughout the summer stratification period (see section "Dissolved oxygen"). Rapid depletion of oxygen and development of anaerobic conditions is common to very productive lakes and reservoirs. The extent of damage to the fishery caused by the current rate of depletion is not known; however, if the depleted zones continue to expand, the effect on living organisms would be considerable. Seasonal monitoring of dissolved oxygen and nutrients at site M5 needs to be continued in order to determine if the depletion of dissolved oxygen is increasing. Also nutrients as well as plant productivity needs to be monitored in the reservoir inflow and outflow in order to detect the possibility of increasing productivity and eutrophication.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF SEDIMENTS IN THE RESERVOIR

The interaction between the sediments and overlying water significantly affect the chemical and physical characteristics of lakes and reservoirs, and the processes governing those interactions are complex. During 1979-80, efforts were made to provide some information pertaining to the sediments that would aid planning of more detailed investigations. The quantity and rate of sediment deposition were studied by comparison of bathymetric profiles and by determination of age of sediment cores using radiochemical-dating techniques (lead-210). The quantity of coal and trace metals in the sediments, and particle size of the sediments were determined at selected sites.

Deposition of Sediment

A bathymetric survey was conducted and cores of bottom sediment were collected from Scofield Reservoir during 1979-80. The purpose of the survey was to: (1) Provide a basis for estimating the total sediment yield from inflowing streams subsequent to an earlier survey by the U.S. Bureau of Reclamation (1943), and (2) provide more detailed bathymetric measurements at selected cross sections so that future deposition can be evaluated more accurately. The cores were sliced into sections and the age of the sediment was determined by use of the radioisotope lead-210. The age of each section was determined so that estimates of the rate of sediment deposition could be computed.

Bathymetric Survey

Bathymetric soundings were made for four reservoir cross sections during September 1979 (fig. 14). These cross sections were located using surveyed points around the shore of the reservoir. Reference posts were established at these surveyed points on the shore of the lake. Then, by using a range finder located on the shore of the lake and through radio communication with the boat operator, 1 to 3 intermediate buoys were located within each cross section.

Figure 14 (caption on next page) near here

A recording fathometer, mounted in the boat, was then used to record depths across each section. The boat traversed across each section at a constant speed from a point near the shoreline and notes were made on the recorder when an intermediate reference point was passed. The fathometer recordings were then superimposed on a map of the reservoir and 1-foot contour intervals were drawn for altitudes up to 7,612 feet, which was the average altitude of the water surface during the period the bathymetric surveys were made. From this map, altitude-volume relationships were developed (fig. 15).

Figure 15 (caption on next page) near here

Figure 14.--Bathymetric profiles, 1979. (See fig. 2 for location.)

Figure 15.--Relationship of reservoir altitude and storage during 1943 and 1979 and net change due to sediment deposition.

The total volume of sediment that was deposited in Scofield Reservoir during 1943-79 was computed by comparing the 1979 annd 1943 bathymetric surveys, it (wet volume) was found to be 3,000 acre-feet. Using the ratio of 60 pounds of dry sediment per cubic foot of wet sediment (as determined from laboratory analyses of core samples), the dry weight of sediment was determined to be 3.9 million tons. For the approximately 113 square miles of drainage area upstream from the reservoir, this is equivalent to an average sediment yield of about 960 tons per square mile per year, or about 0.5 acre-foot per square mile per year. Since 1943, sediment deposition has decreased the original storage capacity of the reservoir about 4 percent.

Radiochemical Dating

An estimate of the rate of sediment accumulation also was made by determining the age of sediments for cores collected at sites M30 and M65. The core-sampling device used is shown in figure 16. The age of the sediments was determined by use of the radioisotope lead-210.

Figure 16 (caption on next page) near here

The radiochemical analyses were performed using procedures described by I.C. Yang (U.S. Geological Survey, written commun., April 8, 1981).

Lead-210 by gamma scan.--Ninety grams of the core sample were placed in a plastic counting vial and the gamma radiation was counted for 2 days in a lead-shielded (lithium) gamma spectrometer. The lead-210 region of interest at 46,500 electron volts was integrated and the background was subtracted. The counting efficiency was determined by spiking a calibrated solution into 90 grams of the same background sediment (deeper sediment) and counting with the same geometry. The results for lead-210 in the samples were reported in picocuries per gram (dry weight).

Lead-210 by chemical separation.--For this method, samples were analyzed in duplicate. Standards and blanks were processed concurrently, to obtain accurate recovery. Five-gram portions of each core sample were heated in a muffle furnace at 400° Celsius for 3 hours to remove volatile organic compounds. The samples were placed in teflon beakers for digestion, using two digestion methods. One method uses a mixture of hydrochloric, nitric, and hydrofluoric acid in a ratio of 1:1:4 (by volume). The other method uses a mixture of hydrochloric acid, nitric acid, and hydrogen peroxide in a ratio of 1:1:4 (by volume). These digestion methods were used alternately until satisfactory dissolution was obtained. The residue was completely dried after each digestion.

Figure 16.--Sampling apparatus used for collecting cores of bottom sediments.

(Photograph by Jeanette E. Dodge.)

After dissolution, a mixture (1:1 ratio) of hydrochloric and sulfuric acid was added, reduced to 50 milliliters, and then 10 milliliters of concentrated sulfuric acid was added to convert the salts to sulfate and remove nitrate and chloride. This solution was evaporated to a white fuming residue and then dissolved in 700 milliliters of deionized water. The sample was then analyzed for lead-210 as a water sample by a standard U.S. Geological Survey method.

Radium-226.--The radium-226 concentration in the cores was determined separately using 1-gram samples. After total dissolution (as with lead-210) the solution was analyzed by the radon de-emanation method. To obtain the nonsupported lead-210 values, the radium-226 concentrations in picocuries per gram were substracted from the lead-210 total values.

Lead-210, which has a half-life of about 21.4 years, is an unstable radioactive form of lead found in the sediment and decays to the more stable form, lead-206. The older, deeper sediments have a lower lead-210 activity than the surface sediments. By plotting the activity of lead-210 for different depths of sediment, a curve was drawn to determine the age of the sediments (fig. 17). The rate of accumulation for the two (wet) cores ranged from 0.18 to 0.60 centimeter per year and averaged about 0.31 centimeter per year.

Figure 17 (caption on next page) near here

The standard error of the mean of the six measurements was 0.02 centimeter per year; and for a 90-percent probability level, the confidence interval of the sample mean is 0.31 ± 0.04 centimeter per year. Therefore, for the average rate of accumulation, there is a 90-percent probability that the average for the two samples is somewhere between 0.27 and 0.35 centimeter per year. By converting the average rate of accumulation of wet sediment to an average rate of dry sediment and estimating the reservoir area in which the sediment was deposited, the average sediment yield from the drainage basin was estimated as 0.2 acre-foot per square mile per year. This is 2.5 times less than the rate of 0.5 acre-foot per square mile per year computed from the bathymetric surveys. Both estimates, however, are in the same range as the yield of 0.10 to 0.5 acre-foot per square mile per year that is indicated on the U.S. Department of Agriculture (1973) map for the drainage area upstream from Scofield Reservoir.

Figure 17.--Relationship of relative lead-210 activity and depth of sediment, 1980.

The bathymetric survey and radiochemical-dating techniques both have errors associated with the computed sediment yields. The 1943 bathymetric map has a 5-foot contour interval, whereas the 1979 map has a 1-foot contour interval. Future bathymetric surveys should yield accurate sedimentation rates provided that the cross sections (± 0.5-foot depth) used in 1979 are duplicated with equivalent accuracy. In the radiochemical-dating technique cores from only two sites were used and the samples were sliced into 7.5- to 10-centimeter sections. Radiochemical dating would provide more satisfactory results if samples are collected at more sites and the core sliced into sections of perhaps 1 to 5 centimeters. Samples collected at sites L90, M5, M30, and M65 (fig. 2) would provide a much more accurate determination of sediment accumulation especially if the homogeneity of the samples also is determined.

Particle Size

Particle or grain size is one of the most important factors in determining mechanisms and rates of transfer of solutes between lake or reservoir water and sediments. Because of the importance of surface reactions in lake sediments, fine-grained materials have the most potential for interaction with lake water. Surface areas of typical clay-size sediment are measured in square meters per gram, whereas sand-size sediments are measured in terms of square centimeters per gram (Jones and Bowser, 1978, p. 182).

To determine the quantity of clay-sized sediments near the inflow areas of Scofield Reservoir, core samples were collected at sites M65 and L90 (fig. 2). The cores were separated into three equal sections and each section was analyzed for the percent of clay-size particles therein--that is, particles with a mean diameter of less than 0.004 millimeter. The percent particle size less than 0.004 millimeter diameter for the average depth of the core is shown in figure 18. At sites L90 and M65, the clay-sized fraction of the upper 20 centimeters ranged from about 16 to 26 percent of the sediment, and below 20 centimeters the clay-sized fraction ranged from 28 to 33 percent of the sediment.

Figure 18 (caption on next page) near here

Figure 18.--Relationship between depth and quantity of sediment with mean diameter less than 0.004 millimeter, August 1980.

Coal

The distribution of coal was determined in the cores from sites M30 and M65 (fig. 2). The vertical distribution of coal in the sediment and the approximate time of deposition is shown in figure 19. The core from site M65 near the inflow of Mud Creek had a considerable quantity of coal most of which was deposited prior to about 1950. The core from site M30 near the middle of the reservoir had much less coal than the core from site M65; this is because site M30 is farthest from Mud Creek, the principal source of coal-bearing fluvial sediment. As at site M65, most of the coal at site M30 was deposited prior to about 1950.

Figure 19 (caption on next page) near here

Trace Metals and Other Minor Elements

Trace metals and other minor elements in the sediments were studied by the following methods:

1. Simulated anaerobic conditions were allowed to develop in water in contact with sediment cores, and then the concentration of selected trace elements was determined for the filtrate.

2. Trace elements were analyzed in the silicate, nonsilicate, and nondetrital phases of separate sediment cores using selective leaching techniques.

Simulated Anaerobic Environment

An experiment involving the development of an anaerobic environment was performed using cores collected from the reservoir at sites M30, R50, M65, and R90 (fig. 2) during September-October 1979. The experiment was performed in an attempt to determine the kinds of metals and other minor elements occurring during periods of stratification, and to provide guidelines for additional sampling of the water and sediments. During September-October 1979, when the first water samples were collected, the reservoir was well mixed and oxygenated; therefore, the concentration of dissolved metals and other minor elements in the deep layers was not representative of concentrations during periods of stratification when anaerobic or near anaerobic conditions are present.

During sampling, about 6 to 8 inches of water was trapped above the sediment cores in the 2-inch diameter, PVC core-sampling tubes. The tubes were capped, sealed, and stored in the laboratory at room temperature (approximately 25^{o} Celsius) until sufficient time had elapsed for anaerobic conditions to develop in the columns of water. Then, in situ measurements of dissolved oxygen and pH were made. Water was siphoned off, filtered, and preserved for analyses of concentration of selected trace metals or elements and nitrogen.

Figure 19.--Vertical distribution of coal in sediment cores, 1980.

Chemical analyses of the concentration of nitrate (NO_3), nitrite (NO_2), and ammonia (NH_4), as well as that of major ions were made so that the redox potential (pE) could be calculated (table 8). The redox potential (pE) was

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Table 8 (next page) near here

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computed using the WateQ2 model (Ball, Norstrom, and Jenne, 1980) and the model computation was based on the equilibria between ammonia (NH_4) and nitrate (NO_3) for the following reaction:

$$NO_3^- + 10H^+ + 8e^- = NH_4^+ + 3H_2O$$

It appeared, from consideration of the proximity of the core-sampling sites to inflowing streams, that pE varied according to the quantity of organic material available (table 8). The smallest values of pE as well as the largest concentrations of manganese and iron occurred in the cores collected at sites near the tributary inflow (sites M65 and R90), whereas the largest values of pE and smallest concentrations of iron and manganese occurred at sites more distant from the inflow points (sites R50 and M30). Presumably, there would be more organic material deposited near the points of inflow to the reservoir and the pE developed in a sealed sample from near those inflow points would be smaller.

The relationship between the concentration of the trace elements and of pH with pE are shown for each of the four sediment cores in figure 20.

Figure 20 (caption on next page) near here

The concentrations of arsenic, iron, lead, and manganese increased inversely with pE whereas zinc increased directly with pE. The concentration of dissolved metals in the simulated anaerobic environment suggests (but does not necessarily confirm) that the concentration of metals in the sediments are greater at a given site since the solubilities of the metals vary according to the redox state of the water.

The concentrations of metals in sediment in Scofield Reservoir could be a function of the availability of the metals as well as the redox state of the water. Therefore, to assess the effects of trace-metal transport to the reservoir, it was concluded that additional sediment sampling needs to focus on the quantities and solubility of metals in the sediments at sites both near the inflow from areas of coal mining and at various distances from these inflow sites.

Table 8.--Values of pH and pE, and concentration of dissolved oxygen, nitrogen, and dissolved metals and elements from water in contact with sediment cores

Site: See figure 2 for location.

	Site M30	Site R50	Site M65	Site R90
Temperature (degrees Celsius)	25.0	24.0	24.0	24.0
pH	6.84	6.55	6.95	7.13
pE	6.56	6.44	6.02	6.14
Milligrams per liter				
Dissolved oxygen	.10	.25	.12	.50
Ammonia (NH_4 as N)	.011	.019	8.4	.124
Nitrite (NO_2 as N)	.009	.005	.014	.022
Nitrate (NO_3 as N)	.561	3.2	.046	.878
Micrograms per liter				
Arsenic (As)	2	1	4	1
Beryllium (Be)	0	0	0	0
Cadmium (Cd)	1	4	1	0
Chromium (Cr)	10	0	0	0
Copper (Cu)	2	5	1	3
Iron (Fe)	30	60	4,000	120
Lead (Pb)	3	2	3	5
Manganese (Mn)	20	40	720	220
Mercury (Hg)	0	0	0	0
Nickel (Ni)	5	3	3	5
Selenium (Se)	0	0	0	0
Zinc (Zn)	10	20	10	10

Figure 20.--Relation of concentration of dissolved trace metals to pE, and of pH to pE for an artificially developed anaerobic zone, October 1979.

Silicate, Nonsilicate, and Nondetrital Phases

Additional sediment cores at sites M30 and M65 were collected from Scofield Reservoir during August 1980. The cores were sliced into sections and analyzed by the U.S. Geological Survey's laboratory in Denver, Colorado for arsenic, cobalt, copper, nickel, mercury, lead, zinc, manganese, iron, lead-210, coal, and loss on ignition. Several of the metals are potentially toxic pollutants and the effect of metal-enriched sediments on benthic organisms and fish has been noted by several investigators, including Bryan and Hummerstone (1973) and Ayling (1974).

The metals were partitioned into the silicate, nonsilicate, and nondetrital phases using leaching experiments described by Skei and Paus (1979, p. 240-241). The U.S. Geological Survey laboratory performed the chemical analyses of the sediments using methods that were slightly modified (methods 1-3) from those presented by Skei and Paus and are described by Delora Boyle (U.S. Geological Survey, written commun., April 8, 1981).

Total extractable metals (method 1).--A 0.5-gram portion of dried sediment was transferred to the teflon beaker used in the decomposition bomb. Five milliliters of hydrofluoric acid, 3 milliliters of hydrochloric acid, and 3 milliliters of nitric acid were added to the sample. The bomb was then sealed and placed in an oven at 120° Celsius for 2 hours. After cooling, the liquid from the bomb was placed in 50 milliliters of saturated boric acid solution. Because there was some insoluble material present, the solution was filtered through a Whatman 40 filter and diluted to 100 milliliters prior to analysis.

Nonsilicate extractable metals (method 2).--A 0.5-gram portion of sample was transferred to a round-bottom flask equipped with a condenser. After careful addition of 5 milliliters of concentrated nitric acid and 1.5 grams of potassium bromide, the resulting mixture was refluxed for 2 hours. The digested mixture was diluted to about 40 milliliters, filtered through a Whatman 40 filter, and diluted to 50 milliliters prior to analysis.

Nondetrital extractable metals (method 3).--One gram of dried sediment was transferred to an Erlenmeyer flask. One hundred fifty milliliters of 20-percent acetic acid was added and the flask was shaken for 12 hours at room temperature. The solutions were then filtered through Whatman 40 filter and diluted to 250 milliliters prior to analysis.

Nondetrital extractable metal is considered to be easily removable (and probably available to biota). Included are metals bound in the easily soluble amorphous compounds of manganese and iron, and metals loosely held in ion-exchange and sorbed positions or attached to organic matter. Also included are metals in water that fills intergranular spaces of the sediments. The nonsilicate extractable metal is considered to include all metals (including the nondetrital) except those bound in the silicate minerals. The quantities of metals bound in the silicate and oxide minerals may be determined as the difference between the total extractable metals (method 1) and the nonsilicate extractable metals (method 2). The quantities of metal held tightly in organic material, in sulfides, or strongly attached to clays may be determined as the difference between the nonsilicate extractable metal (method 2) and the nondetrital extractable metal (method 3). Loss on ignition provides an estimate of the quantity of organic matter.

The results of the analyses (tables 9 and 10) were plotted in figures 21 and 22 to show the depth variation of trace metals for the three leaching tests. In addition, the differences of concentration between methods 1 and 2 and between 2 and 3 are differentiated by color to show the additional metal solubilized by progressively stronger leaching tests. For example, the blue shading represents the quantity of metal bound in the silicate and oxide minerals (method 1 minus method 2); the red shading represents the quantity of metal tightly held in the organic material, in sulfides, or strongly adsorbed to clays (method 2 minus method 3); and the green shading is the nondetrital or easily soluble metal. The concentration of metals determined as the difference between methods 2 and 3 are, hereafter, referred to as the "sulfide fraction."

Tables 9 and 10 (next pages) near here

Figures 21 and 22 (captions on next pages) near here

Table 9.--Chemical analyses of sediment cores from site M30, August 1980

[See figure 2 for location of site.]

Method: 1, total extractable metal; 2, nonsilica extractable metal; 3, nondetrital extractable metal.

Depth of sediment (centimeters)	Loss on ignition (percent)	Method	Parts per million								
			Arsenic	Cobalt	Copper	Nickel	Mercury	Lead	Zinc	Manganese	Iron
0-10	0.9	1	0.80	50	48	60	0.38	60	116	526	13,600
		2	--	10	28	27	.00	40	58	468	13,500
		3	.25	10	13	25	.02	25	20	493	4,200
10-20	1.0	1	.80	40	33	60	.08	50	96	332	14,000
		2	--	10	31	27	--	40	63	373	14,300
		3	.50	10	19	25	.02	25	25	343	4,025
20-30	.7	1	.00	40	15	50	.20	50	64	442	12,200
		2	--	10	20	15	.00	20	38	398	8,900
		3	.25	10	19	12.5	.02	.00	15	435	3,625
30-41	.8	1	.40	40	20	50	.46	40	62	368	11,200
		2	--	10	17	15	.02	--	34	323	9,900
		3	.00	10	13	12.5	.02	--	13	358	2,800

Table 10.--Chemical analyses of sediment cores from site M65, August 1980

[See figure 2 for location of site.]

Method: 1, total extractable metal; 2, nonsilica extractable metal; 3, nondetrital extractable metal.

Depth of sediment in centimeters	Loss on ignition (percent)	Method	Parts per million								
			Arsenic	Cobalt	Copper	Nickel	Mercury	Lead	Zinc	Manganese	Iron
0-7.5	1.0	1	0.40	50	20	40	0.20	50	88	374	14,200
		2	--	10	28	15	.00	20	43	304	10,000
		3	.25	10	19	12.5	.00	0	35	305	2,900
7.5-15	.8	1	.20	30	10	20	.16	20	42	162	7,660
		2	--	10	17	5	.00	5	37	163	7,400
		3	.00	10	13	12.5	.02	0	28	165	1,700
15-22.5	.8	1	.40	30	40	70	.18	40	56	252	9,660
		2	--	10	20	10	.00	20	36	276	7,000
		3	.00	10	13	12.5	.00	25	30	268	2,325
22.5-30	.6	1	.40	40	15	30	.08	20	42	272	9,360
		2	--	10	17	10	.00	20	30	208	5,900
		3	.00	0	13	12.5	.02	20	18	203	1,550

Figure 21.--Vertical profiles of trace metals extracted from sediments by selective leaching methods and loss on ignition in sediment cores from site M30, 1980. (Site M30 is shown in fig. 2.)

Figure 22.--Vertical profiles of trace metals extracted from sediments by selective leaching methods and loss on ignition in sediment cores from site M65, 1980. (Site M65 is shown in fig. 2).

Total extractable arsenic ranged from 0.00 to 0.80 part per million at site M30 and from 0.20 to 0.40 part per million at site M65. The largest concentration occurred in the near-surface section at site M30, but there is no apparent arsenic enrichment near the surface at site M65. Most of the arsenic at both sites occurred in either the nondetrital (easily soluble) or silica-bound (difficult solubility) fractions.

Total extractable cobalt ranged from 40 to 50 parts per million at site M30 and from 30 to 50 parts per million at site M65. The largest concentrations occurred in the near-surface sections at both sites. Cobalt occurred in the silica-bound fraction (with a small quantity occurring in the nondetrital fraction) at both sites.

Total extractable copper ranged from 15 to 48 parts per million at site M30 and from 10 to 40 parts per million at site M65. The largest concentration occurred in the near-surface section at site M30 but in a deeper section at site M65. Some silica-bound copper occurred in the near-surface section at site M30 but otherwise, most of the copper occurred in either the nondetrital or sulfide fraction at both sites.

Total extractable nickel ranged from 50 to 60 parts per million at site M30 and from 20 to 70 parts per million at site M65. The largest concentrations occurred in the near-surface section at site M30, and in a deeper section at site M65. At both sites most of the nickel occurred in the silica-bound fraction and a small quantity occurred in the nondetrital fraction.

Total extractable mercury ranged from 0.08 to 0.46 part per million at site M30 and from 0.08 to 0.20 part per million at site M65. The largest concentrations occurred in the deepest section at site M30 and near the surface at M65. Virtually all of the mercury at both sites occurred in the silica-bound fraction, which is the least soluble fraction. The maximum concentration of mercury in the nondetrital and easily soluble fraction was 0.02 part per million at both sites.

Total extractable lead ranged from 40 to 60 parts per million at site M30 and from 20 to 50 parts per million at site M65. The largest concentrations occurred in the near-surface sections at both sites. Lead occurred in the nondetrital, sulfide, and silica-bound fraction at site M30 but only in the sulfide and silica-bound fraction at site M65. In the near-surface section at site M30, about one-half of the lead occurred in the nondetrital fraction and about equal quantities occurred in the sulfide and silica-bound fraction. In the near-surface section at site M65, approximately equal quantities of lead occurred in the sulfide and silica-bound fractions.

Total extractable zinc ranged from 62 to 116 parts per million at site M30 and from 42 to 88 parts per million at site M65. The largest concentrations of total extractable zinc occurred in the near-surface sections, with generally decreasing concentrations with depth at both sites. Zinc occurred in the nondetrital, sulfide, and silica-bound fractions at both sites, and at site M30, the concentration in all three fractions generally decreased with depth.

Total extractable manganese ranged from 332 to 526 parts per million at site M30 and from 162 to 374 parts per million at site M65. The largest concentrations occurred in near-surface sections at both sites, and virtually all of the manganese was in the nondetrital fraction at both sites.

Total extractable iron ranged from 11,200 to 14,000 parts per million at site M30 and from 7,660 to 14,200 parts per million at site M65. The largest concentrations occurred in the near-surface section at site M65 and in a deeper section at site M30. The iron occurs in all three fractions but most was in the nondetrital and sulfide fractions at both sites.

The differences between the concentration of trace metals in the sediments near the inflow of Mud Creek (site M65) and those in the middle of the reservoir (site M30) were too small to indicate that sediments related to coal mining in the Mud Creek drainage have affected the trace-metal characteristics of the bottom sediments of the reservoir. Sediments deposited at site M65 clearly contain more coal than do the sediments deposited at site M30; however, the concentrations of most of the trace metals in the near-surface sediments at site M65 were no larger than at site M30.

The data are not sufficient to indicate a trend of trace-metal enrichment in the near-surface sediments. It should be noted, however, that the largest total extractable concentrations of seven of the nine metals occurs in the near-surface layer of sediment at both sites. Most of those metals occur in either the nondetrital (method 3) or silica-bound fractions (method 1 minus method 2). Only iron, zinc, lead, and copper had significant quantities of metals that occurred in the sulfide fraction (method 2 minus method 3).

More detailed studies of the sediments in Scofield Reservoir are needed, and the following procedures are needed for those studies:

1. Collect cores at site L90 near the inflow of Fish Creek, at site M5 near the dam, as well as additional cores at sites M30 and M65. The cores need to be limited to the upper 20 centimeters at each site and sliced into sections of perhaps 1 to 5 centimeters.

2. Perform chemical analyses of the cores using the selective leaching tests described in this report.

3. Monitor sediment concentrations in Eccles Canyon during both thunderstorm and snowmelt runoff. Sufficient data need to be collected to compute total sediment loads. The type and quantity of trace metals and other minor elements associated with the sediments also need to be determined.

EFFECTS OF THE RESERVOIR ON THE QUANTITY AND TEMPERATURE OF WATER IN THE PRICE RIVER

During October 1, 1978–August 31, 1980, the outflow from Scofield Reservoir as measured at site S37 on the Price River (fig. 2), was 67,500 acre-feet (table 4). Approximately 55,000 acre-feet of water was stored in the reservoir on August 31, 1980 and 46,500 acre-feet on October 1, 1979, representing an increase in storage of 8,500 acre-feet. Evaporation from and precipitation on the reservoir was estimated from National Oceanic and Atmospheric Administration records, at Scofield Dam to be about 8,000 and 2,900 acre-feet, respectively. (See for example National Oceanic and Atmospheric Administration, July 1980.) The quantity of bank storage is undetermined and is incorporated with the residual quantity of unmeasured inflow, which was calculated to be 2,000 acre-feet. Neglecting bank storage, the net depletion to the Price River was the quantity lost to evaporation (8,000 acre-feet) which was about 10 percent of the total inflow. This depletion is more than offset by the regulated more uniform flow in the river downstream from the reservoir and the flood protection, recreation and beneficial use of flows that would be lost without the reservoir.

Streamflow temperatures were monitored during the 1980 water year to determine the reservoir's effect on the temperature of the Price River. The average monthly temperatures at site S2 on Fish Creek upstream from the reservoir and site S37 on the Price River downstream from the dam are illustrated in figure 23. The water is released from the dam at an altitude of 7,586 feet where its temperature parallels, but is slightly greater than that measured in the reservoir at site M5 for that level (fig. 9).

Figure 23 (caption on next page) near here

The average monthly temperatures of the Price River ranged from 3.5° Celsius during December to 18.8° Celsius during July, whereas the average monthly temperature of Fish Creek ranged from 0.0° Celsius during December to 18.6° Celsius during July. The largest difference in temperature between those inflow and outflow sites occurred between November and January, when the temperature of the outflow was about 4° Celsius warmer than that of inflow from Fish Creek.

Figure 23.--Temperature of Fish Creek upstream from Scofield Reservoir and of Price River downstream from Scofield Reservoir, 1980 water year.

SUMMARY AND CONCLUSIONS

1. During the first 11 months of the 1980 water year, Fish Creek contributed 72 percent, Pondtown Creek 6 percent, and Mud Creek 16 percent of the inflow to Scofield Reservoir. Precipitation on the reservoir and inflow from other small tributaries (unmeasured) and ground-water seepage contributed the remaining 6 percent of the inflow.

2. Based on the records of Fish Creek, inflow to the reservoir during the 1980 water year was about 80 percent greater than the 1938-81 annual average inflow.

3. During October 1, 1979-August 31, 1980, the discharge-weighted average concentration of dissolved solids in the combined inflow of Fish, Pondtown, and Mud Creeks was 195 milligrams per liter. The discharge-weighted average concentration in the outflow for the same period was 175 milligrams per liter. The predominant ions in the inflow, the reservoir, and the outflow were calcium and bicarbonate. Chemical precipitation of calcium carbonate in the reservoir is believed to have caused most of the 20-milligram-per-liter decrease of concentration between the inflow and the outflow.

4. The concentration of total nitrogen and phosphorus was large in most inflowing streams during April-June 1980, and most of the total loads of those constituents were produced during that high-runoff period.

5. During October 1, 1979-August 31, 1980, the estimated discharge-weighted average concentration of total nitrogen in the combined inflow of Fish, Pondtown, and Mud Creeks, was 1.1 milligrams per liter (0.8 dissolved + 0.3 suspended). The discharge-weighted average concentration of total phosphorus in the combined inflow was 0.06 milligram per liter (0.01 dissolved + 0.05 suspended).

6. Unusually large concentrations of nitrogen and phorphorus occurred in runoff from Eccles Canyon during May 1980. The large concentrations probably are associated with flushing of residual debris left in the basin during clearing of forest land in an underground coal development area.

7. During October 1, 1979-August 31, 1980, the discharge-weighted average concentration of total nitrogen in the outflow from the reservoir was 0.9 milligram per liter (0.6 dissolved + 0.3 suspended), and that of total phosphorus was 0.03 milligram per liter (0.01 dissolved + 0.02 suspended). The large decrease of concentration of phosphorus between the combined inflow and the outflow is due in part to settling of suspended matter or use through photosynthetic processes in the reservoir or both.

8. The trophic state of Scofield Reservoir was evaluated on the basis of the nutrient content of the inflow, of water in storage, of the outflow, and on the basis of dissolved-oxygen depletion during the summer stratification period. The data indicate that the reservoir is either mesotrophic or borderline between mesotrophic and eutrophic, and that it may become highly eutrophic unless corrective measures are taken to limit nutrient inflow.

9. In order to detect the possibility of increasing productivity and eutrophication of Scofield Reservoir, nutrients need to be monitored in Mud Creek and in the outflow from the reservoir. Also, seasonal data need to be collected from the reservoir at a site near the dam.

10. Scofield Reservoir is dimictic with turnovers in the spring and fall. Direct thermal stratification occurred during the summer months between the periods of turnover. Maximum thermal and chemical stratification occurred in late July just prior to the autumn turnover.

11. Except during the turnover periods, dissolved oxygen was considerably depleted below an altitude of 7,590 feet where about 20 percent of the water is stored. The brief period during and following the turnover was the only time when anaerobic conditions did not exist below an altitude of about 7,580 feet. During the summer stratification period, which began after the spring turnover, the depletion of dissolved oxygen in the deeper layers of water was paralleled by supersaturated concentration in the shallow layer. The simultaneous occurrence of depletion and supersaturation occurred as a result of photosynthetic processes.

12. During September-October 1979 and August 1980, the concentration of dissolved arsenic, lead, and mercury in Scofield Reservoir did not exceed the maximum contaminant levels set by the U.S. Environmental Protection Agency for public-water systems.

13. Bathymetric profiles made at selected reservoir cross sections during September 1979 can be used to assess future rates of sediment deposition.

14. Sediment deposition in Scofield Reservoir during 1943-79 was estimated to be 3,000 acre-feet. The average annual sediment yield of the reservoir's drainage basin, as determined from bathymetric surveys and dating with radioisotopes, ranged from 0.2 to 0.5 acre-foot per square mile.

15. Most of the coal deposition in the reservoir occurred prior to about 1950. Since 1943, the deposition of sediment has decreased the storage capacity of Scofield Reservoir by about 4 percent.

16. The difference between the concentration of trace metals in the sediments near the inflow of Mud Creek and those in the middle of the reservoir was too small to indicate that sediments related to coal mining have affected the trace metal characteristics of the sediments. The concentration of total extractable mercury in the sediments near the inflow of Mud Creek ranged from 0.08 to 0.20 part per million and at a site near the middle of the reservoir the concentration ranged from 0.08 to 0.46 part per million. However, virtually all of the mercury is silica bound, which is the least soluble fraction. The maximum concentration of mercury in the nondetrital and easily soluble fraction was 0.02 part per million at both sites.

17. Fluvial sediment needs to be monitored in Eccles Canyon to determine the effects of clearing of forested land for coal development. Both thunderstorm and snowmelt runoff need to be monitored so that sufficient data are collected to compute sediment loads.

18. Trace metals in the sediment in the streams and in Scofield Reservoir need to be studied in greater detail.

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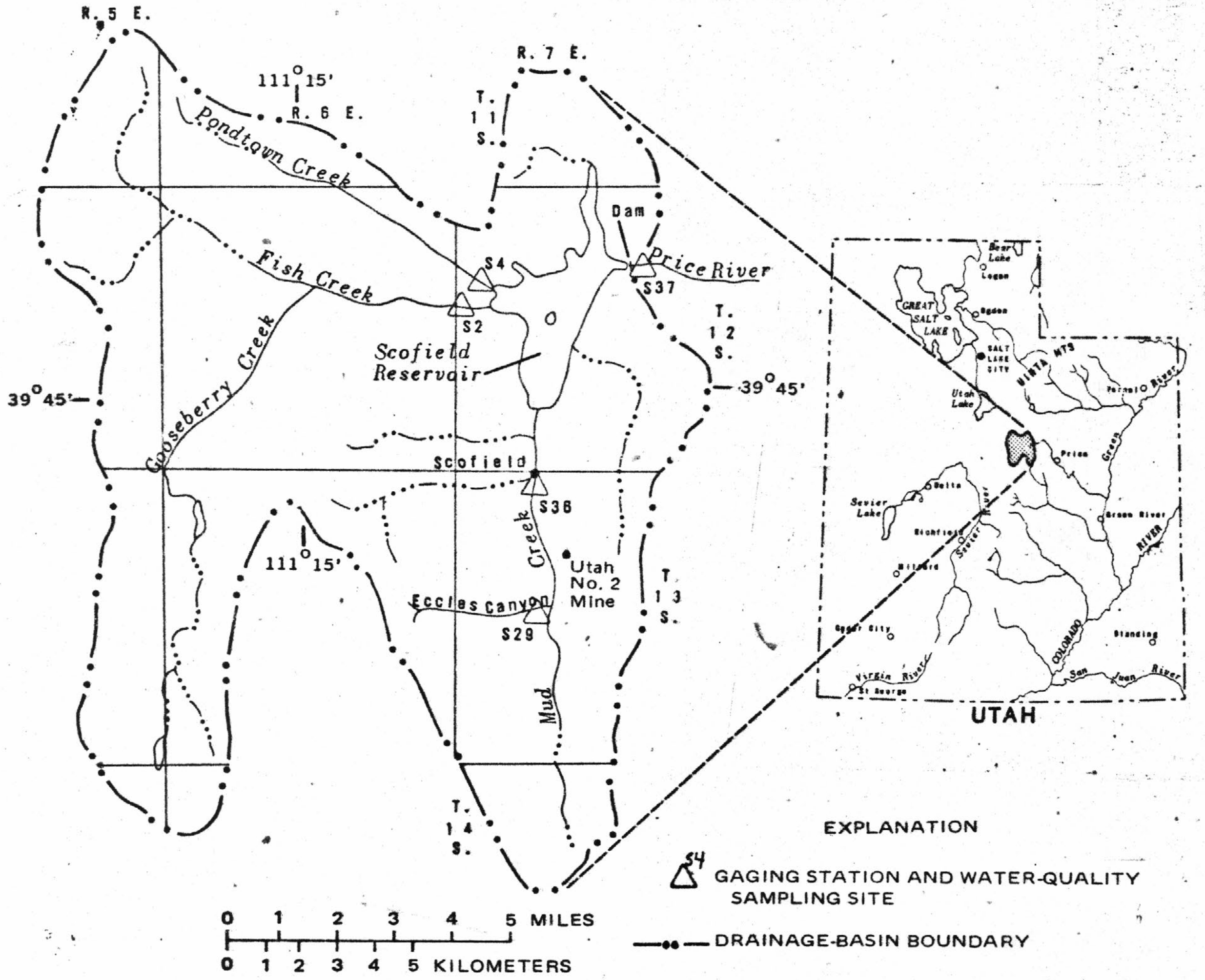


Figure 1.—Location of the Scofield Reservoir drainage basin and gaging stations and water-quality sampling sites on streams.

FIGURE 2

EXPLANATION

S4 ▲	GAGING STATION AND WATER-QUALITY SAMPLING SITE ON STREAM-- Data available in Waddell and others (1982, tables 9 and 11-13).
L90 ☒	WATER-QUALITY SAMPLING SITE IN RESERVOIR WHERE IN SITU MEASUREMENTS MADE FOR TEMPERATURE, PH, SPECIFIC CONDUCTANCE, AND DISSOLVED OXYGEN-- Data available in Waddell and others (1982, tables 18-20).
M110 ☐	SITE IN RESERVOIR WHERE IN SITU MEASUREMENTS MADE FOR TEMPERATURE, PH, SPECIFIC CONDUCTANCE, AND DISSOLVED OXYGEN-Data available in Waddell and others (1982, table 20).
M5, M30, M65, R50, R90	SITE IN RESERVOIR WHERE CORE SAMPLES OF BOTTOM SEDIMENTS WERE COLLECTED-- (Tables 8, 9, and 10).
A______A′	LINES ALONG WHICH BATHYMETRIC PROFILE WAS DETERMINED-- Letters indicate profile shown in figure 14. Other profiles are available in the District office of the U. S. Geological Survey, Water Resources Division, in Salt Lake City, Utah.

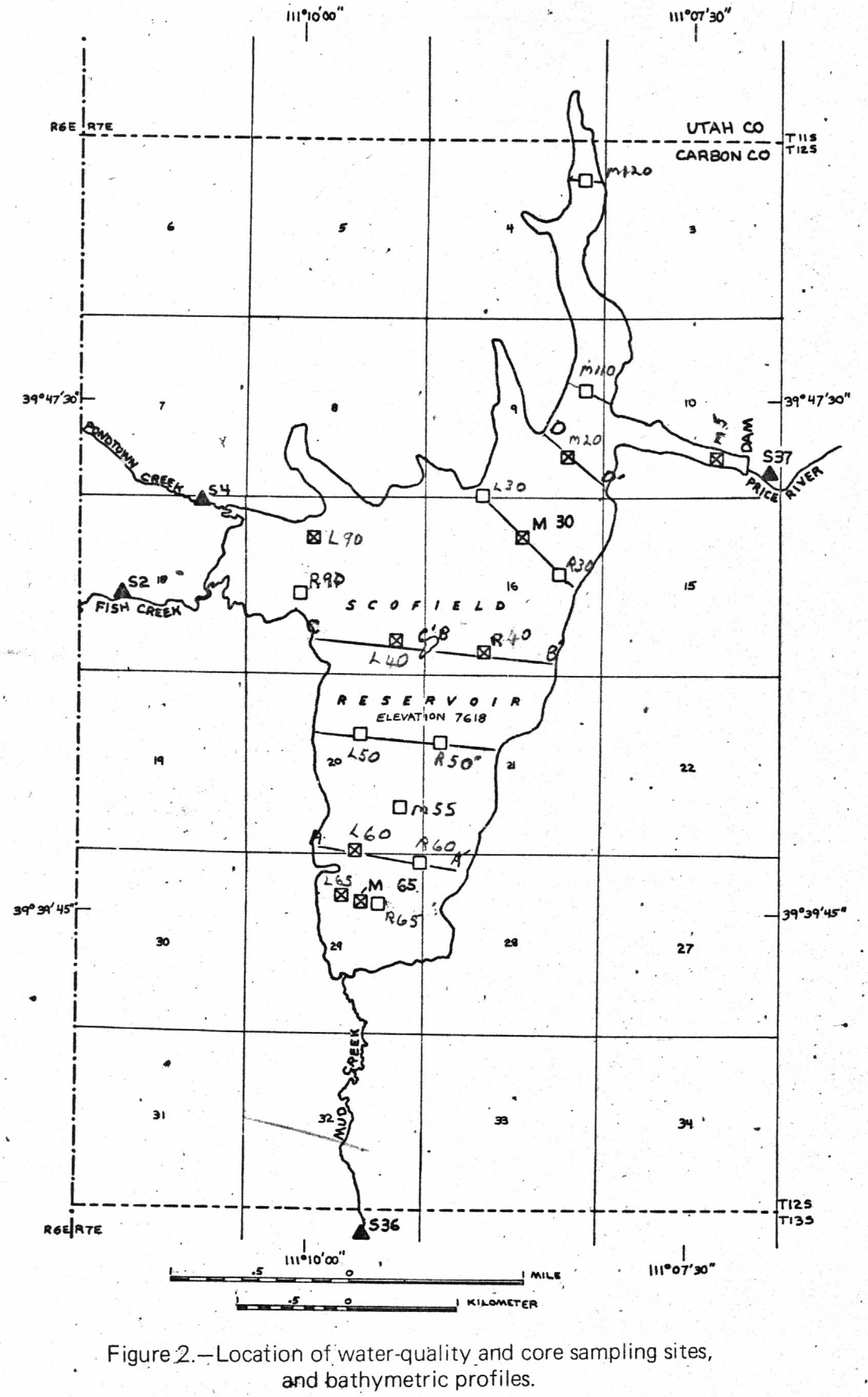


Figure 2.—Location of water-quality and core sampling sites, and bathymetric profiles.

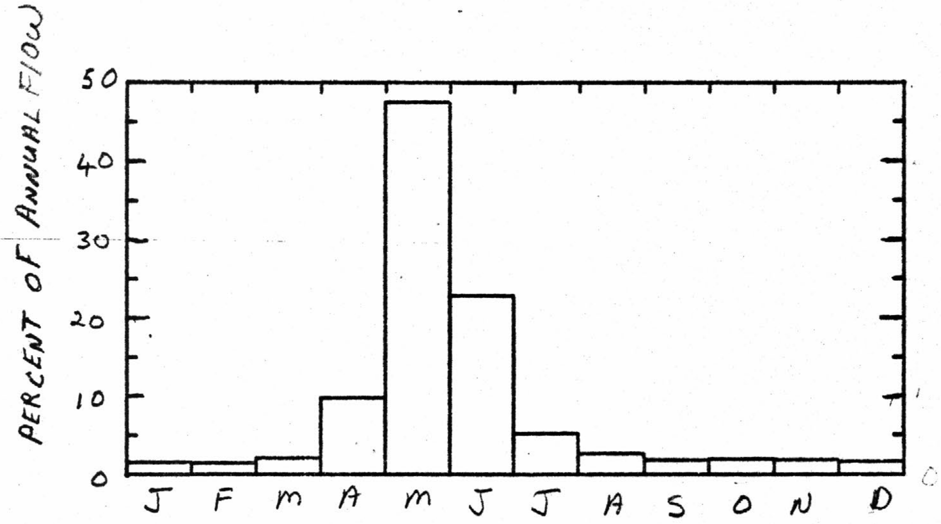
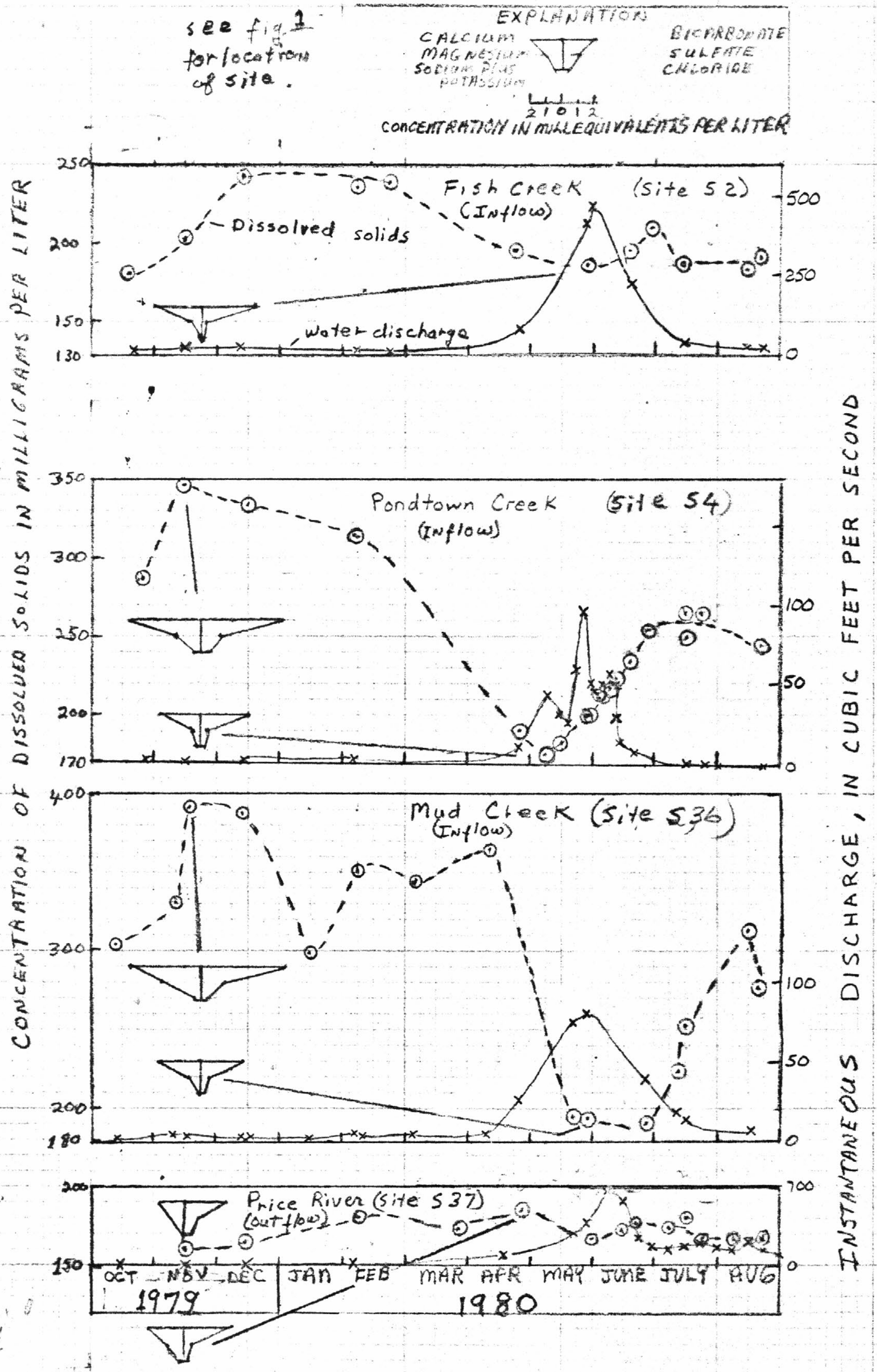


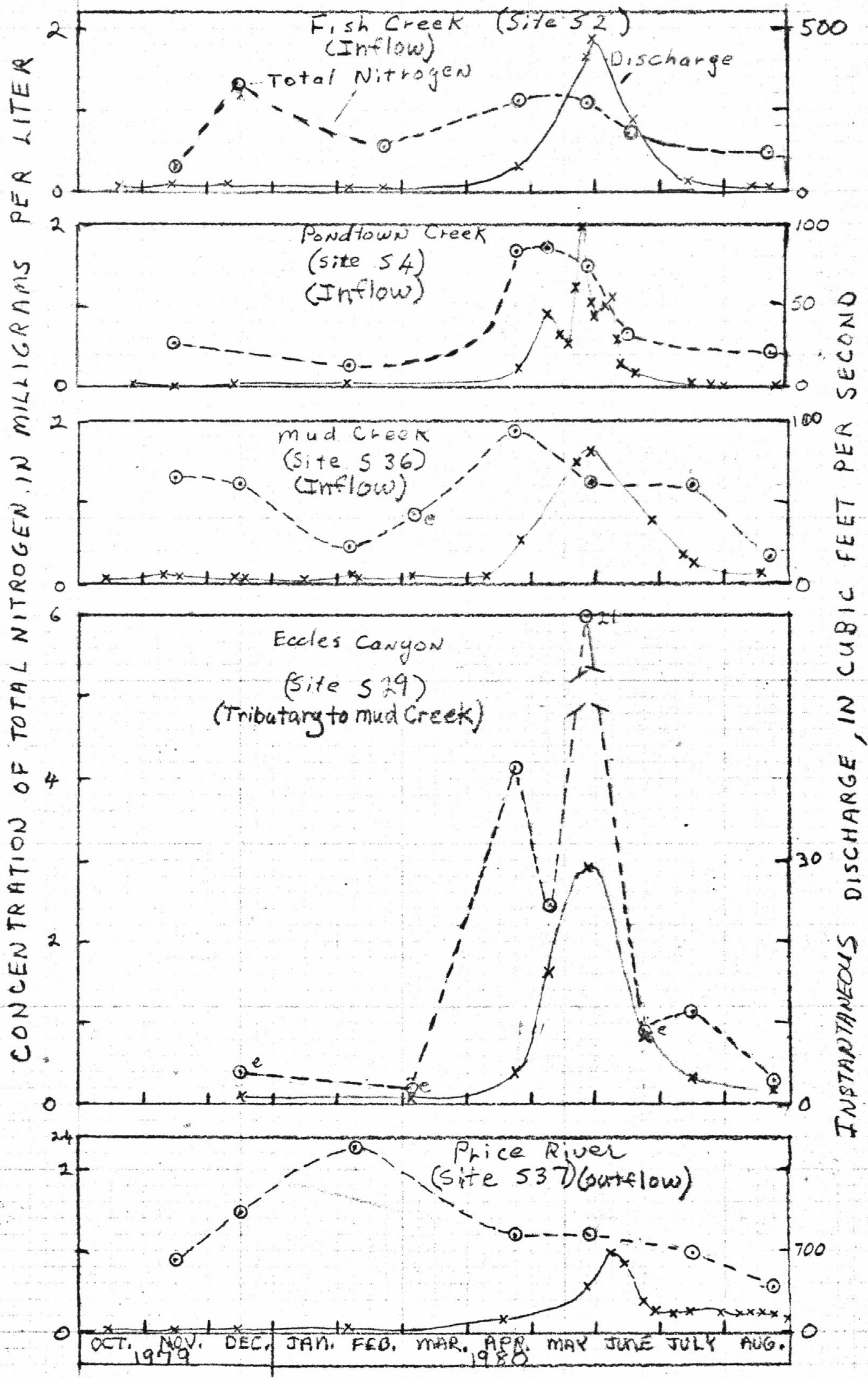
Figure 3.—Average monthly distribution of annual flow at site S2 on Fish Creek, 1938-81.



see fig 1 for location of site.

Figure 4.—Variation of dissolved solids, water discharge, and chemical composition of stream inflow and reservoir outflow (Price River), October 1979-August 1980.

see fig. 1 for location of site



'Figure 5.—Variation of total nitrogen and water discharge in stream inflow and reservoir outflow (Price River) and in runoff from Eccles Canyon, November 1979-August 1980.

Figure 6.--View of upper part of Eccles Canyon showing area being cleared for fire protection and road right-of-ways. (Photograph by Jeanette E. Dodge, U. S. Geological Survey, 1979.)

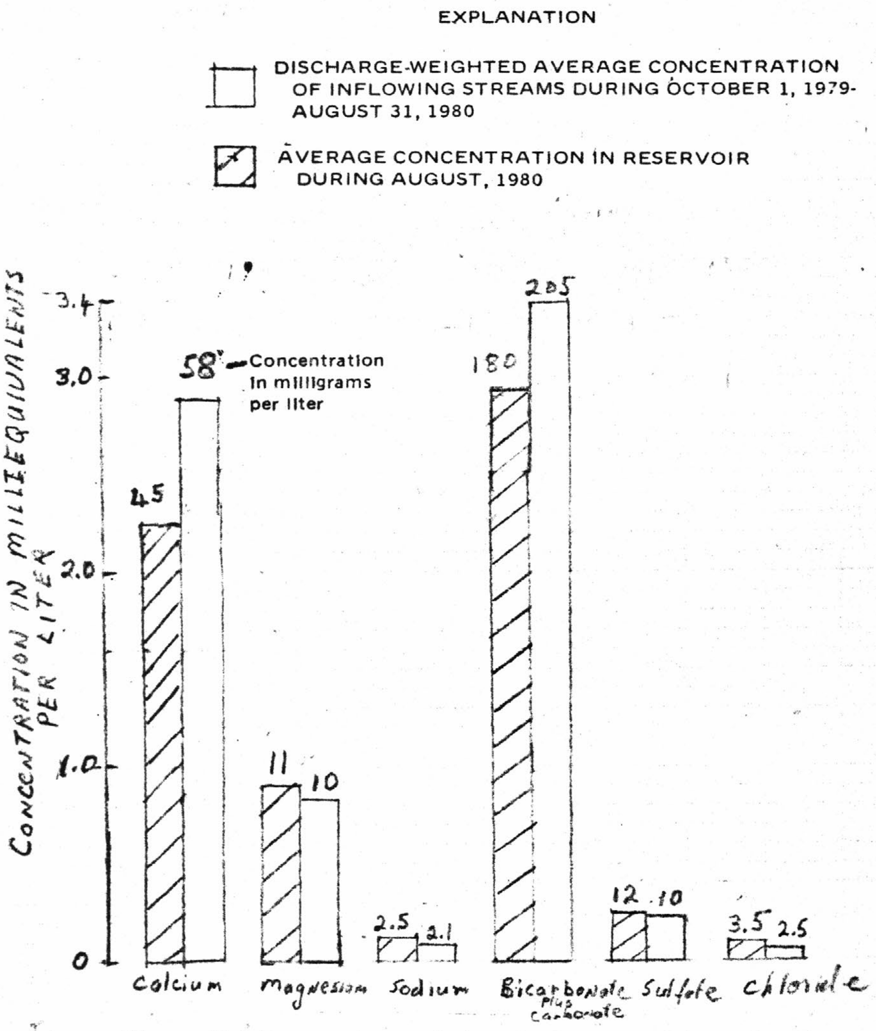


Figure 7.—Comparison of chemical composition of major inflowing streams during October 1, 1979-August 31, 1980, to average composition of Scofield Reservoir during August 1980.

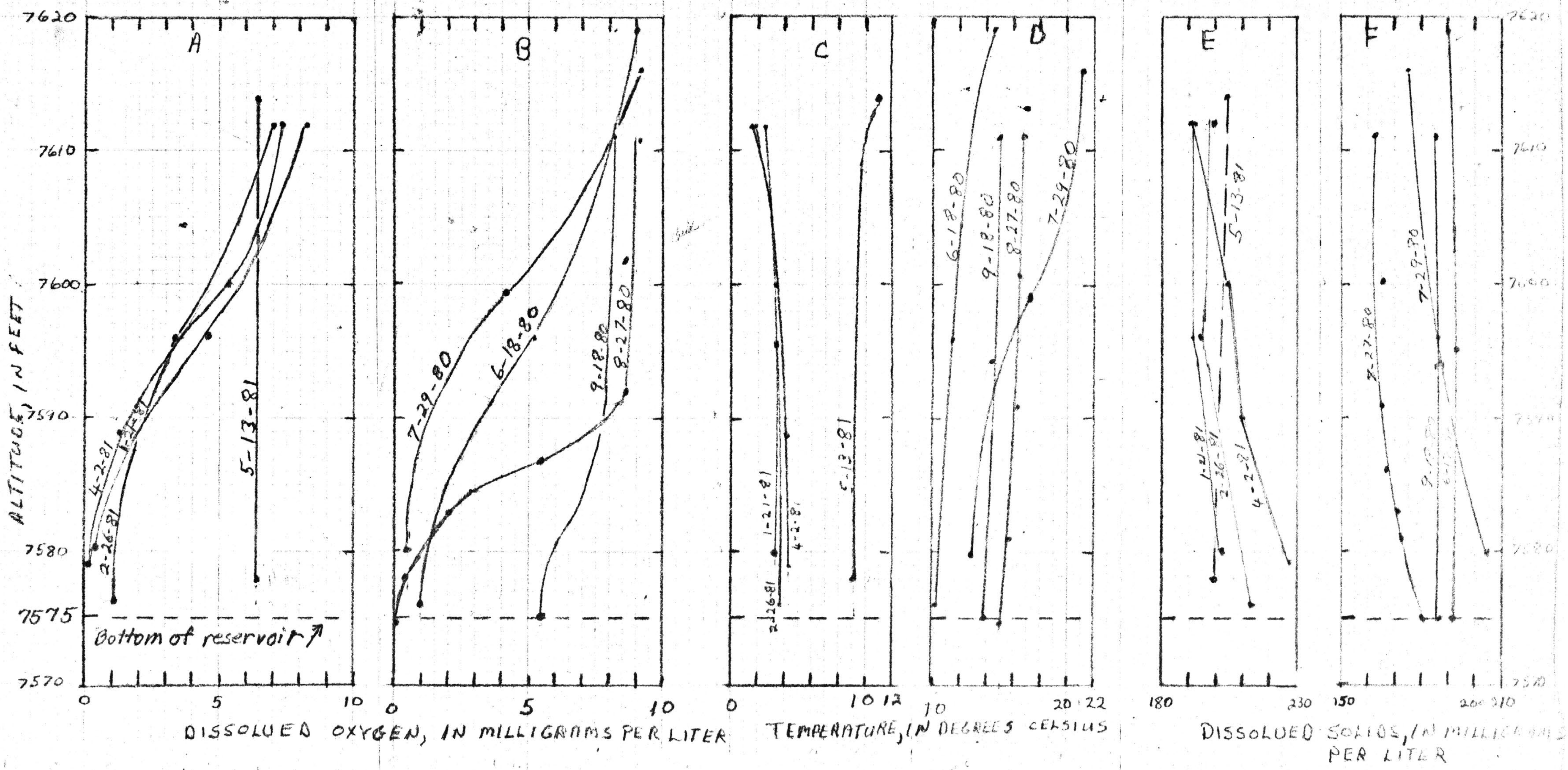


Figure 8.—Vertical profiles of concentration of dissolved oxygen, water temperature, and concentration of dissolved solids at site M5, near dam, 1980-81.

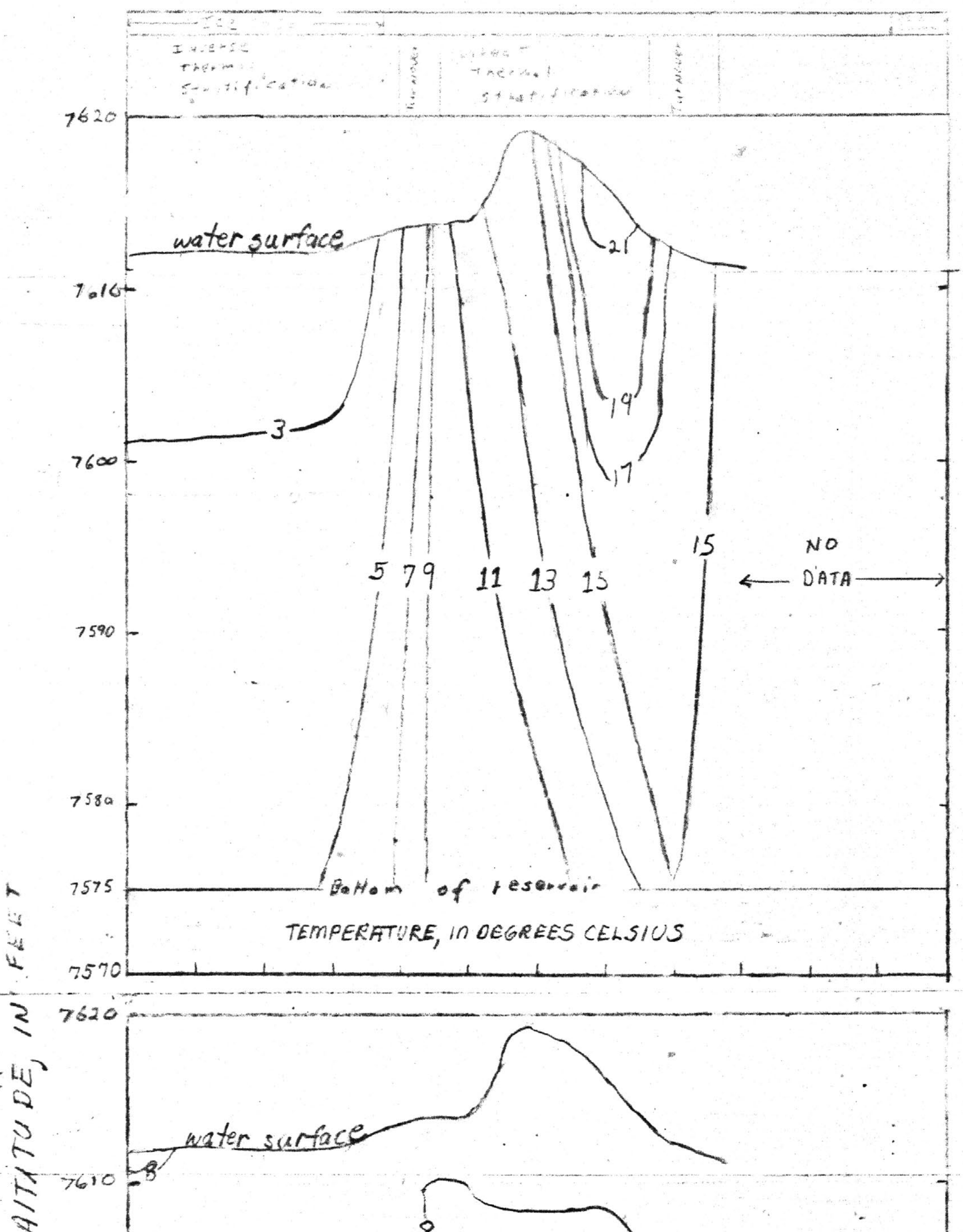
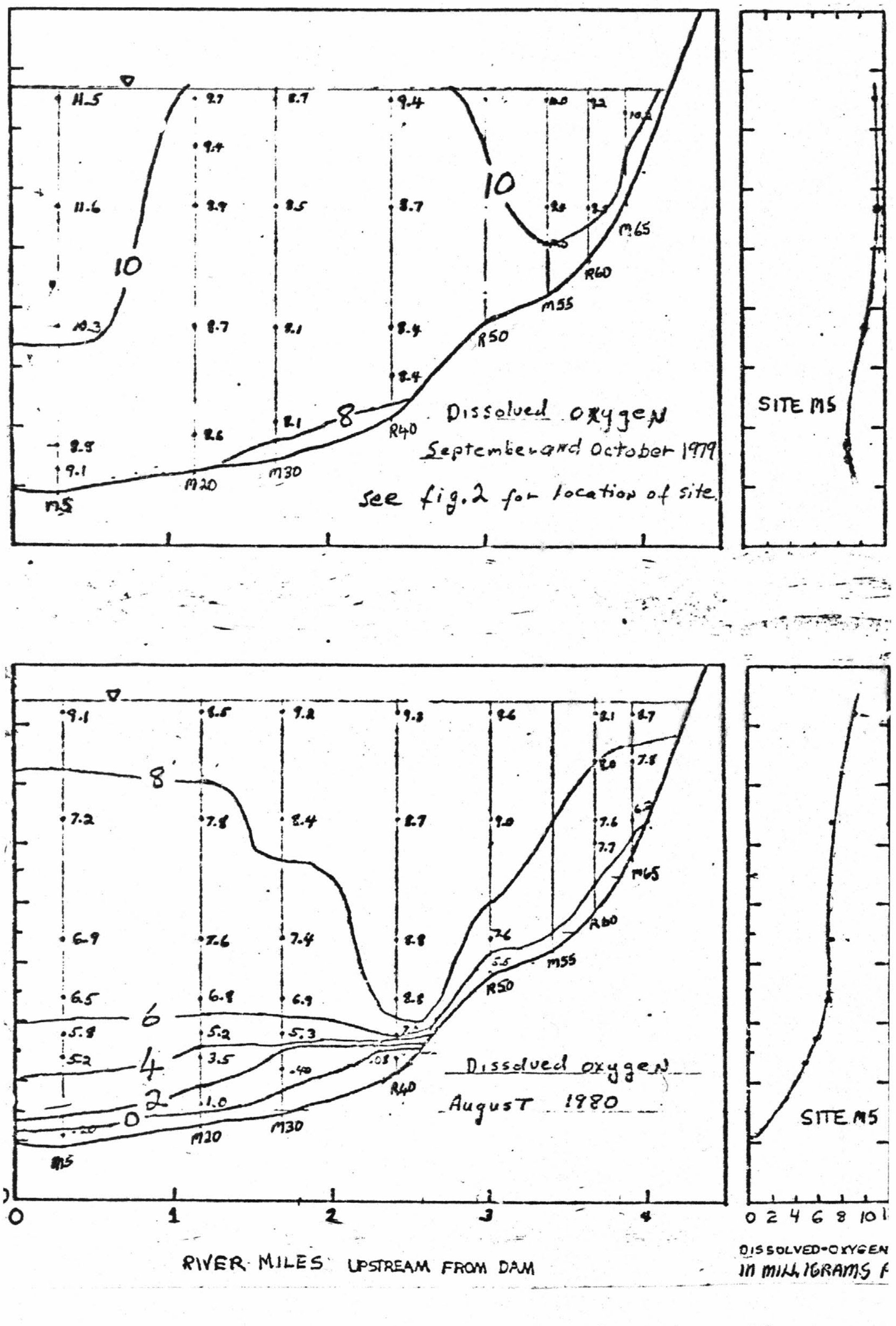


Figure 9.—Depth-time diagram of dissolved oxygen and temperature, showing periods of ice cover, thermal stratification and turnover at site M5, January-May 1981 and June-September 1980.

(Delete values on final)



e 10.—Profiles of dissolved-oxygen concentration during September and October 1979, and August 1980.

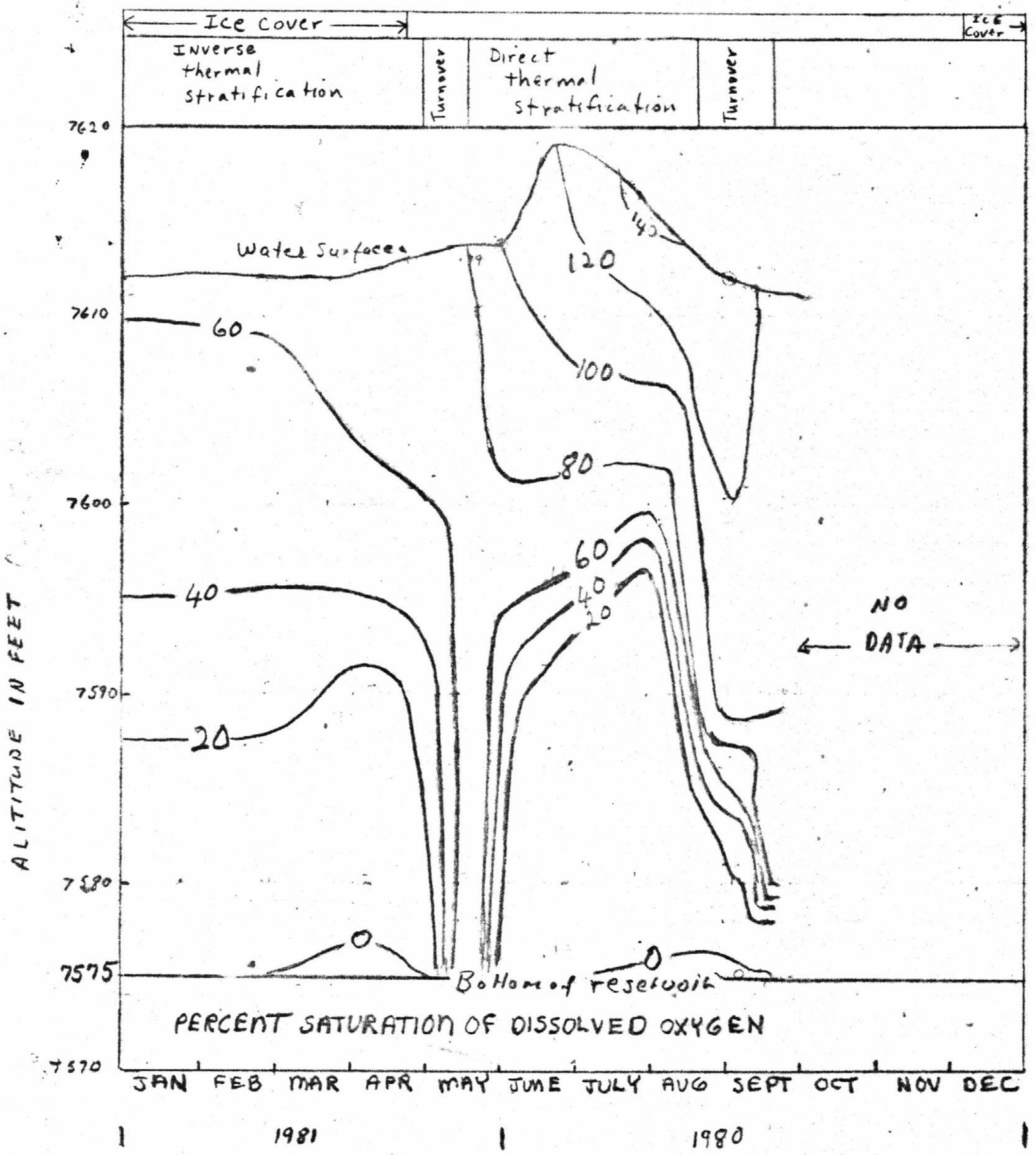


Figure 11.—Depth-time diagram of percent saturation of dissolved oxygen at site M5, January-May 1981 and June-September 1980.

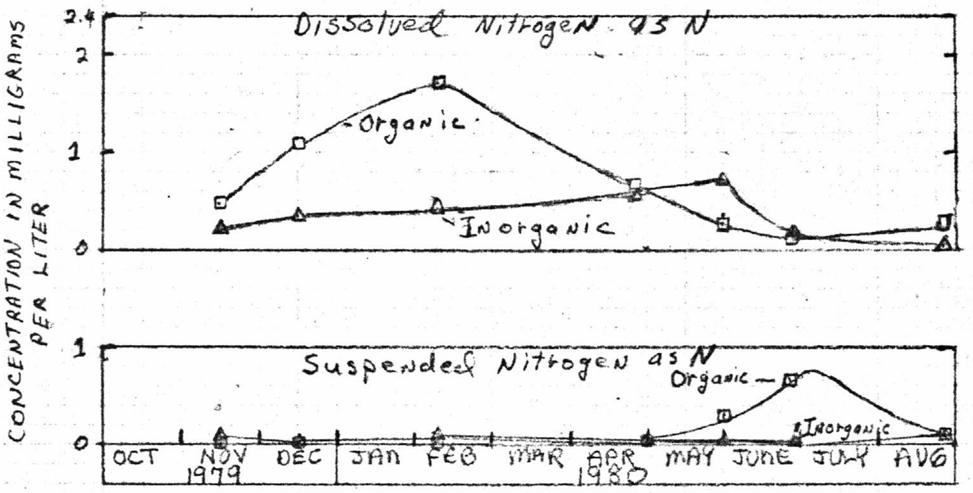


Figure 12.—Variation of dissolved and suspended forms of nitrogen in reservoir outflow (Price River), November 1, 1979-August 31, 1980.

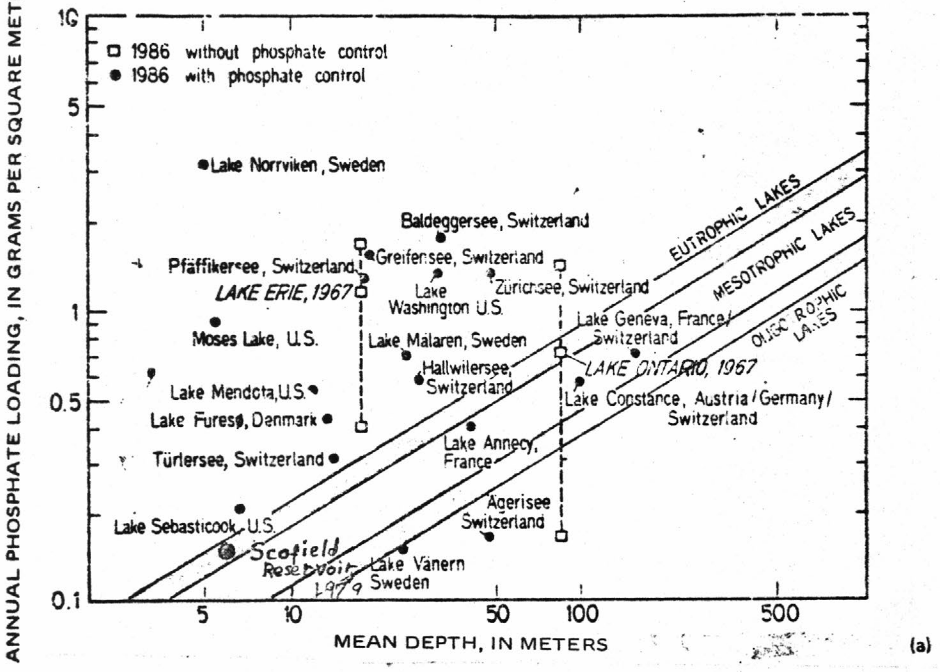


Figure 13.—Relationship between inflow loads of total phosphorus, mean depth, and trophic state of selected reservoirs and lakes. (Modified from Stumm and Baccini, 1978, fig. 15; published with permission.)

Checked DWD

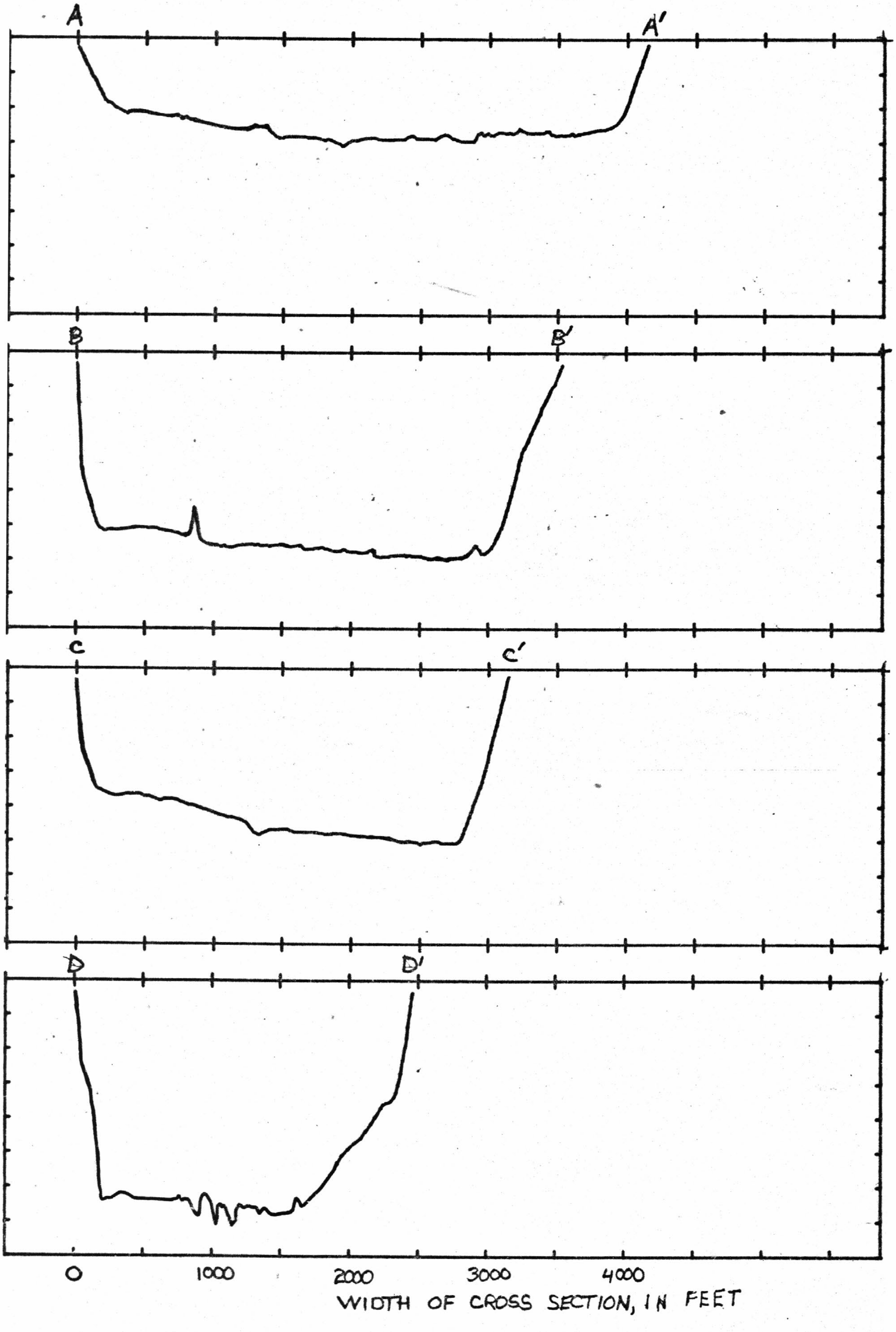


Figure 14.—Bathymetric profiles, 1979. (See fig. 2 for location.)

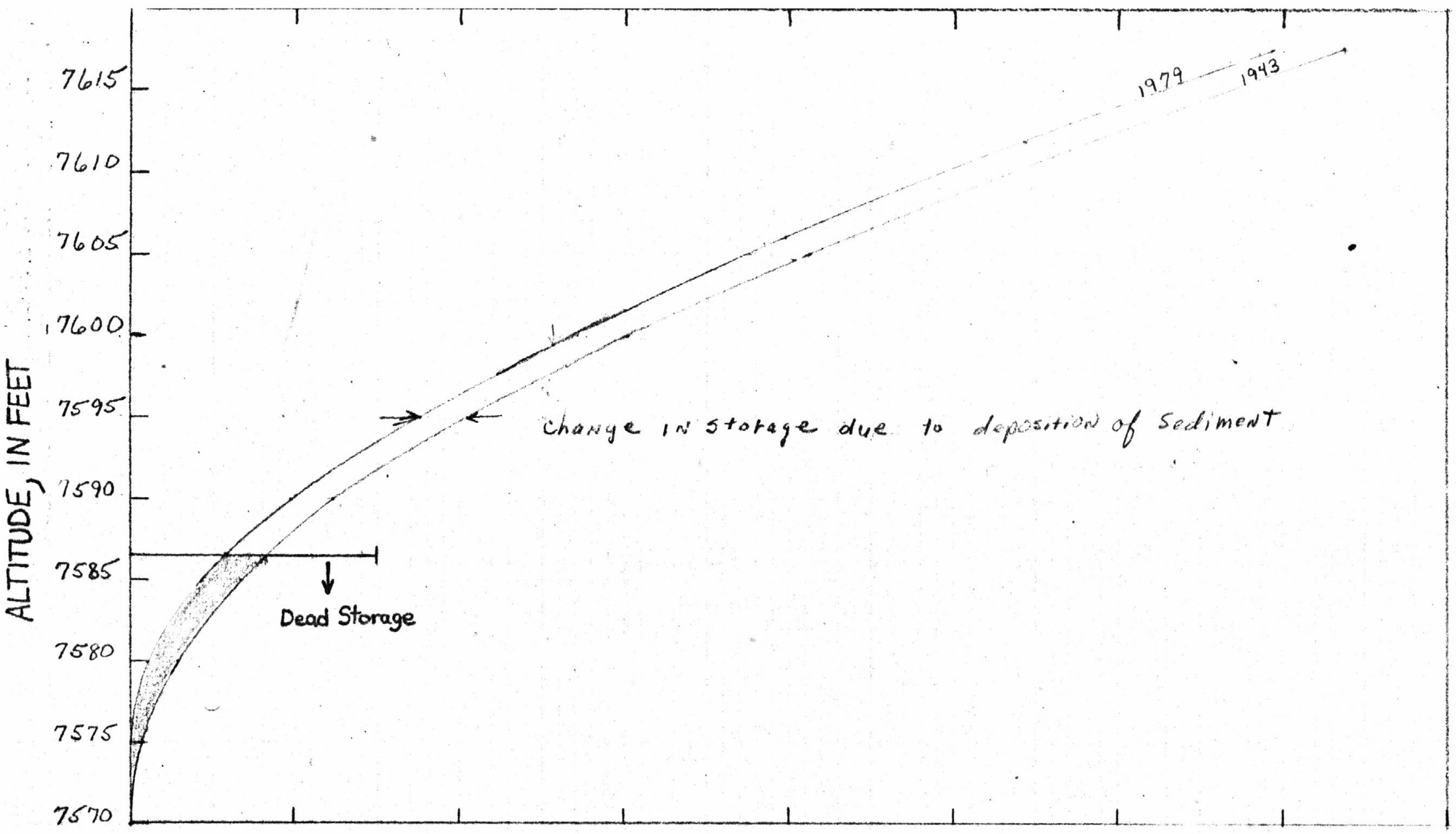
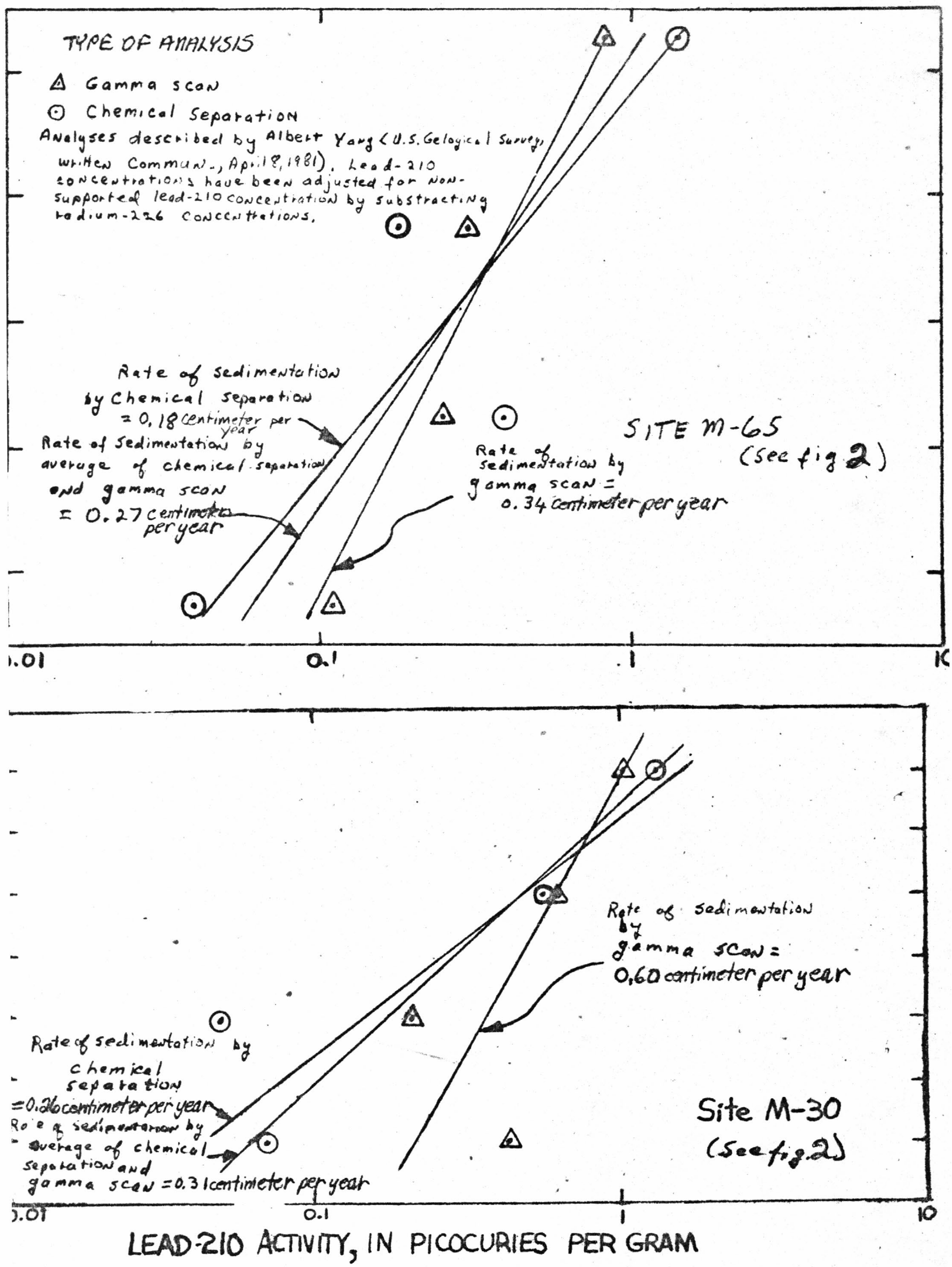

7615
7610
7605
7600
7595
7590
7585
7580
7575
7570
ALTITUDE, IN FEET
1979
1943
Change in storage due to deposition of Sediment
Dead Storage

Figure 16.--Sampling apparatus used for collecting cores of bottom sediments. (Photograph by Jeanette E. Dodge, U. S. Geological Survey.)



Analyses described by Albert Yang (U.S. Gelogical Survey, written Commun., April 8, 1981). Lead-210 concentrations have been adjusted for non-supported lead-210 concentration by substracting radium-226 concentrations.

Figure 17.— Relationship of relative ~~lead-210~~ activity and depth of sediment in Scofield Reservoir, 1980.

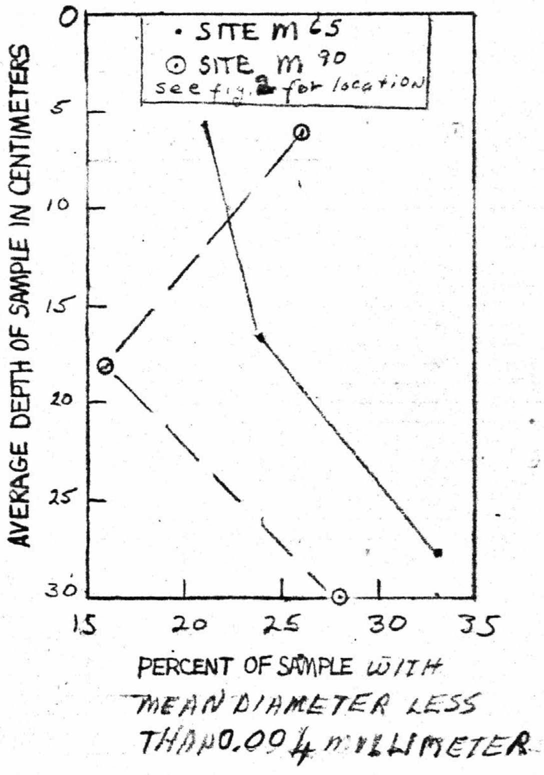
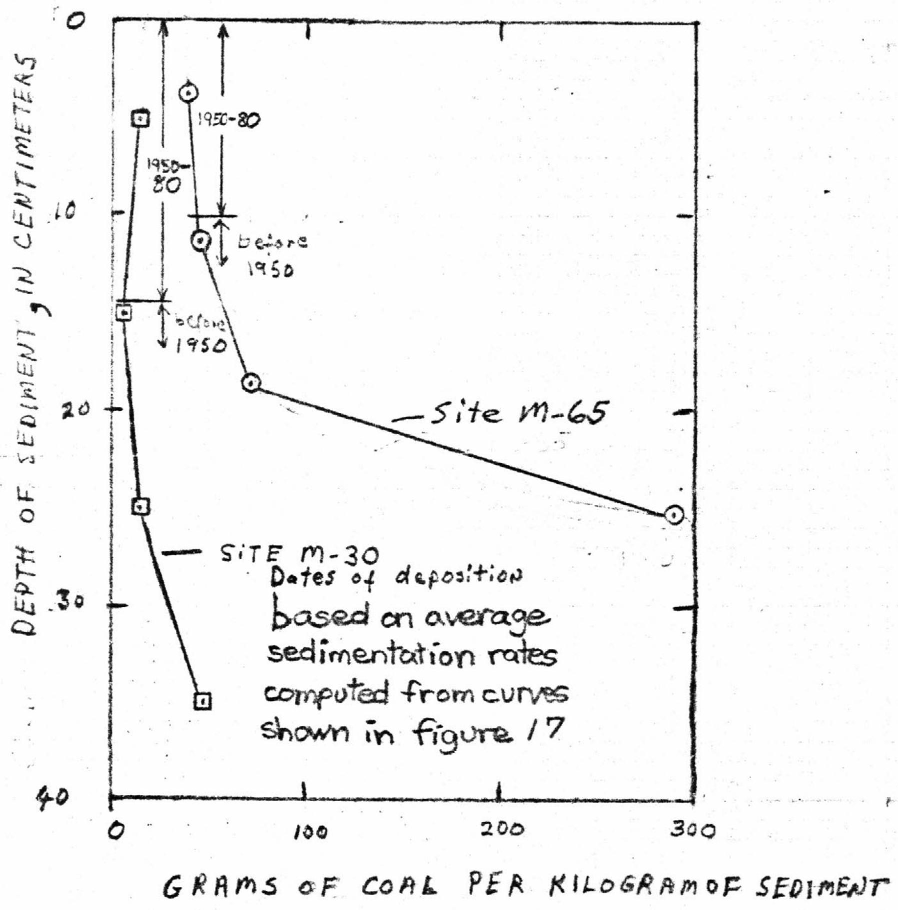


Figure 18.—Relationship between depth and quantity of sediment with mean diameter less than 0.004 millimeter, August, 1980.

Checked by DWD



Dates of deposition based on average sedimentation rates computed from curves shown in figure 17

Figure 19.— Vertical distribution of coal in sediment cores, 1980

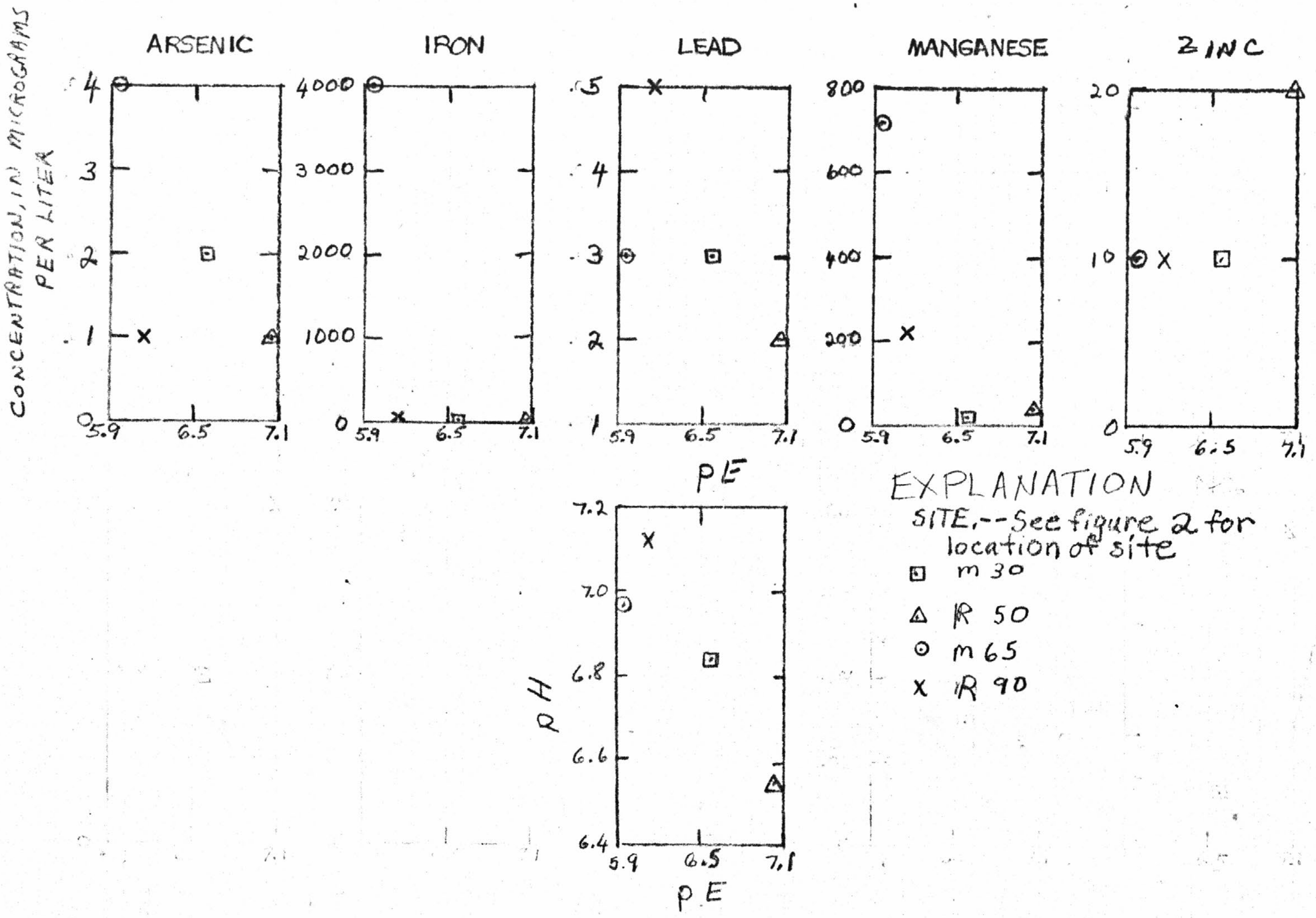
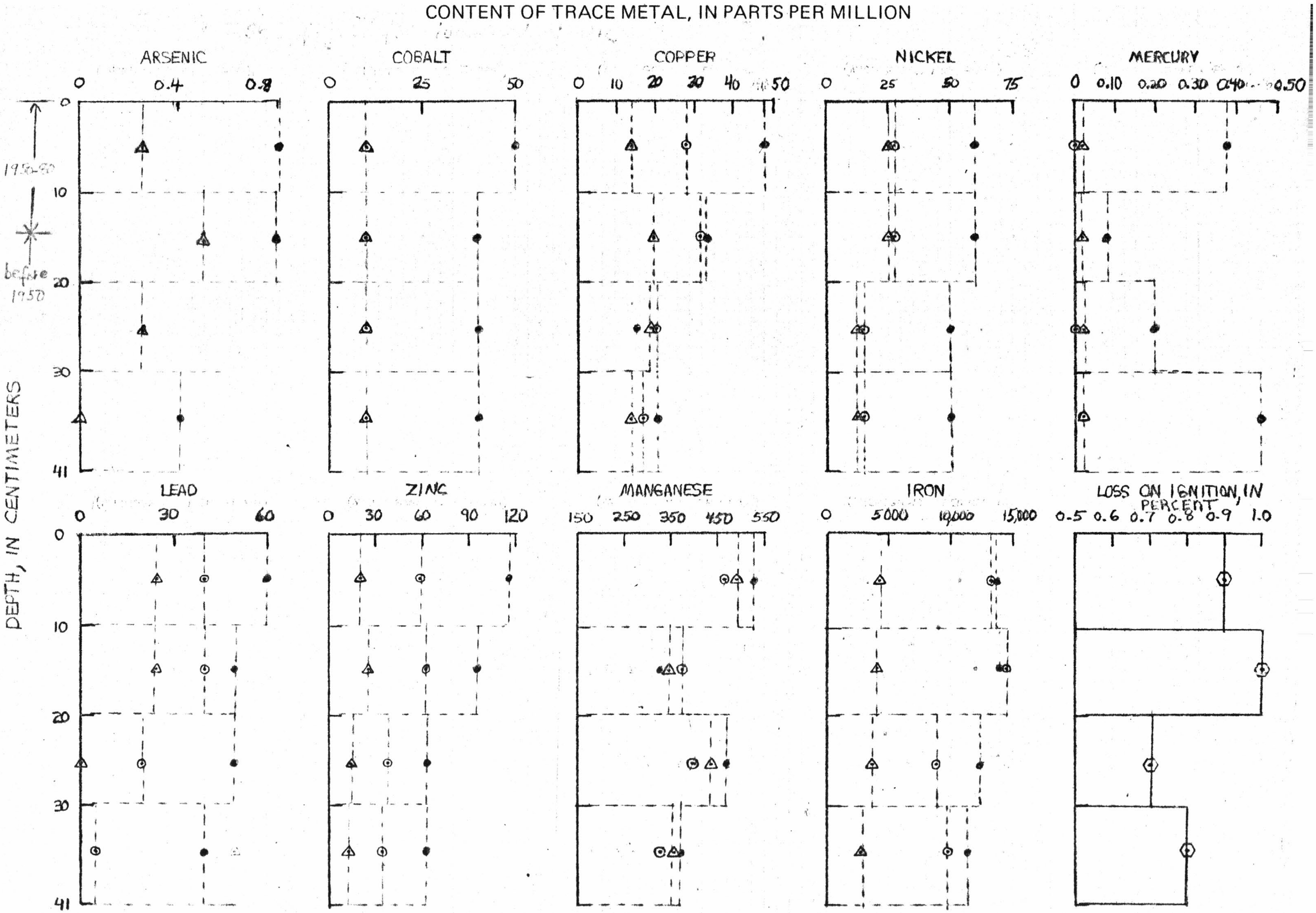


Figure 20.—Relation of concentration of dissolved trace metals to pE, and of pH to pE for an artificially developed anaerobic zone, October 1979.

EXPLANATION

- ● TOTAL EXTRACTABLE METAL (METHOD 1)
- ⊙ NONSILICA EXTRACTABLE METAL (METHOD 2)
- △ NONDETRITAL EXTRACTABLE METAL (METHOD 3)
- ⬡ LOSS ON IGNITION
- ☐ CONTENT OF METALS BOUND IN THE SILICATE AND OXIDE MINERALS—Determined as the difference in concentration between methods 1 and 2
- ☐ CONTENT OF METALS IN SULFIDES, HELD TIGHTLY IN ORGANIC MATERIAL OR STRONGLY SORBED TO CLAYS—Determined as difference in concentrations between methods 2 and 3
- ☐ CONTENT OF METALS IN NONDETRITAL MATERIAL WHICH INCLUDES METALS BOUND IN THE EASILY SOLUBLE AMORPHOUS COMPOUNDS OF MANGANESE AND IRON AND METALS LOOSELY HELD IN ION-EXCHANGE AND SORBED POSITIONS OR ATTACHED TO ORGANIC MATTER—Determined by method 3

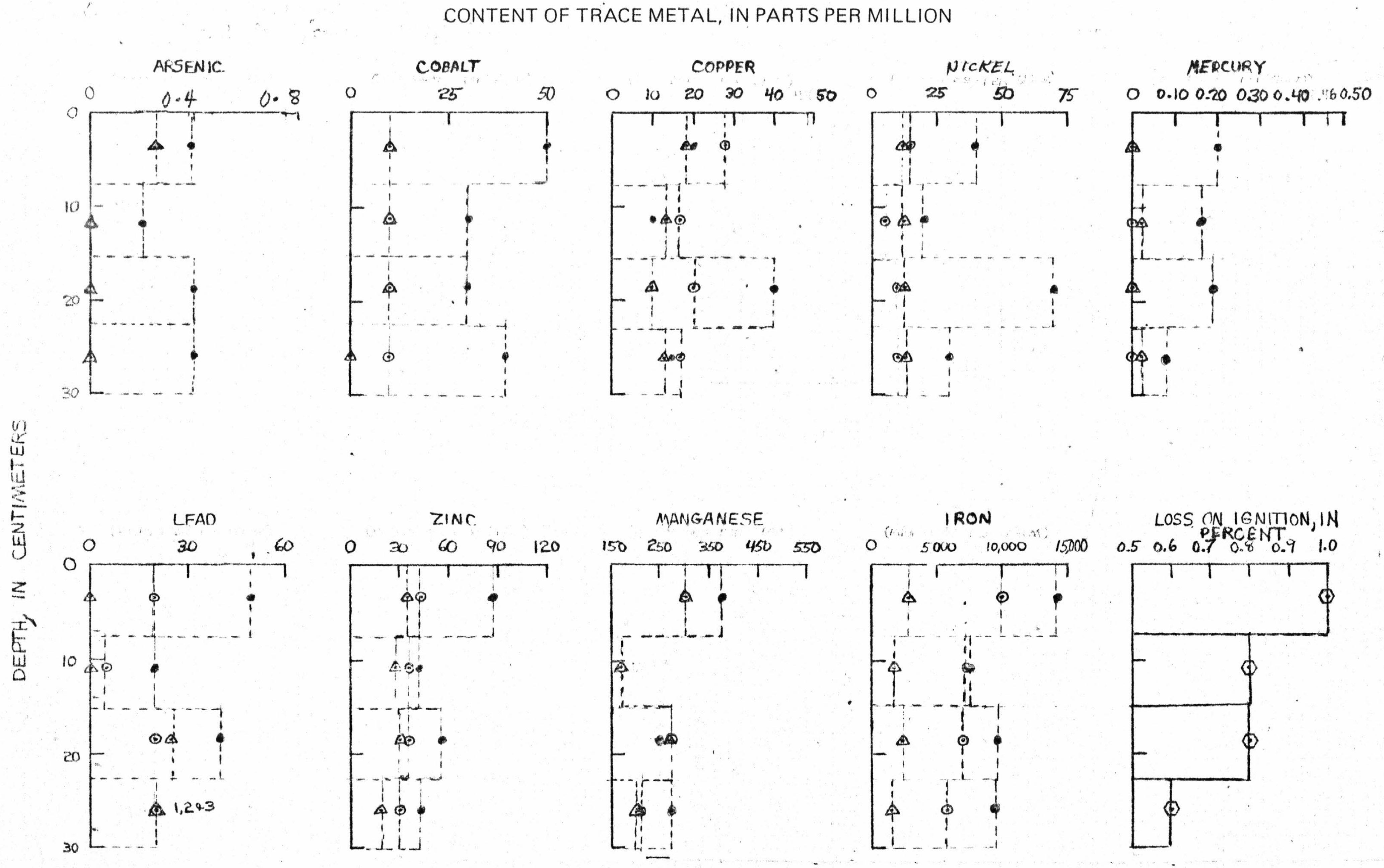
Figure 21.—Vertical profiles of trace metals extracted from sediments by selective leaching methods and loss on ignition in sediment cores from site M30, 1980. (Site M30 is shown in fig. 2.)


CONTENT OF TRACE METAL, IN PARTS PER MILLION
ARSENIC
0
0.4
0.8
COBALT
0
25
50
COPPER
0
10
20
30
40
50
NICKEL
0
25
50
75
MERCURY
0
0.10
0.20
0.30
0.40
0.50
LEAD
0
30
60
ZINC
0
30
60
90
120
MANGANESE
150
250
350
450
550
IRON
0
5000
10,000
15,000
LOSS ON IGNITION, IN PERCENT
0.5
0.6
0.7
0.8
0.9
1.0
DEPTH, IN CENTIMETERS
0
10
20
30
41
1950-80
before 1950

EXPLANATION

- ● TOTAL EXTRACTABLE METAL (METHOD 1)
- ⊙ NONSILICA EXTRACTABLE METAL (METHOD 2)
- △ NONDETRITAL EXTRACTABLE METAL (METHOD 3)
- ⬡ LOSS ON IGNITION
- ☐ CONTENT OF METALS BOUND IN THE SILICATE AND OXIDE MINERALS—Determined as the difference in concentration between methods 1 and 2
- ☐ CONTENT OF METALS IN SULFIDES, HELD TIGHTLY IN ORGANIC MATERIAL OR STRONGLY SORBED TO CLAYS—Determined as difference in concentrations between methods 2 and 3
- ☐ CONTENT OF METALS IN NONDETRITAL MATERIAL WHICH INCLUDES METALS BOUND IN THE EASILY SOLUBLE AMORPHOUS COMPOUNDS OF MANGANESE AND IRON AND METALS LOOSELY HELD IN ION-EXCHANGE AND SORBED POSITIONS OR ATTACHED TO ORGANIC MATTER—Determined by method 3

Figure 22.—Vertical profiles of trace metals extracted from sediments by selective leaching methods and loss on ignition in sediment cores from site M65, 1980. (Site M65 is shown in fig. 2.)


CONTENT OF TRACE METAL, IN PARTS PER MILLION
ARSENIC
0
0.4
0.8
COBALT
0
25
50
COPPER
0
10
20
30
40
50
NICKEL
0
25
50
75
MERCURY
0
0.10
0.20
0.30
0.40
0.50
LEAD
0
30
60
ZINC
0
30
60
90
120
MANGANESE
150
250
350
450
550
IRON
0
5000
10,000
15,000
LOSS ON IGNITION, IN PERCENT
0.5
0.6
0.7
0.8
0.9
1.0
DEPTH, IN CENTIMETERS
0
10
20
30
1,2 & 3

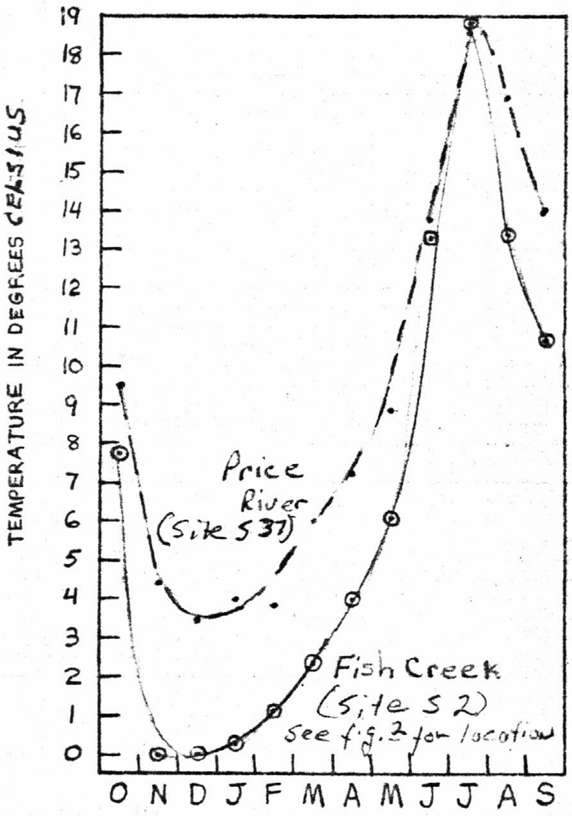


Figure 23.—Temperature of Fish Creek upstream from Scofield Reservoir and of Price River downstream from Scofield Reservoir, 1980 water year.