

# **SURVEY OF FENA RESERVOIR, ISLAND OF GUAM-- LIMNOLOGICAL RECONNAISSANCE**

By James W. LaBaugh

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## METRIC CONVERSION FACTORS

The SI (International System) units used in this report may be converted to inch-pound units by use of the following conversion factors:

<i>Multiply SI unit</i>	<i>By</i>	<i>To obtain inch-pound unit</i>
meter (m)	3.281	foot
square kilometer (km <sup>2</sup> )	0.386	square mile
micrometer (μm)	0.003	inch
cubic meter (m <sup>3</sup> )	35.31	cubic foot
microgram per liter (μg/L)	6.242x10 <sup>-8</sup>	pound per cubic foot
milligram per liter (mg/L)	6.242x10 <sup>-5</sup>	pound per cubic foot
siemens (S)	1	mhos
degree Celsius (°C)	F=9/5°C+32	degree Fahrenheit
liter	3.531x10 <sup>-2</sup>	cubic foot
milligram per kilogram (mg/kg)	0.002	pounds per ton

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## **ABSTRACT**

Fena Reservoir, located in the south-central part of Guam, was constructed in 1950-51 to provide a dependable water supply for the U.S. Navy. At the request of the U.S. Navy, the U.S. Geological Survey conducted a sedimentation survey and a limnological reconnaissance of Fena Reservoir during November and December 1979.

During the limnological reconnaissance of Fena Reservoir, samples of the water column and bottom sediment were obtained for analysis at five sites within the reservoir. Major-ion analyses of filtered surface water indicated that calcium and bicarbonate were the dominant cation and anion in the reservoir. Thermal stratification was recorded at all five sites. Temperature data indicated a distinct hypolimnion at three of the sampling sites below a depth of 8 meters. Vertical profiles of pH changed with depth as did those of specific conductance. Marked clinograde distributions of dissolved oxygen were evident at all but the shallowest sites. Inverse clinograde distributions of total phosphorus, dissolved nitrate plus nitrite and dissolved ammonia were measured at the two deepest sites. Total organic carbon had no distinct profile and had an average concentration of 13.8 milligrams per liter. Data also are provided for nutrient analysis of the sediment.

## **INTRODUCTION**

In 1951, the U.S. Navy completed a dam which formed a major reservoir on the Fena River in south-central Guam. Fena Reservoir has a drainage area of 15.04 km<sup>2</sup> (square kilometers), a surface area of 0.78 km<sup>2</sup>, and a volume of 9.698x10<sup>6</sup> m<sup>3</sup> (cubic meters), and is the principal source of surface water on the island (Curtis, 1984). A description of the reservoir and its watershed is given by Kennedy Engineers, Inc. (1973).

At the request of the U.S. Navy, the U.S. Geological Survey conducted a sedimentation study and a limnological reconnaissance of Fena Reservoir during November and December 1979. The purpose of the sedimentation study was to conduct a topographic survey of Fena Reservoir in order to determine the change in storage caused by sediment accumulation (Curtis, 1984). The objective of the limnological reconnaissance was to obtain limnological data in conjunction with the sediment survey in order to characterize the water quality and sediment chemistry of the reservoir at the time of the survey and to facilitate comparison with data collected during a previous survey of the reservoir in 1973. Results of the limnological reconnaissance are presented in this report.

## **Methods of Study**

The reservoir was sampled to determine various water-quality and sediment-chemistry characteristics at the sites shown in figure 1. Water samples were collected on November 20, 1979, for chemical analysis, and sediment-samples were collected on December 6, 1979, for sediment-chemistry analyses. At each site, on November 20, water temperature, specific conductance, dissolved-oxygen concentration, and pH were measured with a multiprobe digital water-quality analyzer at the surface and at 1-meter intervals to the bottom of the water column. Surface samples for major-ion analyses of both unfiltered and filtered (0.45 micrometer) water were collected at each site by manual immersion of sample bottles.

At each site, the reservoir was sampled at the surface and at discrete depths for determination of total organic carbon, total alkalinity, total iron, total manganese, and total silica. Both unfiltered and filtered (0.45 micrometer) samples for phosphorus, nitrate plus nitrite, ammonia, and Kjeldahl nitrogen were collected. The total organic carbon samples were collected with a sewage-wastewater sampler. All other samples were collected at discrete depths with a 4-liter PVC van Dorn bottle, and at the surface by manual immersion of sample bottles. Sediment samples were collected with a bed-material sampler, model BM-54.

After collection, all samples were cooled to 4°C and transported to the U.S. Geological Survey water-quality laboratory in Denver, Colo., or the Fena Laboratory, U.S. Navy Public Works Center, Guam, for subsequent analyses. All samples for analysis of total organic carbon, unfiltered samples for analysis of total phosphorus, all filtered samples, and all sediment samples were analyzed by the U.S. Geological Survey. All other samples were analyzed by the Fena Laboratory.

## **Analytical Results**

Major-ion analyses of filtered surface water indicated that calcium and bicarbonate were the dominant cation and anion at each site in the reservoir (fig. 2). The proportions of cations, calcium > sodium > magnesium > potassium observed in Fena Reservoir, are typical of those found in drainage basins underlain by igneous rock (Wetzel, 1975). Anionic proportions were bicarbonate > chloride > sulfate, and the dominance of chloride over sulfate may reflect the effect of oceanic atmospheric inputs to the reservoir (Hutchinson, 1957). The average total hardness of water in the reservoir indicated the water is one the lower end of the moderately hard scale of Brown and others (1970). The mean total-dissolved solids value for this study was 133 mg/L (milligrams per liter) calculated from the concentration data of the major ions. Regarding relative proportions of the cations and anions, major-ion analyses of unfiltered samples produced the same results.

Thermal stratification was recorded at all sites in Fena Reservoir (fig. 3). The vertical differences in temperature measured in this study are similar to those measured in other tropical lakes and reservoirs that are thermally stratified (Juday, 1915; Lewis, 1973; Ganapati, 1973; Marshall and

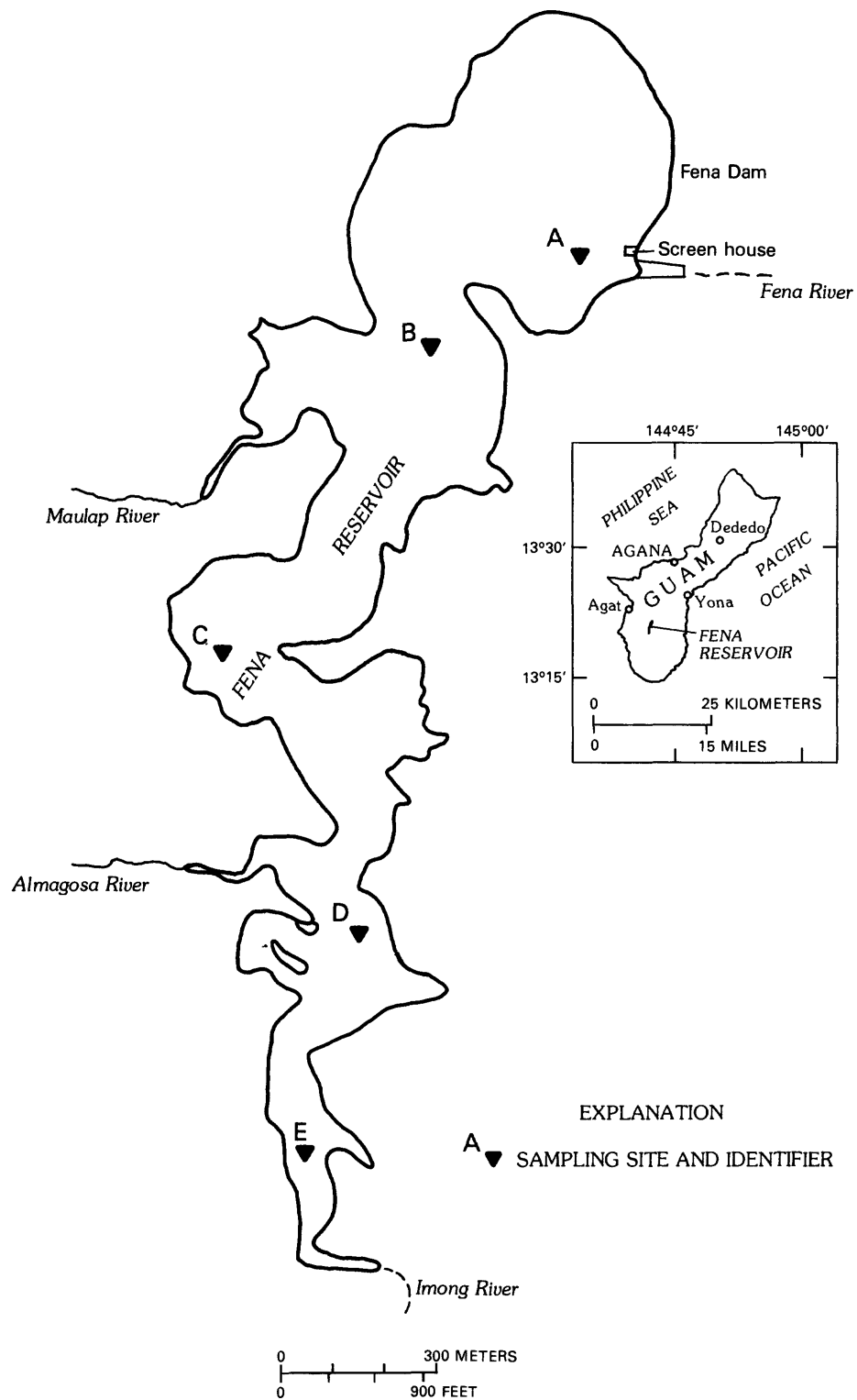


Figure 1.--Location of sampling sites.

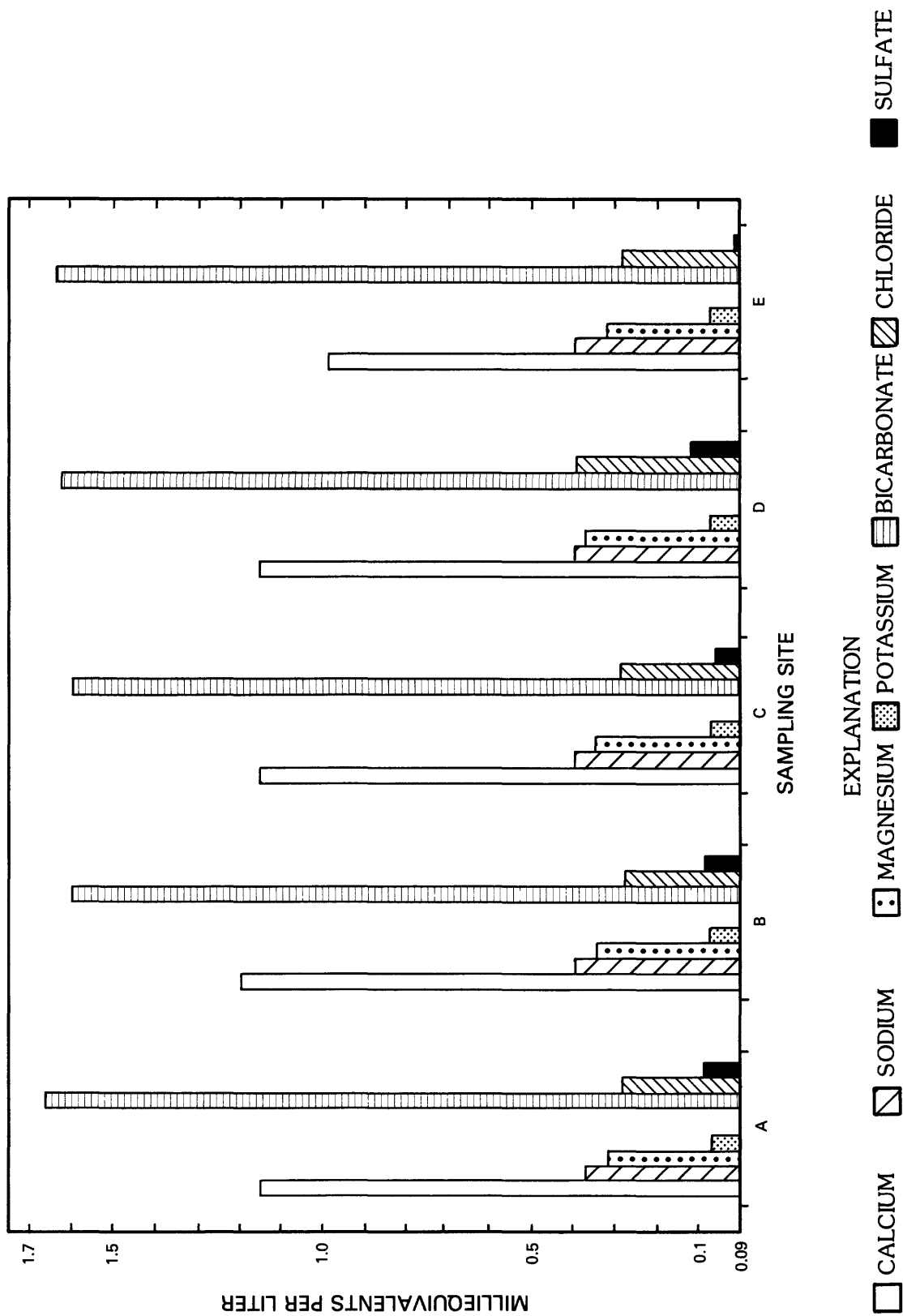


Figure 2.--Major-ion relationships.

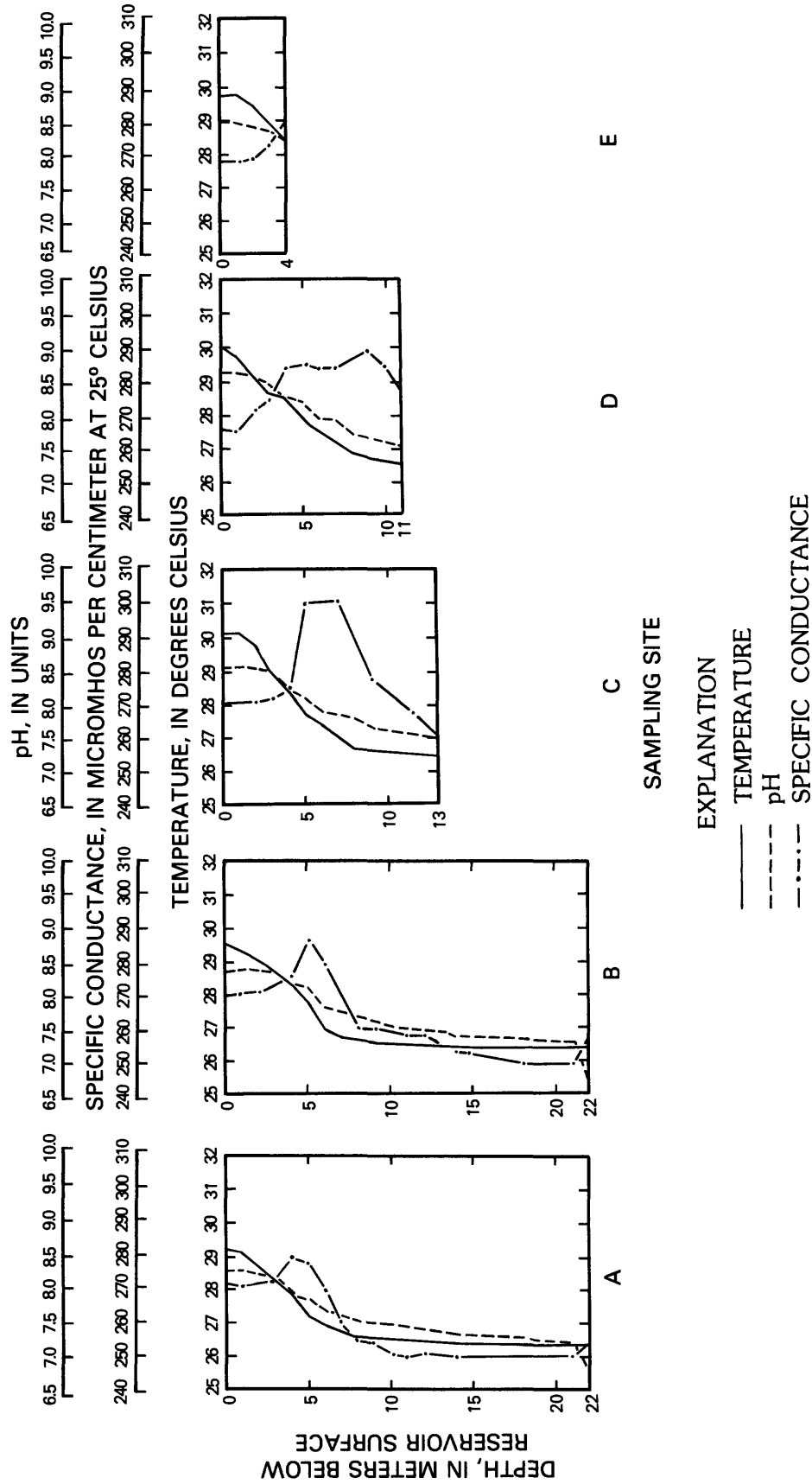


Figure 3.--Temperature, specific conductance, and pH, November 20, 1979.



Falconer, 1973; Ball and Glucksman, 1978; and van der Heide, 1978). Because of the greater density differences associated with each degree temperature change for the higher temperatures of tropical lakes (Juday, 1915), thermal stratification occurs in tropical lakes within ranges that would not facilitate stable thermal stratification as in temperate lakes. The minimum difference in temperature for the entire water column of 1.28°C was measured at the shallowest site (site E).

Temperature data indicated a distinct hypolimnion existed at sites A, B, and C below a depth of 8 meters. The mean temperature of the hypolimnion of Fena Reservoir, 26.4°C, is slightly less than that predicted, 27.9°C, on the basis of altitude by Lewis' (1973) equation for tropical water bodies. Although the distinction between the epilimnion and metalimnion was not clear based on vertical temperature profiles at each site, the use of these profiles with dissolved-oxygen data (Juday, 1915, Marshall and Falconer, 1973) shows a means by which these strata can be identified (fig. 4). The epilimnion had its maximum depth (4 meters) at site B.

Specific-conductance data (fig. 3) showed there were pronounced differences in specific conductance with depth at all sites. A distinct maximum occurred in the metalimnion at sites A, B, C, and D. This zone of greater conductance increased in depth at the upstream sites (sites C and D) in the reservoir, in contrast to the uniform distribution of specific conductance found by Kennedy Engineers, Inc. (1973). This contrast may be due to time of sampling, or to the effect of the river inflows, which have greater specific-conductance values, or both, as discussed by W. F. Curtis (U.S. Geological Survey, written commun., 1980).

The vertical profiles of pH (fig. 3) also demonstrated changes with depth. The mean pH values of the epilimnion and hypolimnion of the reservoir, calculated from hydrogen-ion data, were 8.41 and 7.33, respectively. The greater pH values in the epilimnion may be attributed to photosynthetic activity.

Marked clinograde distributions of dissolved oxygen (fig. 4) were evident in Fena Reservoir at all but the shallowest site (site E). Anaerobic conditions existed in the hypolimnion at sites A, B, C, and D. No odor of hydrogen sulfide could be detected in the process of discrete-depth sampling of the anaerobic hypolimnion of the reservoir. The measurement of saturation values greater than 100 percent for dissolved oxygen in the upper layers of the reservoir probably were due to photosynthetic activity.

During a study conducted in February and March 1973, Kennedy Engineers, Inc. (1973) recorded dissolved-oxygen profiles different from those of this investigation. Their measurement of an aerobic water column coincided with the dry period, during which tropical lakes commonly have isothermal conditions and undergo complete mixing (Lewis, 1973)--hence, the differences in the two studies.

Total-iron concentrations had an inverse clinograde distribution at sites A, B, C, and D (fig. 5); the larger values in the hypolimnion being coincident with anaerobic conditions. The largest difference in total-iron

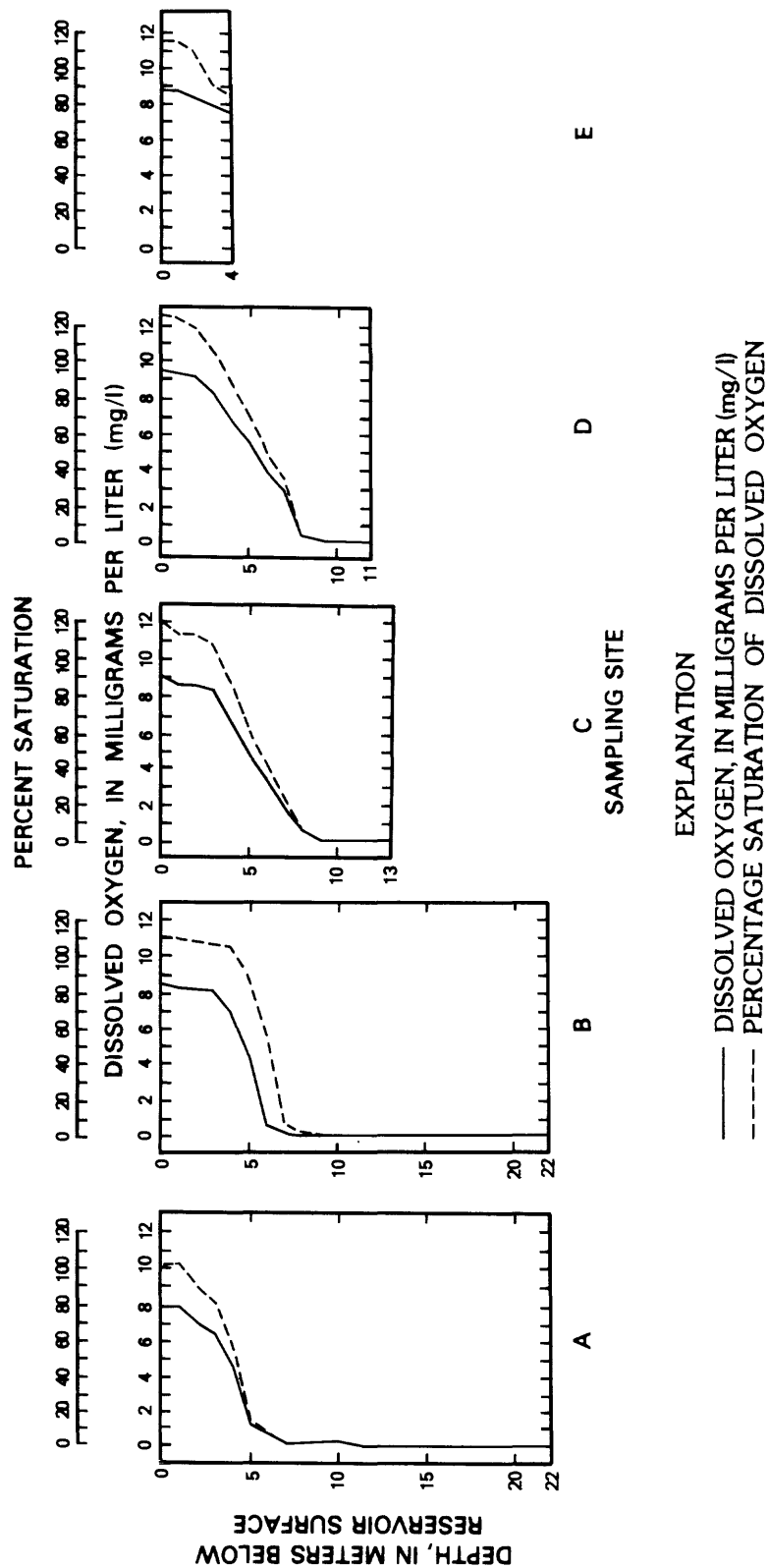


Figure 4.--Dissolved oxygen and percent saturation, November 20, 1979.

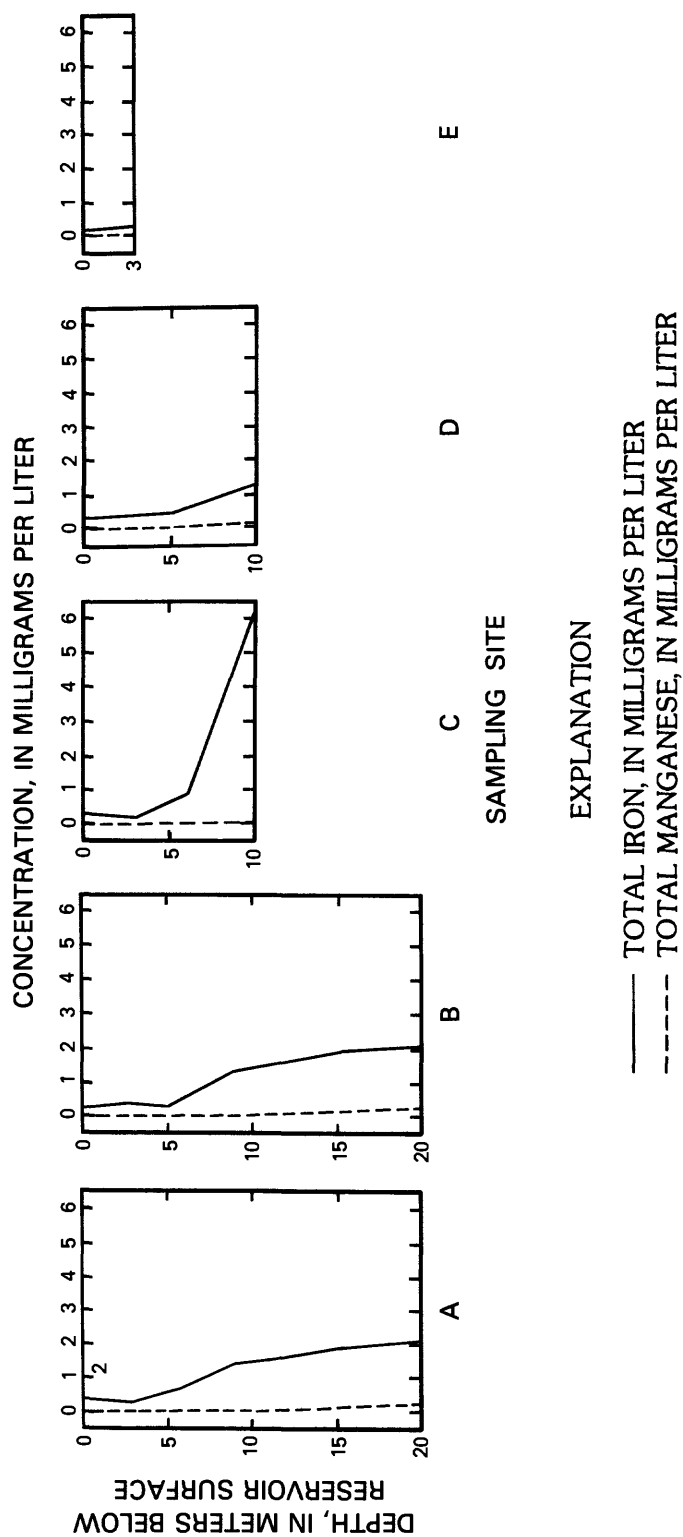


Figure 5.--Total iron and total manganese, November 20, 1979.

concentrations between the epilimnion and hypolimnion, 5.86 mg/L, was measured at site C. Total-manganese concentrations had an inverse clinograde distribution at sites A, B, and C, although the distribution was less pronounced than that for total iron. The largest difference in total-manganese concentrations between the epilimnion and hypolimnion, 0.21 mg/L, was measured at site B. These distributions of total iron and manganese are typical of water bodies with clinograde dissolved-oxygen profiles when the hypolimnion is anaerobic (Hutchinson, 1957).

Inverse clinograde distributions of total phosphorus, dissolved nitrate plus nitrite, and dissolved ammonia were measured at the two deepest sites, A and B (figs. 6 and 7). These types of distributions are characteristic of water bodies having dissolved oxygen profiles where a coincident anaerobic hypolimnion is present (Hutchinson, 1957). Total nitrate plus nitrite, total ammonia, and total Kjeldahl nitrogen also had inverse clinograde distributions at sites A and B (total nitrogen data are not shown in fig. 7). There was no distinct vertical pattern of dissolved nitrogen or phosphorus in Fena Reservoir during this study.

Kennedy Engineers, Inc. (1973), found isochemical distributions of nutrients coincident with an aerobic hypolimnion at the time of their study. As previously mentioned, differences in nutrient distribution between this investigation and the Kennedy Engineers, Inc. (1973) study are due to the season when samples were collected. In this study the total nitrogen-total phosphorus ratio by weight for the epilimnion was 13:1 indicating phosphorus is the element limiting plant biomass quantities in the reservoir. During the period of the previous study, Kennedy Engineers, Inc. (1973), suspected nitrogen limitation.

No distinct vertical profile was derived from total-organic-carbon data (fig. 8). The average concentration of total organic carbon during this study, 13.8 mg/L, was greater than reported previously for Fena Reservoir (Kennedy Engineers, Inc., 1973) and was in the range of total-organic-carbon concentrations occurring in highly productive lakes (Likens, 1975). No distinct vertical profile was observed for either total alkalinity (fig. 9) or total silica (fig. 10). In this study the average concentrations for the entire water column were 85 mg/L for total alkalinity and 13.2 mg/L for total silica, the latter being very close to the world freshwater average (Livingstone, 1963). Total alkalinity concentrations reported in the 1973 study (Kennedy Engineers, Inc., 1973) were within the range of concentrations determined during this investigation. Total silica concentrations were slightly less than those reported previously by Kennedy Engineers, Inc. (1973), which included U.S. Geological Survey data from 1972.

Results of nutrient analyses from the sediment samples collected on December 6, 1979, are presented in figure 11. The concentrations of total nitrogen and phosphorus at site A were larger than those reported for the same site in the 1973 study (Kennedy Engineers, Inc., 1973). Nearly 100 percent of the nitrogen in the sediments is organic. With the exception of site D, almost all of the carbon in the sediments is organic. The average concentrations of total nitrogen, total phosphorus, and total carbon in the sediment were 652 mg/kg, 15,340 mg/kg, and 39,400 mg/kg.

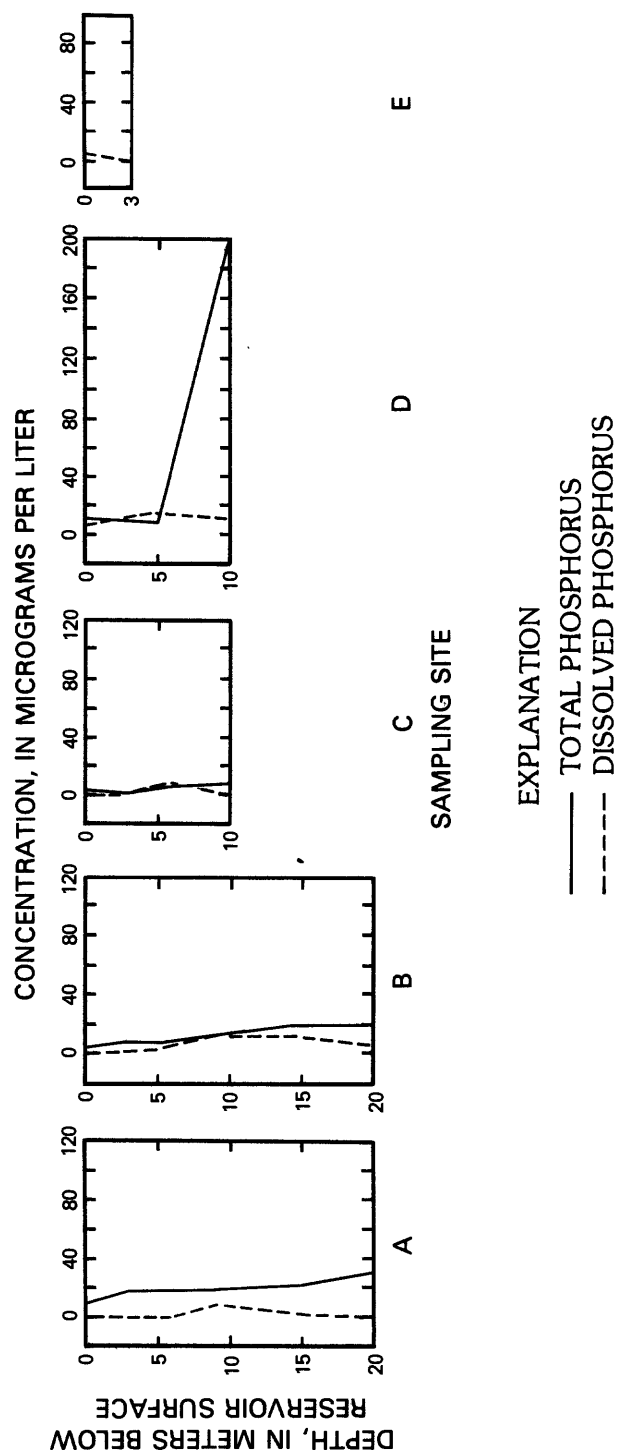


Figure 6.--Dissolved and total phosphorus, November 20, 1979.

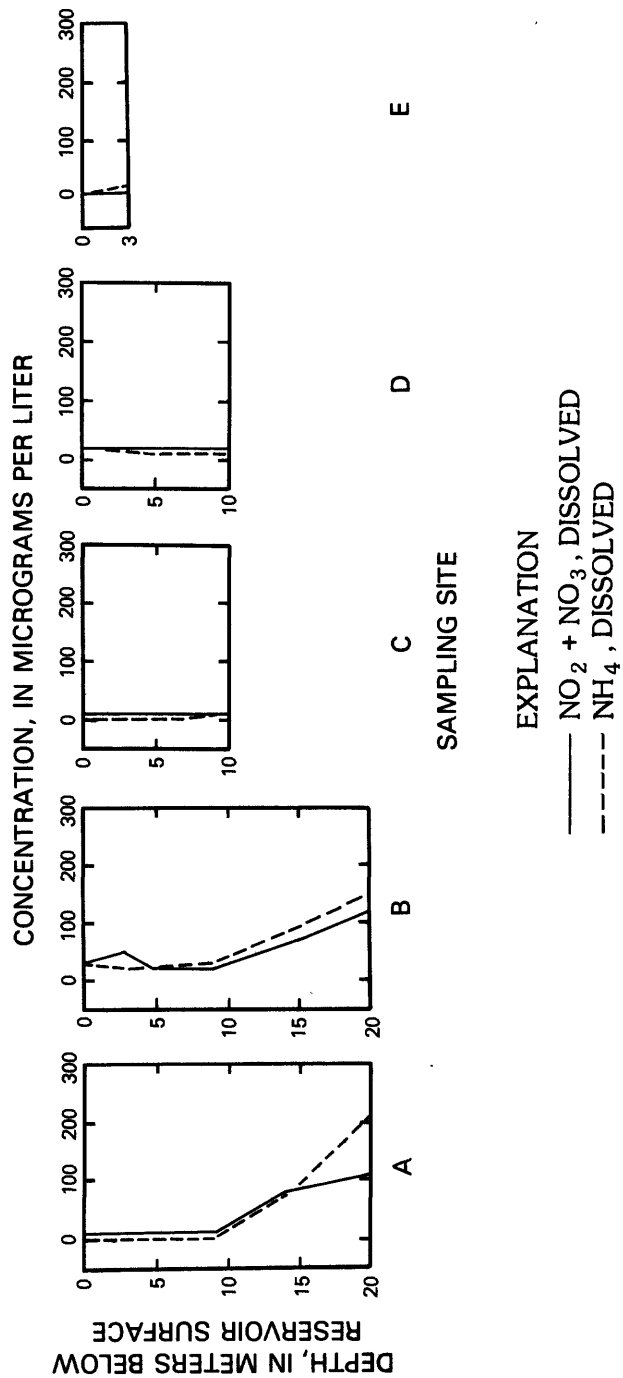


Figure 7.--Dissolved nitrogen, including nitrate plus nitrite and ammonia, November 20, 1979.

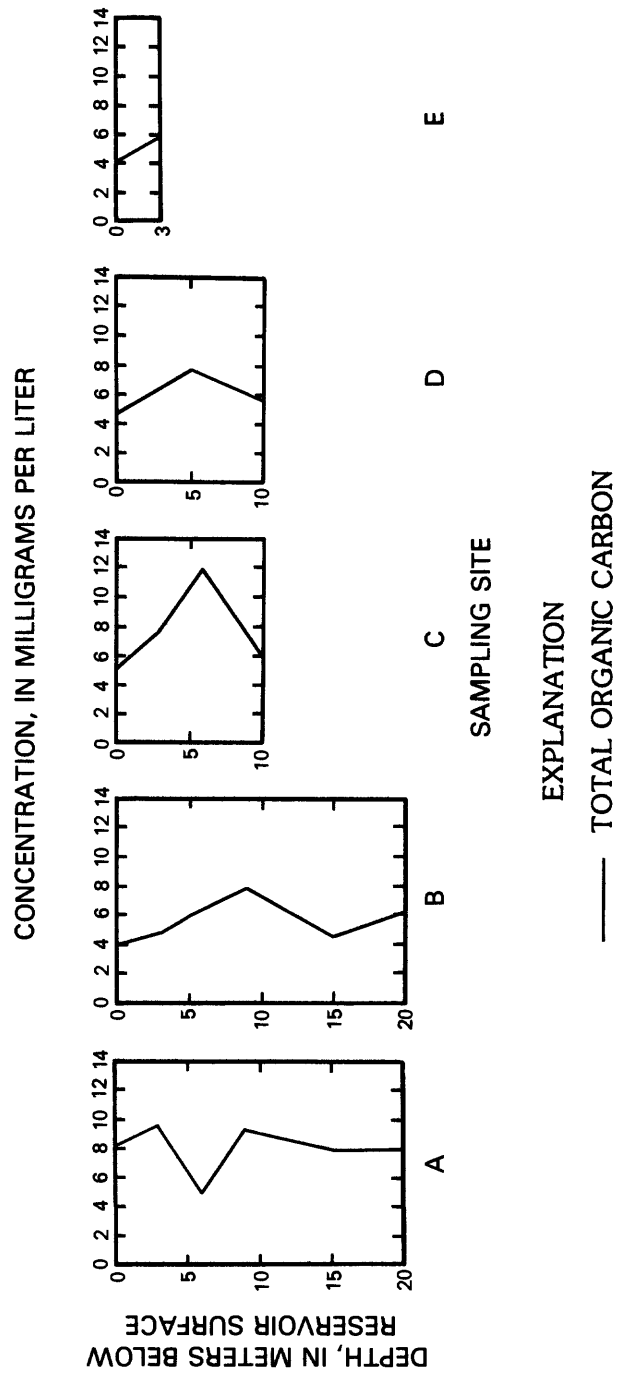


Figure 8. --Total organic carbon, November 20, 1979.

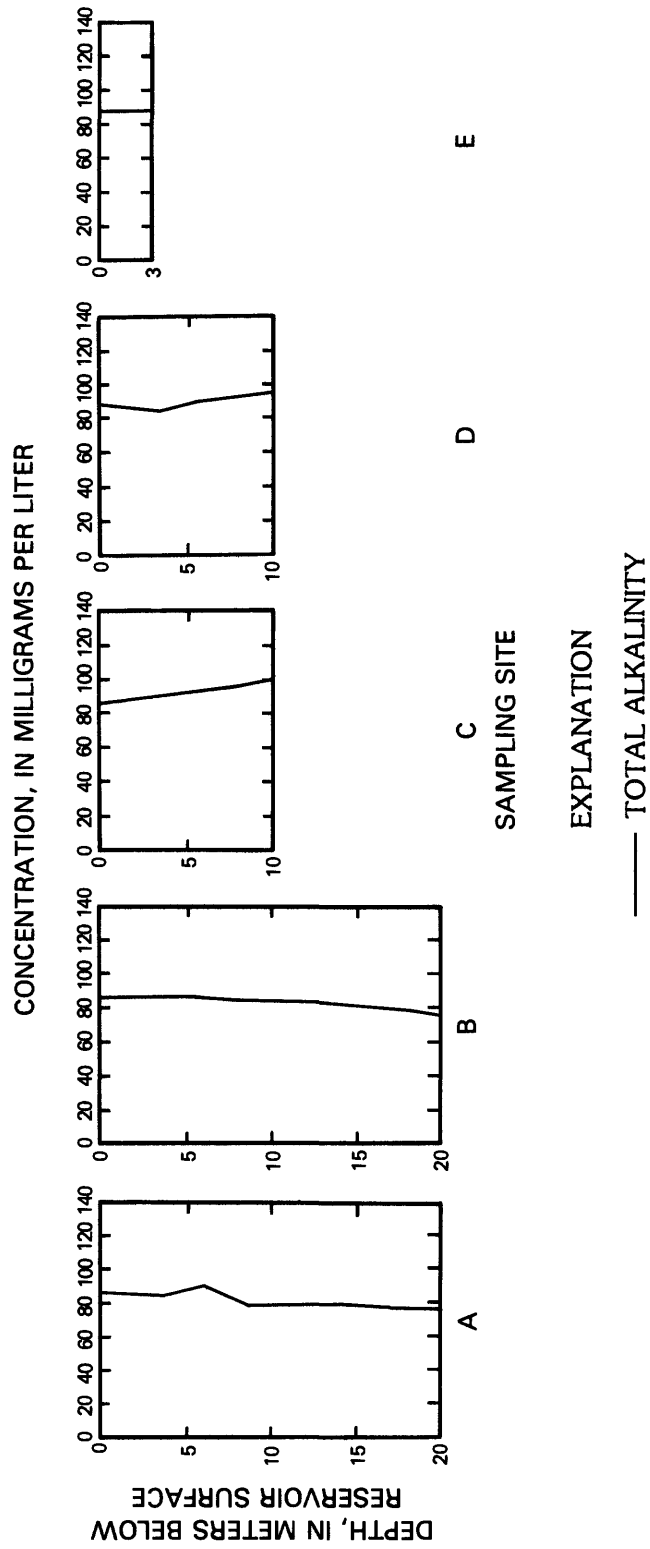


Figure 9.--Total alkalinity, November 20, 1979.



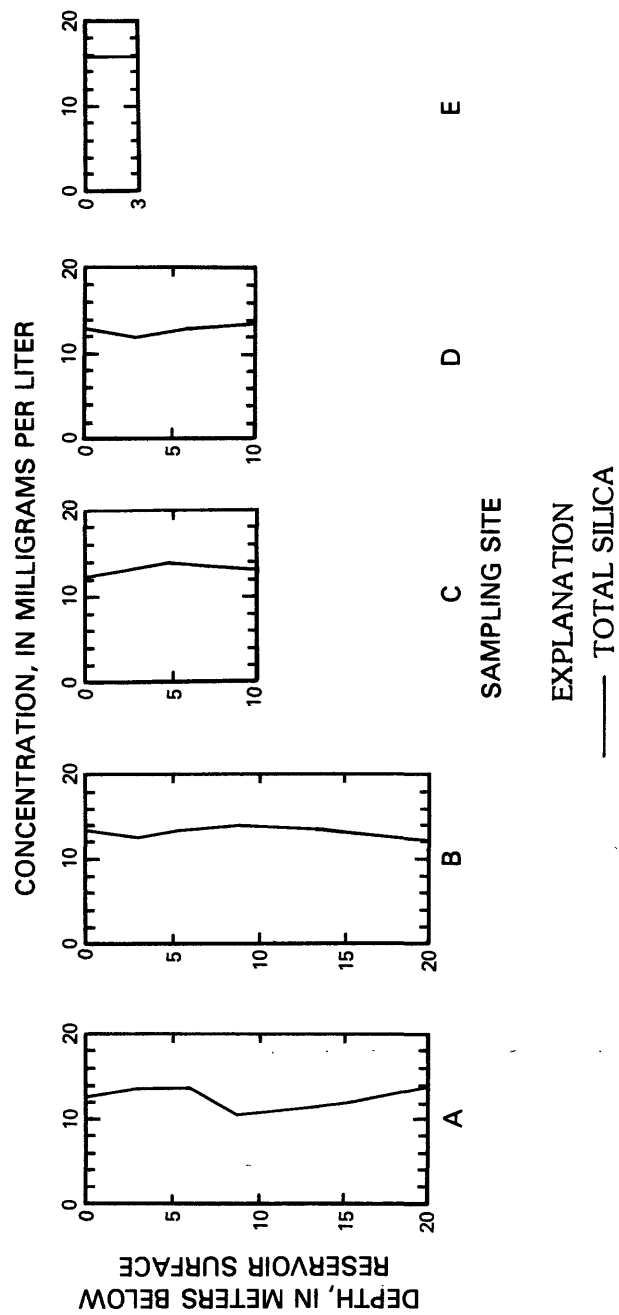


Figure 10.--Total silica, November 20, 1979.

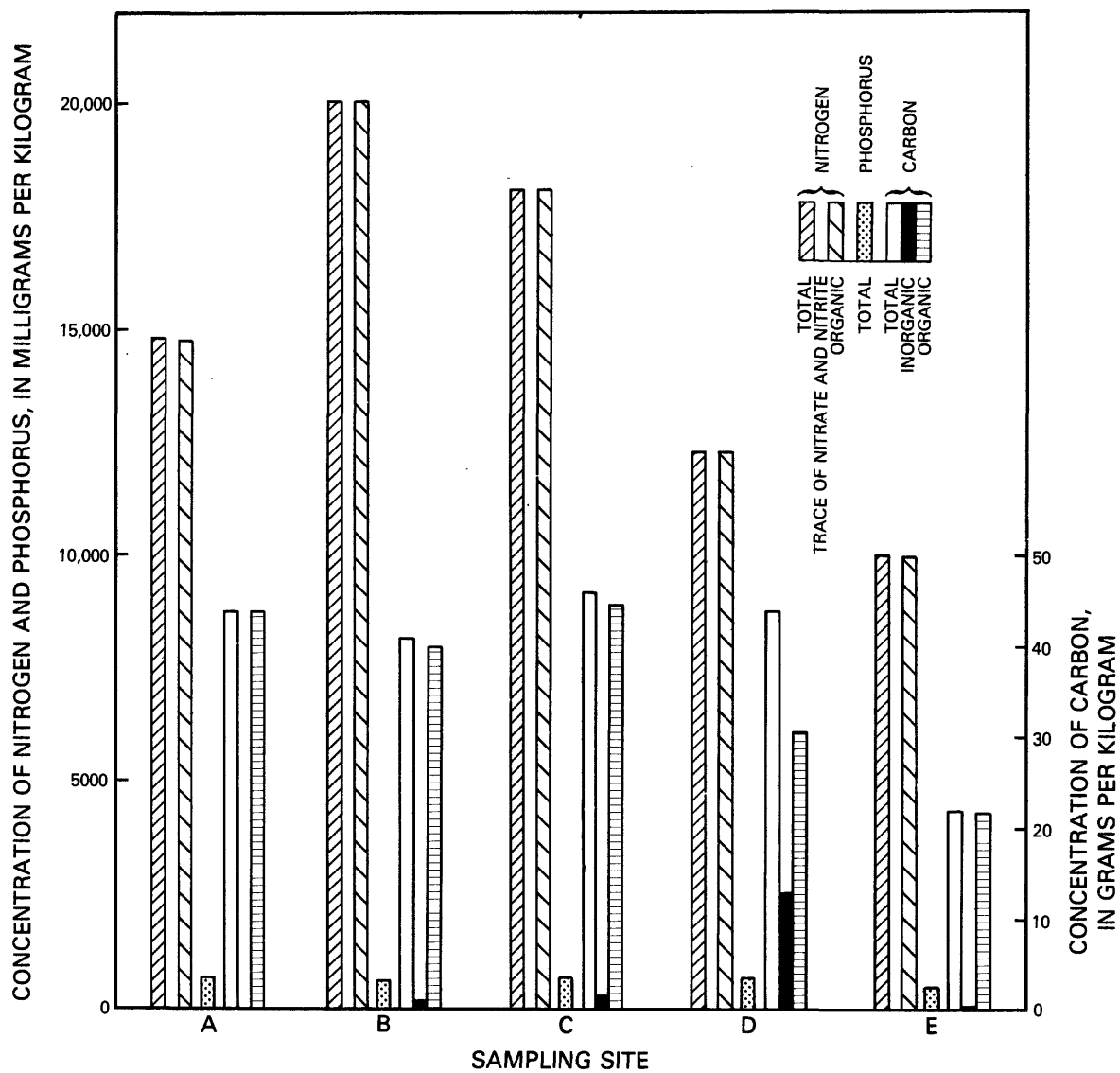


Figure 11.--Concentrations of nitrogen, phosphorus, and carbon in bottom sediments, December 6, 1979.

Organic material produced within a water body has a carbon to nitrogen (C:N) ratio of approximately 12:1 and decomposition processes usually result in an increase in the C:N ratio (Hutchinson, 1957). Data for sediments in Fena Reservoir indicate the C:N ratio is less than 12:1. The ratio of 2.5:1 by weight for the sediments in Fena Reservoir indicates there is some process occurring in the reservoir that results in greater nitrogen content relative to carbon content in the sediments. For example, Brezonik (1973) has indicated bacterial nitrogen fixation can occur in anaerobic sediments of tropical lakes. Also, ammonia can be sorbed into clays or other particulates in the sediments and thereby become unavailable for further microbial transformation.

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