WATER QUALITY OF FREMONT LAKE AND NEW FORK LAKES, WESTERN WYOMING--A PROGRESS REPORT

By David A. Peterson, R. C. Averett, and K. L. Mora

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CONVERSION FACTORS

Multipy	*By*	*To obtain*
centimeter	0.3937	inch
cubic hectometer	810.7	acre-foot
cubic meter per second	35.31	cubic foot per second
kilogram per cubic meter	0.0624	pound per cubic foot
kilometer	0.6214	mile
liter	0.2642	gallon
milliliter	.06	ounce
meter	3.281	feet
microgram	1,000	milligram
micrometer	0.00004	inch
milligram	0.00004	ounce
millimeter	0.0394	inch
square kilometer	0.3861	square mile
square meter	10.76	square foot
metric ton	1.102	ton

To convert degree Celsius (°C) to degree Fahrenheit (°F), use the following formula:

$$°F = 9/5(°C) + 32$$

Multiply	*By*	*To obtain*
inch	2.540	centimeter
foot	0.3048	meter
mile	1.609	kilometer
mile per hour	1.609	kilometer per hour

To convert degree Fahrenheit (°F) to degree Celsius (°C) , use the following formula:

$$°C = 5/9(°F - 32)$$

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ABSTRACT

Fremont Lake and New Fork Lakes in the New Fork River drainage of western Wyoming were selected for a comprehensive study of hydrologic processes affecting mountain lakes in the Rocky Mountains. Information is needed about lakes in this area to assess their response to existing and planned development. The concerns include regional issues such as acid precipitation from gas-sweetening plants, coal-fired powerplants, and smelters, as well as local issues, such as shoreline development and raising outlet control structures.

Fremont Lake and New Fork Lakes are located in the foothills of the Wind River Range, in glacially formed basins. The lakes are underlain by glacial till and granitic bedrock. Fremont Lake has a maximum depth of 185 meters and New Fork Lakes have a maximum depth of 62 meters.

Onsite measurements included vertical profiles, water transparency, lake inlet and outlet streamflow measurements, and mapping of the delta of Fremont Lake. Vertical profiles of temperature, specific conductance, dissolved oxygen, and pH in the lakes indicated strong thermal stratification during the summer and isothermal conditions during December 1983 and May 1984. Relatively large volumes of water flow into the lakes during the spring as a result of snowmelt. During spring runoff, Pine Creek deposits most of the annual average sediment of 800 metric tons to the delta of Fremont Lake.

Biological samples were collected from the lakes to examine some of the lower levels of the food chain. Phytoplankton populations were variable, with average concentrations less than 5,000 cells per milliliter. Chlorophyll *a* concentrations were weakly correlated with phytoplankton concentrations. Zooplankton concentrations were small, less than 6 organisms per liter. The number of benthic invertebrates per unit area in Fremont Lake was extremely small.

The lake waters and inflow and outflow streams were chemically dilute. Average dissolved-solids concentrations were 13 milligrams per liter in samples from Fremont Lake and 24 milligrams per liter in samples from New Fork Lakes. Calcium and bicarbonate were the predominant ions. Sample concentrations of phosphorus and nitrogen were small, usually less than detection limits of the methods used.

Trace-metal concentrations in the lakes were similar to those in precipitation and generally were small. Precipitation chemistry was variable.

Dissolved organic-carbon concentrations were about 1 milligram per liter in the study lakes. Concentrations of fulvic and humic acids were large in the inlet of Fremont Lake during the spring, relative to concentrations in the lakes and concentrations in the inlet on other dates.

1.0 INTRODUCTION

1.1 Introduction to Study

LAKES ARE PART OF COMPLEX HYDROLOGIC SYSTEMS

Lakes of the New Fork River drainage are being studied in relation to their entire hydrologic systems.

Fremont Lake and New Fork Lakes in the New Fork River drainage (fig. 1.1), were selected for a comprehensive study of hydrologic processes affecting the lakes. This report, prepared in cooperation with the Wyoming Water Development Commission, summarizes the progress after the first year of a 4-year study. The results reflect work by U.S. Geological Survey personnel from Wyoming and Denver, Colorado.

Previous limnological studies of the area include bathymetric maps of Fremont Lake and New Fork Lakes by Leopold (1980, p. 1755-1757) and limnological data from Fremont Lake in Rickert and Leopold (1972). Biological measurements of Fremont Lake have been made by Grabowski (1982). Miscellaneous measurements of water quality have been made on both lakes during the past 15 years by personnel of the U.S. Geological Survey. In 1983, prior to this study, a general limnological reconnaissance was conducted. During the reconnaissance, profiles of temperature, specific conductance, dissolved oxygen, and pH were made, and samples of water for analysis of principal ions and nutrients were collected from five lakes in the New Fork River drainage. The reconnaissance indicated that Fremont Lake and New Fork Lakes were suitable for more detailed study, with transfer value to other Rocky Mountain lakes.

Many alpine and subalpine western lakes, such as Fremont Lake and New Fork Lakes, are extremely dilute solutions (Rickert and Leopold, 1972; Larson and Donaldson, 1970; and Larson, 1970). Dilute-solution waters contain small concentrations of dissolved solids (usually less than 50 milligrams per liter) and are relatively unbuffered.

Dilute-solution lakes are fragile ecosystems and are susceptible to contamination from human use. For example, in Sequoia National Park, Silverman and Erman (1979) and Taylor and Erman (1979 and 1980) studied high-altitude, dilute-solution lakes that were being affected by backpackers and horse packers camping on the shoreline. These were relatively small, remote lakes with a short season of use. The effects of human activities on the quality of these lakes were substantial.

An additional problem associated with dilute-solution lakes is the potential change in the pH of the water by acid precipitation. Dilute-solution lakes are susceptible to rapid pH changes because they are relatively unbuffered. Also of interest are other pollutants introduced from the atmosphere by both dry fallout and the scrubbing effect of precipitation.

Regional and local concerns include acid precipitation resulting from gas-sweetening plants, smelters, coal-fired powerplants, and other sources in southwestern Wyoming and the Rocky Mountains. An example is the gas-sweetening plant currently (1985) being constructed as part of the Riley Ridge Natural Gas Project (fig. 1.1).

Effects on water quality from local development on Fremont Lake also are a concern. Proposals include raising the height of the outlet control structure to provide for more storage of irrigation water, constructing a 400-boat marina, and constructing a large campground.

The above statements are not meant to imply that dilute-solution lakes in the western United States are being destroyed by excessive recreational use, water-level manipulation, or atmospheric materials. Fortunately, most western lakes still contain water that is undegraded in spite of human activities. Unfortunately, however, we know too little about these lakes. When a plan to alter their hydrologic regime is proposed, either too little information is available, or the wrong kinds of information are available to provide a substantial degree of prediction concerning the effects of the alteration.

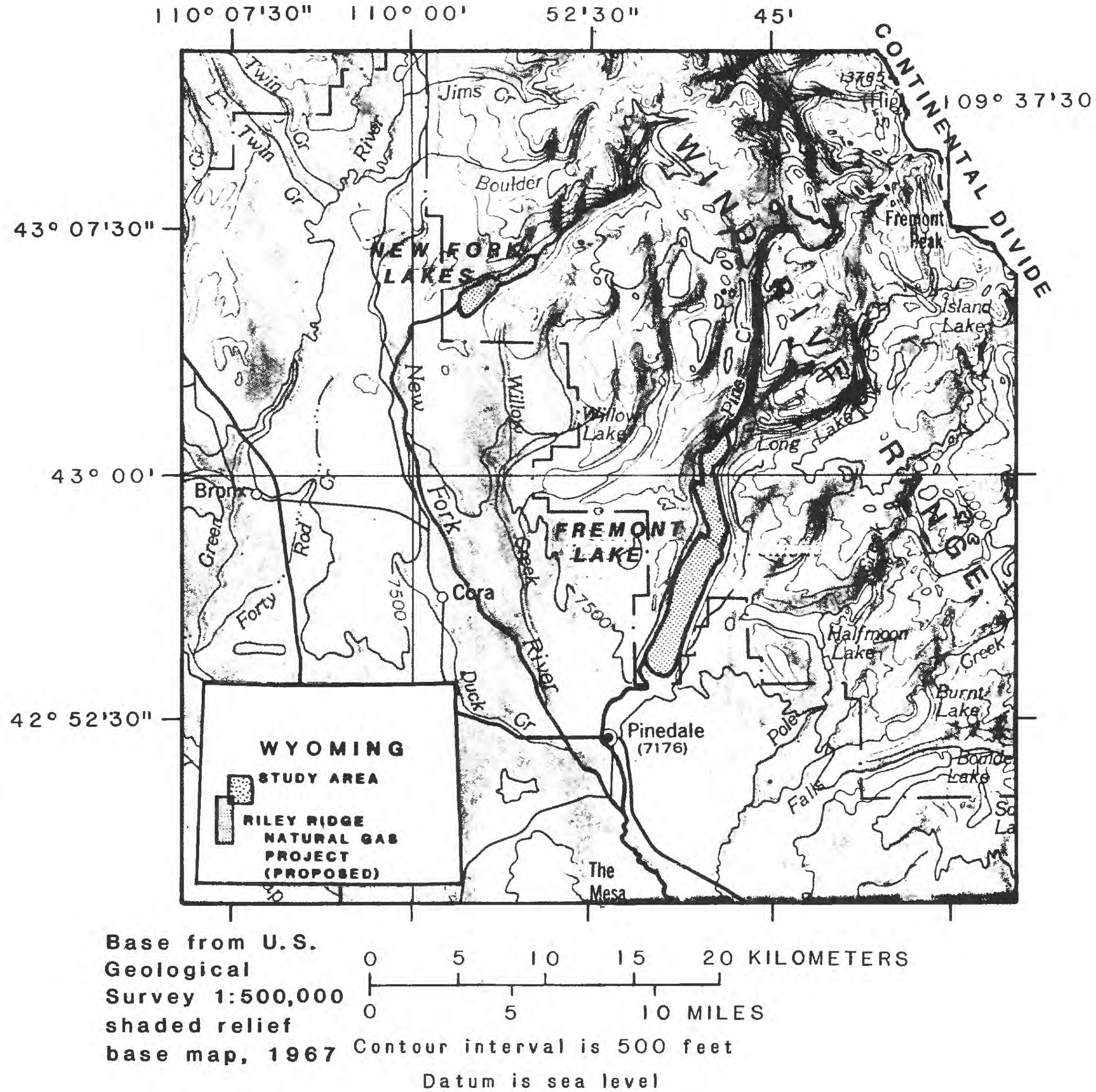


Figure 1.1--Fremont Lake and New Fork Lakes are located in the foothills of the Wind River Range, western Wyoming. The study area is located northeast of the Riley Ridge Natural Gas Project area, which is a proposed large development of sour gas wells, treatment and transportation facilities, and gas-sweetening plants (U.S. Department of the Interior, 1983).

1.2 Objectives, Scope, and Study Design

BASELINE INFORMATION NEEDED

Effects of human-related activities and natural processes may be predicted through analysis of baseline information.

The objectives of the study are as follows:

1. Describe the physical, chemical, and biological features of the waters of Fremont Lake and New Fork Lakes.
2. Determine the effects of the inorganic and organic chemical composition of the lake water on the biological community of the lakes.
3. Determine the physical, chemical, and biological composition of the inlet water and compare it with the outlet water. From this comparison, determine how the lakes affect the quality of the outflow waters.
4. Determine the sorption of materials on sediments. Determine the significance of the sorption as a source of nutrients to plants, or as a sink (loss of available nutrients from the system).
5. Provide conceptual or mathematical model(s) for predicting response to human-caused alterations to the lakes. At this point, only simple models will be attempted.
6. Evaluate potential for transfer of knowledge and relations of these two lakes to other lakes.

The study has been divided into two phases: An initial data-collection phase that was completed in 1984, and an interpretive study phase that began in 1985 and includes additional data collection. This progress report describes accomplishments during the data-collection phase.

Sampling during the data-collection phase was intensive in June, August, and October 1984 and less intensive in July and September of 1984. During the June, August, and October trips, data collected included measurements for construction of profiles of temperature, specific conductance, dissolved oxygen, and pH; and samples for determinations of concentrations of phytoplankton, chlorophylls a and b, zooplankton, principal ions, nutrients, trace metals, and organic matter. During July or September or both, data collected included soundings and cores of the delta deposits; profiles of temperature, specific conductance, dissolved oxygen, and pH; and samples for determinations of concentrations of phytoplankton, chlorophylls a and b, and zooplankton. Samples for determination of the benthic invertebrates of the lake bottom and drifting invertebrates of the inflow and outflow streams were collected during August and October. The methods, dates, and location of measurements and sample collection are described in more detail in each respective unit. A general description of the measurements and sample-collection sites follows.

Sites for measurements and sample collection were established in each of the lakes and their inflow and outflow streams (fig. 1.2) and are listed by name, latitude, and longitude in table 1.2. Measurement and sample-collection sites in the lakes generally are in the deepest parts. Location of streamflow-gaging stations are shown and described in unit 3.3.

Table 1.2.--*Latitude and longitude of measurement and sample-collection sites*

[Latitude and longitude in degrees, minutes, and seconds]

Site name	Latitude	Longitude
Fremont Lake, site 1	42 56 19 N.	109 48 35 W.
Fremont Lake, site 2	42 59 10 N.	109 47 30 W.
Pine Creek upstream from Fremont Lake	43 01 28 N.	109 46 37 W.
Pine Creek downstream from Fremont Lake	42 54 23 N.	109 50 13 W.
New Fork Lakes, site 1	43 05 26 N.	109 57 09 W.
New Fork Lakes, site 2	43 06 11 N.	109 55 40 W.
New Fork River upstream from New Fork Lakes	43 06 34 N.	109 54 47 W.
New Fork River downstream from New Fork Lakes	43 05 13 N.	109 58 05 W.

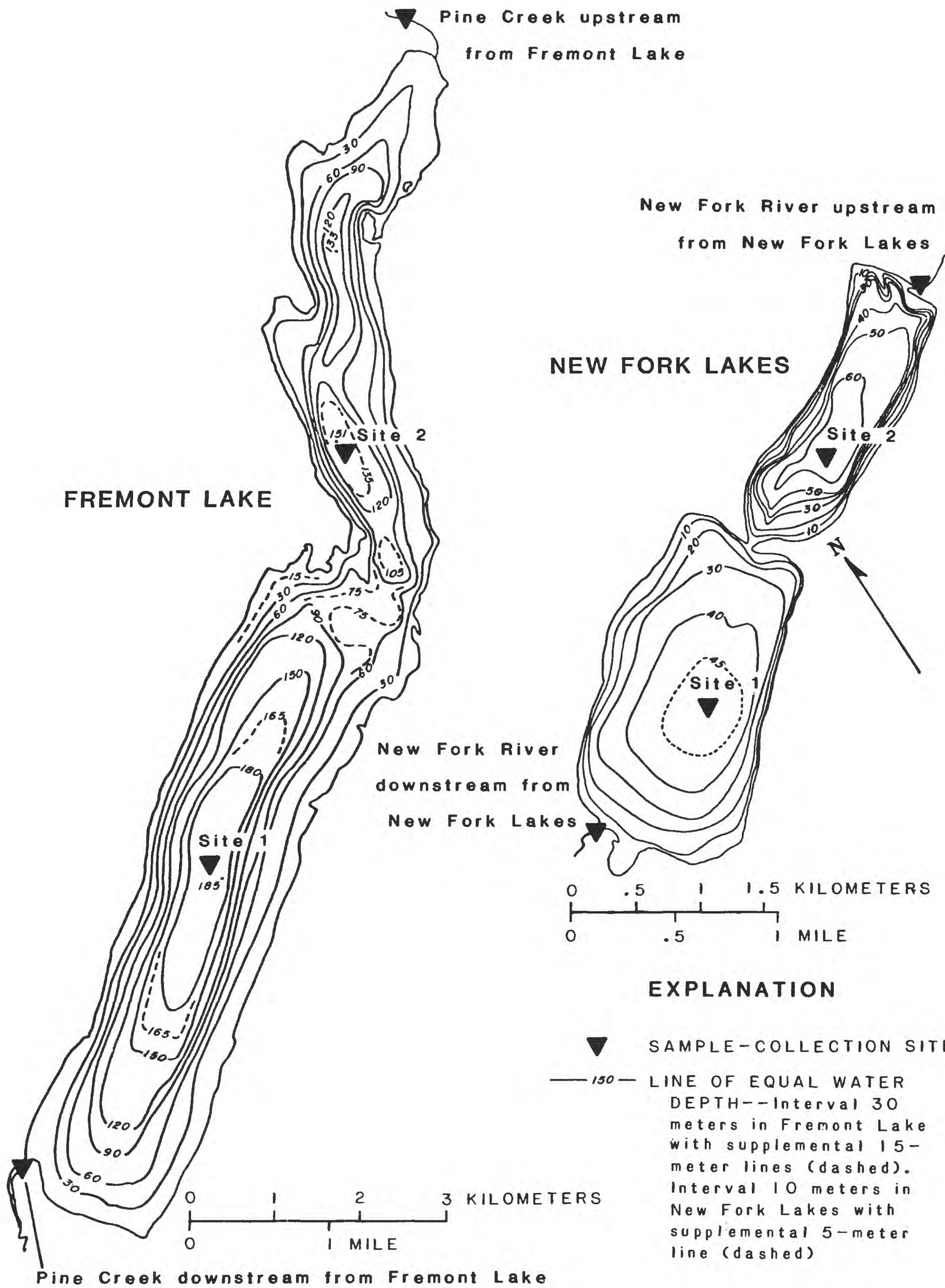


Figure 1.2--Location of measurement and sample-collection sites in the lakes and streams. Bathymetric maps modified from Leopold (1980, p. 1755-57).

2.0 PHYSIOGRAPHY

2.1 Climate

AIR QUALITY AND CLIMATE ARE MONITORED

Wind River Range is subject of intense environmental interest.

The study area is located near the southwest border of a Class I air-quality area in the Wind River Range, which, based on a National scale, indicates that the air quality is excellent. The air quality of the Wind River Range near the study area is the subject of intense interest. The air quality presently (1985) is being monitored to help document present-day conditions.

Detailed climatological data, including snowpack and precipitation chemistry, are being collected in the Wind River Range. These data are being collected by the National Oceanic and Atmospheric Administration, the U.S. Bureau of Land Management, the U.S. Environmental Protection Agency, the U.S. Forest Service, and the U.S. Soil Conservation Service.

The climate of the study area is a product of its location, altitude, and topography. The study area is affected by maritime air currents borne eastward on the prevailing westerly winds. Wind roses representing wind speed and direction data collected from Lander's Hunt Field and Rock Springs' Municipal Airport are shown in figure 2.1-1 (period of record is 1948-80). Winds were calm 16 percent of the time at Lander and 9.9 percent of the time at Rock Springs. Maximum wind speeds recorded at the Lander and Rock Springs airports were 69 and 72 miles per hour (National Oceanic and Atmospheric Administration, 1985).

Precipitation differs with altitude and, to a lesser extent, location. The mountains annually may receive as much as 40 inches of precipitation; lower altitudes may receive as little as 9 inches during a year (Wyoming State Engineer, 1970). The quantity of precipitation that occurs from year-to-year also is variable. Average monthly precipitation received at Kendall and Pinedale are shown in figure 2.1-2.

Most wintertime precipitation is in the form of snow. The cold climate allows much of the snow to be retained, especially in the mountains. At lower altitudes, however, most snow is removed by the wind and sun, and retention occurs mainly as drifts in draws and shaded areas. The warming of the atmosphere during the spring increases the moisture available for precipitation, causing more precipitation during May and June. Summertime precipitation occurs as light rain and occasional intense thunderstorms that generally move in an easterly direction.

Large ranges of seasonal and daily temperatures characterize the area. The range between extreme maximum and extreme minimum daily temperatures during any given year may be as much as 140 °F. January generally is the coldest month and July generally is the warmest month. The high altitude of the study area, as well as its northerly latitude, is responsible for comparatively low average temperatures (fig. 2.1-3).

High altitude and northerly latitude also are responsible for short growing seasons. The growing season of the study area is relatively short, about 70 days (Wyoming State Engineer, 1970). Soil temperature at a depth of 6 feet varies much less than air temperature and lags the air-temperature pattern by about 1 month.

Average temperature, growing season, radiation, and other climatological factors affect the rate at which plants consume water. Evapotranspiration is greatest during July, but continues to be significant well into the fall due to the warm soil temperature (Lowham, in press). Evapotranspiration rates generally are greater at lower altitudes.

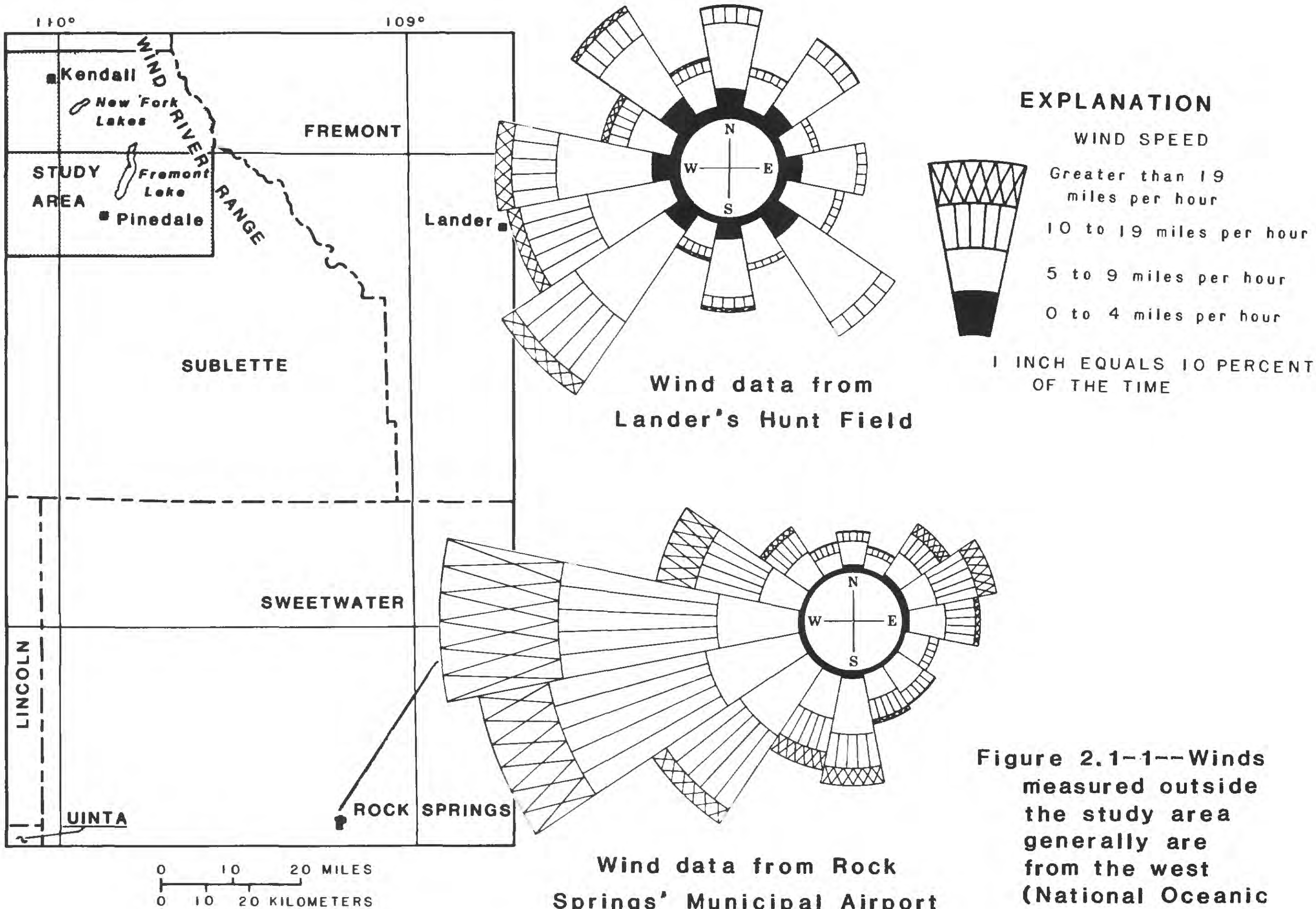
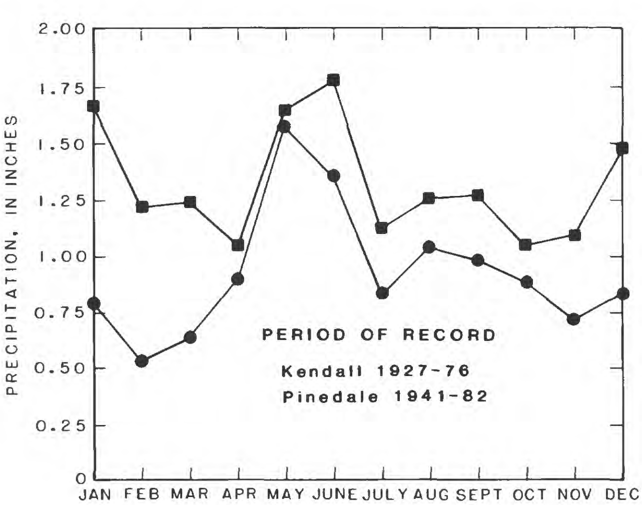
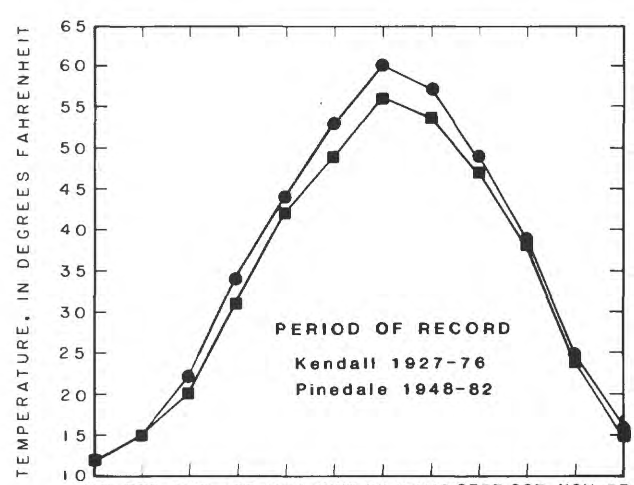


Figure 2.1-1--Winds measured outside the study area generally are from the west (National Oceanic and Atmospheric Administration, 1985).





EXPLANATION

■ KENDALL--Altitude 7,645 feet above sea level ● PINEDALE--Altitude 7,175 feet above sea level

Figure 2.1-2--Average monthly precipitation at Kendall and Pinedale (National Oceanic and Atmospheric Administration, 1985).

Figure 2.1-3--Average monthly temperatures at Kendall and Pinedale (National Oceanic and Atmospheric Administration, 1985).

VEGETATION AFFORDS AN OPPORTUNITY TO MONITOR AIR QUALITY

Vegetation surveys are conducted in the Wind River Range.

Plants may be used to monitor the effects of acid deposition. Exposed grasses and leaves may show physical evidence of damage from acid deposition. However, these generally do not reflect long-term trends because they have relatively short longevity. Pine trees may be monitored to determine long-term trends.

Another long-lived group of plants that possibly might be the most sensitive to air pollution is lichens. Lichens are stable, shallow-rooted plants that accumulate pollutants efficiently but are fairly resistant to long-term acid deposition. Various aspects of lichen monitoring may include growth rates and succession, and elemental analysis of plant samples.

Although the practical applications of lichen monitoring are not yet fully developed or accepted, lichens have been used worldwide as an indicator of air-pollution severity and extent. Preliminary lichen surveys have been conducted near the study area (U.S. Department of Agriculture, 1984, p. 210). Also, the U.S. Bureau of Land Management is conducting a vegetation study, which includes the establishment of permanent lichen plots (U.S. Department of the Interior, 1983, p. 5-17).

The general vegetative types in the area are sagebrush and grasslands, irrigated cropland, conifer-aspen forest, and alpine-type vegetation at altitudes above timberline (fig. 2.2). Vegetative zones are related to quantities of precipitation that are locally received and retained.

The sagebrush and grassland areas generally support deep-rooted and hearty vegetation. Thickspike wheatgrass, Idaho fescue, bluebunch wheatgrass, canby bluegrass, big sagebrush, antelope bitterbrush, mountain mohogany, and forbs are represented in areas receiving less precipitation (Young and Singleton, 1977). Sagebrush and grasslands support moderate to limited grazing; these lands locally may be irrigated but usually are not used for cultivated crops.

Irrigated croplands comprise a considerable part of the study area. Native hay and alfalfa are most commonly produced in these areas.

The conifer-aspen forests consist of Douglas-fir, alpine fir, lodgepole pine, and Engelmann spruce, mixed with stands of aspen (Young and Singleton, 1977). These forested mountainous areas and mountain valleys are used for livestock grazing during the summer and also for producing native hay.

The mountain valley sides of Fremont Lake and New Fork Lakes are vegetated with sagebrush and sparse stands of aspen on east-facing slopes and mixed conifers on north- and west-facing slopes. Aspen has conspicuously colonized an area where fire has destroyed the conifers. Various pine trees and shrubs, which could be important indicators of rising water levels, border the shorelines of Fremont Lake and New Fork Lakes. Virtually no aquatic vegetation is emergent from the shorelines of the two lakes.

Alpine-type vegetation at altitudes above timberline is part of a fragile ecosystem. These plants generally are shallow rooted or rootless.

Potential effects on vegetation related to air-quality degradation include changes in growth, mortality, reproduction, diversity, visible injury, succession, and productivity (U.S. Department of the Interior, 1983, p. 5-15). Some additional sources of information about vegetative conditions in the Wind River Range include Peterson (1984), U.S. Department of Agriculture (1984), U.S. Department of the Interior (1983), Wyoming State Engineer (1970), and Young and Singleton (1977).

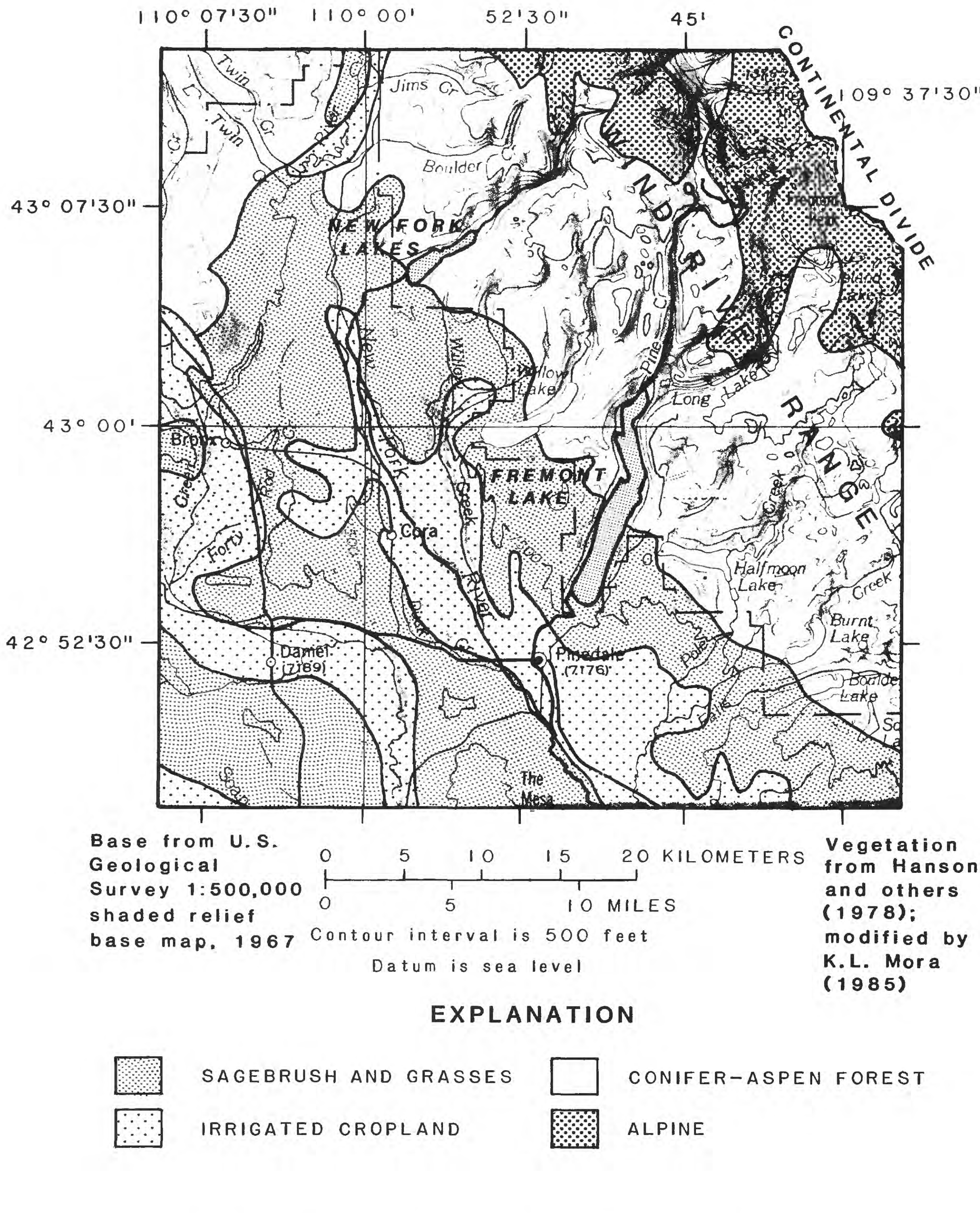


Figure 2.2--Generalized vegetation types.

2.3 Geology and Soils

GLACIAL ACTIVITY CREATED FREMONT LAKE AND NEW FORK LAKES

Precambrian rocks and glacial deposits cover most of the area; soils differences primarily are due to differences in parent material and to climatic variations.

The Wind River Range primarily consists of Precambrian granite, which is more than 2.5 billion years old. The core of the mountain range is cut by several predominantly northwest-trending steep-angle faults (fig. 2.3-1). These faults have greatly affected the direction and extent of the glacial erosion (Richmond, 1984, p. 76).

The Wind River Range was extensively glaciated during the Pleistocene Ice Age. Two major glacier advances, the Bull Lake and Pinedale ice movements, shaped the topography of the study area. The final retreat of Pinedale ice occurred about 9,000 years ago (Richmond, 1969).

Fremont Lake and New Fork Lakes are classic examples of high-altitude glacial lakes. The elongate lakes lie in granitic troughs that were scoured by glacial ice. Both lake outlets are plugged by terminal moraines (fig. 2.3-2).

Rocks from Precambrian age to Holocene age are present in the area (Welder, 1968). Bedrock is Precambrian granite with associated crystalline rocks. Glacial deposits of sand, gravel, and till form an apron along the foot of the Wind River Range. Alluvial deposits of sand and gravel border Green River and New Fork River and their major tributaries; gravel blankets some terraces above stream levels. Rock outcrops are common.

The land surface near the lakes is composed of unsorted till of various ages (Rickert and Leopold, 1972). Although the steep mountain slopes bordering parts of the lakes are almost exclusively exposed bedrock, the lake narrows and mountain valleys are morainal with virtually no exposed bedrock.

The following soils descriptions primarily are from a U.S. Soil Conservation Service contribution to a report by the Wyoming State Engineer (1970) and a report by Young and Singleton (1977).

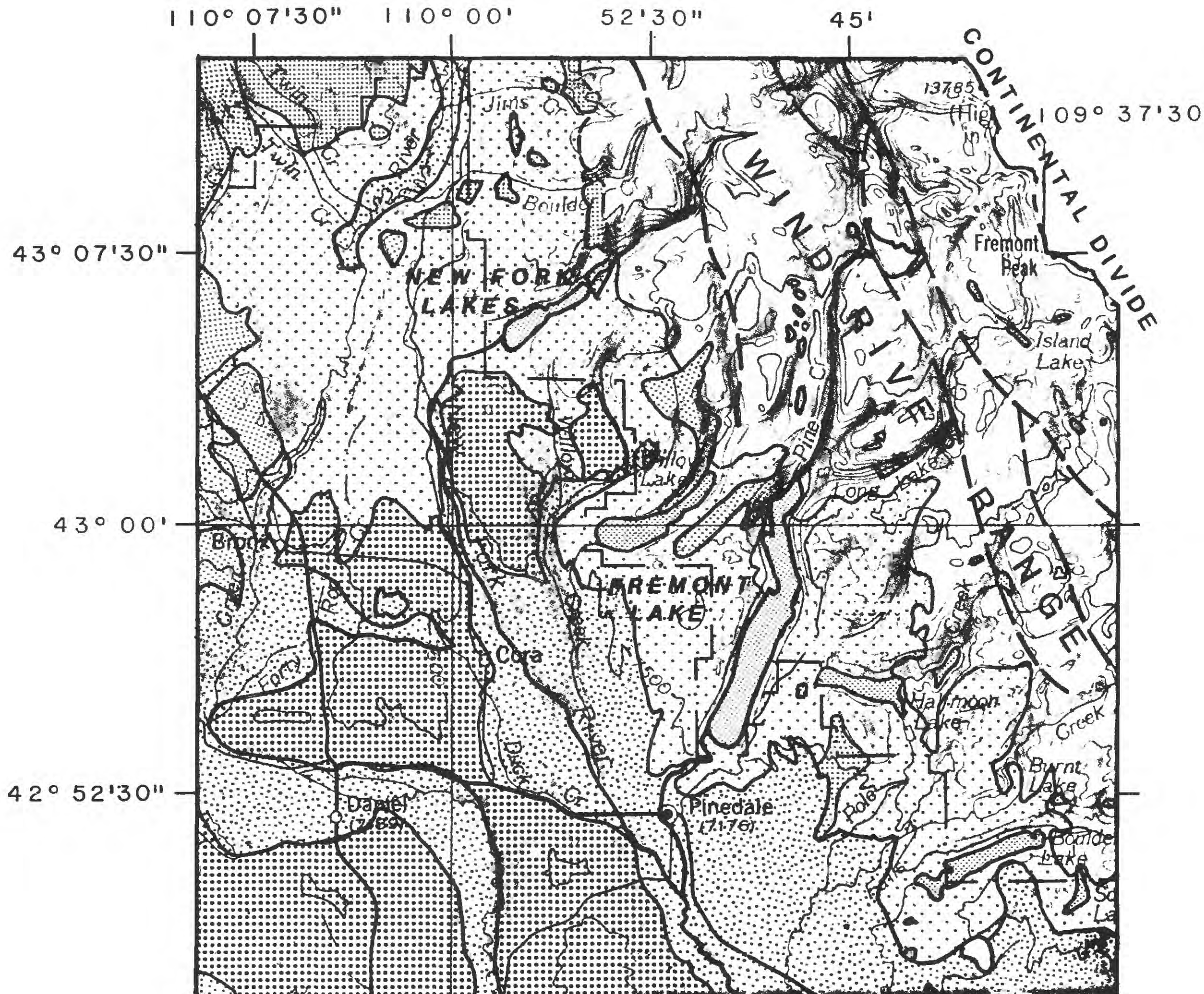
The mountain soils, formed from transported igneous bedrock, are shallow to deep, well drained, and moderately permeable. Runoff potential is slow to moderately rapid.

Mountain valley soils are deep to moderately deep, well drained, and underlain by sand, gravel, and cobble. These soils are moderately permeable and are moderately porous to very porous.

The foothills are mostly glacial moraines. These soils are very cobbly, deep, and well drained. These soils are moderately to very permeable. Runoff potential is slow to moderately rapid.

Upland soils are located in the nearly level to rolling terrain dissected by the flood plain of the Green River and its tributaries. These soils are developing from weathered shale and sandstone and contain variable proportions of soluble salts or alkali deposits or both. These soils are moderately deep, well drained, and moderately permeable.

Flood-plain soils are found primarily near the Green River and its major tributaries. These soils are formed in alluvium derived primarily from weathered shale and sandstone. Generally, these soils contain some soluble salts or alkali deposits or both. These soils are moderately deep to deep and are underlain by gravel and cobble. They are loamy to clayey and tend to be poorly drained. They are slightly to moderately permeable and are moderately porous. Runoff potential is moderately rapid to rapid.



Base from U.S. Geological Survey 1:500,000 shaded relief base map, 1967

0 5 10 15 20 KILOMETERS

0 5 10 MILES

Contour interval is 500 feet

Datum is sea level

Geology from Welder, 1968, modified by K.L. Mora, 1985

EXPLANATION

- QUATERNARY ALLUVIUM--Includes deposits underlying terraces and floodplains
- QUATERNARY GLACIAL DEPOSITS
- TERTIARY UNDIVIDED--Mostly Bridger, Green River, Wasatch, and possibly Fort Union equivalents
- WASATCH FORMATION--Main body of Wasatch Formation
- CRETACEOUS THROUGH CAMBRIAN ROCKS
- PRECAMBRIAN ROCKS
- CONTACT
- FAULT, APPROXIMATELY LOCATED

Figure 2.3-1--Generalized geology.

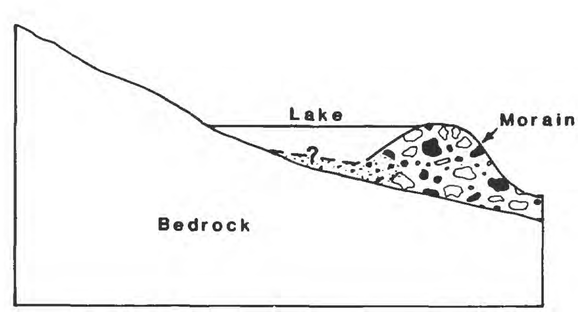


Figure 2.3-2--Typical glacial lakes are retained by moraine dams.

DEPTH OF LAKES IS EXCEPTIONAL

Fremont Lake has a maximum depth of 185 meters; New Fork Lakes have a maximum depth of 62 meters.

Fremont Lake is the seventh deepest lake in the conterminous United States, excluding the Great Lakes (Rickert and Leopold, 1972, p. D173). Fremont Lake is characterized by steep sides, both above the water level (fig. 2.4) and below. A constriction of Fremont Lake divides the lake into northern and southern parts, separated by a relatively shallow area and marked by narrowing of the lake width. The northern part of Fremont Lake has many bays and an irregular shoreline compared to the fairly regular shoreline and few bays of the southern part. The notably flat bottom of Fremont Lake in the southern part may be due to sediment deposited by density currents (Rickert and Leopold, 1972, p. D176).

New Fork Lakes, like Fremont Lake, consists of two parts separated by a constriction that is much narrower than that of Fremont Lake. The constriction between the northeastern and southwestern parts of New Fork Lakes is called the Narrows; the water depth in the Narrows is less than 10 meters. The shoreline of New Fork Lakes is fairly regular, with the only bay being in the southwestern part.

Inflow to the lakes principally is by streams originating high in the Wind River Range. The headwaters of Pine Creek, which is the principal inlet to Fremont Lake, are at the Continental Divide. The New Fork River, which is the principal inlet to New Fork Lakes, originates at a lower altitude and has a smaller drainage area than Pine Creek. The drainage areas and other statistics pertaining to the lakes are listed in table 2.4.

Table 2.4.--*Descriptive information about the study lakes*

[modified from Leopold, 1980, p. 1754]

Characteristics	Metric Units	
	Fremont Lake	New Fork Lakes
Drainage area (square kilometers)	196	75.1
Lake area (square kilometers)	20.6	4.97
Water-surface altitude (meters)	2,261	2,383
Lake volume (cubic hectometers)	1,690	160
Maximum depth (meters)	185	62
Average depth (meters)	82	33
Maximum drawdown (meters)	0.9	3.0
Useable storage (cubic hectometers)	18.5	14.9

Characteristics	Inch-pound units	
	Fremont Lake	New Fork Lakes
Drainage area (square miles)	75.7	29.0
Lake area (square miles)	7.96	1.92
Water-surface altitude (feet)	7,418	7,819
Lake volume (acre-feet)	1,370,000	130,000
Maximum depth (feet)	607	203
Average depth (feet)	269	108
Maximum drawdown (feet)	3.0	9.8
Useable storage (acre-feet)	15,000	12,100

Figure 2.4--Fremont Lake during November, 1984. View is looking north from near the center of the lake.

3.0 ONSITE MEASUREMENTS

3.1 Profiles of Temperature, Specific Conductance, Dissolved Oxygen, and pH

3.1.1 Introduction and Methods

PROFILES ARE USED TO SHOW DEGREE OF STRATIFICATION

Stratification is the layering of a lake or reservoir water into distinct zones.

Lakes, reservoirs, and ponds can be stratified in several ways, but the most common is temperature, or thermal stratification. A thermally stratified water body can be divided into three layers: the epilimnion, the metalimnion, and the hypolimnion (fig. 3.1.1-1). When stratified, these layers have little interchange of water between them. Differences in water density resulting from temperature differences cause formation of the layers. The epilimnion, or surface layer, contains the warmest water during the summer and the coldest water during winter, in temperate climate lakes. The epilimnion is subject to circulation, or mixing, by the wind. The degree of circulation is dependent on environmental factors such as the orientation of the lake and nearby topography relative to the prevailing winds. The metalimnion, or middle layer, is sometimes called the thermocline, or zone of maximum temperature change, and was defined by Birge (1898, p. 295) as the zone where temperature decreases at least 1 °C per meter increase in depth. The hypolimnion is the relatively stagnant bottom layer, in which the density of water is greatest.

Thermal stratification prevents overturn, or circulation between the top and bottom layers of a lake. When a lake becomes vertically isothermal (uniform temperature from top to bottom), the density differences that prevented circulation no longer exist. In the classic temperate-climate lake, overturn (complete circulation) occurs twice per year, in the spring and fall (dimictic); some lakes overturn once per year (monomictic).

Overturn is critical to lakes because it reverses the physical and chemical changes of the water that occur during stratification. For example, the epilimnion may become depleted of nutrients, whereas the hypolimnion may become depleted of dissolved oxygen. Phytoplankton in the epilimnion may deplete nutrients from the epilimnion before they sink to the hypolimnion and bottom sediments. Because of the stratification, these nutrients brought to the hypolimnion and bottom sediments by the phytoplankton cannot return to the epilimnion. Photosynthesis by phytoplankton produces dissolved oxygen in the epilimnion, but the hypolimnion generally is too dark for photosynthesis and hence oxygen renewal. As a result, dissolved oxygen becomes depleted in the hypolimnion through decay of organic matter. During prolonged thermal stratification, dissolved-oxygen concentrations in the hypolimnion may become too small to support aquatic life. After a complete overturn of the water body, nutrient and oxygen supplies are renewed throughout the water column and the cycle begins again as stratification develops.

Profiles of the study lakes were obtained using a Hydrolab System 8000.[1] Individual components consisted of model 8002 data control unit; battery pack; series 8100 water-quality data transmitter (also called probe) (see fig. 3.1.1-2); a Lexan sonde to protect the probe while in use (equipped with stirrer for dissolved oxygen); and a 200-meter long databus cable, marked at selected intervals. Equipment calibration for specific-conductance, dissolved-oxygen, and pH measurements was done immediately before beginning the profiles, using the procedures described by the manufacturer. Calibration checks after profiling showed little drift during operation. The System 8000 is factory calibrated for temperature; the operation manual specifies accuracy of ±0.15 °C.

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[1]Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

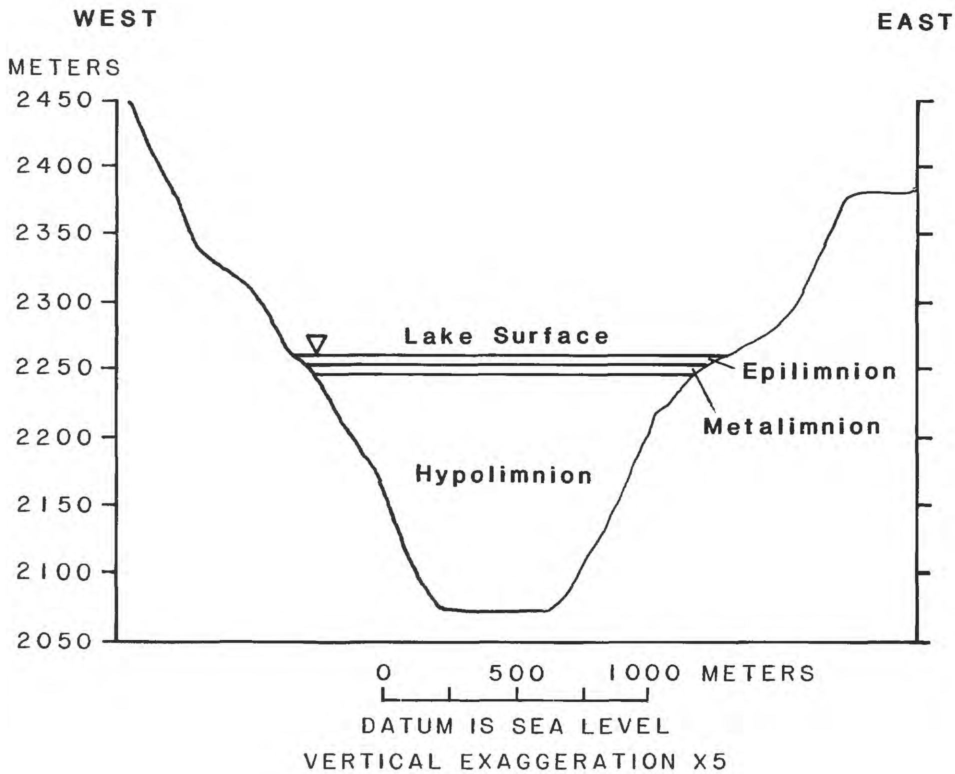


Figure 3.1.1-1--Stratification in Fremont Lake during August, 1984.

Figure 3.1.1-2--Hydrolab probe, which is in a sonde, being lowered though a hole in the ice on Fremont Lake, February 22, 1984.

PROFILES SHOW STRONG THERMAL STRATIFICATION DURING THE SUMMER

Vertical profiles of temperature, specific conductance, dissolved oxygen, and pH showed strong thermal stratification during the summer in Fremont Lake and New Fork Lakes.

Thermal stratification appeared to be strongest during August, based on profiles measured during 11 sampling periods at two sites in Fremont Lake and two sites in New Fork Lakes. The lake waters were isothermal during December 1983 and May 1984. Circulation may have been complete, from the surface to the bottom of the lakes, during December, but incomplete during May. Rickert and Leopold (1972, p. D178) noted circulation in Fremont Lake during the spring extended to less than 90 meters below the surface, because of rapid warming of the water by the sun after ice breakup. Profiles from representative dates, shown in figure 3.1.2, illustrate the annual cycle. These profiles were measured at site 1 in Fremont Lake and site 2 in New Fork Lakes, with the exception of February 23, 1984, when the profiles were measured at site 1 in New Fork Lakes.

The annual thermal cycle includes ice covering the lakes. Ice cover on Fremont Lake generally forms in January; the average date of ice breakup is May 15 (Leopold, 1980, p. 1758). The early June profiles indicate that slight thermal stratification had developed after ice breakup on the lakes. Solar radiation to the lakes increased the surface temperatures to a recorded maximum of nearly 20 °C in August. The surface temperature decreased slowly throughout the fall, but slight stratification still existed in early November. Measurements during February indicated a profile typical of a temperate-climate lake in winter, with colder, less dense water near the ice surface and warmer, denser water near the lake bottom.

The epilimnion and metalimnion were thin, relative to the depth of the lakes. At its maximum thickness, the epilimnion was about 14 meters thick at site 2 in Fremont Lake during September 1984. The thickness of the metalimnion never exceeded 10 meters. The hypolimnetic water temperature of 3.6 to 4.1 °C corresponded with the temperature of water with maximum density (approximately 4 °C, dependent on pressure). Differences between the measured and the calculated temperature of water with maximum density are within the accuracy of the instruments used. All of the profile data, including temperature, are useful to indicate changes with depth or date on a relative basis, but are not considered absolute values.

Specific-conductance values in the lakes generally increased with depth during the summer and fall. In contrast, specific-conductance values were largest near the surface during February. This reversal in specific conductance supports a hypothesis of complete circulation (overturn) during December 1983.

The profiles of dissolved oxygen and pH often indicated a subsurface maximum near the top of the metalimnion. The larger values may be due to increased phytoplankton production at these depths. Dissolved oxygen and pH were not measured in New Fork Lakes during February because of equipment malfunction.

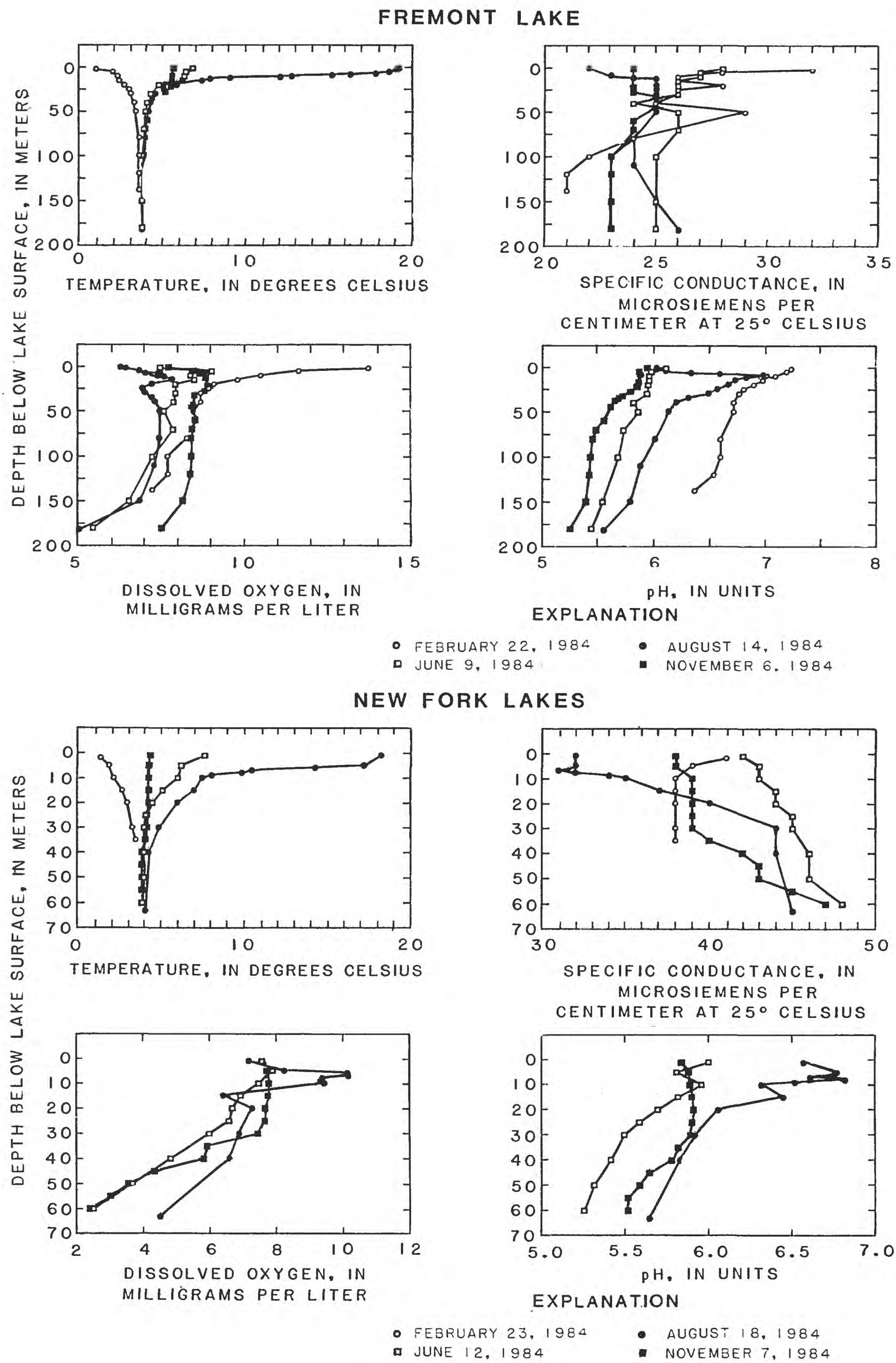


Figure 3.1.2--Depth profiles from representative dates indicating strong thermal stratification during late summer.

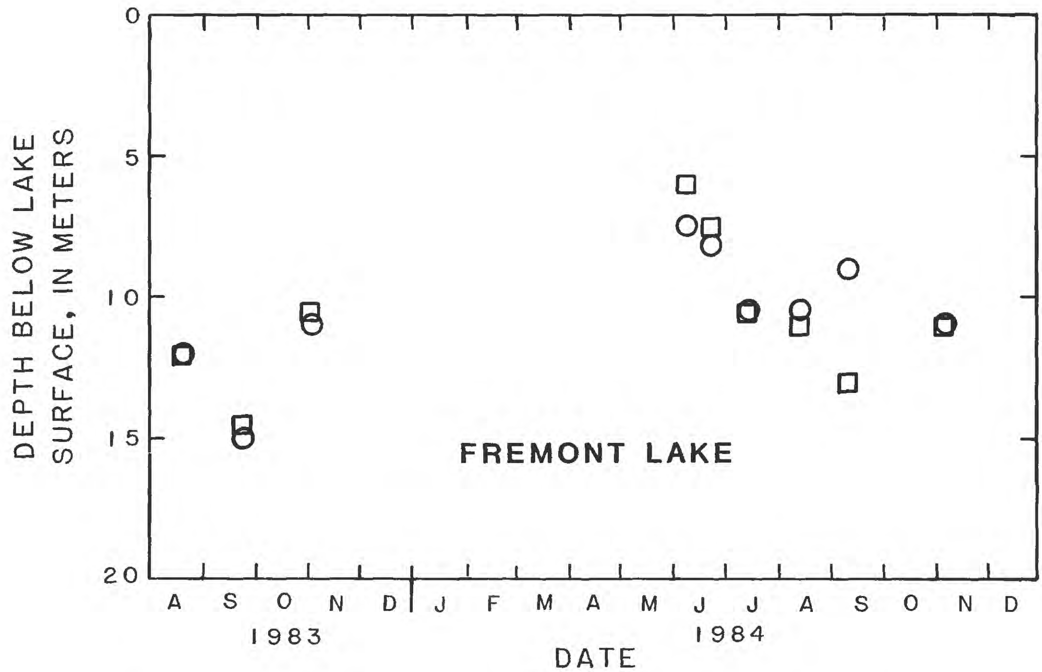
WATER IN FREMONT LAKE AND NEW FORK LAKES IS CLEAR

Water in the lakes was the most transparent during the fall and the least transparent during June and July.

Water in Fremont Lake generally was more transparent than the water in New Fork Lakes. Water transparency was measured with a Secchi disk; the measurements in the lakes ranged from 3.2 to 15 meters below the surface (fig. 3.2). For comparison, Secchi-disk measurements in Seminoe Reservoir, in central Wyoming, ranged from 0.8 to 4.7 meters during 1976 and 1977 (U.S. Geological Survey, 1977, p. 376-380, and 1978, p. 396-400).

The Secchi disk used was 20 centimeters in diameter, with black and white quadrants, and attached to a line marked at measured intervals. The disk was lowered into the water from the shaded side of the boat until it disappeared from sight, then lowered an additional distance, and raised until it reappeared. The measurement was the average of the depths of disappearance and reappearance. The Secchi disk is somewhat subjective because variables such as glare, waves, or the viewer's eyesight affect the measurement, but it does provide a comparative measurement.

The Secchi-disk measurements can be used to estimate the depth of the euphotic zone, or the zone where sufficient light is available for photosynthesis by aquatic plants. Estimation of the euphotic zone aids in understanding lake productivity, because the aquatic plants form the base of the food chain. The estimate is obtained by multiplying the Secchi-disk measurements by a factor, which varies with lake conditions. A factor of 3 commonly is used (Cole, 1975, p. 117-118).



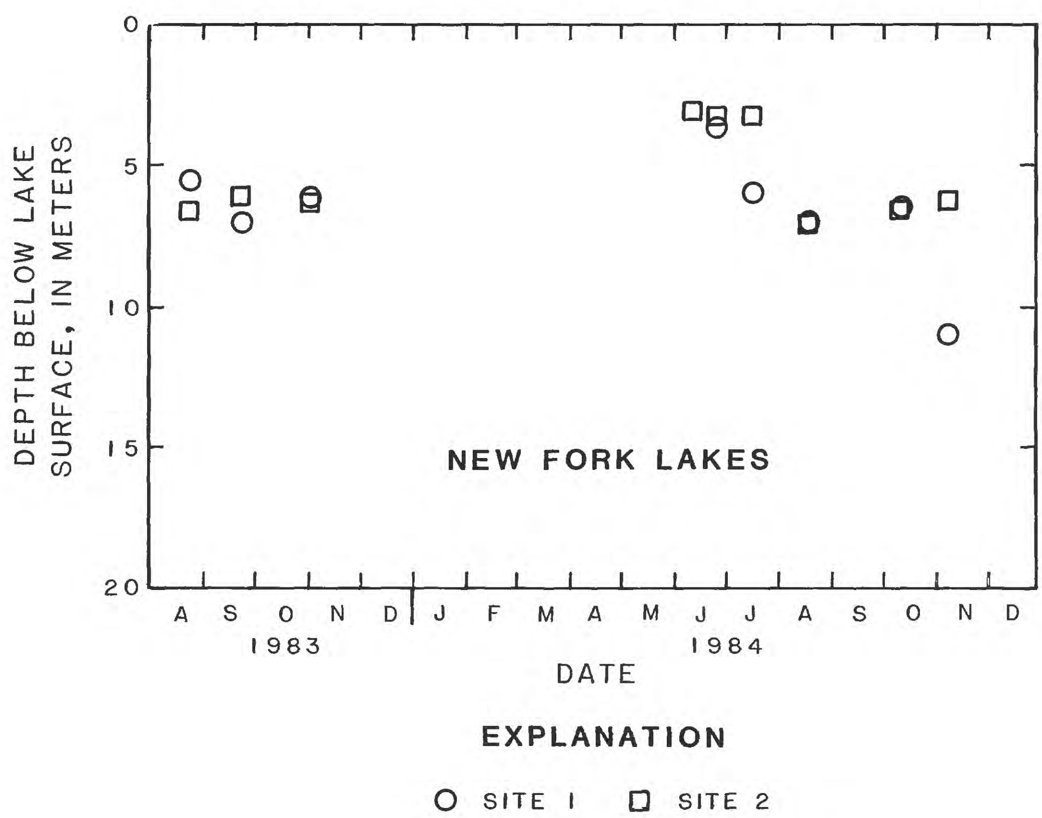


Figure 3.2--Secchi-disk measurements indicating the water in Fremont Lake generally is more clear than the water in New Fork Lakes.

INFLOW IS LARGEST DURING SPRING

Melting snow contributes relatively large volumes of water during the spring runoff season; outflow from the lakes is partly regulated through control structures.

Peak runoff in the area occurs during May and June, and minimum flow occurs during winter, based on the hydrograph of Pine Creek upstream from Fremont Lake (fig. 3.3-1). About 30 years of streamflow record are available from each of the two streamflow-gaging stations noted in figure 3.3-1. Outflow from the lakes is partly controlled by structures installed to provide water storage for irrigation. The outlet structures allow a maximum drawdown of 0.9 meter in Fremont Lake and 3.0 meters in New Fork Lakes.

Streamflow-gaging stations were installed in October 1984, at the outlet of Fremont Lake and the inlet of New Fork Lakes. These stations began operating before the spring runoff season of 1985 and were operated through the ice-free period. Location of the gaging stations are shown in figure 3.3-2; the names are listed in table 3.3. Miscellaneous streamflow measurements were made near each station in August and October, 1984. The installation downstream from Fremont Lake consisted of three stations: one station to measure Pine Creek and two stations to measure two irrigation ditches at their point of diversion from Pine Creek. Installation of three stations was necessary because conditions upstream from the diversions were unsuitable for a gage site. A streamflow-gaging station was operated on Pine Creek near the outlet of Fremont Lake during water years 1910-12 and 1915-18, but was located downstream from the point of diversion.

Streamflow-gaging station 09193000 on the New Fork River below New Fork Lakes was operated by the U.S. Geological Survey during water years 1938-72. A hydrograph of streamflow at this station during 1960-72 is shown in figure 3.3-1. A gage was re-established at this site in May 1984 by personnel from the University of Wyoming and operated during the ice-free period.

Measurements of streamflow into and out of the lakes, when available on a comprehensive basis, will be used in conjunction with chemical data. Concentrations of constituents in the inflow will be compared to those of the outflow, on a discharge-weighted basis. This will help determine the effect of the lakes on the water quality of the inflow waters. Streamflow records are also needed to calculate a chemical budget for the lakes.

The streamflow-gaging station numbers listed in table 3.3 are unique eight-digit identification numbers. Station numbers customarily are assigned by the U.S. Geological Survey to locations where samples or measurements are made on a routine basis. The first two digits indicate the river basin in which the station is located; for example, 09 refers to the Colorado River Basin. The remaining six digits are based on position in the river basin and increase in the downstream direction.

Table 3.3.--*Streamflow-gaging station numbers and names*

Streamflow-gaging station	
Number	Name
09192750	New Fork River above New Fork Lakes
09193000	New Fork River below New Fork Lakes
09196500	Pine Creek above Fremont Lake
09196940	Fremont Ditch near Pinedale
09196950	Highland Ditch near Pinedale
09197000	Pine Creek below Fremont Lake

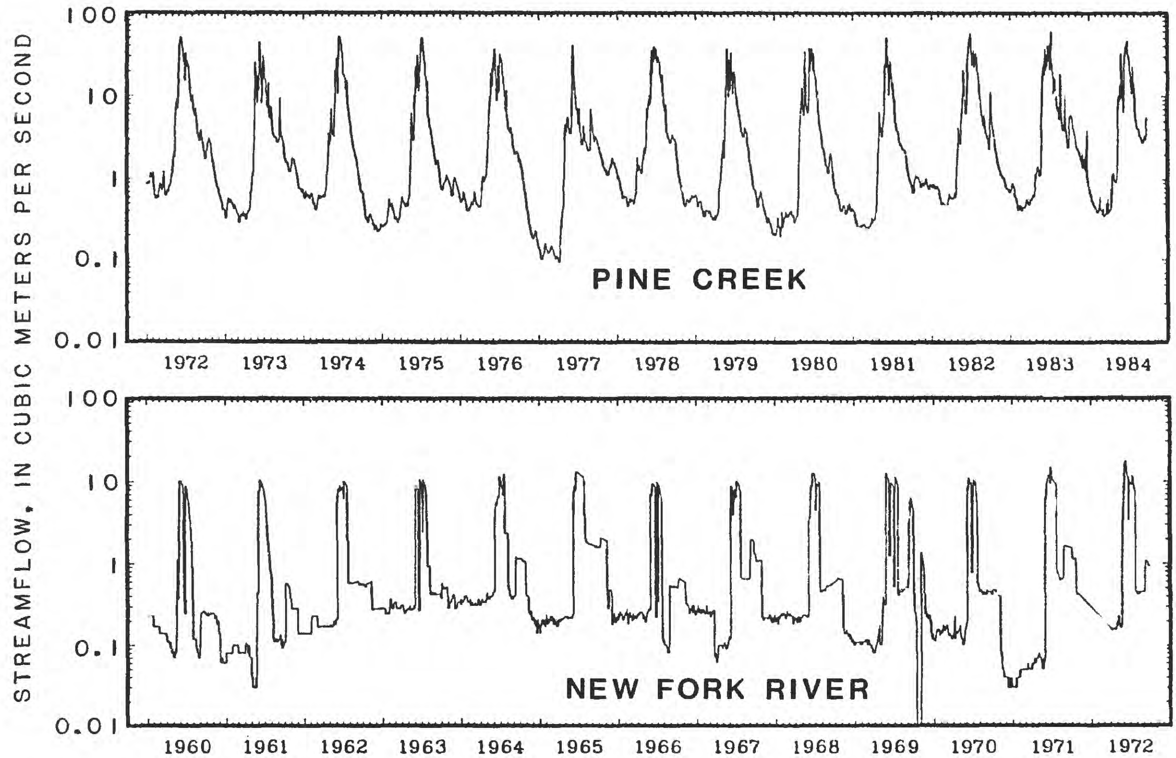


Figure 3.3-1--Hydrographs of streamflow in Pine Creek above Fremont Lake (station 09196500) and the New Fork River below New Fork Lakes (station 09193000).

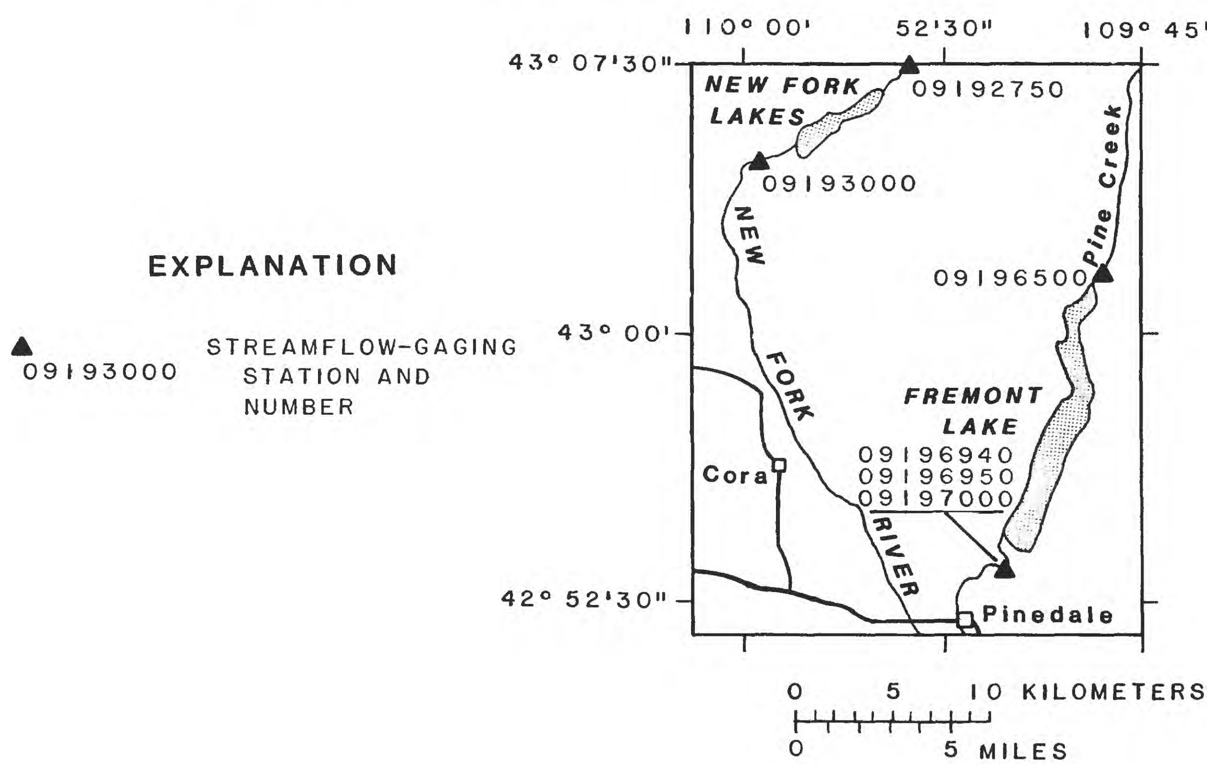


Figure 3.3-2--Location of streamflow-gaging stations. The station names are listed in table 3.3.

DELTA FORMED IN FREMONT LAKE

An estimated 800 metric tons of sediment enter Fremont Lake annually from Pine Creek.

Fremont Lake's inlet stream, Pine Creek, has developed a delta in the lake near the mouth of the stream. This delta consists of sediments that have entered the lake primarily during spring runoff. During 1984, the delta was mapped with a sonar recorder by making 12 traverses (fig. 3.4-1). The traverse data was used to draw a bathymetric map of the delta (fig. 3.4-2).

The delta sediments are contributed by Pine Creek through two processes: suspended sediment and bedload. Calculations from contemporary suspended-sediment concentrations and streamflow at gaging station 09196500 indicate that about 728 metric tons of suspended sediment enter Fremont Lake during an average year. Although the bedload in Pine Creek has not been measured, it is conservatively established to be about 10 percent of the total sediment load, based on findings in nearby streams. Thus, the average annual total sediment load is estimated to be about 800 metric tons. At 1,600 kilograms per cubic meter, this would indicate an annual volume of sediment of 500 cubic meters. If sedimentation has occurred at this rate since the glacial origin of Fremont Lake, some 10,000 years ago, the total volume of sediment that has entered the delta is about 5 million cubic meters. Core samples were collected from the delta for physical, chemical, and biological analyses, but analytical data are not available at the time of this writing.

EXPLANATION

▲ 09196500 STREAMFLOW–GAGING STATION AND NUMBER

—(1)— TRAVERSE AND NUMBER

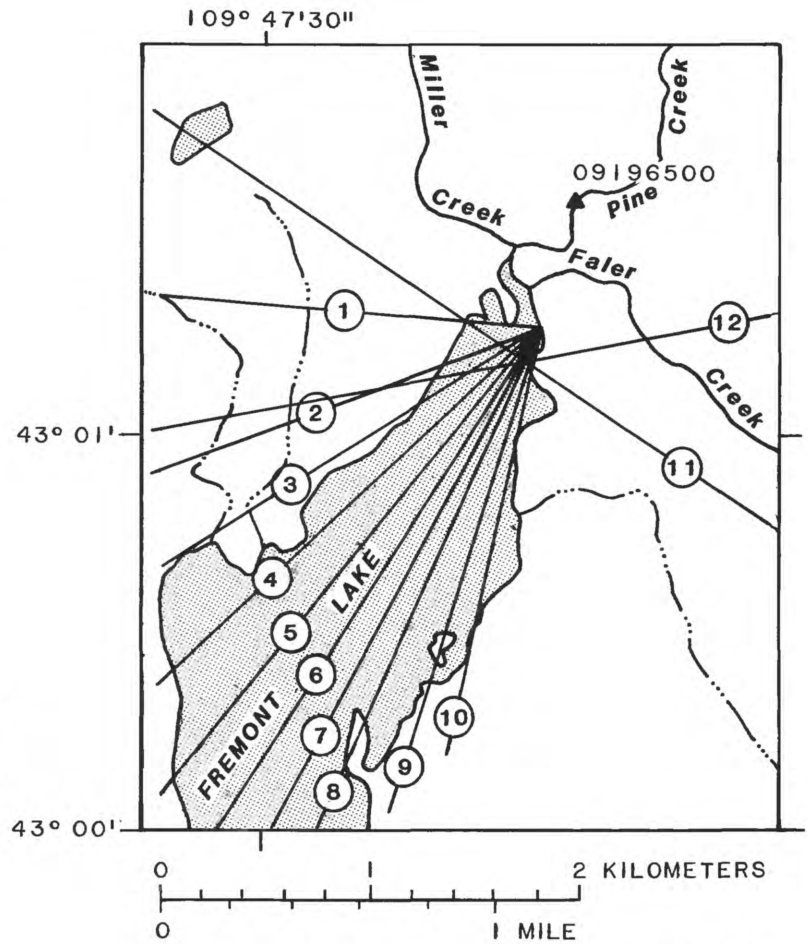


Figure 3.4-1--Location of traverses used to map delta at inlet of Pine Creek to Fremont Lake.

EXPLANATION

—50— LINE OF EQUAL WATER DEPTH--Interval, in meters, is variable

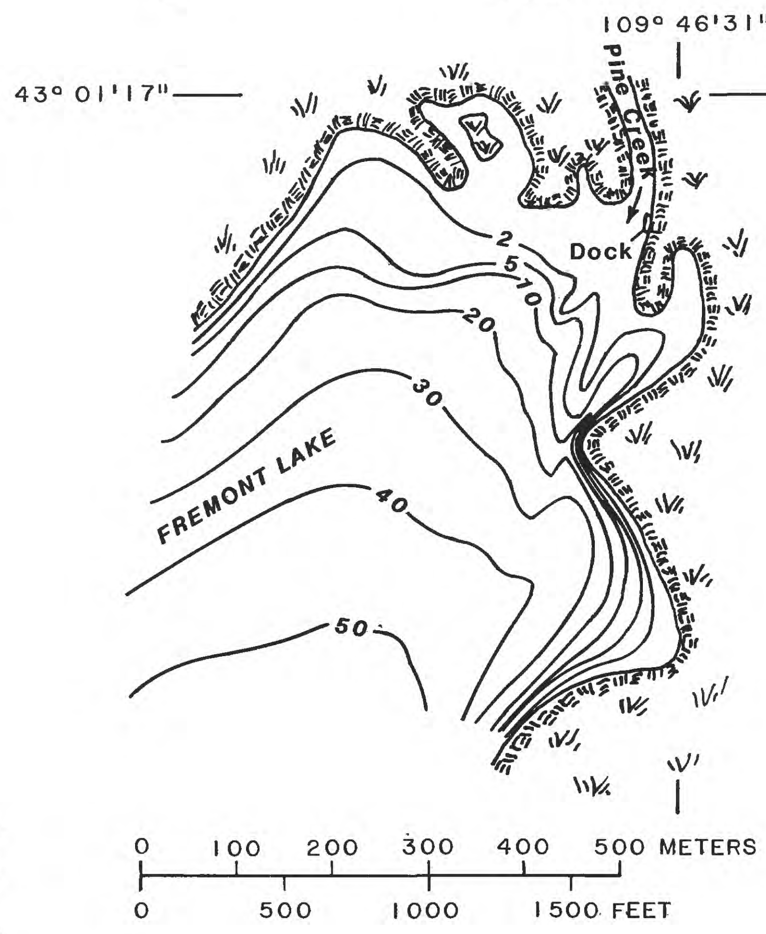


Figure 3.4-2--Bathymetric map of the delta of Fremont Lake.

4.0 BIOLOGY

4.1 Introduction

LAKES ARE ECOSYSTEMS

Lake ecosystems, like terrestrial ecosystems, are comprised of organisms within food chains and trophic levels.

Organisms inhabiting lakes can be assigned to a trophic pyramid such as shown in figure 4.1-1. The dissolved organic matter, which forms the base of the pyramid, is derived from terrestrial, atmospheric, and aquatic sources, such as decomposing plants. Phytoplankton and benthic (bottom) plants are the primary producers in the aquatic food chain, using sunlight for photosynthesis. In Fremont Lake and New Fork Lakes, phytoplankton are more important than benthic plants as primary producers, because benthic plants are sparse. Benthic invertebrates and zooplankton are the primary consumers of phytoplankton. Fish occupy the highest level of the aquatic trophic pyramid. Not shown in the diagram are the bacteria, fungi, and other decomposers that recycle nutrients and minerals bound in organic matter such as tree leaves and dead organisms. Also, some organisms may utilize more than one trophic level as a food source. The trophic pyramid of a stream ecosystem is similar to that of a lake ecosystem, although zooplankton are generally absent and benthic invertebrates (fig. 4.1-2) usually are more abundant and diverse.

Aquatic organisms interact with and may alter their environment. For example, photosynthesis by phytoplankton may increase the pH and dissolved-oxygen concentration in the euphotic zone, and in some cases causes calcium carbonate to precipitate. Dissolved-oxygen concentrations may decrease during dieoff and decomposition of algal blooms.

Nutrient concentrations, mainly phosphorus and nitrogen, have a major effect on productivity of the phytoplankton and benthic plants. Lakes with small nutrient concentrations and low levels of productivity are called oligotrophic lakes. Moderate nutrient concentrations and moderate productivity are associated with mesotrophic lakes, and large concentrations and high productivity are associated with eutrophic lakes. Eutrophic lakes are characterized by excessive algal production, and commonly have thick beds of benthic plants along the shore. Eutrophic lakes also may experience algal blooms, which can make the water appear as green as pea soup, permeate the water with a foul smell and taste, release toxins, cause depletion of dissolved oxygen during dieoff, or any combination of these. Eutrophication of lakes is a natural process, but commonly is accelerated by human activities.

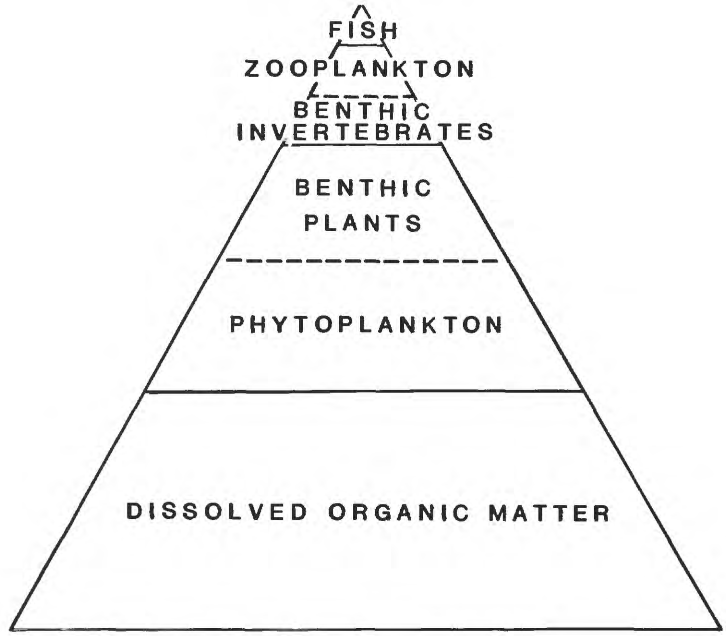


Figure 4.1-1--Trophic pyramid of biomass and dissolved organic matter. The proportional areas of the pyramid are based on the proportions of weight among the trophic levels (modified from Juday, 1942, p. 120).

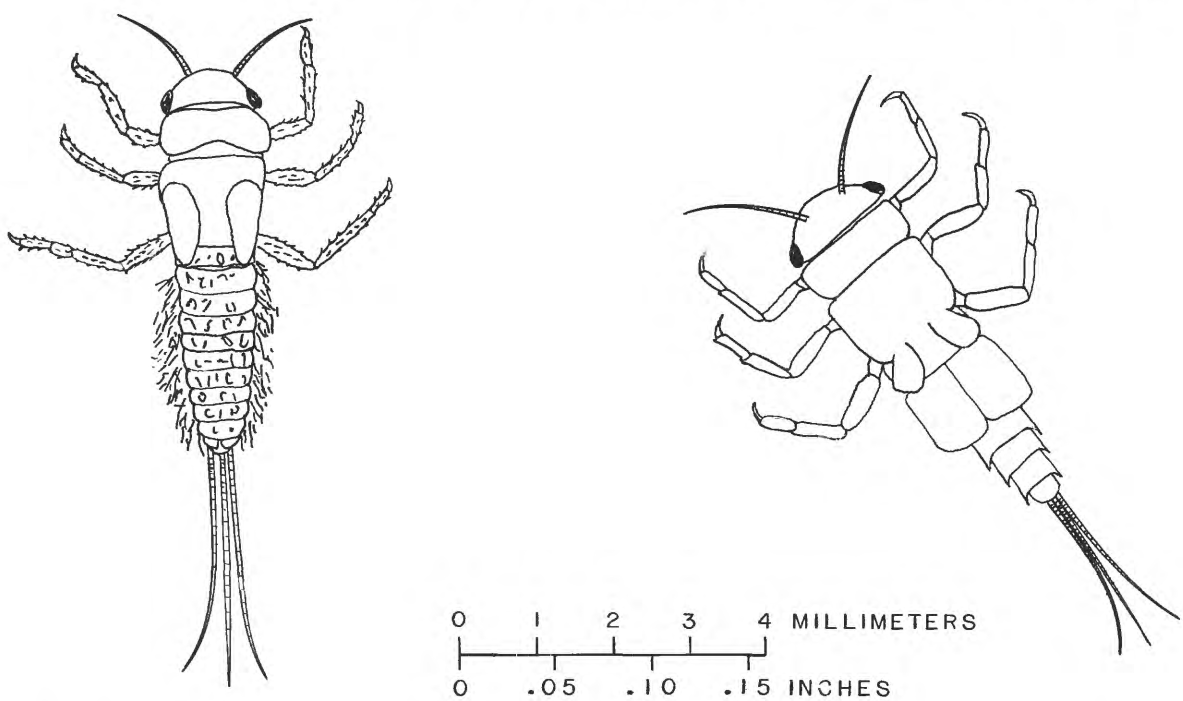


Figure 4.1-2--Mayfly nymphs (Ephemeroptera) are inhabitants of streams and lakes throughout Wyoming. Presence or absence in the study area of the species shown above has not been verified, because the invertebrate analyses were not completed at the time of this writing.

PHYTOPLANKTON POPULATIONS WERE VARIABLE

Phytoplankton concentrations and compositions varied with date and depth of sample collection.

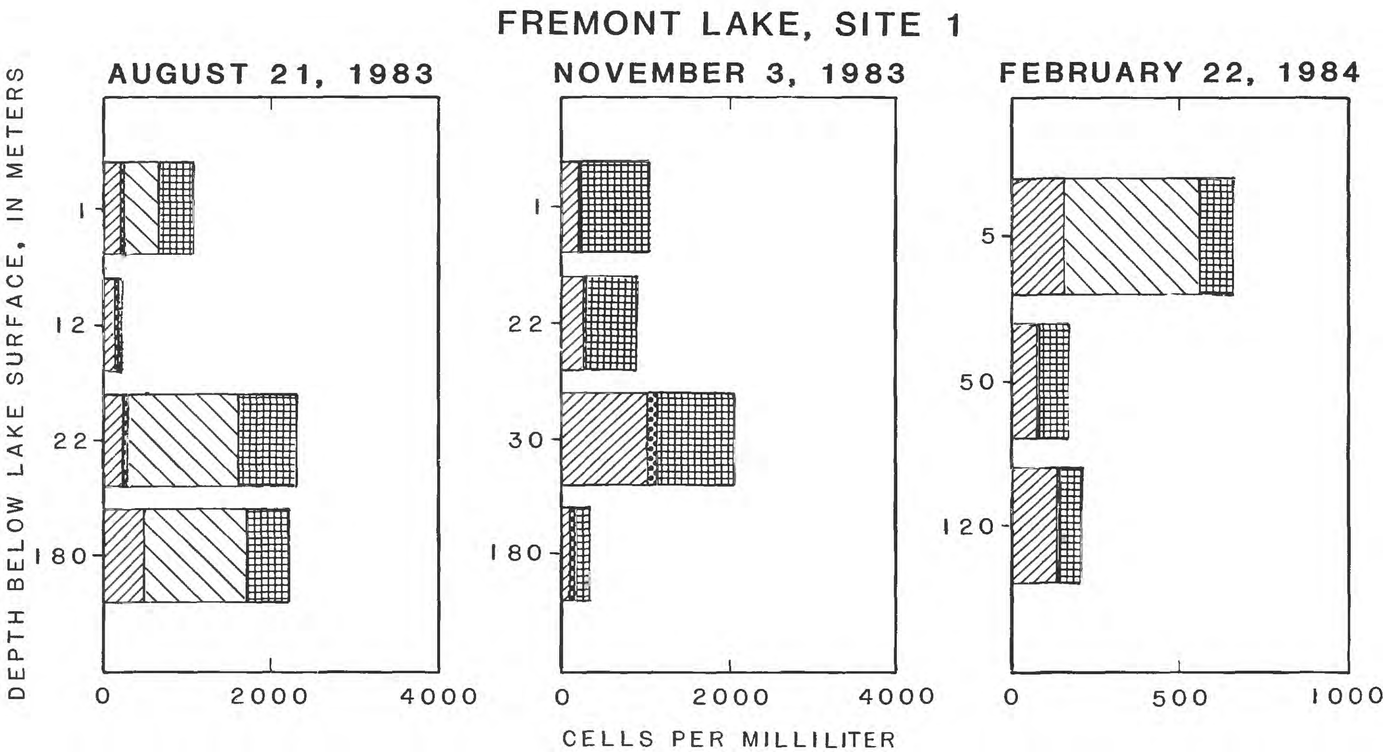
Examples of the variability in phytoplankton (suspended algae) populations in Fremont Lake and New Fork Lakes are presented in figure 4.2. Concentrations generally were greatest in the upper 20 to 30 meters of the lakes, which is the upper euphotic zone. Concentrations at site 1 in Fremont Lake ranged from 168 cells per milliliter at a depth of 50 meters on February 22, 1984, to 25,229 cells per milliliter at a depth of 15 meters on August 17, 1984; the average concentration was 4,840 cells per milliliter. Concentrations at site 2 in New Fork Lakes ranged from 52 cells per milliliter at a depth of 50 meters on October 12, 1984, to 5,940 cells per milliliter, at a depth of 1 meter, also on October 12, 1984; the average concentration was 1,710 cells per milliliter. Concentrations during six sampling periods are listed in table 4.2. The phytoplankton and zooplankton concentrations and taxonomic analyses are listed by the U.S. Geological Survey (1985, p. 438-448).

The composition of the phytoplankton varied with sampling date and depth. Blue-green algae (Cyanophyta) predominated in samples from Fremont Lake during November 1983 and October 1984. Blue-green algae also predominated in samples from New Fork Lakes in November 1983, August 1984, and some of the samples collected at deeper depths in October 1984. This numerical predominance of blue-green algae is somewhat deceptive, because the species detected have small cell sizes, and may not predominate in terms of biomass. Diatoms (Bacillariophyta) are a relatively large-celled phytoplankton that were present in many of the samples, but generally were not numerically predominant. The golden-brown algae (Chrysophyta) sometimes predominated in Fremont Lake. Green algae (Chlorophyta) were predominant in samples from the shallowest depths of site 2 at New Fork Lakes in June and October 1984, but decreased in numbers or were absent in samples collected at greater depths.

Table 4.2.--*Phytoplankton concentrations*

Fremont Lake, site 1		New Fork Lakes, site 2[1]	
Depth (meters)	Concentration (cells per milliliter)	Depth (meters)	Concentration (cells per milliliter)
August 21, 1983			
1	1,061	--	--
12	171	--	--
22	2,290	--	--
180	2,200	--	--
November 3, 1983		November 2, 1983	
1	1,040	1	2,586
22	894	20	573
30	2,040	25	480
180	336	50	135
February 22, 1984			
5	656	--	--
50	168	--	--
120	204	--	--
June 11, 1984		June 13, 1984	
1	14,938	10	4,191
10	9,251	20	1,531
20	10,125	30	1,093
30	18,062	40	1,406
40	3,562	50	438
80	5,000	--	--
120	3,221	--	--
150	407	--	--
August 17, 1984		August 18, 1984	
1	2,226	1	1,041
10	6,255	10	1,189
15	25,229	20	64
20	9,390	30	464
30	2,396	40	339
40	977	50	765
80	214	--	--
170	665	--	--
October 18, 1984		October 12, 1984	
1	12,350	1	5,940
10	9,068	12	4,817
20	12,050	20	4,420
30	1,650	30	2,015
40	1,314	40	2,404
80	365	50	52

[1]Samples were not collected from New Fork Lakes, site 2 in August 1983 and February 1984.



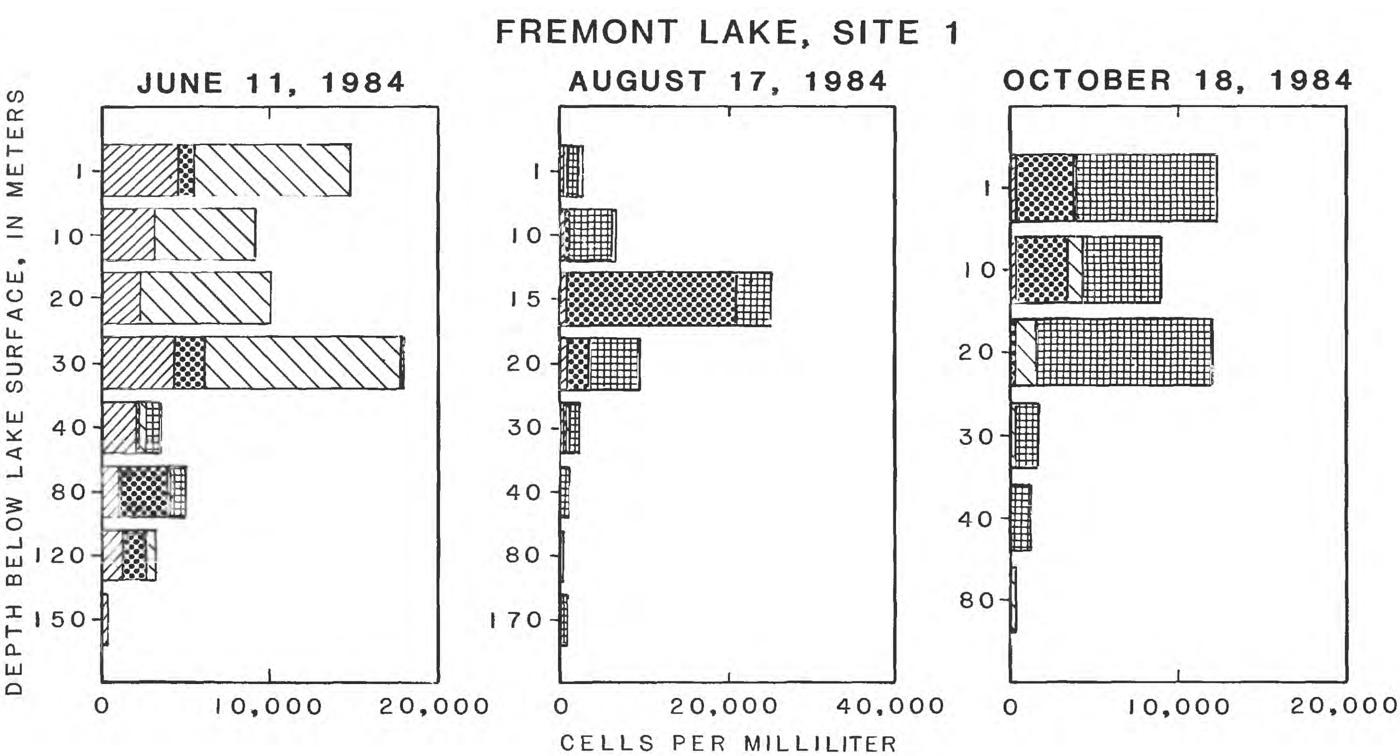
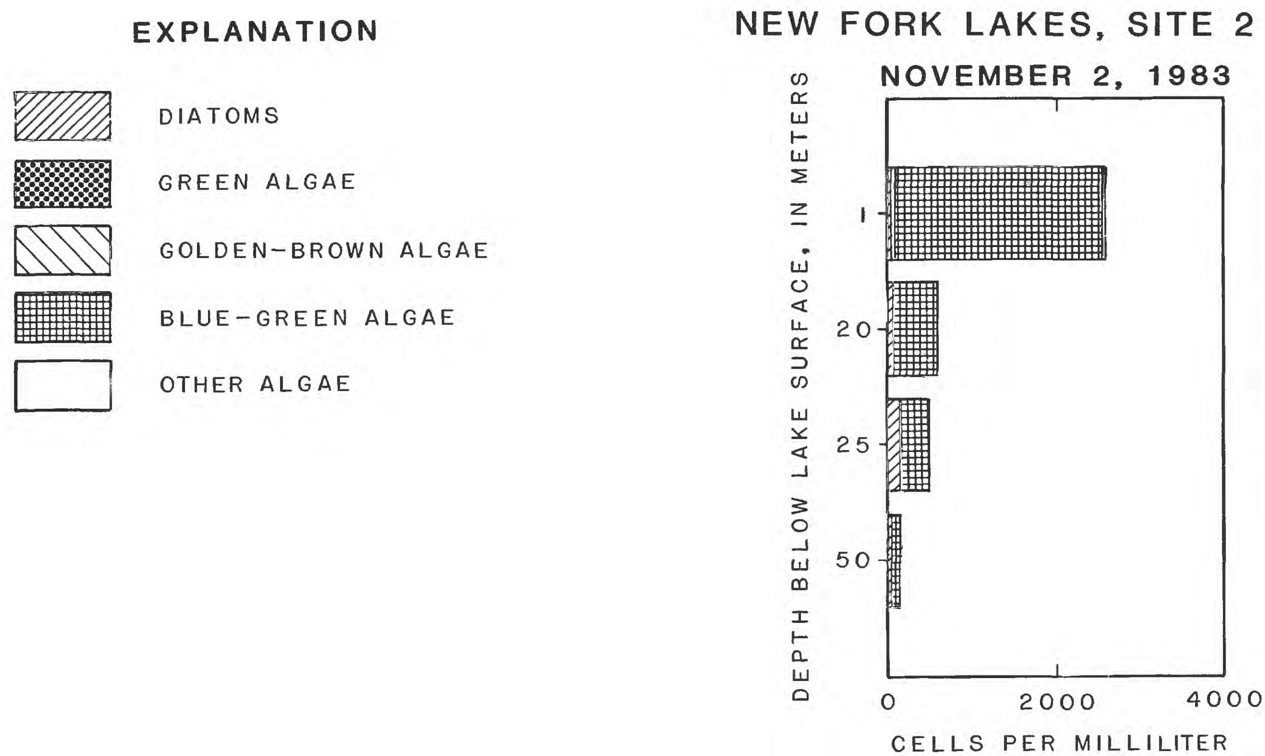
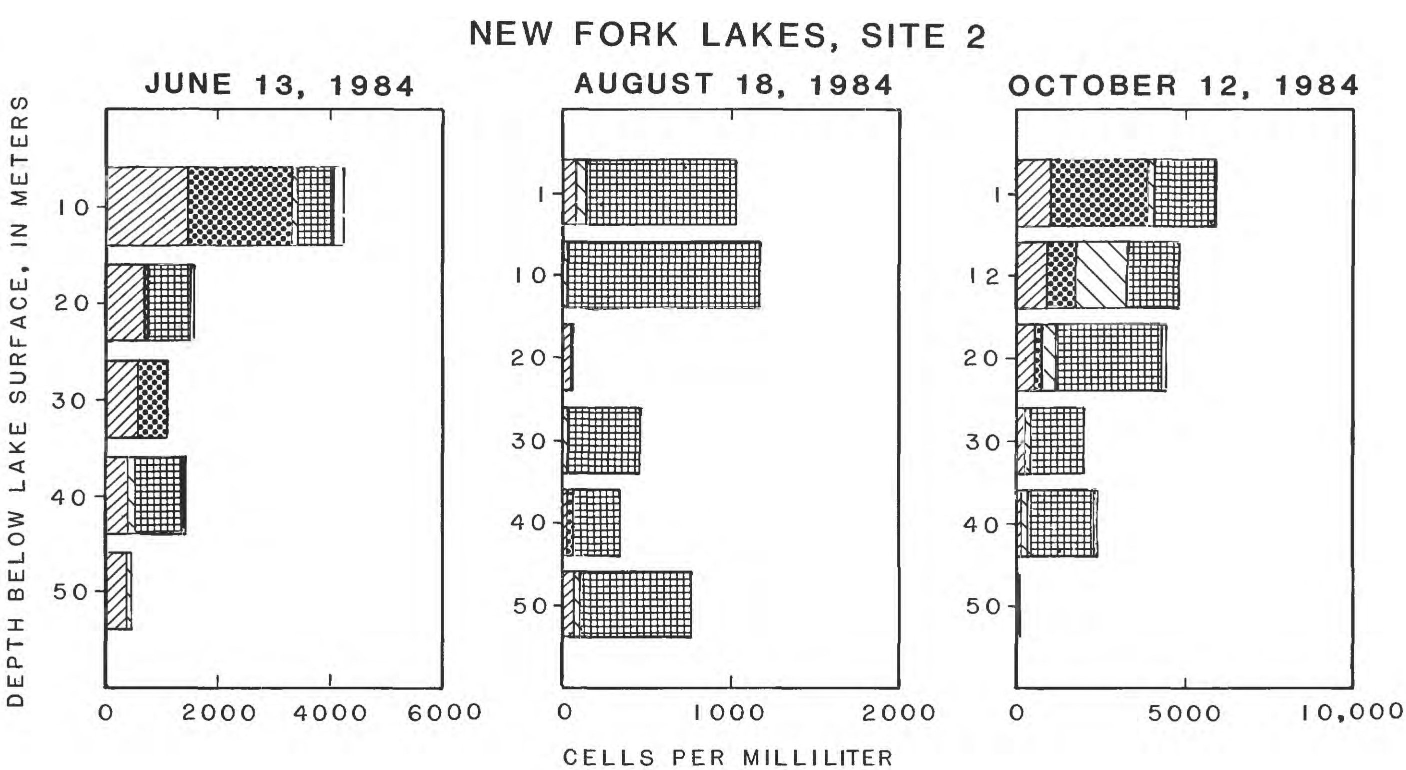


Figure 4.2--Phytoplankton concentration and composition.


EXPLANATION
DIATOMS
GREEN ALGAE
GOLDEN-BROWN ALGAE
BLUE-GREEN ALGAE
OTHER ALGAE
NEW FORK LAKES, SITE 2
NOVEMBER 2, 1983
DEPTH BELOW LAKE SURFACE, IN METERS
1
20
25
50
0
2000
4000
CELLS PER MILLILITER


NEW FORK LAKES, SITE 2
JUNE 13, 1984
AUGUST 18, 1984
OCTOBER 12, 1984
DEPTH BELOW LAKE SURFACE, IN METERS
10
20
30
40
50
0
2000
4000
6000
1
10
20
30
40
50
0
1000
2000
1
12
20
30
40
50
0
5000
10,000
CELLS PER MILLILITER

CHLOROPHYLL CONCENTRATIONS WERE VARIABLE

The concentrations of chlorophyll a varied with depth and date of sampling.

Samples of chlorophylls a and b were collected in conjunction with some of the phytoplankton samples from Fremont Lake and New Fork Lakes. Several types of chlorophyll can be found in phytoplankton cells, depending on which types of algae are present. Chlorophylls a and b are relatively common types of chlorophyll and generally are sampled in limnological studies as indicators of algal biomass. Concentrations of chlorophyll a at site 1 in Fremont Lake ranged from less than the detection limit of 0.1 microgram per liter to 7.8 micrograms per liter (fig. 4.3); the median concentration was 0.4 microgram per liter. Concentrations of chlorophyll a at site 2 in New Fork Lakes ranged from 0.1 to 4.7 micrograms per liter; the median concentration was 0.3 microgram per liter. Samples for chlorophyll b were collected from the lakes, but concentrations generally were less than the detection limit of 0.1 microgram per liter. The analyses have been published by the U.S. Geological Survey (1984, p. 477-478, and 1985, p. 437-445).

Chlorophyll concentrations are sometimes used in lieu of phytoplankton concentrations in situations where a reliable relation between the two concentrations has been calculated. However, the relation between chlorophyll a and phytoplankton concentrations in the study lakes appears to be weak, based on regression relations. The regressions were influenced by the small number of samples, concentrations of chlorophyll a less than the detection limit, and outliers (extreme values) in the data set.

Further study is needed to determine whether a reliable relation between chlorophyll and phytoplankton can be shown from the study lakes. Additional methods of assessing the phytoplankton, such as flourometry, also need to be considered, in order to develop a method transferable to other Rocky Mountain lakes.

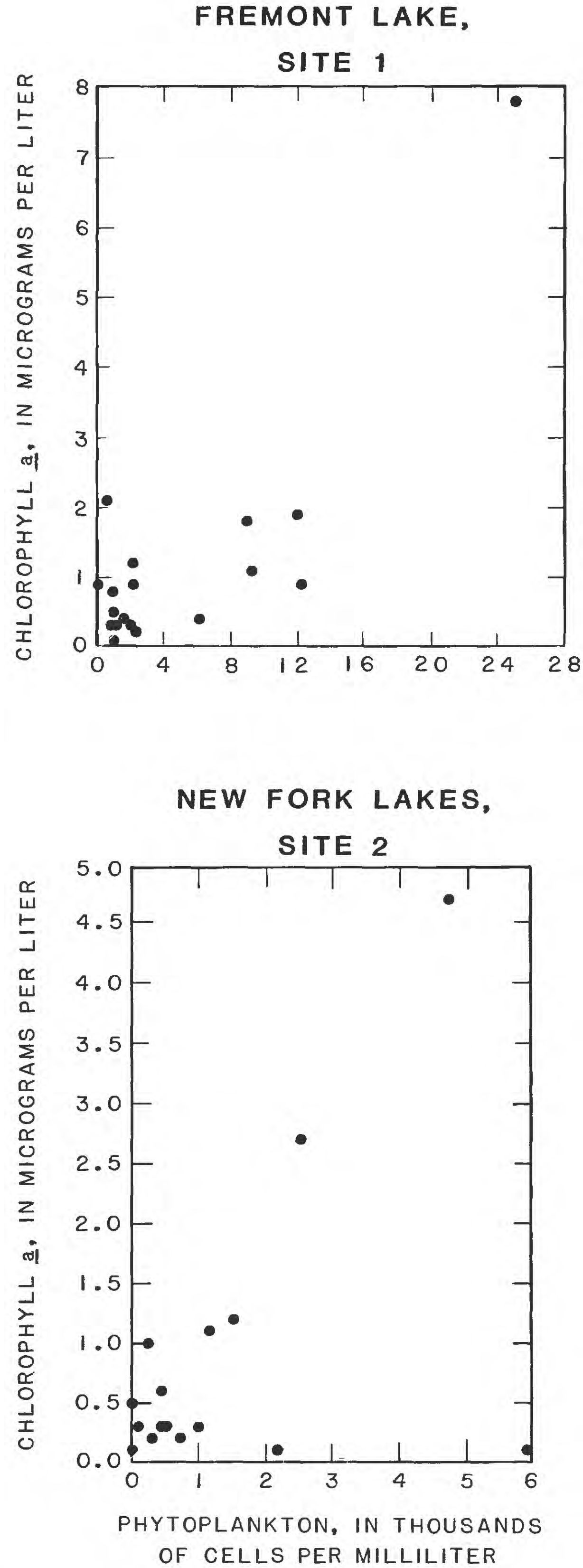


Figure 4.3--Chlorophyll a concentrations versus phytoplankton concentrations. Seven chlorophyll a concentrations from Fremont Lake which were less than the detection limit of 0.1 micrograms per liter are not shown.

SPECIES COMPOSITION OF ZOOPLANKTON WAS SIMILAR IN BOTH LAKES

Zooplankton concentrations were less than 6 organisms per liter.

The species composition of zooplankton was similar in both lakes and the number of species was small (table 4.4). The concentrations of zooplankton found in both lakes also were small, less than 6 organisms per liter. The number of organisms per liter and dry weight of samples collected by vertical tows from 20 meters to the surface are shown in figure 4.4. Based on samples from 3 to 7 vertical tows, most of the zooplankton were collected at depths of less than 20 meters. Zooplankton concentrations were larger in August than in June or October.

Zooplankton were collected in Fremont Lake and New Fork Lakes using a cone-shaped net with a mouth diameter of 0.5 meter and a mesh size of 210 micrometers. The net was lowered to a pre-determined depth and raised vertically. On each date, 3 to 7 vertical tows were collected at each site, from various depths to the surface. Zooplankton were removed from the net, placed in bottles, and preserved with formalin.

The major groups of zooplankton include the Protozoa, Rotatoria (rotifers), and Crustacea (table 4.4). A brief discussion of each group (Pennak, 1978) follows.

Protozoa are single-celled, independent animals, although many form colonies. Members of the Protozoa range in size from 5 micrometers to 5 millimeters and the body shapes are variable. Protozoa are aerobic organisms, but most can live with greatly decreased oxygen concentrations. The free-swimming forms found in lakes are food for larger animals.

Rotatoria (rotifers) have a considerable range of adaptations and forms, and are multicellular. Rotifers generally have much greater oxygen requirements than the Protozoa, although some species such as Keratella (found in Fremont Lake and New Fork Lakes) commonly occur in oxygen-deficient waters. Rotifers are a source of food for larger animals. They may be sessile (attached) or free swimming. Most mountain and oligotrophic lakes contain less than 20 rotifers per liter, especially during the cold months (Pennak, 1978, p. 179). The number of all zooplankton in Fremont Lake and New Fork Lakes was considerably less than this value.

Aquatic Crustacea breathe through gills or through the general body surface, have two pair of antennae, and have jointed appendages. They represent a large number of small multicellular organisms including Daphnia, or waterfleas, and Cyclops. Crustacea are extremely important as a source of fish food and as a control of green-algal production.

Table 4.4.--*Total species of zooplankton collected in June, August, and October 1984*

Fremont Lake, site 1	New Fork Lakes, site 2
PROTOZOA	
Ceratium hirundinella	*Difflugia*
Difflugia	
ROTATORIA	
Kellicottia longispina	*Filinia longiseta*
Keratella cochlearis	*Kellicottia longispina*
Polyarthra	*Keratella cochlearis*
	Lepadella
CRUSTACEA	
Cladocera	
Bosmina longirostris	*Daphnia catawba*
Daphnia catawba	*Daphnia rosea*
Daphnia rosea	*Leptodora kindtii*
Leptodora kindtii	
Ceriodaphina reticulata	
Ccpepoda	
Cyclops bicuspidatus thomasi	*Cyclops bicuspidatus thomasi*
Diaptomus ashlandi nauplii	*Diaptomus ashlandi* nauplii

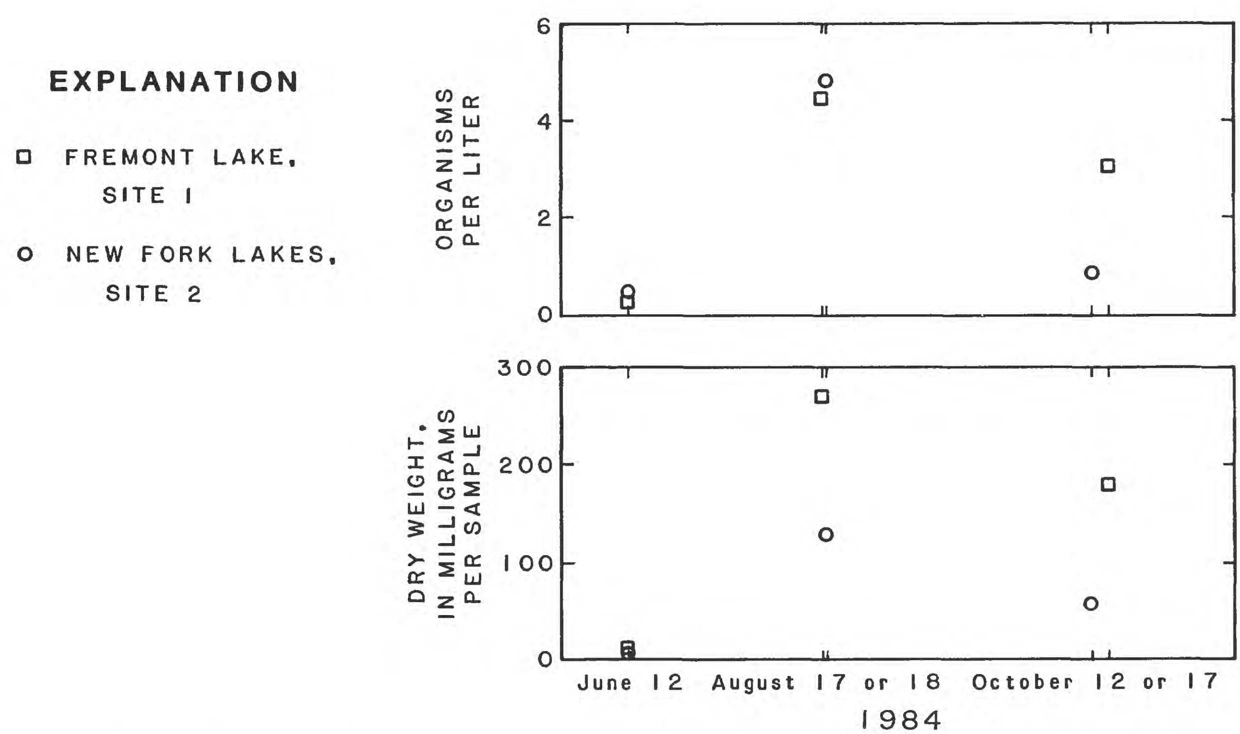


Figure 4.4--Zooplankton numbers and dry weights in samples collected by vertical tows from 20 meters to the lake surface.

4.5 Benthic Invertebrates

NUMBERS OF BENTHIC INVERTEBRATES IN FREMONT LAKE EXTREMELY SMALL

Some Chironomidae were collected from the lake using a grab sampler; drift samples were collected from the inlet and outlet streams.

Benthic (bottom) invertebrate samples were collected from 50 sites in Fremont Lake during August and October 1984, using a Ponar grab sampler. Samples were not collected from New Fork Lakes. The Fremont Lake samples were collected in a longitudinal direction along the greater axis of the lake. Preliminary estimates from the Ponar grab samples revealed a sparse community of only about 15 Chironomidae larvae per square meter. The Chironomidae, also called midges, were identified as the large red *Phaenopsectra* and another genus, either *Einfeldia* or *Chironomus*. The Protozoan Rhizopoda was common in the benthic invertebrate samples. The Chironomid *Procladius* was found in a 150-meter vertical zooplankton tow.

In the inlet stream to Fremont Lake (Pine Creek), drift nets were used to collect invertebrates in diel drift studies conducted in August and October (fig. 4.5). Diel drift studies also were conducted on the outlet stream. Analysis of these samples is incomplete at the time of this writing.

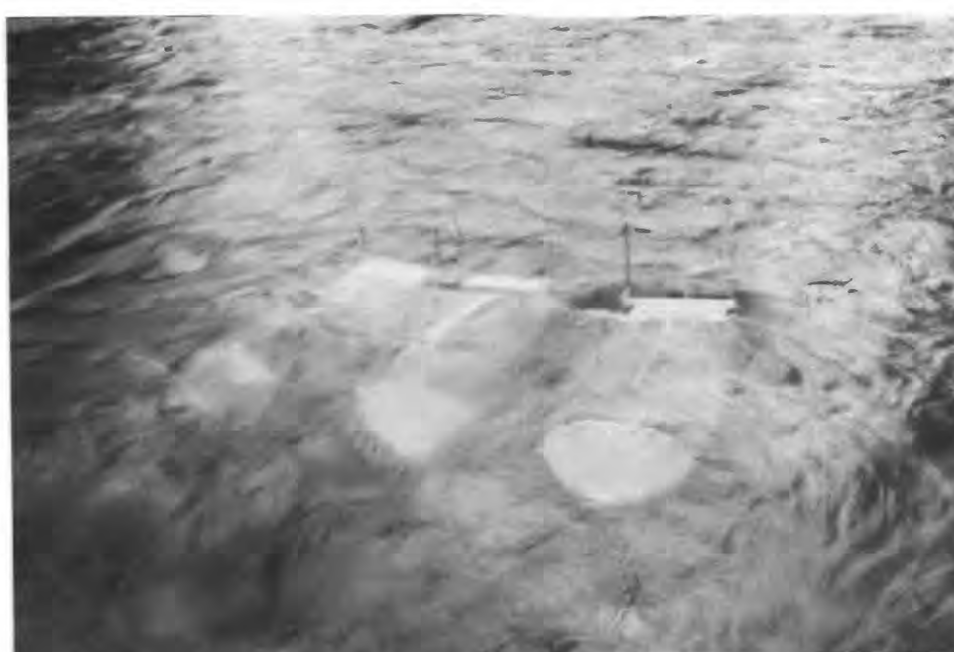


Figure 4.5--Distant and close-up view of nets used to sample drifting invertebrates during diel study in August 1984 in Pine Creek upstream from Fremont Lake.

5.0 DISSOLVED SOLIDS, PRINCIPAL IONS, AND NUTRIENTS

5.1 Introduction and Methods

WATER QUALITY MAY AFFECT USE

The concentrations of dissolved solids, principal ions, and nutrients affect the use of the water.

Determination of water quality largely is dependent on the intended use (fig. 5.1-1 and tables 5.1-1 and 5.1-2). For example, a water supply might contain a concentration of dissolved solids acceptable for irrigation, but too large for industrial use without treatment. The concentration of dissolved solids in the study lakes and streams is much less than the national standards for drinking water, irrigation, and livestock. Selected standards or guidelines of dissolved-solids concentrations are listed in table 5.1-1.

The principal ions also affect the use of the water. The water of the study lakes and streams is soft, according to the hardness classifications listed in table 5.1-2. Hardness is governed by calcium and magnesium, which are two of the principal ions. The other principal ions are sodium, potassium, bicarbonate, sulfate, and chloride. Sodium concentrations are sometimes a concern to persons with heart problems. Large sulfate concentrations in drinking water can have a laxative effect; sulfate concentrations in the study lakes and streams are relatively small.

Nutrient concentrations may affect water use through lake eutrophication and the danger of nitrates as a health hazard. Large nitrate concentrations can be a health hazard, because of the possibility of methoglobinemia, or "blue-baby" disease. Nitrate concentrations in the study lakes and streams are much less than the upper limit of 10 milligrams per liter nitrate nitrogen recommended by the U.S. Environmental Protection Agency (1976, p. 201-209).

The methods of sample collection in the lakes varied slightly from methods used at stream sites (site locations shown in fig. 5.1-2). Samples were collected, with an acrylic Kemmerer bottle, at site 1 in Fremont Lake and site 2 in New Fork Lakes, excepting samples collected at site 1 in New Fork Lakes on February 23, 1984. Samples were collected from the streams by dipping the sample container into flowing water. All sample containers were thoroughly rinsed with sample water prior to filling. Samples for analysis of dissolved solids and principal ions were pumped through a membrane filter with pores having a diameter of 0.45 micrometer, and acidified as appropriate. Samples for analysis of dissolved nutrients were filtered in the same manner, treated with mercuric chloride, chilled, and shipped in dark-colored bottles. Samples were analyzed at the U.S. Geological Survey laboratory in Denver, Colorado. The analyses have been published (U.S. Geological Survey, 1984, p. 477-478, and 1985, p. 436-449) and are listed in the WATSTORE computer file.

Table 5.1-1.--*Classification of water for various concentrations of dissolved solids*

Classification	Dissolved-solids concentration (milligrams per liter)
National secondary drinking-water standard[1]	500
Water from which no detrimental effects on crops will usually be noticed[2]	500
Excellent for all classes of livestock and poultry[3]	1,000
Average in Fremont Lake, site 1	13
Average in New Fork Lakes, site 2	24

[1]U.S. Environmental Protection Agency, 1979, p. 42,195-42,202.
[2]U.S. Environmental Protection Agency, 1976, p. 399.
[3]National Academy of Sciences and National Academy of Engineering, 1973, p. 308.

Table 5.1-2.--*Classification of water by hardness content*

Classification	Hardness concentration, as calcium carbonate (milligrams per liter)
Soft	Less than 60
Moderately hard	60 - 120
Hard	120 - 180
Very hard	More than 180
Average in Fremont Lake, site 1	7
Average in New Fork Lakes, site 2	14

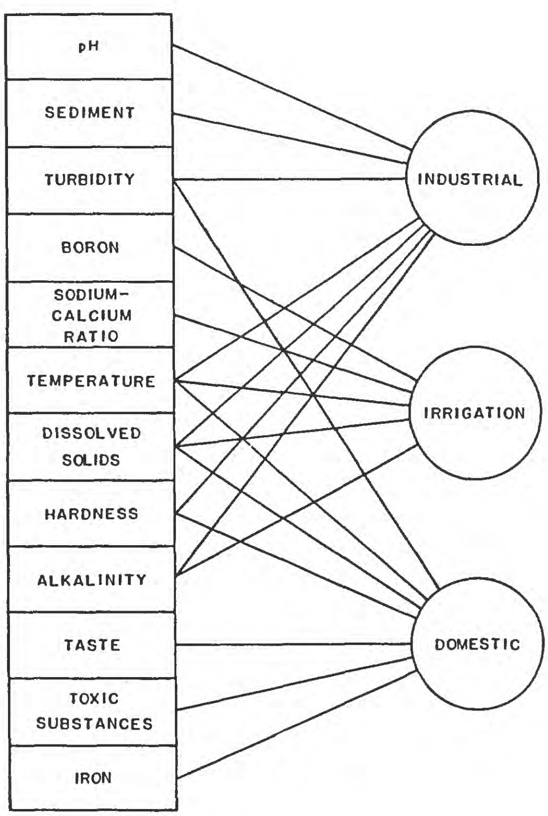


Figure 5.1-1--Properties and constituents that affect the intended use of water.

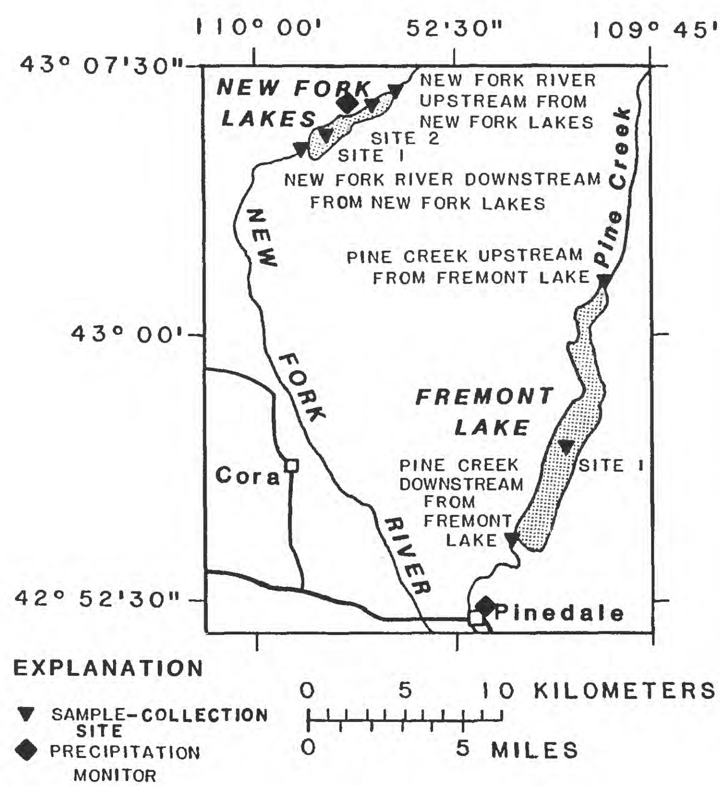


Figure 5.1-2--Location of collection sites for samples analyzed for dissolved solids, principal ions, nutrients, and trace metals.

CONCENTRATIONS OF DISSOLVED SOLIDS AND MAJOR IONS WERE QUITE SMALL

The average concentration of dissolved solids in Fremont Lake was 13 milligrams per liter; the average concentration of dissolved solids in New Fork Lakes was 24 milligrams per liter.

The concentrations of dissolved solids and principal ions in the inflow and outflow streams were in the same ranges as their respective lakes; the concentrations are shown in figures 5.2-1 to 5.2-4. Rickert and Leopold (1972, p. D182) note the dissolved-solids concentration of Fremont Lake is remarkably small for the large size and drainage area of the lake. On a worldwide basis, Fremont Lake belongs to a special class of large, ultradilute lakes.

The predominant cation (positively charged ion) in the lakes and streams was calcium and the predominant anion (negatively charged ion) was bicarbonate, on both a microequivalent-per-liter and milligram-per-liter basis. In Fremont Lake, calcium concentrations ranged from 105 to 130 microequivalents per liter (2.1 to 2.6 milligrams per liter) and bicarbonate concentrations ranged from 164 to 197 microequivalents per liter (10.0 to 12.0 milligrams per liter). Concentrations in New Fork Lakes were slightly larger; calcium concentrations ranged from 170 to 279 microequivalents per liter (3.4 to 5.6 milligrams per liter) and bicarbonate concentrations ranged from 262 to 410 microequivalents per liter (16.0 to 25.0 milligrams per liter).

The bicarbonate concentrations indicate that the lakes and streams are not well buffered. Bicarbonate is the principal component of alkalinity, or buffering capacity, within the pH range of the lakes and streams. Based on their work in high-altitude lakes in Colorado, Turk and Adams (1983, p. 350) indicated that lakes with alkalinity concentrations less than 200 microequivalents per liter are sensitive to acidification by precipitation with pH similar to that of the northeastern United States. On the basis of bicarbonate concentrations, Fremont Lake is sensitive to acidic precipitation. Several of the samples from Pine Creek upstream and downstream from Fremont Lake also contained bicarbonate concentrations less than 200 microequivalents per liter.

Vertical profiles generally showed an increase of dissolved-solids and principal-ion concentrations in the study lakes in August and November 1983, and in June and August 1984, particularly in New Fork Lakes. In February 1984, the dissolved-solids and principal-ion concentrations in the study lakes remained relatively constant with depth. Further work is needed to determine the significance of these changes with regard to lake stratification and overturn.

The dilute concentrations in the lake waters affected some of the sample analyses. The residue-on-evaporation method of measuring dissolved solids proved to be unsatisfactory, probably because of the dilute concentrations. The residue-on-evaporation concentrations reported by the laboratory showed little correlation with the calculated dissolved-solids concentrations, which are shown in the figures. Chloride concentrations in samples collected from Fremont Lake in February 1984 were less than the detection limit of 0.2 milligram per liter and are omitted from figure 5.2-4. The sum of the anions was slightly larger than the sum of the cations, for most of the samples. The methods of analysis are a possible source of the disparity.

Further work is needed to calculate a chemical budget for the lakes. Additional chemical sampling of the lakes, and their inflow and outflow streams, in conjunction with streamflow records from the inflow and outflow streams, is needed to attempt to develop chemical models of the hydrologic systems.

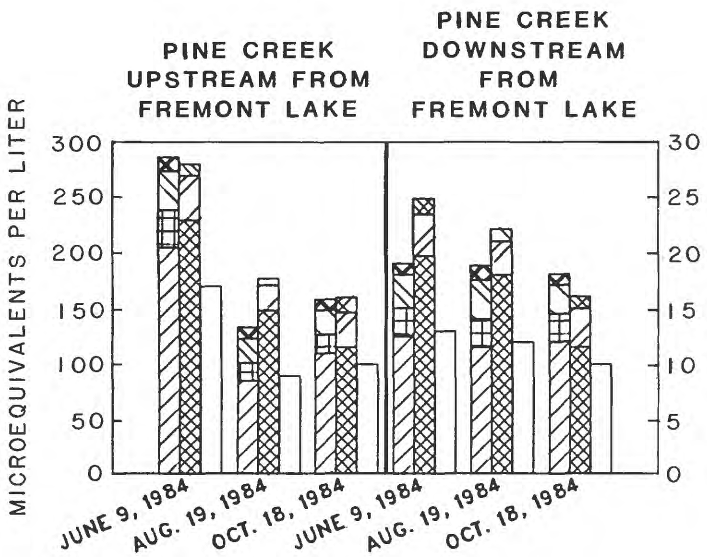


Figure 5.2-1--Dissolved-solids and principal-ion concentrations in Pine Creek upstream from and downstream from Fremont Lake, in 1984.

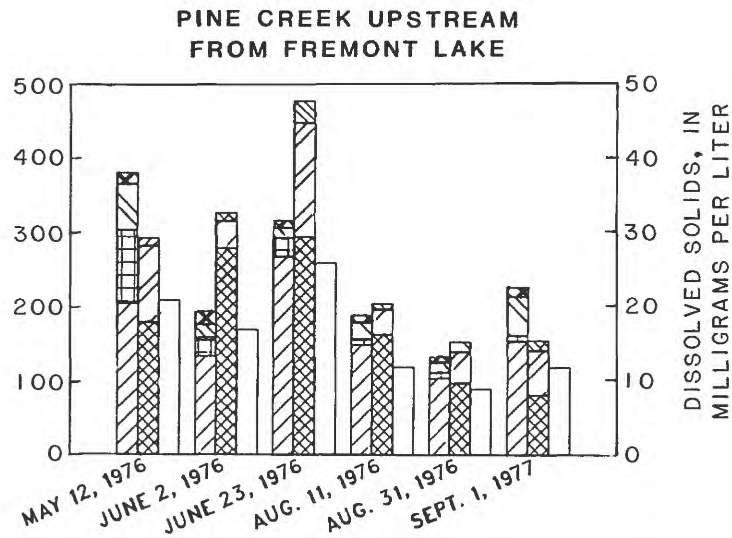


Figure 5.2-2--Dissolved-solids and principal-ion concentrations in Pine Creek above Fremont Lake (streamflow-gaging station 09196500) in 1976 and 1977.

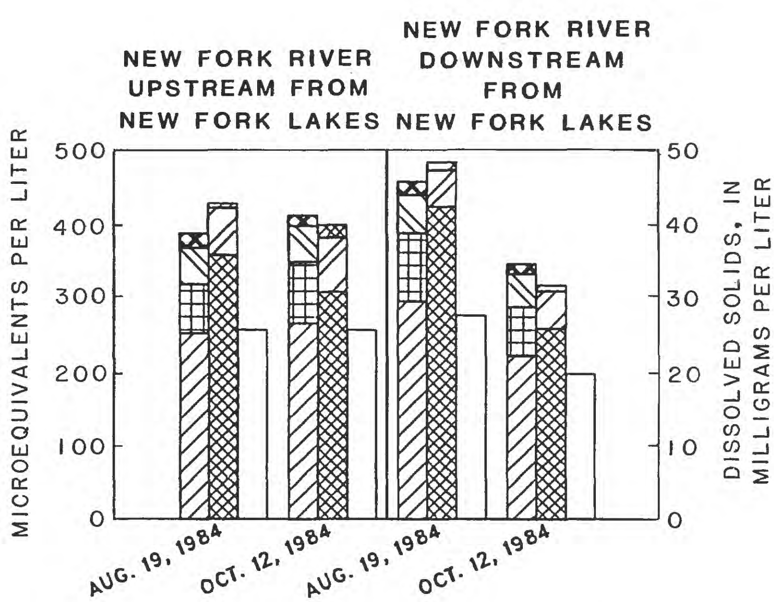
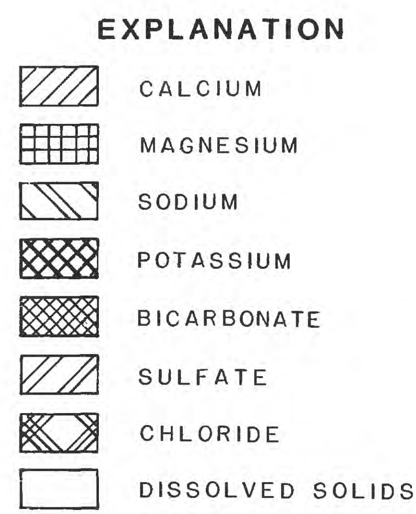


Figure 5.2-3--Dissolved-solids and principal-ion concentrations in the New Fork River upstream and downstream from New Fork Lakes.



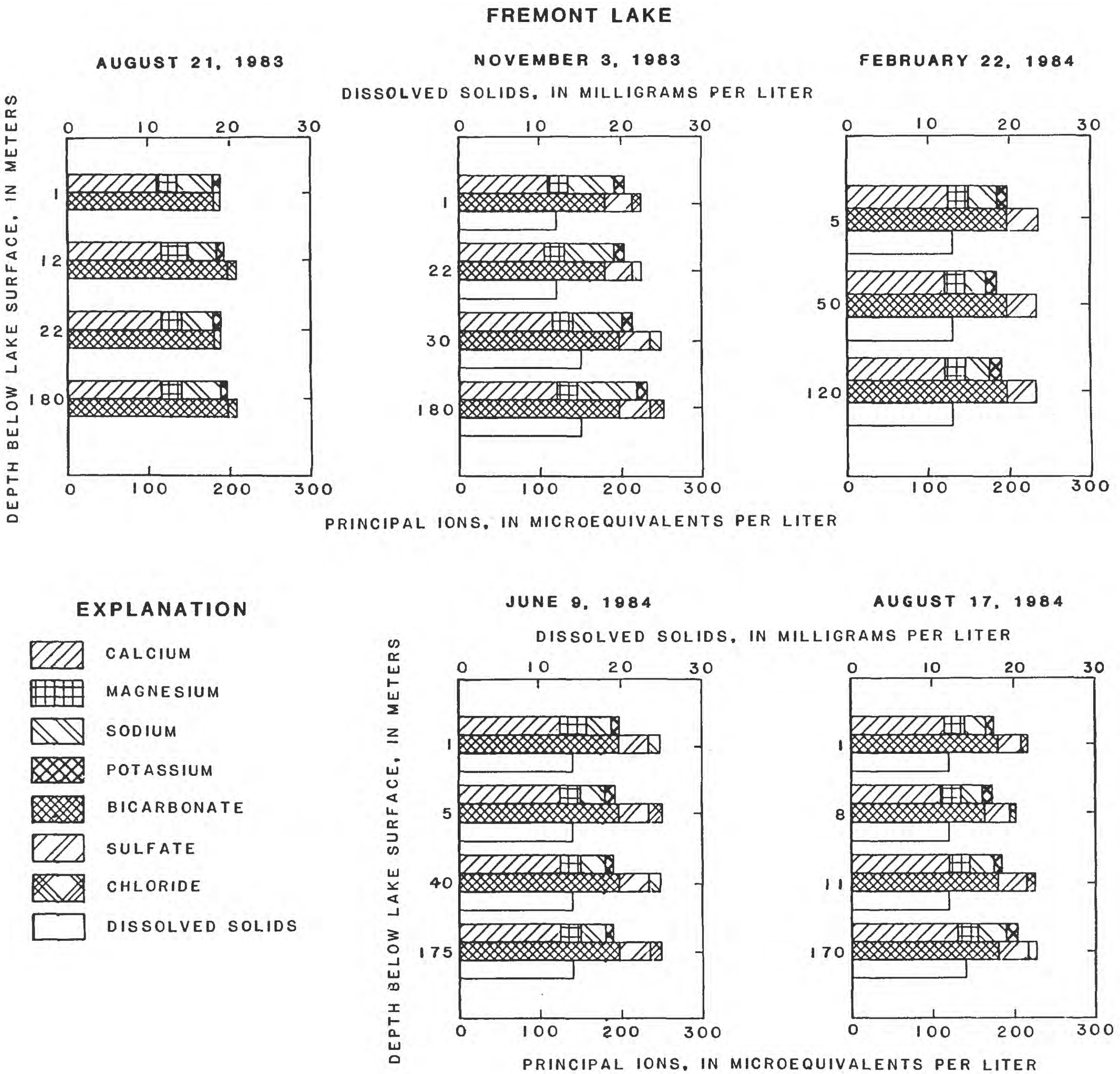
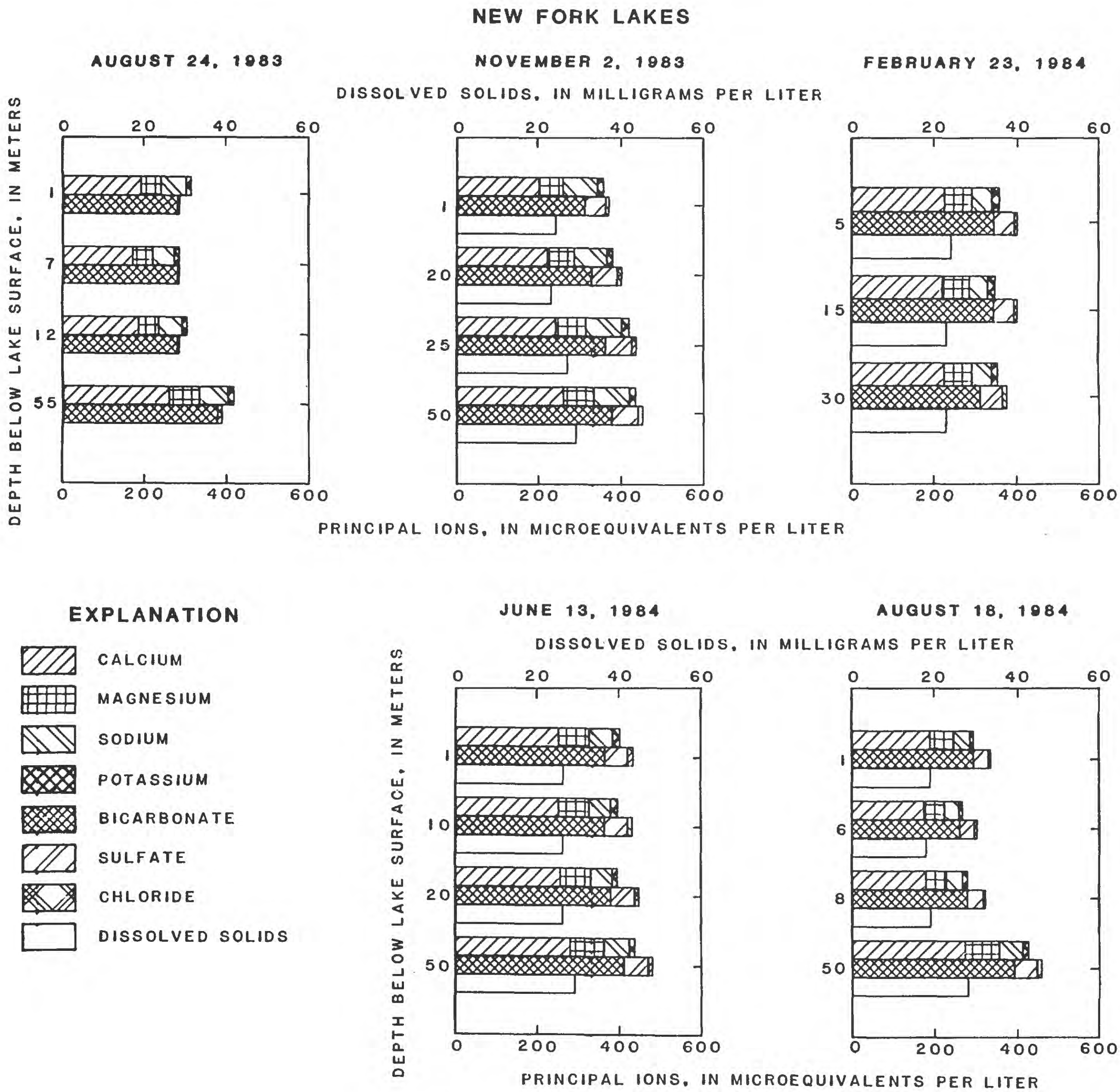


Figure 5.2-4--Dissolved-solids and principal-ion concentrations at various depths in Fremont Lake and New Fork Lakes.


NEW FORK LAKES
AUGUST 24, 1983
NOVEMBER 2, 1983
FEBRUARY 23, 1984
DISSOLVED SOLIDS, IN MILLIGRAMS PER LITER
DEPTH BELOW LAKE SURFACE, IN METERS
PRINCIPAL IONS, IN MICROEQUIVALENTS PER LITER
EXPLANATION
CALCIUM
MAGNESIUM
SODIUM
POTASSIUM
BICARBONATE
SULFATE
CHLORIDE
DISSOLVED SOLIDS
JUNE 13, 1984
AUGUST 18, 1984
DISSOLVED SOLIDS, IN MILLIGRAMS PER LITER
DEPTH BELOW LAKE SURFACE, IN METERS
PRINCIPAL IONS, IN MICROEQUIVALENTS PER LITER

NUTRIENT CONCENTRATIONS WERE SMALL

Concentrations of phosphorus and nitrogen were small; concentrations of dissolved silica were smaller in Fremont Lake than in New Fork Lakes.

Phosphorus concentrations were small, generally less than detection limits, in the study lakes and in the inflow and outflow streams. The phosphorus concentrations were much less than concentrations associated with nuisance algal growths (blooms). The recommended limit of total phosphorus for prevention of nuisance growths is 0.1 milligram per liter in streams not discharging directly to lakes or reservoirs (Mackenthun, 1973). The concentrations of total phosphorus in the study lakes and streams generally were near or less than the detection limits of 0.01 or 0.005 milligrams per liter, depending on the analytical method used. Additionally, the recommended limits of phosphate for prevention of nuisance algal growths are: total phosphate (as phosphorus) should not exceed 0.05 milligram per liter in any stream where it enters a lake or reservoir, nor 0.025 milligram per liter within the lake or reservoir (U.S. Environmental Protection Agency, 1976, p. 356). By comparison, the concentrations of total phosphate (as phosphorus) in the study lakes and streams generally were less than 0.01 or 0.002 milligram per liter, depending on the detection limit of the analytical method used. On the basis of phosphorus concentrations, Fremont Lake and New Fork Lakes are oligotrophic.

Concentrations of dissolved and total nitrite plus nitrate (as nitrogen) in the study lakes and streams were less than the detection limit of 0.10 milligram per liter. Most concentrations of total ammonia plus organic nitrogen (as nitrogen) were less than the detection limit of 0.2 milligram per liter. Nitrogen is an important nutrient for algae, but is generally less important than phosphorus as a key element in lake eutrophication. On the basis of nitrogen concentrations, Fremont Lake and New Fork Lakes are oligotrophic.

Concentrations of dissolved silica were smaller in Fremont Lake than in New Fork Lakes (fig. 5.3). The median concentration of silica in Fremont Lake was 1.4 milligrams per liter. The concentrations of silica in samples from 1 meter and 22 meters below the surface of Fremont Lake on November 3, 1983, were reported as less than 1.2 milligrams per liter. The median concentration of silica in New Fork Lakes was 3.5 milligrams per liter; the average concentration was 3.6 milligrams per liter.

Dissolved silica is an important nutrient to phytoplankton, particularly diatoms. Diatom growth may be limited if silica concentrations are too small (Hutchinson, 1967, p. 443-452 and Cole, 1975, p. 246-247). Further analysis is required to determine the relation between silica concentrations and phytoplankton growth in the study lakes.

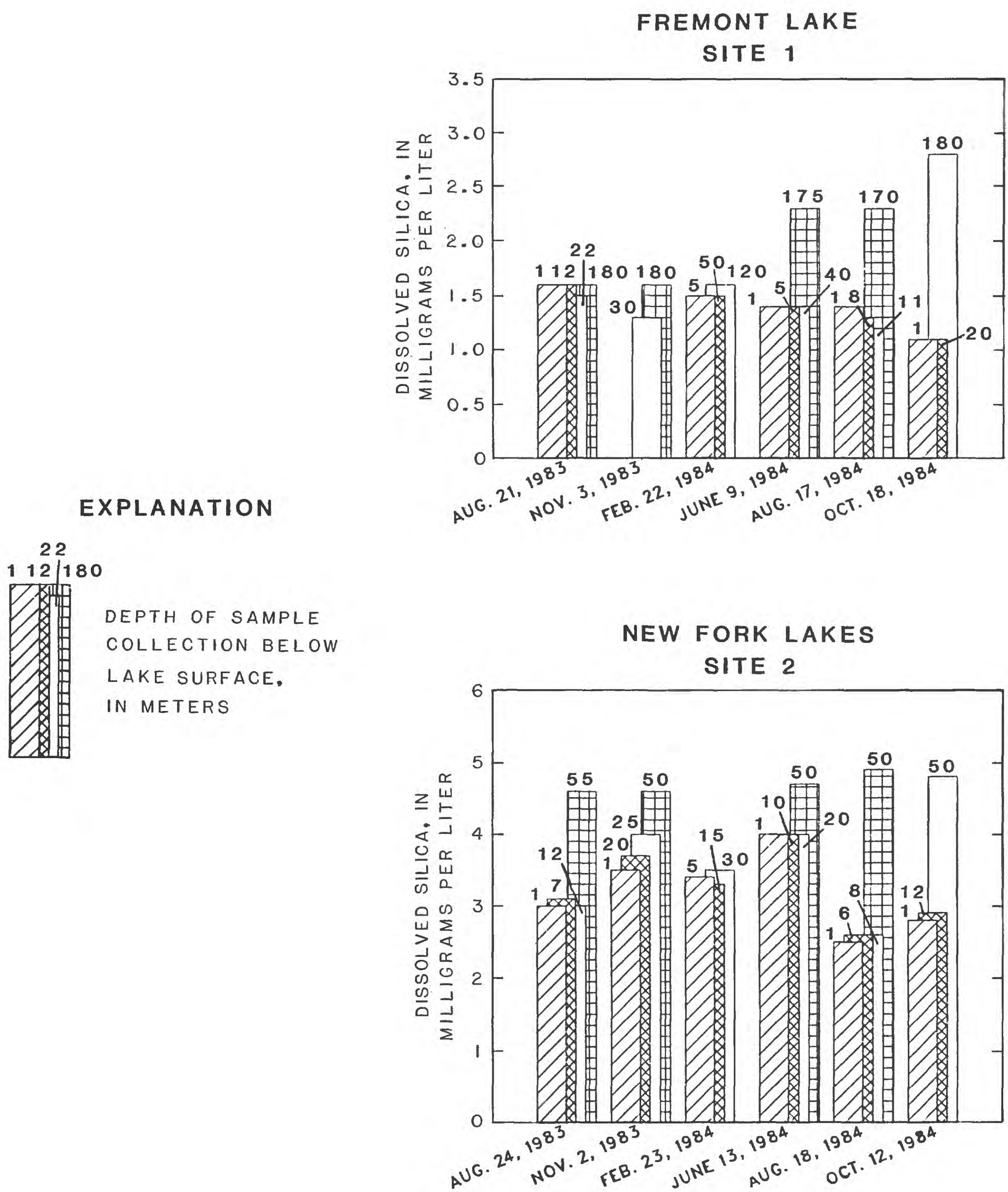


Figure 5.3--Silica concentrations.

6.0 TRACE-METAL CHEMISTRY

CONCENTRATIONS OF TRACE METALS IN LAKES, STREAMS, AND PRECIPITATION WERE SMALL AND VARIABLE

Concentrations of iron and manganese were the largest determined and had the greatest variability.

Water samples for trace-metal analysis were collected from Fremont Lake and New Fork Lakes and their inlets and outlets, to establish an appropriate sample-collection strategy and to determine the mass balance of trace metals in the lakes. In June, August, and October 1984, water for trace-metal analyses was simultaneously collected with water for analyses of principal ions and organic compounds. All samples were pumped through a membrane filter with a 0.45-micrometer pore diameter, and acidified to pH 2. All trace-metal analysis was by inductively-coupled plasma, atomic-emission spectrometry.

Trace-metal concentrations in the lakes and streams were variable. The greatest variability was in manganese and iron, which also had the largest concentrations. Trace-metal concentrations are listed in table 6.0.

Atmospheric precipitation samples were collected near Fremont Lake and New Fork Lakes using Aerochemetrics samplers. Separate trace-metal collectors were used to collect precipitation at both lakes on an event basis. The collector is an inverted umbrella funnel made of Teflon material, which was precleaned with ultra-pure nitric acid.

Precipitation samples collected near Fremont Lake contained small trace-metal concentrations, with dissolved iron ranging from 8.5 to 97 micrograms per liter. Trace-metal concentrations in precipitation samples collected near New Fork Lakes generally were similar to those collected near Fremont Lake. Precipitation samples from the New Fork Lakes site also were analyzed for major ions. There seemed to be no consistent relation between either pH or specific conductance and time in the precipitation samples. As an example, the specific-conductance values ranged from 4.5 during October to 39 microsiemens per centimeter at 25 °C during June and September 1984.

Additional sample collection and analysis of trace metals in the lakes, streams, and precipitation is planned for 1985. Further analysis will aid in calculating chemical budgets for the lakes.

Table 6.0.--*Trace-metal concentrations in lake, stream, and precipitation samples*

[Values flagged with less than symbol (<) were smaller than the detection limit. Samples for trace metals were not collected from New Fork Lakes in August 1984]

Location	Date of collection	Trace-metal concentrations (micrograms per liter)									
		Barium	Beryllium	Cadmium	Chromium	Copper	Iron	Manganese	Lead	Strontium	Zinc
Fremont Lake											
Depth at site 1:											
1 meter	06/09/84	3.3	<0.1	1.9	0.5	1.9	14	12	1.1	8.9	0.5
150 meters	06/07/84	7.8	< .1	1.3	.3	1.6	10	2.3	1.0	8.7	1.3
Inlet	06/09/84	7.3	< .1	1.3	.6	5.3	15	1.6	4.4	9.3	2.8
Outlet	06/09/84	6.4	< .1	1.1	.4	1.5	9.2	.9	1.4	8.2	.4
Depth at site 1:											
1 meter	08/17/84	2.2	< .1	2.1	.4	2.3	11	.8	.6	10	.2
150 meters	08/17/84	5.1	< .1	2.0	.7	2.6	23	17	1.6	14	3.5
Inlet	08/18/84	4.6	< .1	3.6	< .01	.4	30	1.5	.5	11	.2
Outlet	08/18/84	2.9	< .1	2.4	< .01	1.7	24	1.9	.4	18	.3
Depth at site 1:											
1 meter	10/18/84	1.8	< .1	1.8	< .01	1.6	2.5	1.7	.4	7.5	.3
150 meters	10/18/84	2.0	< .1	2.1	.2	2.2	3.2	.9	.5	9.2	.3
Inlet	10/18/84	3.0	< .1	3.2	< .01	2.3	4.8	1.0	1.6	7.1	.3
Outlet	10/18/84	2.8	< .1	1.9	< .01	1.7	4.3	.8	.6	8.8	.2
New Fork Lakes											
Depth at site 2:											
1 meter	06/26/84	11	< .1	1.5	1.5	3.1	36	4.8	1.5	19	.3
50 meters	06/26/84	8.5	< .1	1.6	< .01	2.8	40	34	16	< .1	7.1
Inlet	06/26/84	9.9	< .1	1.7	2.6	1.5	131	10	1.8	9.9	10
Outlet	06/26/84	7.3	< .1	1.5	< .01	.3	33	4.4	.7	19	.2
Depth at site 2:											
1 meter	10/18/84	4.0	< .1	2.2	.03	2.3	14	2.5	.5	15	20
50 meters	10/18/84	1.4	< .1	2.4	.2	.9	6.6	3.7	.6	5.5	24
Inlet	10/18/84	3.5	< .1	1.3	< .01	1.4	9.1	2.0	.9	12	.3
Outlet	10/18/84	2.0	< .1	2.5	< .01	.2	5.5	.3	.3	9.4	.2
Precipitation samples											
Fremont Lake											
	06/07/84	8.8	< .1	2.0	< .01	20	97	14	15	5.3	75
	06/13/84	4.2	< .1	1.9	.6	8.9	8.5	11	2.1	4.3	38
New Fork Lakes											
	08/15/84	10	< .1	1.3	< .01	8.9	103	13	4.4	2.2	11
	08/16/84	7.1	< .1	--	--	18	250	9.2	--	--	4.8

7.0 ORGANIC CHEMISTRY

7.1 Introduction and Methods

PROCEDURES FOR DETERMINING ORGANIC MATTER ARE COMPLEX AND COSTLY

Analyses of organic matter from water at various depths allows fresh insight to lake productivity.

A primary purpose of the study of Fremont Lake and New Fork Lakes was to obtain information about the organic-matter resources of the lake systems. Organic matter long has been a neglected part of lake-limnology studies because of the cost and lack of definitive analytical techniques. Today, organic chemistry has noticeably advanced, and particularly of interest to this study is the analysis of dissolved organic carbon and fulvic and humic materials. With the development of analytical procedures as well as an understanding of these constituents in nature, it is possible to obtain data for determining the trophic status (energy and material resources) of lakes. It is also possible to relate the organic chemical resources to the inorganic chemical resources, and to relate both of these factors to the biological resources of the lake. A review of the scientific literature indicates that this is the first time whereby sufficient water samples were collected for analysis of humic and fulvic materials from freshwater lakes, at depths such as those found in the study lakes.

Each of the 3 sampling periods for organic chemistry required 4 to 6 weeks of effort. Sample collection was conducted in June, August, and October 1984. Water samples for analysis of humic and fulvic materials were collected from both lake surfaces (1-meter depth), from 150 meters at site 1 in Fremont Lake (fig. 7.1-1), and from 46 meters at site 2 in New Fork Lakes. Samples also were collected from the inlet and outlet streams of the lakes (fig. 7.1-2). Between 2,270 to 3,866 liters of water were collected from each sampling depth or location during each sampling period. All water was pumped through silver filters with a 0.45-micrometer pore diameter. From this filtered water, the average suspended-material concentration (in milligrams per liter) and the average dissolved organic-carbon concentration in each lake was calculated.

Figure 7.1-1--Collection of samples for organic material at site 1 in Fremont Lake. The water was pumped from a selected depth into stainless-steel milk cans, then transported to shore.

Figure 7.1-2--Sampling the outlet of Fremont Lake. The outlet structure bisects the photograph.

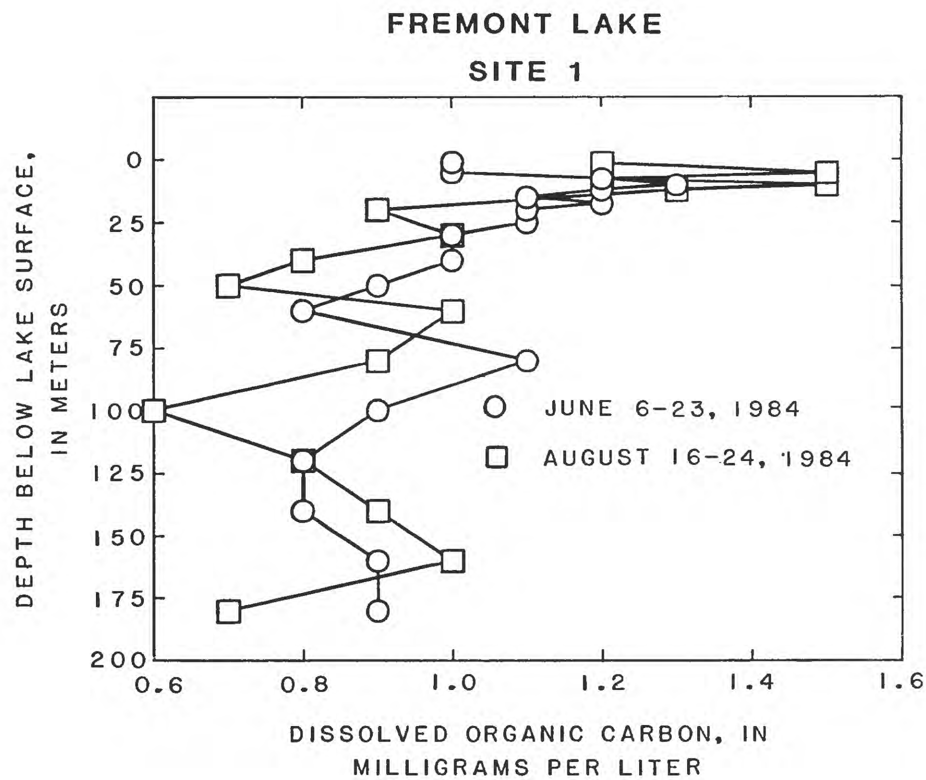
DISSOLVED ORGANIC-CARBON AND SUSPENDED-MATERIAL CONCENTRATIONS WERE SMALL

Concentrations of dissolved organic carbon in Fremont Lake and New Fork Lakes ranged from 0.5 to 2.6 milligrams per liter.

Vertical profiles of dissolved organic carbon were collected during two sampling periods (fig. 7.2). The average concentration of dissolved organic carbon in the study lakes was about 1.0 milligram per liter, which is small when compared to many freshwaters that average about 5 milligrams per liter. Concentrations of dissolved organic carbon were slightly larger in the bottom water of New Fork Lakes than in Fremont Lake.

The inlet and outlet streams contained concentrations of dissolved organic carbon similar to those of their respective lakes, with the exception of June 1984, when concentrations were relatively large in the inlet streams. In June 1984, concentrations of dissolved organic carbon in Pine Creek upstream from Fremont Lake were 2.2 milligrams per liter and in New Fork River upstream from New Fork Lakes, 1.4 milligrams per liter.

The suspended-material concentrations in Fremont Lake, New Fork Lakes, and the inlet and outlet streams were generally small, less than 1.0 milligram per liter. In June 1984, the suspended-material concentrations in New Fork Lakes and the New Fork River upstream and downstream from the lakes were larger, reaching a maximum of 3.7 milligrams per liter at site 2 in New Fork Lakes. Much of the suspended material probably was algae and bacteria.



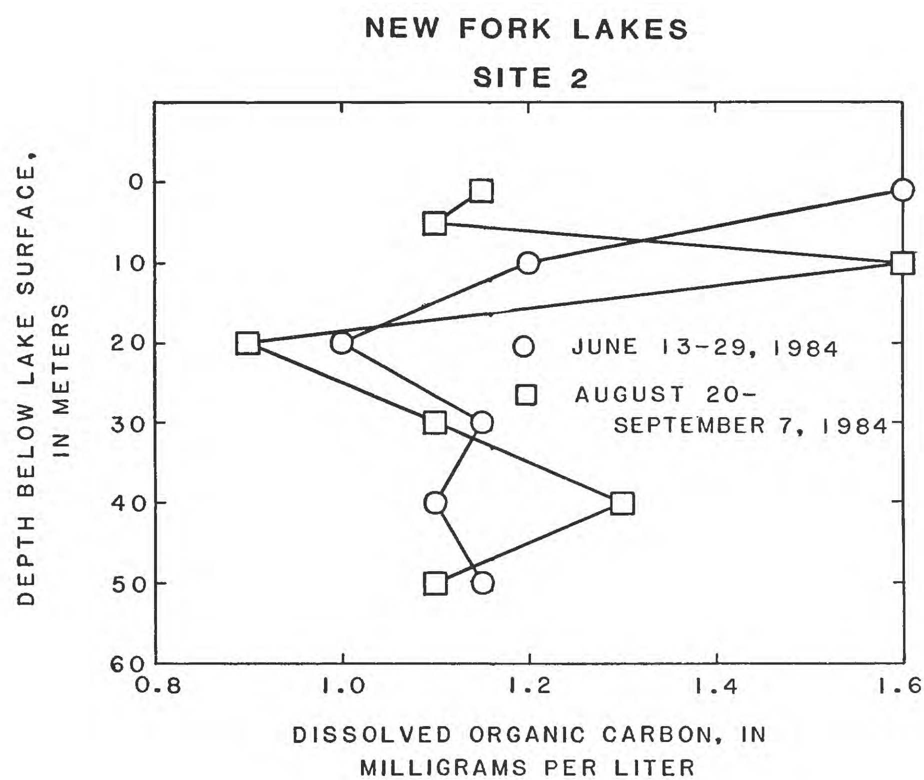


Figure 7.2--Vertical profiles of dissolved organic carbon.

7.3 Fulvic and Humic Material

FULVIC- AND HUMIC-ACID CONCENTRATIONS IN FREMONT LAKE INLET WERE LARGE DURING SPRING

Concentrations of fulvic and humic materials at other sites and during other seasons were similar.

The concentrations of fulvic and humic material are listed in table 7.3. On a per liter basis, the concentrations of both humic and fulvic acids were remarkably similar for the inlet, outlet, lake surface and with depth in the lakes. The exception was the Fremont Lake inlet during June 1984 when it contained an unusually large concentration of both fulvic and humic materials. This is an important finding and merits further investigation.

Work is presently underway to determine the chemical structure and other characteristics of the fulvic and humic material. The samples have been concentrated, freeze dried, and some samples have been chemically analyzed. The physical appearances of the dried samples from Fremont Lake and New Fork Lakes are quite different, possibly indicating different sources or reflecting different vegetation types.

The elemental concentrations for fulvic acids from Fremont Lake and New Fork Lakes were remarkably similar. The hydrogen-carbon ratios also were quite similar. There were, however, some variations in the carbon-nitrogen ratios. Similar elemental concentrations of the lake humic acids are being analyzed.

Table 7.3.--*Concentrations of fulvic and humic material*

Date of sample collection	Sample-collection site	Sample-collection depth (meters)	Concentration (milligrams per liter)
		Fremont Lake	
Fulvic material			
06/84	Inlet	1	1.81
08/84	Inlet	1	.27
11/84	Inlet	1	.52
06/84	1	1	.42
08/84	1	1	.45
11/84	1	1	.73
08/84	1	8	.46
06/84	1	180	.42
08/84	1	180	.40
11/84	1	180	.48
06/84	Outlet	1	.52
11/84	Outlet	1	.56
Humic material			
06/84	Inlet	1	.33
08/84	Inlet	1	.04
11/84	Inlet	1	.13
06/84	1	1	.03
08/84	1	1	.04
11/84	1	1	.05
08/84	1	8	.04
06/84	1	50	.03
08/84	1	50	.03
11/84	1	50	.04
06/84	Outlet	1	.04
11/84	Outlet	1	.04

Table 7.3.--*Concentrations of fulvic and humic material*--Continued

Date of sample collection	Sample-collection site	Sample-collection depth (meters)	Concentration (milligrams per liter)
		New Fork Lakes	
Fulvic material			
06/84	Inlet	1	1.12
08/84	Inlet	1	.60
11/84	Inlet	1	.54
06/84	2	1	.83
08/84	2	1	.77
11/84	2	1	.83
08/84	2	6	.70
06/84	2	46	.78
08/84	2	46	.85
11/84	2	46	.98
06/84	Outlet	1	1.09
11/84	Outlet	1	.59
Humic material			
06/84	Inlet	1	.17
08/84	Inlet	1	.07
11/84	Inlet	1	.07
06/84	2	1	.22
08/84	2	1	.09
11/84	2	1	.14
08/84	2	6	.10
06/84	2	46	.15
08/84	2	46	.11
11/84	2	46	.13
06/84	Outlet	1	.06
11/84	Outlet	1	.07

8.0 SUMMARY AND FURTHER INVESTIGATIONS

LAKES ARE FOCUS OF COMPREHENSIVE STUDY

The study of Fremont and New Fork Lakes includes examination of their physical, chemical, and biological composition.

The ongoing study of Fremont Lake and New Fork Lakes began in 1984, after a reconnaissance study in 1983. The reconnaissance indicated that Fremont Lake and New Fork Lakes were suitable for more detailed study, with transfer value to other Rocky Mountain lakes. During 1984, data collection was emphasized, in order to describe the physical, chemical, and biological composition of the lakes. This progress report describes the results of the data-collection phase.

Fremont Lake and New Fork Lakes were chosen for study because of concern about possible effects of existing and planned regional and local development. The study comprehensively examined several features of the lakes and streams (fig. 8.0), including common limnological measurements, such as temperature profiles and principal-ion chemistry, and relatively new or untried measurements of trace-metal and organic substances.

Vertical profiles of temperature, specific conductance, dissolved oxygen, and pH indicated strong thermal stratification during the summer and isothermal conditions during December 1983 and May 1984. Circulation may have been complete (overturn) during December and partial during May.

The water of Fremont Lake generally is more transparent than the water of New Fork Lakes. The waters are very clear, relative to many other waters in Wyoming.

The delta of Pine Creek in Fremont Lake was mapped, and the sediment-deposition rate was estimated. Core samples were collected from the delta but have not been analyzed.

Measured biological constituents included phytoplankton, chlorophylls a and b, and zooplankton in Fremont Lake and New Fork Lakes; as well as benthic invertebrates in Fremont Lake. Samples of drifting invertebrates were collected from Pine Creek at the inlet and outlet of Fremont Lake. Phytoplankton concentration and composition were variable; the average concentration was larger in Fremont Lake than in New Fork Lakes. Further work might include investigation of the weak correlation of chlorophyll a concentrations with phytoplankton concentrations. Instead of chlorophyll analysis by ion chromatography, other methods of assessing the phytoplankton, such as flourometry, need to be considered in order to develop a method transferable to other Rocky Mountain lakes. Zooplankton concentrations in the lakes were small, less than 6 organisms per liter. Small numbers per unit area of large, red midge larvae (Diptera: Chironomidae) were found on the bottom of Fremont Lake. Invertebrate drift samples from Pine Creek have not been analyzed at the time of this writing.

Fremont Lake and New Fork Lakes were chemically dilute solutions. Calcium and bicarbonate were the predominant ions in the lakes and inflow and outflow streams. The bicarbonate concentrations indicated the lakes and streams were poorly buffered (small alkalinity concentrations). Based on bicarbonate concentrations, the buffering capacity of Fremont Lake and its inflow and outflow streams usually were less than 200 microequivalents of alkalinity and are sensitive to acidification by precipitation with pH similar to that of the northeastern United States.

Trace-metal concentrations in the lakes were similar to those in precipitation and generally were small. Further sampling of precipitation quantity and quality would aid calculation of a chemical budget for the lakes.

Dissolved organic-carbon concentrations in samples from the study lakes were small, about 1 milligram per liter. Concentrations of fulvic and humic acids were large in samples from the inlet of Fremont Lake during the spring, relative to concentrations in samples from the lakes and on other dates. This is an important finding and merits further investigation.

Additional sample collection from the study lakes and their inflow and outflow streams would facilitate calculation of a budget of principal ions, nutrients, and trace metals. Streamflow records of the inflow and outflow streams also would be instrumental in a budget calculation.

Figure 8.0--View of the northeast end of Fremont Lake, looking toward the sampling site on Pine Creek at the inlet.

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