RECONNAISSANCE OF WATER QUALITY OF PUEBLO RESERVOIR, COLORADO--MAY THROUGH DECEMBER 1985

By Patrick Edelmann

U.S. GEOLOGICAL SURVEY

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PUEBLO WEST METROPOLITAN DISTRICT,

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MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Federal Center
Denver, CO 80225-0046

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CONVERSION FACTORS

Inch-pound units used in this report may be converted to metric units (SI) by using the following conversion factors:

Multiply inch-pound units	*By*	*To obtain metric units*
acre-foot (acre-ft)	1,233	cubic meter
acre-foot per day (acre-ft/d)	1,233	cubic meter per day
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8\ °C + 32$$

The following terms and abbreviations also are used in this report:

cells per milliliter (cells/mL)
colonies per 100 milliliters (col/100 mL)
liter (L)
milliliter (mL)
milligram per liter (mg/L)
microsiemens per centimeter at 25 degrees Celsius (µS/cm)
microgram per liter (µg/L)
micrometer (µm)
nephelometric turbidity units (NTU)
organisms per cubic meter ($organisms/m^3$)
picocuries per liter (pCi/L)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Pueblo Reservoir is the farthest upstream, main-stem reservoir constructed on the Arkansas River and is located in Pueblo County approximately 6 miles upstream from the city of Pueblo. This reconnaissance study provides a better understanding of the reservoir and the quality of water entering Pueblo Reservoir and makes a preliminary assessment of some of the water-quality characteristics of the reservoir.

During the 1985 sampling period, the reservoir was stratified, and underflow from the Arkansas River occurred that resulted in stratification of the water in the reservoir with respect to specific conductance. Concentrations of dissolved solids decreased markedly below the thermocline during June. Later in the summer, dissolved-solids concentrations increased substantially below the thermocline. The variations in specific conductance that occurred in the reservoir generally coincided with variations in specific conductance measured at the Arkansas River at Portland. Substantial depletion of dissolved oxygen occurred near the bottom of the reservoir. The dissolved oxygen minimum of 0.1 milligram per liter occurred during August near the reservoir bottom at transect 7 (near the dam). At the reservoir surface, total-inorganic-nitrogen concentrations averaged about 0.2 milligram per liter and total-phosphorus concentrations ranged from less than 0.01 to 0.05 milligram per liter. At the reservoir bottom, total-inorganic-nitrogen concentration averaged 0.3 milligram per liter, and total-phosphorus concentrations ranged from less than 0.01 to 0.22 milligram per liter. Concentrations of most trace elements were small and were less than the established State water-quality standards for Pueblo Reservoir. However, concentrations of total iron occasionally exceeded the aquatic-life standard near the reservoir bottom at transect 2, and dissolved-manganese concentrations occasionally exceeded the standard for public water supply near the reservoir bottom at transect 2.

Diatoms, green algae, blue-green algae, and cryptomonads comprised the majority of the phytoplankton in Pueblo Reservoir in 1985. The maximum concentration of phytoplankton, average of 41,000 cells per milliliter, occurred in July. Blue-green algae dominated from June to September; diatoms were the dominant group of algae in October. The average concentration of phytoplankton decreased from July to October.

Information about potential inbasin contaminants and transportation-related contaminants was compiled. Currently (1986), the greatest threat of contamination in the upper Arkansas River basin, hence Pueblo Reservoir, probably is from metal mines that discharge to the streams in the vicinity of Leadville. Flammable liquids, combustible liquids, and flammable gases frequently are transported by highway; flammable liquids, combustible liquids, corrosives, oxidizers, and petroleum materials frequently are transported by rail. Depending on the specific compounds, location, and quantity of material spilled, a spill could pose a threat to the quality of water in Pueblo Reservoir.

INTRODUCTION

Pueblo Reservoir is the farthest upstream, main-stem reservoir on the Arkansas River and is located in Pueblo County approximately 6 mi upstream from and west of the city of Pueblo, Colo. (fig. 1). The reservoir is one of southeastern Colorado's most valuable water resources and provides municipal, industrial, and irrigation water, as well as flood control, recreation, fish and wildlife enhancement, and other beneficial uses to the region. More specifically, the reservoir is the sole source of municipal and industrial water supply for the cities of Pueblo and Pueblo West, and supplements the water supplies of St. Charles Mesa (located east of Pueblo, via the Bessemer Ditch), and Colorado Springs, Stratmoor Hills, Security, Widefield, and Fountain, which are located several miles north of Pueblo, via the Fountain Valley Pipeline. In addition, Pueblo Reservoir is one of Colorado's major recreational areas that is used extensively for fishing, boating, and primary contact recreational sports, such as swimming, water skiing, and wind surfing. The reservoir now provides water to a warm-water, cool-water, and cold-water fish hatchery that is located immediately downstream from the dam.

Many of the current and future uses of the reservoir depend on maintaining acceptable water quality. Because Pueblo Reservoir is the farthest upstream, main-stem reservoir on the Arkansas River, it has the potential to become a sink for accidental spills and discharges that occur upstream. The close proximity of a railway and a major highway to the Arkansas River has raised concerns about effects on the reservoir from accidental transportation-related spills. The quality of water of Pueblo Reservoir may be affected by storm runoff, salt loading from irrigation-return flows, upstream discharges of municipal and industrial wastewater, and by extensive recreational use. Concerns over taste and odor problems and other potential water-quality problems that may affect Pueblo Reservoir's many uses led to a 5-year comprehensive water-quality study of Pueblo Reservoir. The study was begun in the spring of 1985 by the U.S. Geological Survey in cooperation with the Pueblo Board of Water Works, Fountain Valley Authority, Southeastern Colorado Water Conservancy District, Pueblo West Metropolitan District, St. Charles Mesa Water District, and the U.S. Bureau of Reclamation. The comprehensive investigation will (1) Determine areal, vertical, and seasonal variations of physical, chemical, and biological characteristics of Pueblo Reservoir; (2) predict reservoir response to various contaminants; and (3) evaluate management alternatives to maximize the reservoir's long-term suitability for various uses.

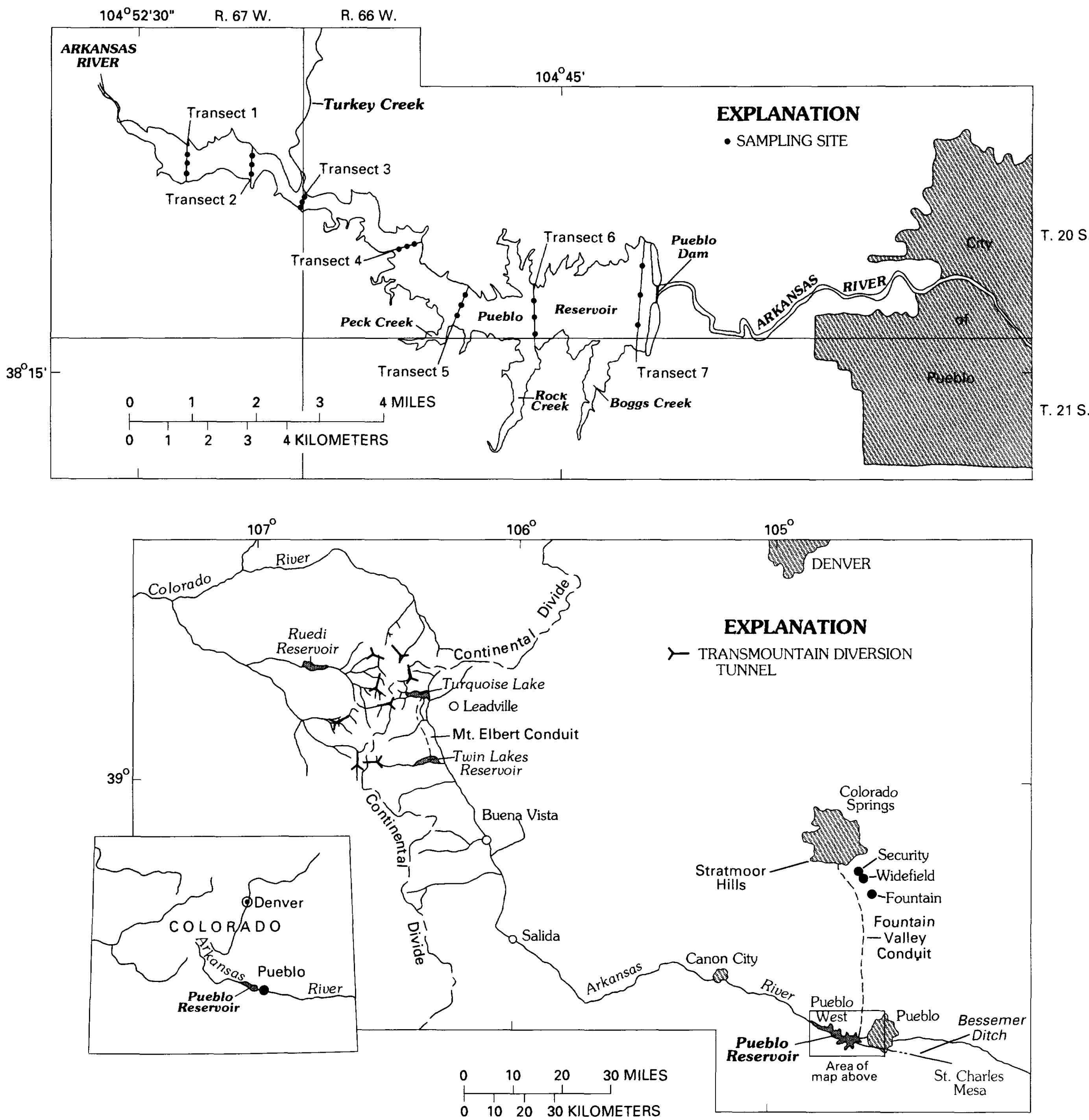

Figure 1.--Location of Pueblo Reservoir in relation to the upper Arkansas River basin and location of sampling sites on Pueblo Reservoir.

Purpose and Scope

This report describes the reconnaissance phase of the comprehensive water-quality investigation of Pueblo Reservoir that was done during 1985. The objectives of this report are to: (1) Provide a better understanding of the reservoir and the quality of water entering the reservoir, and (2) make a preliminary assessment of some of the water-quality characteristics of Pueblo Reservoir. Specifically, this report describes the water quality of the upper Arkansas River basin and the quality of water entering the reservoir. The areal, vertical, and seasonal water-quality variations that occurred in Pueblo Reservoir during 1985 are described. Measurements of water temperature, specific conductance, light transparency, dissolved oxygen, and pH are reported for numerous sites in the reservoir. In addition, analyses of major nutrients (nitrogen and phosphorus), major chemical constituents, and trace elements, and densities and relative abundance of phytoplankton and zooplankton from water samples collected from Pueblo Reservoir are included. Finally, information about potential contaminants to Pueblo Reservoir is provided in the "Supplemental Information" section at the back of the report. The onsite measurements and water samples for chemical and biological analyses were collected during May through December 1985.

Methods of Investigation

After an initial reconnaissance of Pueblo Reservoir was made during May 1985, seven transects were established from the inflow (transect 1) to the dam (transect 7) (fig. 1). Several of the transects are located immediately downstream from tributaries. Three sampling sites were selected along each transect. In addition, station 07097000, Arkansas River at Portland (pl. 1) was selected to monitor the quality of the major source of water entering the reservoir. Station 07099400, Arkansas River above Pueblo, was selected to monitor outflow from the reservoir. Water-quality data collected during the reconnaissance study are available upon request from the U.S. Geological Survey, Water Resources Division, Pueblo Subdistrict office in Pueblo, Colo.

During 1985, measurements of water temperature, specific conductance, light transparency, dissolved oxygen, and pH were made monthly from June through October and during December at most of the 21 sites in the reservoir. Water temperature, specific conductance, dissolved oxygen, and pH were measured at 3-ft intervals from the reservoir surface to the reservoir bottom with a multiparameter instrument. Water temperature, specific conductance, dissolved oxygen, and pH also were measured at station 07097000, Arkansas River at Portland and at station 07099400, Arkansas River above Pueblo. Light transparency was measured with a Secchi disk--a white, flat, circular disk about 8 in. in diameter.

In addition to onsite measurements, water samples were collected monthly from July through October at the middle site of each transect for analyses of chemical and biological constituents. Samples were collected for chemical analyses from near the reservoir surface and from near the reservoir bottom using a 4-L, nonmetallic, 2-ft-long water-sampling bottle. The chemical constituents discussed in this report were analyzed by the U.S. Geological Survey Denver Central Laboratory using methods described by Fishman and Friedman

(1985). With the exception of the nitrogen and phosphorus species, water samples analyzed by the U.S. Geological Survey Denver Central Laboratory were collected as part of the quality-assurance program. These samples were collected during July, August, and September near the reservoir bottom at transect 2 and near the reservoir surface at transect 7. Additional samples collected from the other transects were submitted to a cooperator laboratory for chemical analyses. However, these data were not included in the report because samples analyzed as part of the quality-assurance program in 1985 indicated these data did not meet quality-assurance criteria.

Biological samples were collected for analysis of phytoplankton and zooplankton. Biological analyses were done by Chadwick and Associates[1] of Littleton, Colo. Phytoplankton samples were collected from a single depth near the reservoir surface using a 4-L, nonmetallic, 2-ft-long water-sampling bottle. Samples were preserved using a 37-percent formaldehyde solution. Prior to counting, the phytoplankton sample was thoroughly mixed by vigorous shaking; an aliquot was immediately withdrawn with a clean pipette and transferred to a settling chamber. Algae were allowed to settle for 4 hours for each 10 mL of height in the settling chamber. When buoyant organisms rose to the top of the chamber, it was necessary to do a strip count at the top as well as at the bottom of the chamber. If the sample contained such a great density of algae that there were multiple layers on the bottom of the chamber, or if silt covered and obscured the algae, a 10-mL aliquot that was diluted 5 to 10 times was used for the count. If the sample contained very small densities of algae, the algae were concentrated by allowing additional settling time in order to decrease statistical error in counting. Phytoplankton counts were made using a 200- to 1,000-power microscope (Chadwick and Associates, Littleton, Colo., written commun., 1985).

Zooplankton samples were collected by lowering a 80-μm mesh zooplankton net to within a few feet of the reservoir bottom and towing the net to the reservoir surface at a rate of about 2.5 ft/s. The net was rinsed thoroughly, and zooplankton were transferred to a bottle and preserved with ethyl alcohol. Zooplankton samples were diluted in the laboratory to 40 mL in a small beaker using a 63-μm mesh screen when necessary. The sample then was agitated, and a 1-mL aliquot was withdrawn and placed on a counting cell. The zooplankton were counted in strips using a microscope at 100 power magnification (Chadwick and Associates, Littleton, Colo., written commun., 1985).

DESCRIPTION OF DRAINAGE BASIN

Pueblo Reservoir drains an area of 4,669 mi^2, of which 4,369 mi^2 or about 94 percent drains into the Arkansas River upstream from the reservoir and about 300 mi^2 or about 6 percent drains directly into the reservoir. The upper Arkansas River basin (fig. 1) is a high-elevation, semiarid basin that extends from Leadville to Pueblo (a straight-line distance of 120 mi) and includes all of Lake, Chaffee, Fremont, and Custer Counties, and parts of Saguache, Park, Teller, El Paso, and Pueblo Counties (pl. 1). The basin is bordered by the Sangre de Cristo, Sawatch, and Mosquito Mountain Ranges.

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

Elevations in the basin range from about 4,670 ft above sea level at Pueblo to 14,433 ft at Mount Elbert in Lake County, the highest peak in Colorado. A transition from the mountains to the plains occurs between Canon City and Pueblo.

Climate in the drainage basin is affected greatly by differences in elevation. Mean annual precipitation ranges from less than 12 in. in the plains to more than 40 in. at the crest of the highest mountains (Crouch and others, 1984). Much of the precipitation in the plains is from intense summer thunderstorms. Precipitation in the mountains results in the formation of a deep snowpack that accumulates during the winter months and melts and runs off during the spring and early summer. Storm runoff and snowmelt result in a large percentage of annual streamflow that occurs during a relatively short time (Abbott, 1985).

Ground cover in the basin varies from alpine-type flora around the mountain peaks to various species of grass and cacti in the lower regions. National forests cover about one-third of the area. At lower elevations, pinon pine, juniper, scrub oak, and brush occur frequently along the rocky ridges and some of the canyons, while cottonwood trees, willows, and various types of brush occur in the flatter areas along streams (Federal Water Pollution Control Administration, 1968). The smaller areas that drain directly into Pueblo Reservoir (pl. 1) are characterized as open, rolling plains with numerous uncontrolled washes and gullies.

Most of the population and related activities are concentrated along the broad, gently sloping terrain near the Arkansas River (Crouch and others, 1984). The principal towns are Leadville, Buena Vista, Salida, Westcliffe, Canon City, and Pueblo West (pl. 1). In 1980, there were about 58,000 people residing in the area (U.S. Bureau of the Census, 1981). The area is not heavily industrialized. The principal land use in the area is ranching. Historically, the economy of the area in the vicinity of Leadville was dominated by mining of precious metals, but most of the mines are now (1988) abandoned. This area has produced large quantities of beryllium, coal, copper, gold, lead, molybdenum, silver, thorium, tungsten, uranium, vanadium, and zinc. Other industries in the basin include tourism and manufacturing of bulk cement and gypsum wallboard. The area is serviced by railways and highways that parallel the Arkansas River through the basin.

The Arkansas River derives most of its streamflow from melting of snows that accumulate in the mountains from October to May and flow from inbasin tributaries and transmountain diversions to the Arkansas River in the spring and summer (fig. 2). Springs contribute minor quantities of water to streamflow in the area (Crouch and others, 1984). Runoff from summer thunderstorms at lower elevations can contribute substantial quantities of streamflow for short periods. The streams, other than the Arkansas River, that drain directly into Pueblo Reservoir include Rush Creek, Turkey Creek, Peck Creek, Rock Creek, Boggs Creek, and a few unnamed tributaries (pl. 1). These streams are, for the most part, ephemeral or intermittent, and their flows are derived from springs and precipitation. Under usual streamflow conditions, the quantity of flow contributed to Pueblo Reservoir from these streams is negligible.

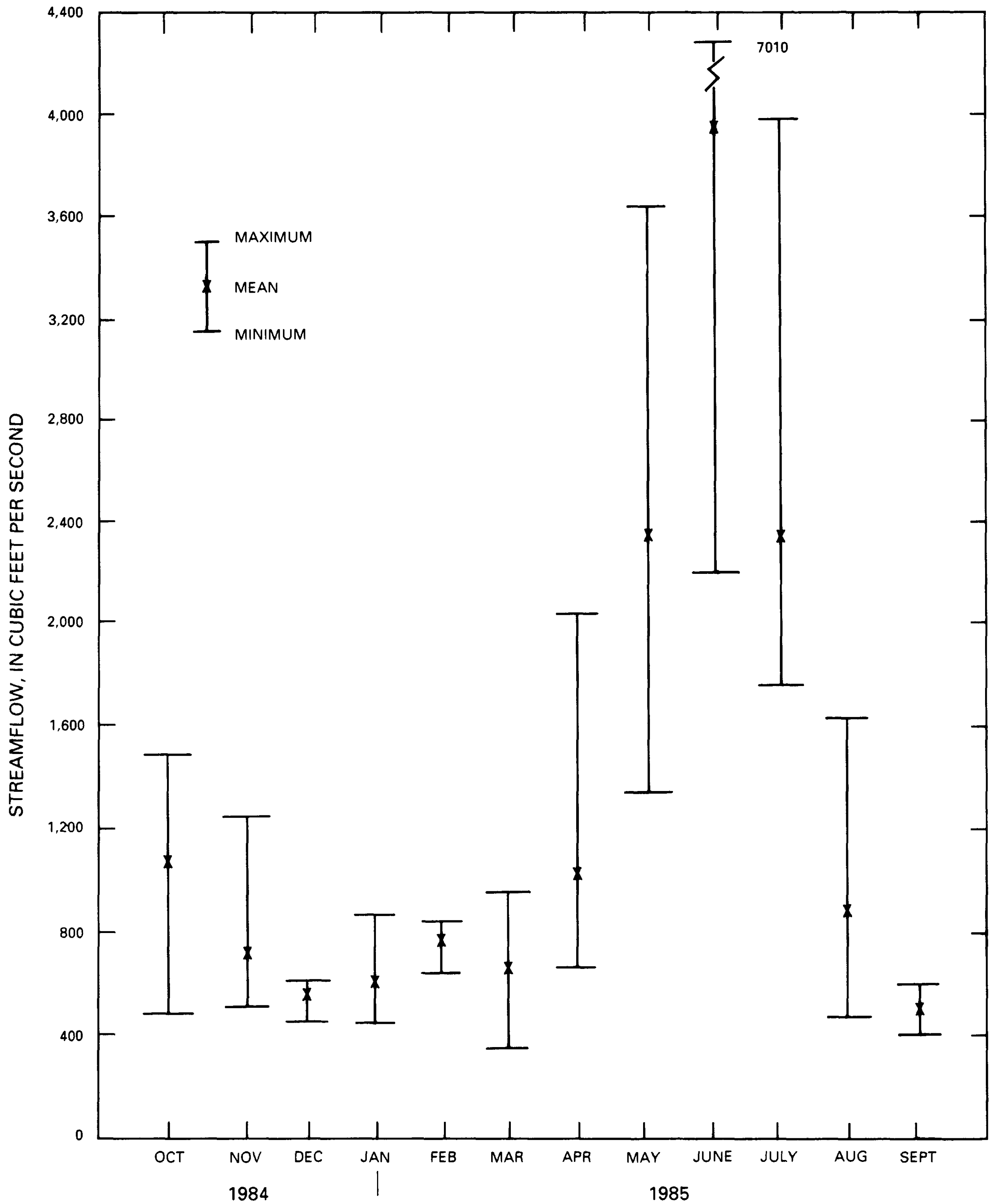


Figure 2.--Minimum, mean, and maximum monthly streamflow at station 07097000, Arkansas River at Portland.

Flow in the Arkansas River upstream from Pueblo Reservoir is regulated by several major and minor off-stream reservoirs. At the Arkansas River at Canon City (station 07096000), the average streamflow for 96 years (1888-1984) was 725 ft^3/s (Ugland and others, 1986). From 1975 to 1982, the annual average streamflow of the Arkansas River was 654 ft^3/s at Canon City and 657 ft^3/s at Portland (station 07097000). During this period, about 80 percent of the annual streamflow at Portland was estimated to be native flow, and about 20 percent was estimated to be transmountain flow. The streamflow-gaging station at Portland is the farthest downstream streamflow-gaging station in the upper Arkansas River basin and is approximately 10 mi upstream from Pueblo Reservoir. From 1983 through 1985, the annual average streamflow was 1,280 ft^3/s at Portland, indicating that almost twice as much water was available for storage in Pueblo Reservoir during this period than from 1975 to 1982.

During the 1985 water year (October 1984 to September 1985), the daily mean streamflow at Portland ranged from 356 ft^3/s during March to 7,010 ft^3/s during June, and the mean for the water year was 1,270 ft^3/s. The summary of minimum, mean, and maximum monthly streamflows (fig. 2) indicates that the smallest monthly mean streamflows occurred during September, December, and January. The largest monthly mean streamflows occurred during May, June, and July. During these months, the average streamflow was 2,780 ft^3/s due to snowmelt runoff, transmountain diversions to the Arkansas River, and reservoir releases in the upper basin.

DESCRIPTION OF PUEBLO RESERVOIR

Pueblo Reservoir is the farthest downstream eastern-slope storage facility of the Fryingpan-Arkansas project, a multipurpose water development authorized by Public Law 87-590. The chief purpose of the project is to divert unappropriated water from the western slope of the Rocky Mountains for use on the more populated and water-short eastern slope. Pueblo Reservoir derives almost all of its contents from water entering through the Arkansas River, which is comprised of native and transmountain flow. The reservoir is formed by a concrete and earth-fill dam on the Arkansas River approximately 6 mi west of Pueblo. The climate at Pueblo Reservoir is characterized by small annual precipitation with periodically intense thunderstorms, large evaporation, moderate-to-high wind movement, low humidity, and a large daily range in temperature (Phillip E. Flores Associates, Inc., 1975).

Pueblo Reservoir is a multipurpose facility which can be described by its space allocation. The reservoir has a total storage capacity of 357,678 acre-ft; 30,355 acre-ft of dead and inactive capacity, which comprises the recreation pool; 234,347 acre-ft conservation pool, which is used in regulating transmountain and native water for municipal, industrial, and irrigation uses; 65,952 acre-ft joint-use pool, which must be vacated and available for flood control from April 15 to November 1 each year; and 27,024 acre-ft of exclusive flood-control capacity. The top of the exclusive flood-control pool is the crest of the spillway at an elevation of 4,898.7 ft. The crest of the dam is 26 ft above the crest of the spillway and would temporarily hold an additional 131,500 acre-ft of flood flows.

Storage in Pueblo Reservoir began in January 1974, and the dam was completed in August 1975. Since impoundment, reservoir elevation, surface area, and storage have varied greatly because of inflow and demand for the stored water (fig. 3). Prior to 1983, after appreciable storage was attained, the reservoir contents varied from 22,680 acre-ft in November 1974 to 111,920 acre-ft in March 1982. Since early 1983, reservoir contents have been greater than 200,000 acre-ft as the result of greater than normal flows from the Arkansas River (fig. 3). During the 1985 water year, reservoir contents varied from 239,960 acre-ft (4,875-ft elevation) in October to 295,480 acre-ft (4,887-ft elevation) in February. Less seasonal fluctuation in reservoir contents occurred from 1983 through 1985 than in previous years (fig. 3).

The reservoir inundates four large canyons and several small canyons. The canyon walls are composed of sedimentary rocks. The Fort Hayes Limestone Member of the Niobrara Formation of Cretaceous age lies at the top of the canyon walls surrounding the reservoir and is about 40 ft thick (Scott, 1972a). Underlying the Fort Hayes Limestone Member is the Carlile Shale which contains, from top to bottom, the Juana Lopez Member (2.5 ft thick), the Codell Sandstone Member (30 ft thick), the Blue Hill Shale Member (100 ft thick), and the Fairport Chalky Shale Member (100 ft thick) (Scott, 1964, 1969, 1972a, 1972b). The reservoir, at most stages, is in contact with the Blue Hill Shale Member, which is insoluble and relatively impermeable (Scott, 1969) and, therefore, inhibits lateral or vertical movement of water from the reservoir. The Codell Sandstone Member is permeable and, where inundated, could transmit water to and from the reservoir depending on reservoir elevation. The Fort Hayes Limestone Member is not very permeable. However, water may flow at the contact between the shale and the limestone beds. If inundated, the Fort Hayes Limestone Member could transmit water to and from the reservoir.

At all pool elevations, the reservoir is dendritic and the shoreline is very irregular. At minimum pool (30,355 acre-ft), the reservoir is about 3.5 mi long and varies in width from a few hundred feet to about 1.3 mi. During the 1985 reconnaissance study, the reservoir was near the top of the conservation pool (about 265,000 acre-ft or about 4,880 ft in elevation). At this pool elevation, the reservoir has a length of more than 9 mi, a width that varies from less than 0.3 to about 2.2 mi, a depth that varies from a few feet near the inflow to about 155 ft at the dam, and a shoreline of about 60 mi.

Water is released from the reservoir through the river outlets, Bessemer Ditch outlet, south outlets, and the fish hatchery outlets. The river outlets, which are located at an elevation of 4,766 ft, or about 114 ft below the reservoir surface during the 1985 data-collection period, release the majority of the water from the reservoir. Water released from the river outlets provides municipal and industrial water to Pueblo. The Bessemer Ditch, which is an irrigation canal, provides water to St. Charles Mesa via the Bessemer Ditch outlet. The Bessemer Ditch outlet is located at an elevation of about 4,780 ft or about 100 ft below the reservoir surface during the 1985 data-collection period. The south outlets deliver water to Pueblo West and the Fountain Valley conduit, which is a 45-mi-long pipeline that delivers water to the city of Colorado Springs and the communities of Stratmoor Hills, Widefield, Security, and Fountain (fig. 1). The south outlets release water from the reservoir through multilevel intake lines located at elevations of

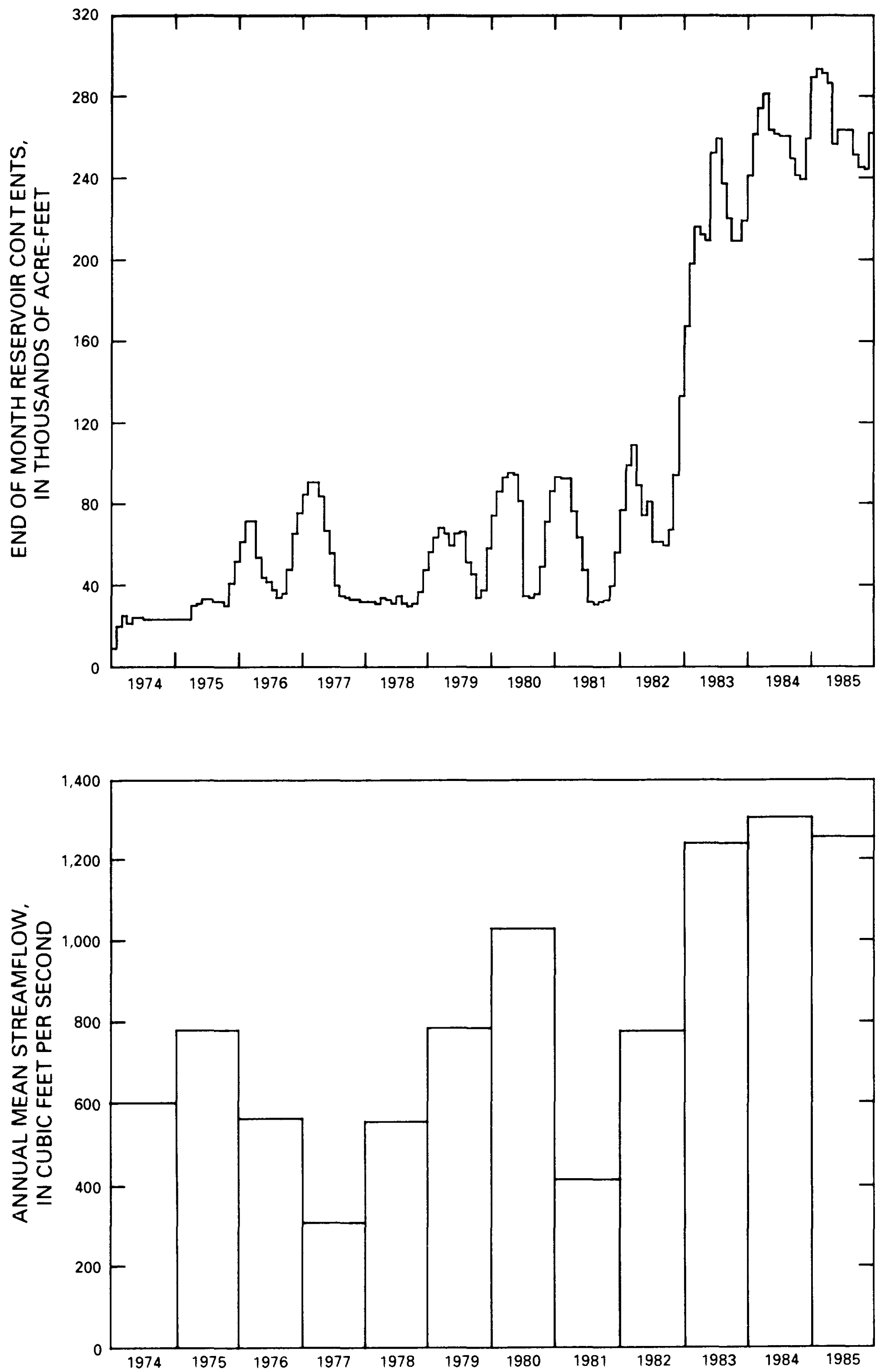


Figure 3.--Pueblo Reservoir end-of-month contents and annual mean streamflow at station 07097000, Arkansas River at Portland, 1974 through 1985 water years.

4,840 ft, 4,805 ft, 4,776 ft, and 4,768 ft. Water can be released concurrently through the south outlets from one or more intake lines. The fish hatchery outlets, which are comprised of multilevel intake lines, can release reservoir water from elevations of 4,851 ft, 4,811 ft, 4,786 ft, or 4,736 ft (U.S. Bureau of Reclamation, written commun., 1986).

Retention time is defined as the time necessary for the volume of water in a reservoir to be replaced by inflowing water or the time necessary for the volume of water in a reservoir to be drained by outflow. The flow-through time may not represent the actual residence time of water entering the reservoir because of various mixing and circulation patterns that occur within the reservoir. During 1985, an average cumulative rate of water released from the reservoir was about 1,320 ft^3/s (2,620 acre-ft/d) (U.S. Bureau of Reclamation, written commun., 1986). This outflow rate is equivalent to an average retention time of 102 days or almost 3.5 months, assuming a reservoir volume of 267,800 acre-ft (average of the end of the month contents for 1985). The retention time for May, June, and July 1985 averaged 48 days (streamflow averaged 2,780 ft^3/s and reservoir contents was 264,000 acre-ft). Large variations in retention time have occurred in Pueblo Reservoir as a result of large variations in storage and outflow. Variations in retention time at varying flows and selected capacities are shown in figure 4 and can range from a few days to several months.

WATER QUALITY OF THE UPPER ARKANSAS RIVER

The chemical quality of water in Pueblo Reservoir is greatly affected by the quality of water in the Arkansas River because the Arkansas River is the primary inflow to Pueblo Reservoir. The chemical quality of the upper Arkansas River basin has been studied by Cain (1987), Crouch and others (1984), Roline and Boehmke (1981), Miles (1977), La Bounty and others (1975), Moran and Wentz (1974), Wentz (1974), and the Federal Water Pollution Control Administration (1968). The reader is referred to these reports for a detailed description of historical water quality of the upper Arkansas River basin. The following discussion is intended to provide an overview of the quality of water in the upper basin and to provide a general understanding of the quality of water entering the reservoir.

The chemical quality of surface water in the upper Arkansas River basin is affected by runoff from snowmelt and rainfall, mine drainage, wastewater-treatment-plant effluents, ground water, and land and water use within the basin. Water entering the basin near the headwaters of the Arkansas River and its tributaries is derived mostly from snowmelt and generally is suitable for most uses (Federal Water Pollution Control Administration, 1968). As the streams come in contact with mine drainage, the pH of water in the streams decreases, and dissolved-solids and metal concentrations increase. The reaches of stream affected by metal-mine drainage were determined by Wentz (1974) (fig. 5) and generally are localized except when abnormal quantities of acid mine drainage are discharged, such as the discharges that occurred during 1983 and 1985. On February 23, 1983, a large quantity of metal-mining sludge was discharged from the Yak Tunnel in the Leadville area. The effect of the discharge on metal concentrations was measured 17 mi downstream on the Arkansas River. During October 1985, another large quantity of metal-mining

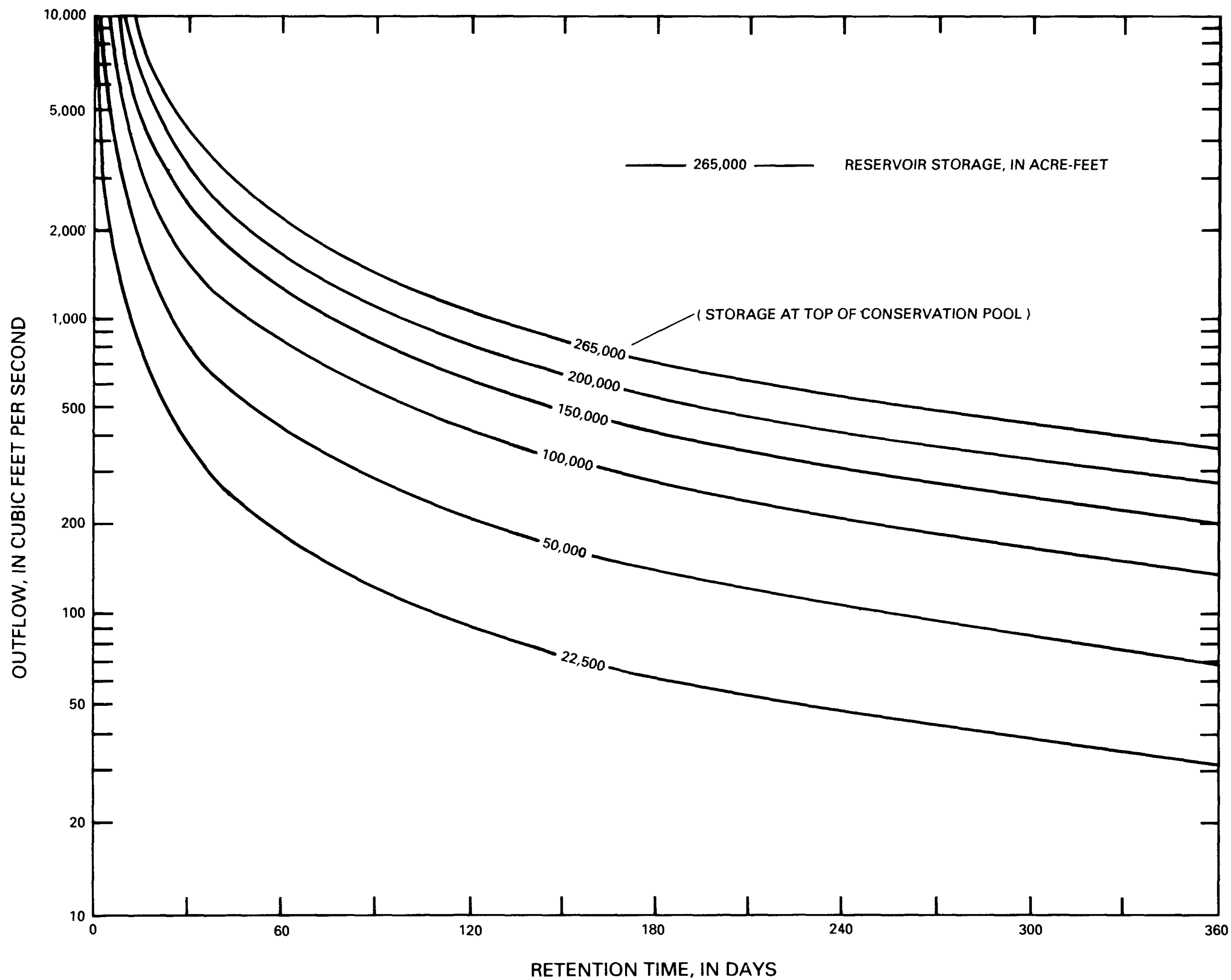


Figure 4.--Relation of retention time, outflow, and reservoir storage.

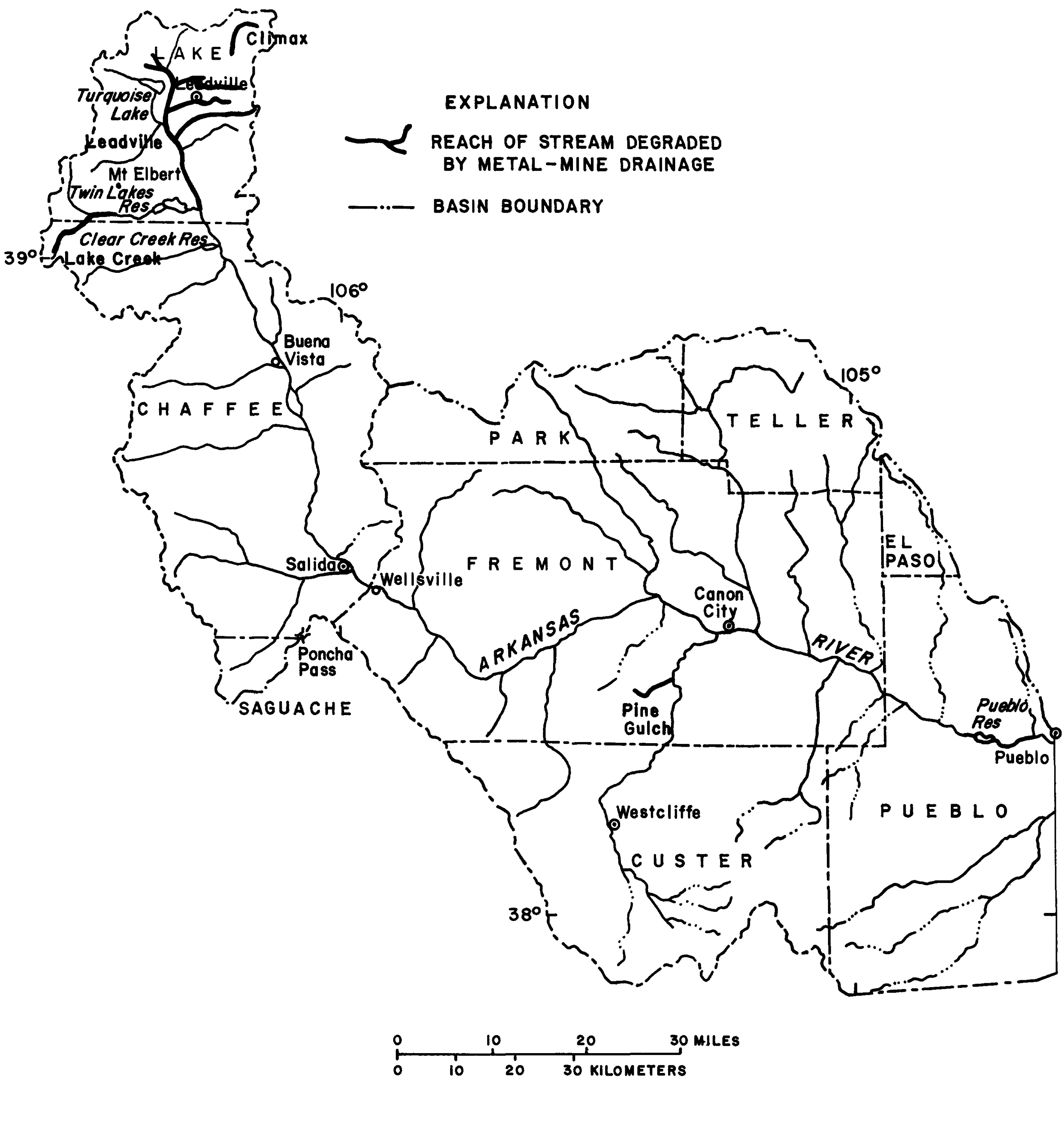


Figure 5.--Streams affected by metal-mine drainage. (From Wentz, 1974, pl. 3)

sludge was discharged from the Yak Tunnel. The color change from this occurrence was visible downstream to Salida or about 60 to 70 mi downstream (Gary Soldano, Colorado Department of Health, Pueblo, Colo., oral commun., 1986). Mine drainage in the Leadville area has resulted in increased concentrations of iron, manganese, and dissolved solids in the Arkansas River between Leadville and Malta. As the acidic water discharged from the mine becomes neutralized in the river, dissolved metals precipitate and coat the stream bottom and decrease the concentrations of dissolved solids and metals in the stream water. However, as the metal coatings are dislodged from the stream bottom and resuspended, the metals are transported farther downstream, possibly as far as Pueblo Reservoir. As the effects of mine drainage are diluted by tributary inflows, the chemical quality of the stream becomes more similar to its original quality. Cain (1987) noted that the smallest mean specific conductance for the Arkansas River occurs at Buena Vista. Specific conductance of water in the Arkansas River is small from Buena Vista to Canon City because: (1) Only small quantities of municipal and industrial wastewater are discharged to the stream as a result of a sparse population and a lightly industrialized area, (2) streams are in contact with igneous and metamorphic rocks that resist chemical weathering (and are relatively insoluble), and (3) only small quantities of irrigation-return flows enter the Arkansas River upstream from Canon City. Between Canon City and downstream from Portland, the mean specific conductance of water in the Arkansas River almost doubles, primarily as a result of large irrigation-return flows and inflows of saline ground water (Cain, 1987).

Chemical quality of water entering Pueblo Reservoir can be summarized using data collected at station 07097000, Arkansas River at Portland (table 1). The U.S. Geological Survey has been analyzing water-quality samples collected at this station since 1977, and daily measurements of water temperature and specific conductance have been made since 1979. Large variations in water temperature occurred during the 1985 water year (fig. 6). During the winter months, water temperatures of 0 °C (freezing) occurred during many days; during the summer, water temperatures as high as 24 °C were measured.

Cain (1987) determined that the mean specific conductance of the water in the Arkansas River at Portland usually is largest from January to March when streamflows are the smallest, and the smallest specific-conductance values occur during June or July when streamflows are the largest. During the 1985 water year, the maximum daily mean specific conductance was 540 µS/cm, which occurred during January 1985 when streamflow was small; the minimum daily mean specific conductance of 140 µS/cm occurred during June 1985 (fig. 6). Cain (1987) determined the relations between: (1) Specific conductance and streamflow, (2) specific conductance and concentrations of dissolved solids, and (3) specific conductance and concentrations of major ions. The relation of specific conductance to streamflow for the Arkansas River at Portland can be expressed using the following equation:

log specific conductance (microsiemens per centimeter at 25 °C)
= 3.61 - 0.37 log streamflow (cubic feet per second).

Table 1.--*Statistical summmary of water-quality data for station 07097000, Arkansas River at Portland, 1977 through 1985*

[ft^3/s, cubic feet per second; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; µg/L, micrograms per liter; pCi/L, picocuries per liter; col/100 mL, colonies per 100 milliters; --, insufficient data to calculate statistic; NA, statistic not applicable]

Constituent	Number of measurements or analyses	Number of measurements less than detection level	Mean[1]	Standard deviation[1]	Twenty-fifth percentile[1]	Median	Seventy-fifth percentile[1]
Streamflow, instantaneous (ft^3/s)	129	0	782	981	267	416	916
Temperature (°C)	105	0	12.6	6.6	6.5	14.0	17.5
Specific conductance (µS/cm)	55	0	440	153	322	450	542
Oxygen, dissolved (mg/L)	53	0	10.4	1.9	8.7	10.5	11.8
pH (standard units)	60	0	NA	NA	7.8	8.1	8.3
Turbidity (NTU)	38	0	27	79	3.0	4.2	15
Nitrogen, dissolved (mg/L)	16	0	.73	.25	.57	.72	.90
Nitrogen, total (mg/L)	21	0	.94	.36	.72	.95	1.1
Nitrite plus nitrate as nitrogen, dissolved (mg/L)	52	0	.29	.14	.17	.26	.38
Nitrite plus nitrate as nitrogen, total (mg/L)	22	0	.31	.30	.14	.26	.31
Ammonia as nitrogen, dissolved (mg/L)	32	2	.08	.05	.03	.06	.12
Ammonia as nitrogen, total (mg/L)	20	2	.07	.06	.02	.05	.10
Ammonia plus organic nitrogen as nitrogen, dissolved (mg/L)	21	0	.42	.17	.34	.45	.50
Ammonia plus organic nitrogen as nitrogen, total (mg/L)	38	0	.77	.66	.50	.60	.87
Phosphorus, orthophosphate, as phosphorus, dissolved (mg/L)	29	4	.03	.02	.01	.03	.04
Phosphorus, dissolved (mg/L)	45	1	.06	.05	.04	.04	.07
Phosphorus, total (mg/L)	39	0	.13	.15	.06	.08	.14

Table 1.--*Statistical summmary of water-quality data for station 07097000, Arkansas River at Portland, 1977 through 1985*--Continued

Constituent	Number of measurements or analyses	Number of measurements less than detection level	Mean[1]	Standard deviation[1]	Twenty-fifth percentile[1]	Median	Seventy-fifth percentile[1]
Hardness (mg/L)	56	0	176	61	130	185	220
Calcium, dissolved (mg/L)	56	0	47	15	36	50	59
Magnesium, dissolved (mg/L)	56	0	13.9	5.7	9.4	14	18
Potassium, dissolved (mg/L)	57	0	2.3	.71	1.9	2.4	2.8
Sodium, dissolved (mg/L)	56	0	22	9.7	14.5	22	28
Chloride, dissolved (mg/L)	56	0	8.2	3.6	5.0	8.6	10.5
Fluoride, dissolved (mg/L)	56	0	.5	.15	.4	.55	.6
Sulfate, dissolved (mg/L)	56	0	99	47	66	96	130
Alkalinity, laboratory (mg/L)	22	0	114	32	91	120	140
Alkalinity, field (mg/L)	34	0	109	33	76	120	130
Carbonate, as calcium carbonate (mg/L)	15	12	1.8	5.4	--	--	--
Bicarbonate, as calcium carbonate (mg/L)	15	0	139	43	106	150	165
Silica, dissolved (mg/L)	56	0	11	2.0	9.0	11	12
Dissolved solids at 180 °C (mg/L)	38	0	263	96	194	264	314
Dissolved solids, sum of constituents (mg/L)	56	0	270	100	195	275	340
Arsenic, dissolved (µg/L)	22	8	1.1	.7	.8	1	1
Arsenic, total (µg/L)	13	1	1.5	.7	1	1	2
Barium, dissolved (µg/L)	22	0	57	16	48	59	67
Cadmium, dissolved (µg/L)	22	15	1.4	1.1	1	1	2
Chromium, total recoverable (µg/L)	13	6	0	0	0	0	0
Cobalt, total recoverable (µg/L)	13	5	2.1	1.4	0	2	3
Copper, dissolved (µg/L)	22	2	6.2	6.2	3	3.5	7
Copper, total recoverable (µg/L)	13	1	15	14.6	7	11	16

Table 1.--*Statistical summmary of water-quality data for station 07097000, Arkansas River at Portland, 1977 through 1985*--Continued

Constituent	Number of measurements or analyses	Number of measurements less than detection level	Mean[1]	Standard deviation[1]	Twenty-fifth percentile[1]	Median	Seventy-fifth percentile[1]
Iron, dissolved (µg/L)	40	2	68	81	20	35	65
Iron, total recoverable (µg/L)	13	0	2,472	2,837	490	1,100	3,900
Lead, dissolved (µg/L)	22	12	6.1	14.7	.5	1.5	6
Lead, total recoverable (µg/L)	13	1	31	35.7	8	13	54
Lithium, dissolved (µg/L)	9	0	16	6.6	11	16	20
Manganese, dissolved (µg/L)	40	1	38	21	21	39.5	51
Manganese, total recoverable (µg/L)	13	0	148	99	80	100	210
Molybdenum, total recoverable (µg/L)	4	0	4.2	1.7	3	4.5	5.5
Nickel, total recoverable (µg/L)	12	0	5.8	4.3	4	5.5	6.5
Selenium, dissolved (µg/L)	22	8	1.3	1.1	.7	1	2
Selenium, total (µg/L)	13	0	2.1	1.2	1	2	2
Strontium, dissolved (µg/L)	9	0	386	198	200	390	500
Zinc, dissolved (µg/L)	22	8	32	23	16	29	41
Zinc, total recoverable (µg/L)	13	0	109	91	40	80	110
Carbon, organic dissolved (mg/L)	11	0	4.9	1.6	3.6	5	5.8
Carbon, organic total (mg/L)	13	0	6.7	3.9	3.2	5.3	9.3
Gross alpha, dissolved (pCi/L)	11	1	7.8	4.2	3.8	8.2	10.5
Gross alpha, suspended total (pCi/L)	11	2	5.8	14	.3	.5	2.4
Gross beta, dissolved (pCi/L)	11	0	4.6	1.8	3.8	4.1	5.4
Gross beta, suspended total (pCi/L)	11	0	5.8	11.9	1.0	1.2	3.2
Coliform, fecal (col/100 mL)	16	0	174	18	43	78	285
Streptococci, fecal (col/100 mL)	29	1	349	663	54	110	270

[1]If the constituent contains one or more measurements less than the detection level then the statistic was estimated using the method of Helsel and Gilliom (1985).

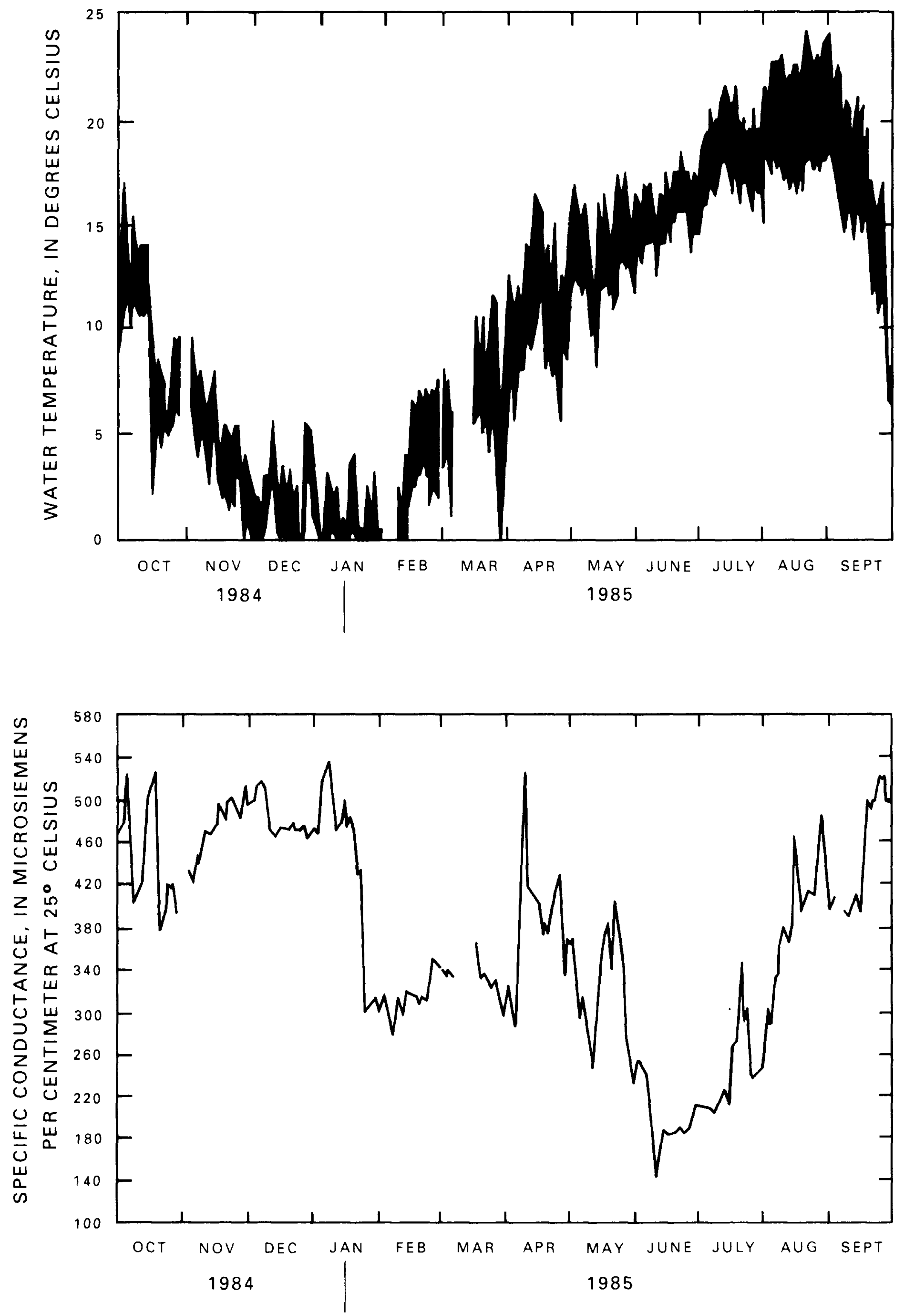


Figure 6.--Variations in daily water temperature and specific conductance for station 07097000, Arkansas River at Portland, 1985 water year.

Using the relation of specific conductance to streamflow, an estimate of the specific conductance of the Arkansas River at Portland at a streamflow of 1,000 ft^3/s would be about 316 μS/cm, and at a streamflow of 200 ft^3/s, the specific conductance would be estimated to be 574 μS/cm. Cain (1987) calculated that the average standard error of this relation is 24 percent. Concentrations of dissolved solids at Portland can be approximated from specific conductance using the following equation:

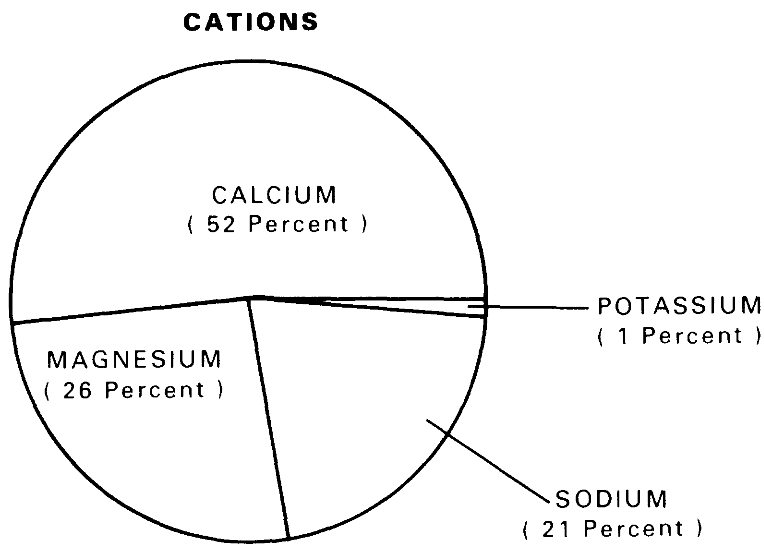
Dissolved solids (milligrams per liter)
= 8.4 + 0.61 specific conductance (microsiemens per centimeter at 25 °C).

Thus, a specific-conductance measurement of 315 μS/cm would have a corresponding dissolved-solids concentration of about 200 mg/L, and a specific-conductance measurement of 570 μS/cm would have a corresponding dissolved-solids concentration of about 356 mg/L. The standard error for this relation is 7.4 percent (Cain, 1987). Relations between specific conductance and concentrations of major ions for water in the Arkansas River between Canon City and Pueblo were developed by Cain (1987) and are listed in table 2. Analyses of 56 samples (table 1) for station 07097000, Arkansas River at Portland, indicate that the predominant ions are calcium and bicarbonate (fig. 7). On the average, calcium comprises 52 percent (based on milliequivalents per liter) of the cations, or positively charged ions; bicarbonate comprises an average of 49 percent of the anions, or negatively charged ions, and sulfate comprises an average of 45 percent of the anions.

Dissolved oxygen, pH, and alkalinity data summarized in table 1 indicate that water in the Arkansas River at Portland is: (1) Well oxygenated, (2) alkaline (pH values usually range from 7.8 to 8.3), and (3) well buffered (median alkalinity equals 120 mg/L as calcium carbonate).

Concentrations of total nitrogen generally are less than 1 mg/L, and organic nitrogen is the dominant nitrogen species. Based on 20 water samples in which total nitrogen species were analyzed, 61 percent of the total nitrogen consisted of organic nitrogen, 32 percent as nitrite plus nitrate, and 7 percent as ammonia. Based on analyses of 16 water samples in which total and dissolved nitrogen were analyzed, about 70 percent of the nitrogen present was dissolved. Concentrations of total phosphorus have ranged from 0.03 to 0.88 mg/L with a mean concentration of 0.13 mg/L and a median concentration of 0.08 mg/L. Based on analyses of 39 water samples in which total and dissolved phosphorus were analyzed, about 40 percent of the phosphorus present was dissolved.

Concentrations of total and dissolved trace elements analyzed from water samples collected at station 07097000, Arkansas River at Portland, by the U.S. Geological Survey are summarized in table 1. Trace elements that have the largest concentrations are barium, iron, manganese, strontium, and zinc. Most of the water samples collected were filtered and analyzed for concentrations of dissolved trace elements. However, a few of the water samples collected were analyzed for concentrations of dissolved and total trace elements. These analyses indicate that most of the trace elements in the Arkansas River are part of or attached to the suspended material.



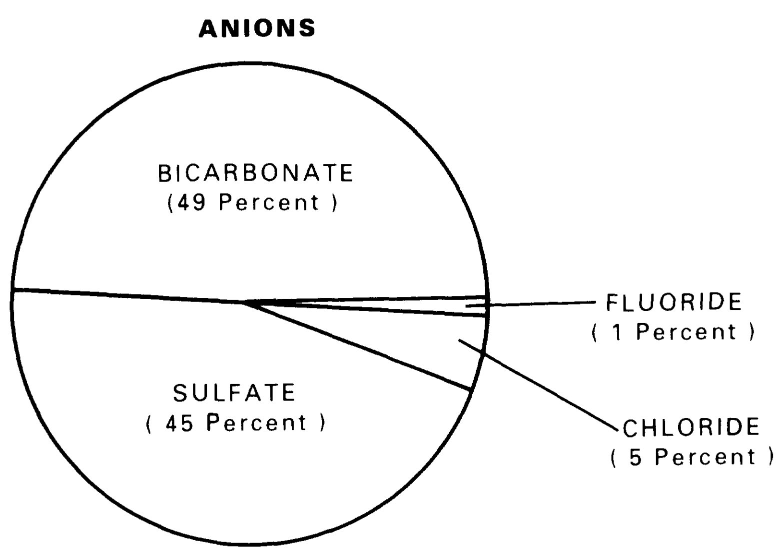


Figure 7.--Percentage (based on milliequivalents per liter) of major ions at station 07097000, Arkansas River at Portland, 1977 through 1985.

Table 2.--*Relations between specific conductance and major ions for surface-water stations along the Arkansas River between Canon City and Pueblo*

[from Cain, 1987]

Station number	Station name	Ion	Number of values	Regression coefficients in the equation ion = a + b(SC)[1] a	b	Coefficient of determination (r^2)	Standard error (percent)
07096000	Arkansas River at Canon City	Calcium	104	2.45	0.114	0.93	6.5
		Magnesium	104	-1.25	.036	.71	18.7
		Sodium	104	-3.75	.054	.94	8.9
		Bicarbonate	104	-10.29	.501	.97	5.0
		Chloride	104	-3.33	.036	.70	24.9
		Sulfate	104	3.37	.098	.73	13.6
07097000	Arkansas River at Portland	Calcium	22	6.25	.096	.93	7.7
		Magnesium	22	-1.39	.035	.81	16.8
		Sodium	22	-3.27	.057	.93	9.9
		Bicarbonate	22	31.42	.228	.83	11.5
		Chloride	22	-1.50	.022	.82	17.5
		Sulfate	22	-14.61	.264	.92	10.6
07099200	Arkansas River near Portland	Calcium	171	2.24	0.109	0.95	7.2
		Magnesium	171	-3.13	.041	.92	11.2
		Sodium	171	-5.26	.057	.92	11.3
		Bicarbonate	171	36.28	.219	.86	9.9
		Chloride	171	-1.84	.020	.84	16.9
		Sulfate	171	-44.90	.349	.94	10.7
07099400	Arkansas River above Pueblo	Calcium	56	7.60	.099	.92	8.4
		Magnesium	56	-3.84	.044	.89	13.3
		Sodium	56	-9.98	.066	.94	10.7
		Bicarbonate	56	57.97	.177	.79	10.9
		Chloride	56	-2.53	.020	.89	14.4
		Sulfate	56	-70.51	.405	.96	9.5

[1]Ion equals ion concentration in milligrams per liter. SC equals specific conductance in microsiemens per centimeter at 25 °C.

WATER-QUALITY CHARACTERISTICS OF PUEBLO RESERVOIR

The physical, chemical, and biological processes within lakes and reservoirs are complex and interrelated. In order to better understand the water-quality characteristics of Pueblo Reservoir, the physical, chemical, and biological constituents measured during the summer of 1985 are discussed in the following sections of this report.

Onsite Water-Quality Measurements

The properties and constituents measured onsite during the summer of 1985 were water temperature, specific conductance, light transparency, dissolved oxygen, and pH. The areal, vertical, and seasonal variations of onsite water-quality measurements are described in the following sections.

Water Temperature

Water temperature is one of the most important environmental properties of a lake because life processes, chemical reactions, and the solubility of chemical constituents in water are temperature dependent. For example, the solubility of dissolved oxygen is inversely related to temperature; that is, the warmer the water the less oxygen can be dissolved in the water. This relation is significant, because at warmer temperatures organisms have an increased metabolic rate but have less oxygen available for their physiological needs.

Water temperature also is a major factor in controlling the density of freshwater. Freshwater is unique because its maximum density occurs at about 4 °C. The density of water decreases as water temperatures vary from 4 °C. Conversely, the density of fresh water increases as water temperatures approach 4 °C. Density also is affected by salinity. Density increases with increasing concentrations of dissolved solids in an approximately linear fashion (Wetzel, 1983). Differences in density inhibit mixing of waters of differing temperatures and salinity and can result in stratification of the water layers. Stratification is a condition whereby less dense water overlies more dense water. Water-temperature measurements are used to determine the depths where various layers of water occur that possibly have different chemical characteristics. When the lake is stratified, the upper water layer or the epilimnion is thermally uniform and contains the warmest water in the lake. Between the epilimnion and hypolimnion is the middle water layer or metalimnion where water temperature rapidly decreases with depth. The thermocline as defined by Wetzel (1983) is the plane of maximum rate of decrease of temperature with depth. The lower water layer containing the coldest water is the hypolimnion.

Selected temperature profiles measured in Pueblo Reservoir during 1985 are shown in figure 8. Temperature profiles measured at transects 3, 5, and 7 during June 1985 indicate that there were multiple water layers and that the reservoir was complexly stratified. As air temperature decreased in the autumn, the upper water layers cooled and mixed, but the lower water layers near the bottom of the reservoir remained stratified; this is indicated by

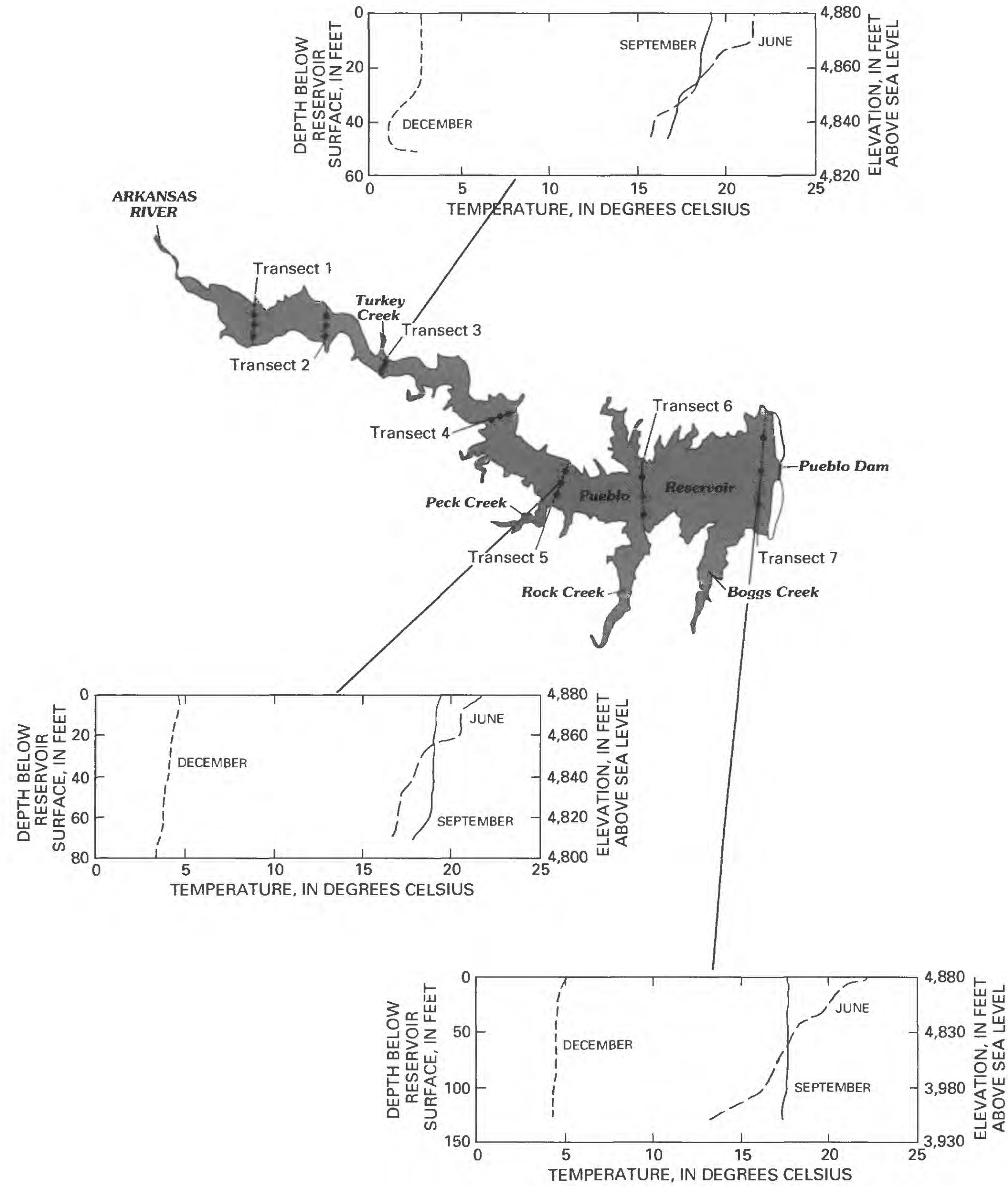


Figure 8.--Selected temperature profiles of Pueblo Reservoir at transects 3, 5, and 7 for June, September, and December 1985.

temperature profiles measured at transects 3 and 5 in September 1985 (fig. 8). During December, the reservoir surface was frozen from the inflow to transect 3. The temperature profile measured at transect 3 during December indicates that the reservoir was inversely stratified at this site (fig. 8). At transect 5, the temperature decreased 1.5 °C throughout the water column; at transect 7, the temperature profile indicates that the water column was completely mixed. Outflow from the dam may have hydrodynamically induced mixing at transect 7 in September and December. Temperature layering in Pueblo Reservoir is controlled largely by air-temperature variations, water temperature of the Arkansas River entering the reservoir, the volume of inflow and outflow in relation to volume of water in the reservoir, reservoir morphology, and the position of the reservoir in relation to wind patterns.

In addition to evaluating stratification, water-temperature measurements were used to evaluate initial routing of the Arkansas River within the reservoir as either overflow, interflow, or underflow. Overflow occurs when inflowing water flows across the reservoir surface and doesn't mix with colder, more dense water because the inflow water density is less than the reservoir water density. Interflow occurs when the inflow enters at an intermediate depth, because the density of inflow is greater than the epilimnion but less than the metalimnion or hypolimnion. Underflow occurs when relatively colder water enters the reservoir and flows to the lowest depth of the reservoir because the inflow water density is greater than the reservoir water density (Wetzel, 1983).

As the Arkansas River enters Pueblo Reservoir, the incoming water flows into a layer in the reservoir that has an equivalent density. However, as water moves through the reservoir, the water's temperature and density change as the result of solar heating, evaporative cooling from wind, and conduction. Therefore, the inflow routing shown in figure 9 should be interpreted only as routing of inflow within the upstream part of the reservoir, and the arrows showing the initial routing of inflow in figure 9 cannot be extended confidently along the same isotherms throughout the entire reservoir. During the 1985 season, underflow occurred in Pueblo Reservoir because the temperature of the Arkansas River was less than, and the density was greater than, that of the reservoir water. Because Pueblo Reservoir was stratified and because stratification controls mixing and circulation patterns within the reservoir, underflow water or hypolimnetic water could be expected to remain in the lower strata beneath the thermocline as the water moved through the reservoir.

Specific Conductance

Differences in specific conductance measured throughout the water column can indicate water layers that have differing dissolved-solids concentrations. With respect to specific conductance, the water in Pueblo Reservoir was stratified during 1985 (fig. 10). During June 1985, specific conductance measured at transects 3 and 5 indicates that a marked decrease in dissolved-solids concentration occurred below the thermocline (figs. 8 and 10), probably as a result of underflow from the Arkansas River that carries snowmelt water with small concentrations of dissolved solids. The specific-conductance profile measured at transect 7 in June (fig. 10) indicates the presence of several water layers of differing dissolved-solids concentrations. During September

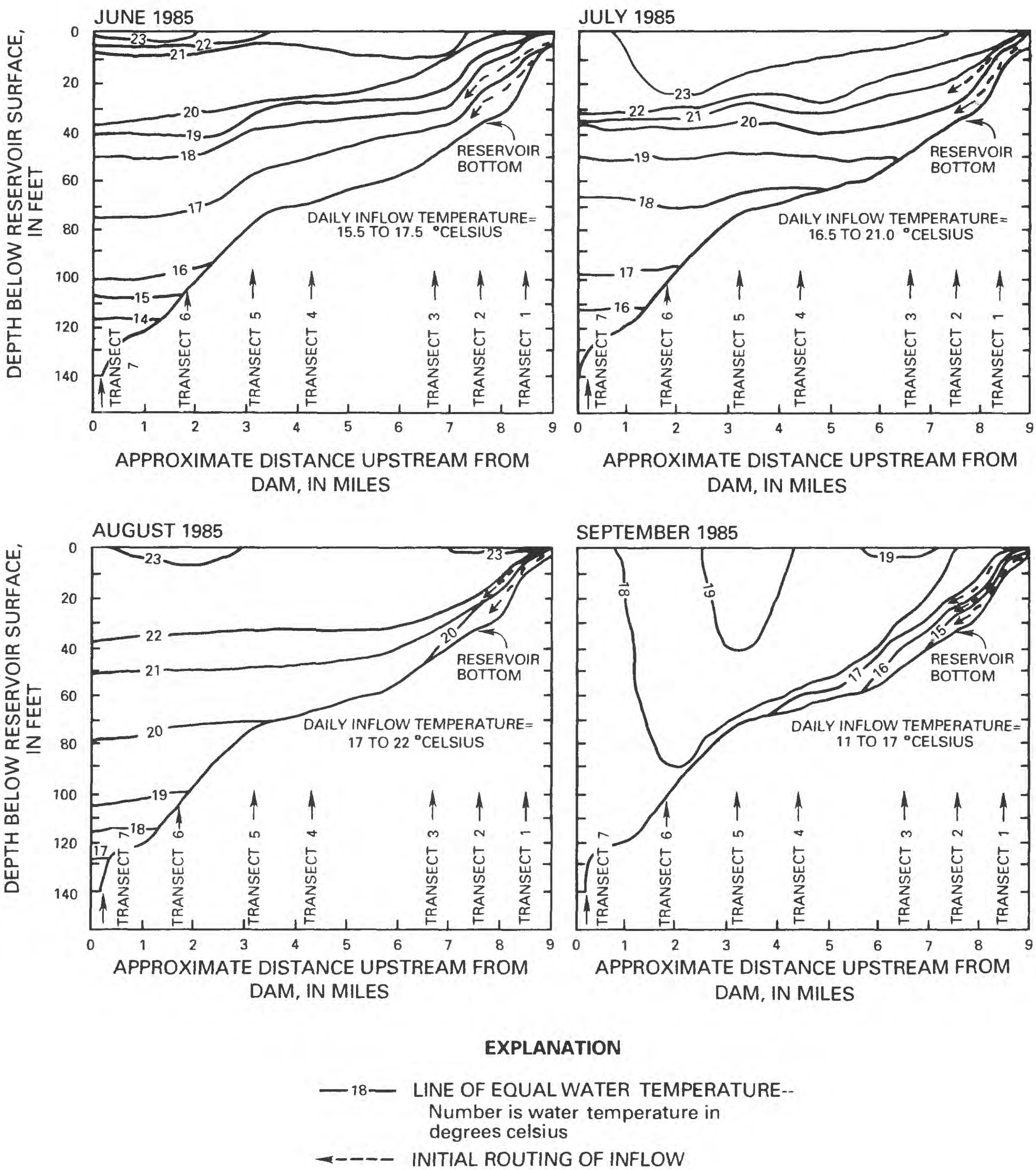


Figure 9.--Thermal structure of Pueblo Reservoir, inflow water temperatures, and initial inflow routing in Pueblo Reservoir, June through September 1985.

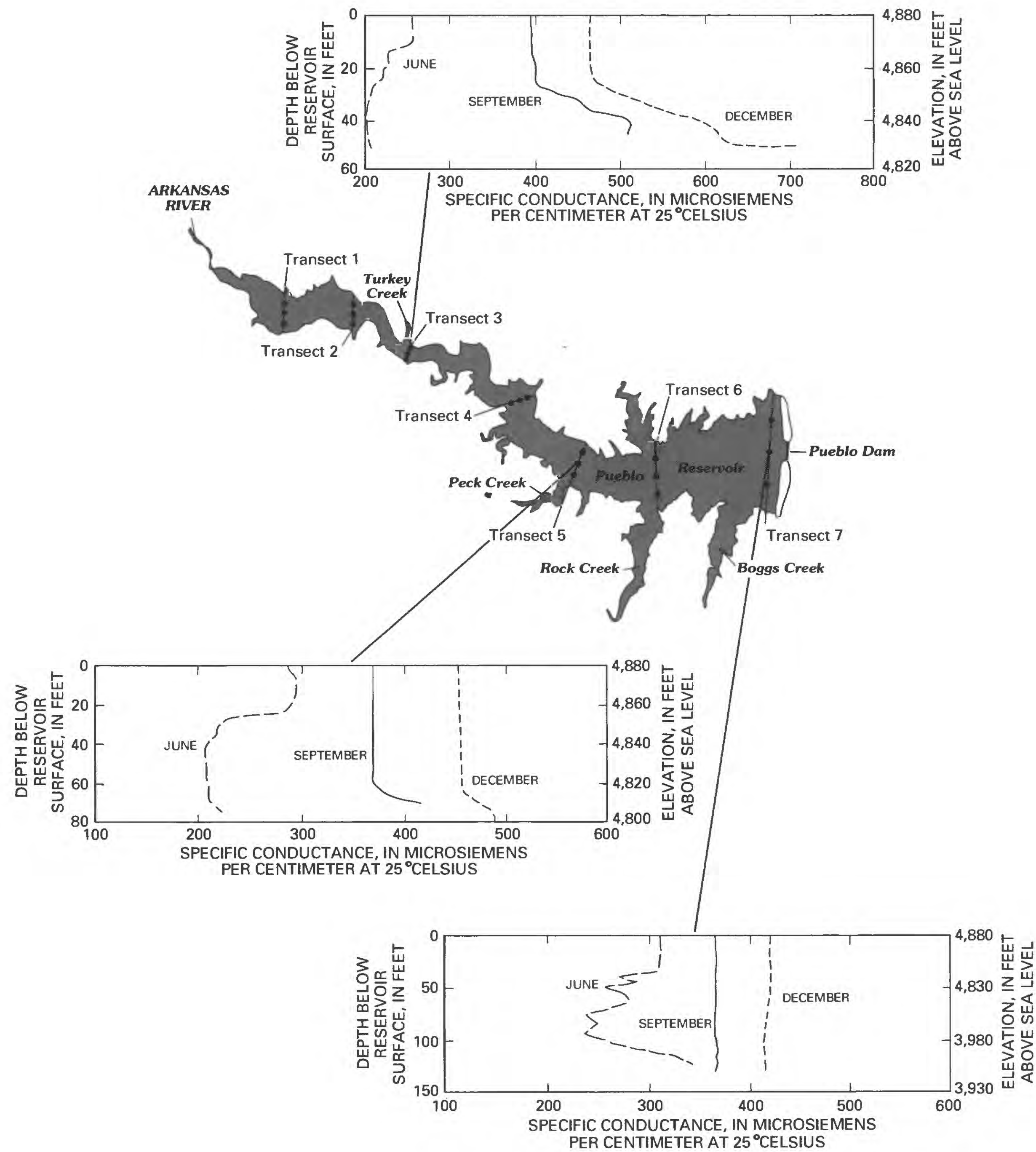


Figure 10.--Selected specific-conductance profiles of Pueblo Reservoir at transects 3, 5, and 7 for June, September, and December 1985.

and December, specific conductance at transects 3 and 5 markedly increased below the thermocline, indicating that concentrations of dissolved solids were much larger in the lower strata near the reservoir bottom, probably as the result of river water underflow that had a greater specific conductance than the reservoir. Specific-conductance measurements at transect 7 were the same throughout the water column during September and December. This indicates that the reservoir was thoroughly mixed near the outflow, possibly as a result of induced mixing from the outflow.

Monthly variations in specific conductance measured at the reservoir surface and reservoir bottom at transects 1, 3, 5, and 7 are shown in figure 11 and indicate that specific conductance increased throughout the reservoir from June through December. At transect 7, the monthly variations are less pronounced than at transects 1, 3, and 5, possibly as a result of withdrawals from the dam that induce mixing. The variations in specific conductance that occurred in the reservoir generally coincided with variations in specific conductance measured at station 07097000, Arkansas River at Portland (fig. 6), and indicate that concentrations of dissolved solids in the reservoir are affected largely by dissolved-solids concentration in the Arkansas River upstream from the reservoir.

Light Transparency

Light transparency is the capability of water to transmit light and determines the depths where sufficient light exists for photosynthesis to occur. The euphotic zone is the area of the lake where light penetration is sufficient for photosynthesis. An approximation of the capability of water in Pueblo Reservoir to transmit light was made using a Secchi disk. The measurement consists of recording the depth at which the disk disappears from view. Secchi-disk depth is a function of the reflection of light from its surface and is affected by surface disturbance (waves), absorption characteristics of the water, color of the water, and dissolved and particulate matter in the water. The Secchi-disk depth correlates closely with percentage of light transmission. At the extremes, Secchi-disk depth can represent from 1- to 15-percent light transmission (Wetzel, 1983). Hutchinson (1957) noted that the Secchi disk disappears from view at about the light-penetration level of 5 percent of surface light. The compensation level, or the depth of water at which oxygen production by photosynthesis equals the oxygen consumption by respiration, usually occurs when light intensity is decreased to about 1 percent of surface light. The depth of the euphotic zone in Pueblo Reservoir is estimated to be about 2 to 3 times the Secchi-disk depth.

Secchi-disk depths ranged from less than 1 ft at transect 1, located near the inflow, to 9.5 ft at transect 6 (fig. 12). In general, Secchi-disk depths increased from transect 1 to transect 7, indicating a possible decrease in suspended sediment and algal biomass from transect 1 to transect 7. During September and October, anomalously small Secchi-disk depths were measured, possibly due to a greater occurrence of cloud cover.

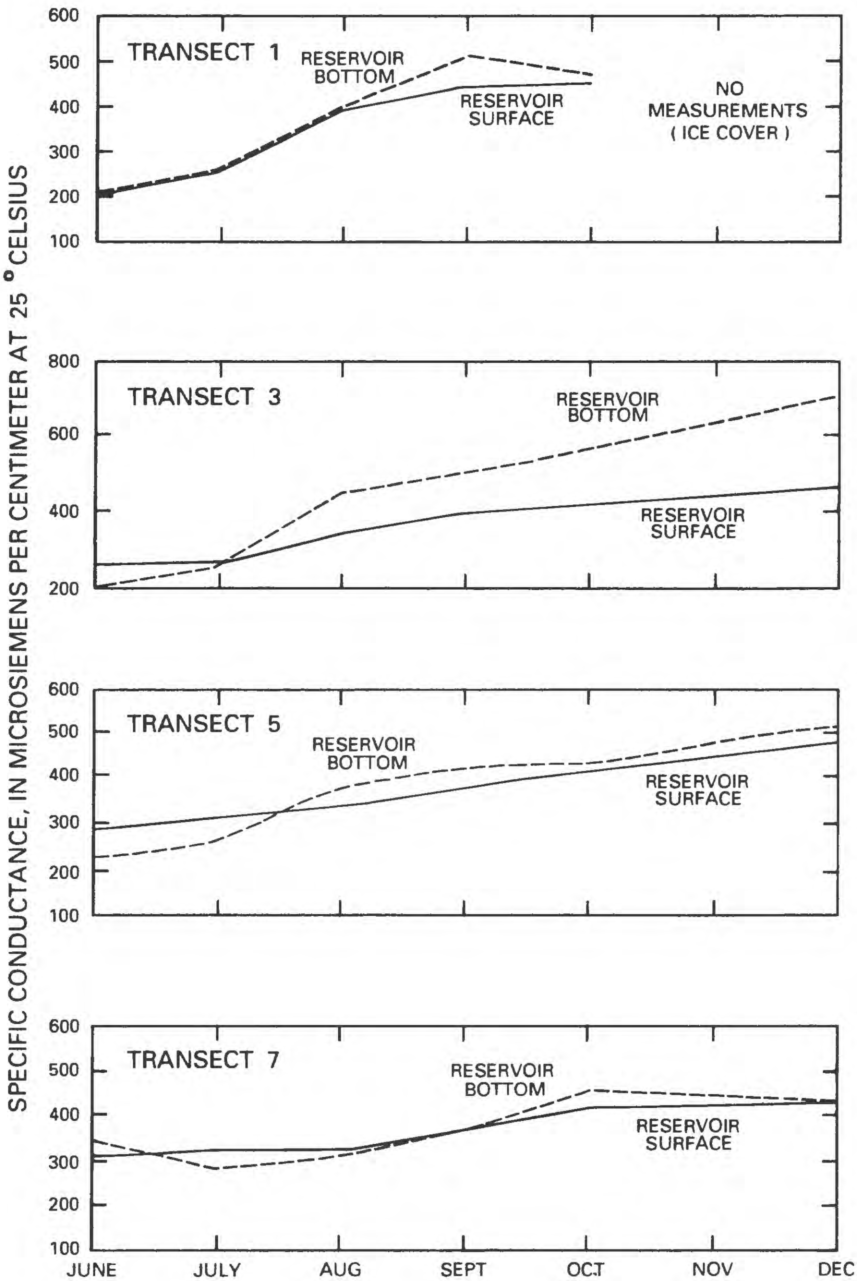


Figure 11.--Monthly variations in specific-conductance measurements of water at the reservoir surface and reservoir bottom for transects 1, 3, 5, and 7 in 1985.

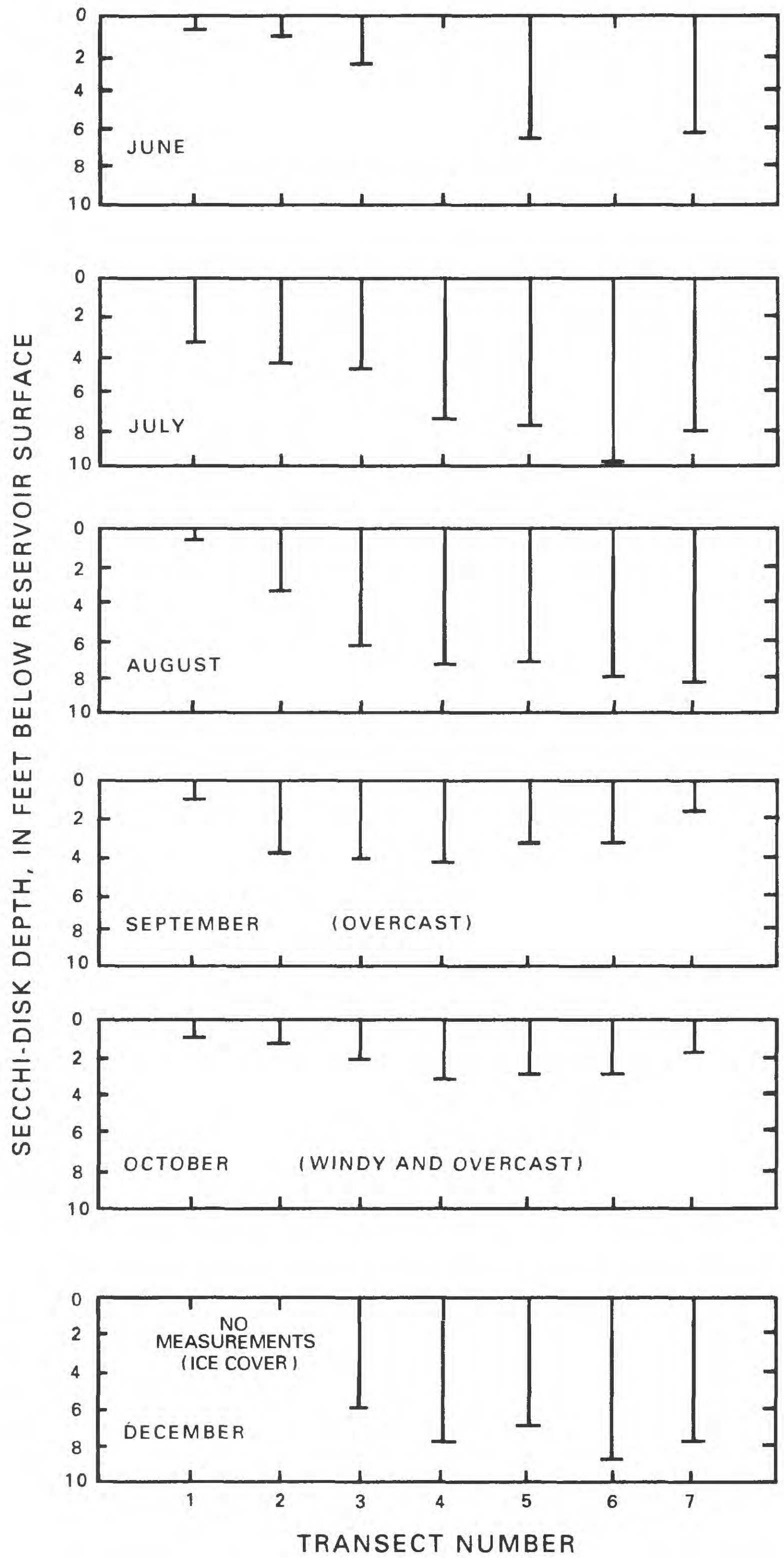


Figure 12.--Measurements of Secchi-disk depths for Pueblo Reservoir, 1985.

Dissolved Oxygen

Dissolved oxygen is an important constituent of water because oxygen is essential to the metabolism of most aquatic organisms and is necessary for aerobic decomposition of organic matter. The dissolved-oxygen concentration in water is inversely related to water temperature and is affected by photosynthesis, respiration, physical interaction of water with the atmosphere (aeration), and oxygen-consuming waste loads. The concentrations of dissolved oxygen in Pueblo Reservoir also are affected by the concentrations of dissolved oxygen input by the Arkansas River. Photosynthetic organisms use carbon dioxide from the water to synthesize carbohydrates and release oxygen. As a result, the water becomes supersaturated with dissolved oxygen when photosynthetic oxygen production is substantial. Dissolved oxygen is used for respiration by aerobic bacteria, plants, and animals, and dissolved-oxygen concentrations become depleted if respiration exceeds the rate of oxygen supply.

In a stratified lake, the thermocline impedes transfer of dissolved oxygen from the epilimnion to the hypolimnion. Hypolimnetic water, as a result of respiration and decomposition of organic matter, may lose all the oxygen gained during the last mixing period. If anaerobic conditions result, large quantities of nutrients and trace elements may be released from the bottom sediments into the water column.

If large quantities of decomposable organic matter are introduced into a lake, oxygen depletion can occur throughout the lake, possibly causing the death of aquatic organisms, primarily fish, because they have large oxygen requirements. Different types of fish require varying concentrations of dissolved oxygen to survive. Cold-water fish, such as trout, require larger concentrations of dissolved oxygen (more than 5 mg/L) than do warm-water fish, such as carp and catfish (more than 4 mg/L) (U.S. Environmental Protection Agency, 1976). Because Pueblo Reservoir is a cold-water fishery, the Colorado Department of Health (1982) established a water-quality standard for dissolved oxygen of 6.0 mg/L during most of the year and 7.0 mg/L during the spawning season.

Selected profiles of dissolved-oxygen measurements made during June, September, and December 1985 (fig. 13) indicate changes in dissolved-oxygen concentration with depth. Small increases in dissolved-oxygen concentrations occasionally occurred near the thermocline and may have been caused by inflow of Arkansas River water that contained relatively large dissolved-oxygen concentrations or because of photosynthetically produced oxygen by phytoplankton that accumulated in this layer of increased density. During June, July, and August, dissolved-oxygen concentrations measured near the reservoir surface were between 7 and 8 mg/L; at the reservoir bottom, dissolved-oxygen concentrations ranged from 6 mg/L at transect 1 to less than 2 mg/L at transect 7 (fig. 14). This indicates that substantial depletion of dissolved-oxygen concentrations occurred in the lower strata of the reservoir, especially between transects 3 and 7. The dissolved oxygen minimum of 0.1 mg/L occurred at the reservoir bottom at transect 7 during August 1985. During September, October, and December, the reservoir was well oxygenated, and much smaller changes in dissolved-oxygen concentrations occurred between the reservoir surface and reservoir bottom as a result of mixing and decreased biological activity in the reservoir. Mixing caused dissolved oxygen to be transported throughout the water column.

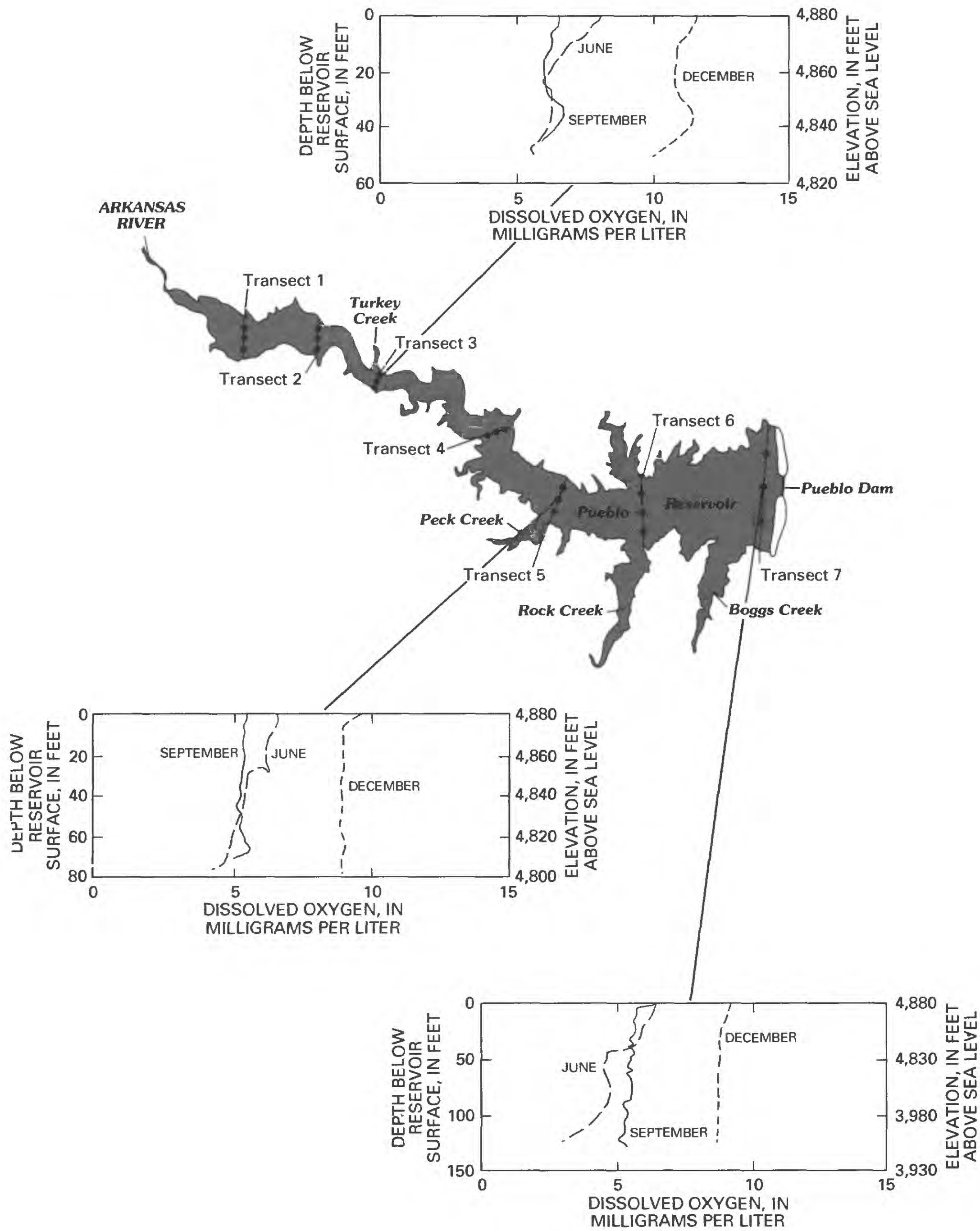


Figure 13.--Selected dissolved-oxygen profiles of Pueblo Reservoir at transects 3, 5, and 7 for June, September, and December 1985.

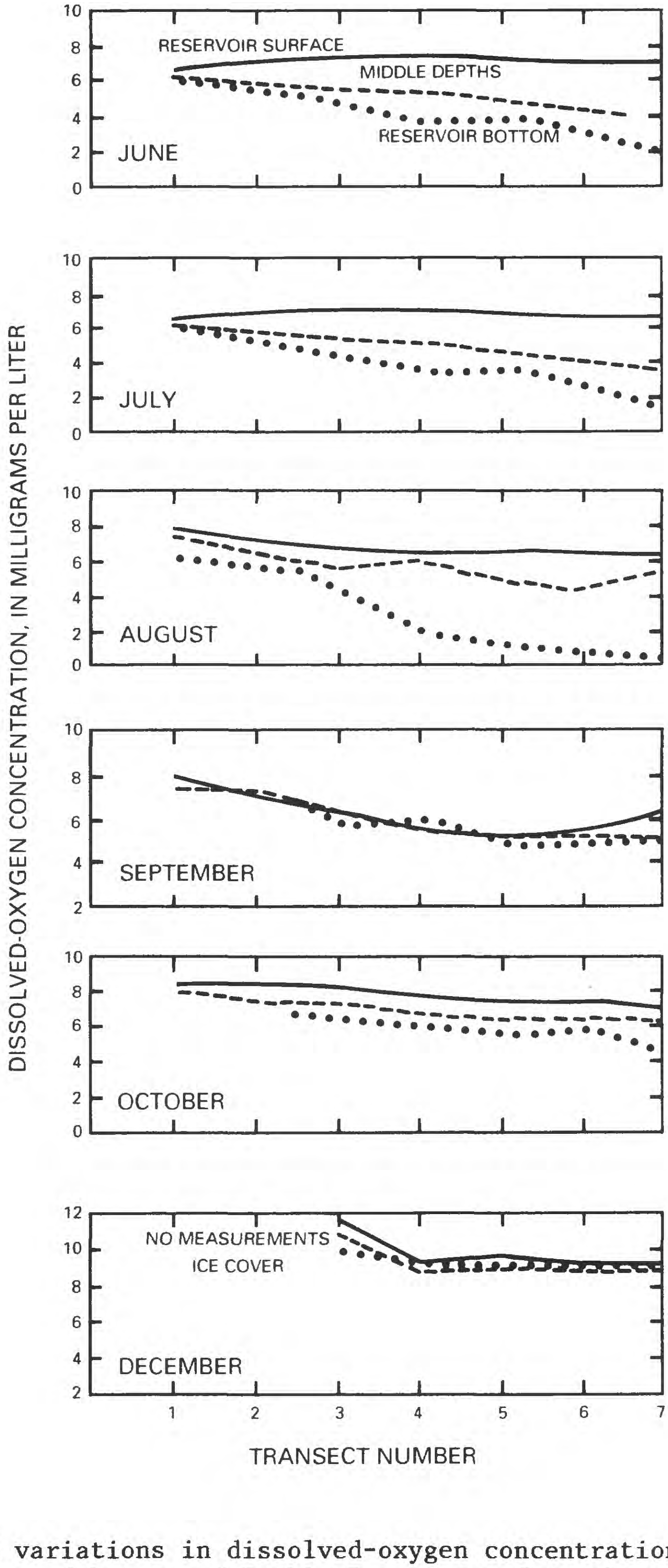


Figure 14.--Areal variations in dissolved-oxygen concentrations at the surface, middle, and bottom of Pueblo Reservoir, June through October and December 1985.

pH

The pH is a measure of the hydrogen ion activity and is important because the solubility of many chemical constituents, including trace elements, and the biological activity of many organisms are pH dependent. Because the pH may affect the suitability of water for various uses, the Colorado Department of Health (1982) established an acceptable pH range of 6.5 to 9.0 for Pueblo Reservoir.

The pH of water in Pueblo Reservoir is altered by photosynthesis and respiration and by the pH of water entering Pueblo Reservoir from the Arkansas River. The pH typically ranged from about 7.5 to 9 during the 1985 sampling period. The consumption of carbon dioxide during photosynthesis increases the pH of water, whereas the release of carbon dioxide during respiration decreases the pH. During the summer (June), the pH values were larger near the reservoir surface as a result of photosynthesis and smaller near the bottom where organic matter is decomposing. During September at transect 3 and to a lesser extent at transect 5 (fig. 15), the pH increased below the thermocline, possibly as a result of inflow from the Arkansas River. During fall and winter, fewer variations in pH occurred with depth because of mixing and decreased biological activity in the reservoir.

Chemical Constituents

The presence and concentrations of various chemical constituents determine the chemical quality of water in lakes. The chemical constituents discussed in this report include nitrogen, phosphorous, major chemical constituents, and trace elements analyzed by the U.S. Geological Survey Denver analytical laboratory using methods described by Fishman and Friedman (1985).

Nitrogen and Phosphorus

Nitrogen and phosphorus species, commonly referred to as major nutrients, often are the plant nutrients most likely to limit phytoplankton growth. Thus, as nutrient concentrations increase, lake productivity increases during a process known as eutrophication. Application of fertilizers and discharge of municipal wastewater increase nutrient loads to many lakes; however, nutrient loadings to the Arkansas River upstream from Pueblo Reservoir are small because of the limited quantity of agricultural and municipal wastewater discharges.

During the summer of 1985, total-nitrogen concentrations in the reservoir ranged from less than 0.2 to 1.2 mg/L and had an average concentration of about 0.6 mg/L. The predominant nitrogen species was organic nitrogen, which is not as readily utilized by algae as nitrate, and ammonia. Organic nitrogen comprised about 60 percent of the total nitrogen. The cumulative concentrations of nitrite, nitrate, and ammonia generally were less than 0.3 mg/L. Total-inorganic-nitrogen concentrations of water samples collected near the reservoir surface ranged from less than 0.02 to 0.6 mg/L (fig. 16). The average total-inorganic-nitrogen concentration near the reservoir surface was about 0.2 mg/L. Total-inorganic-nitrogen concentrations near the reservoir

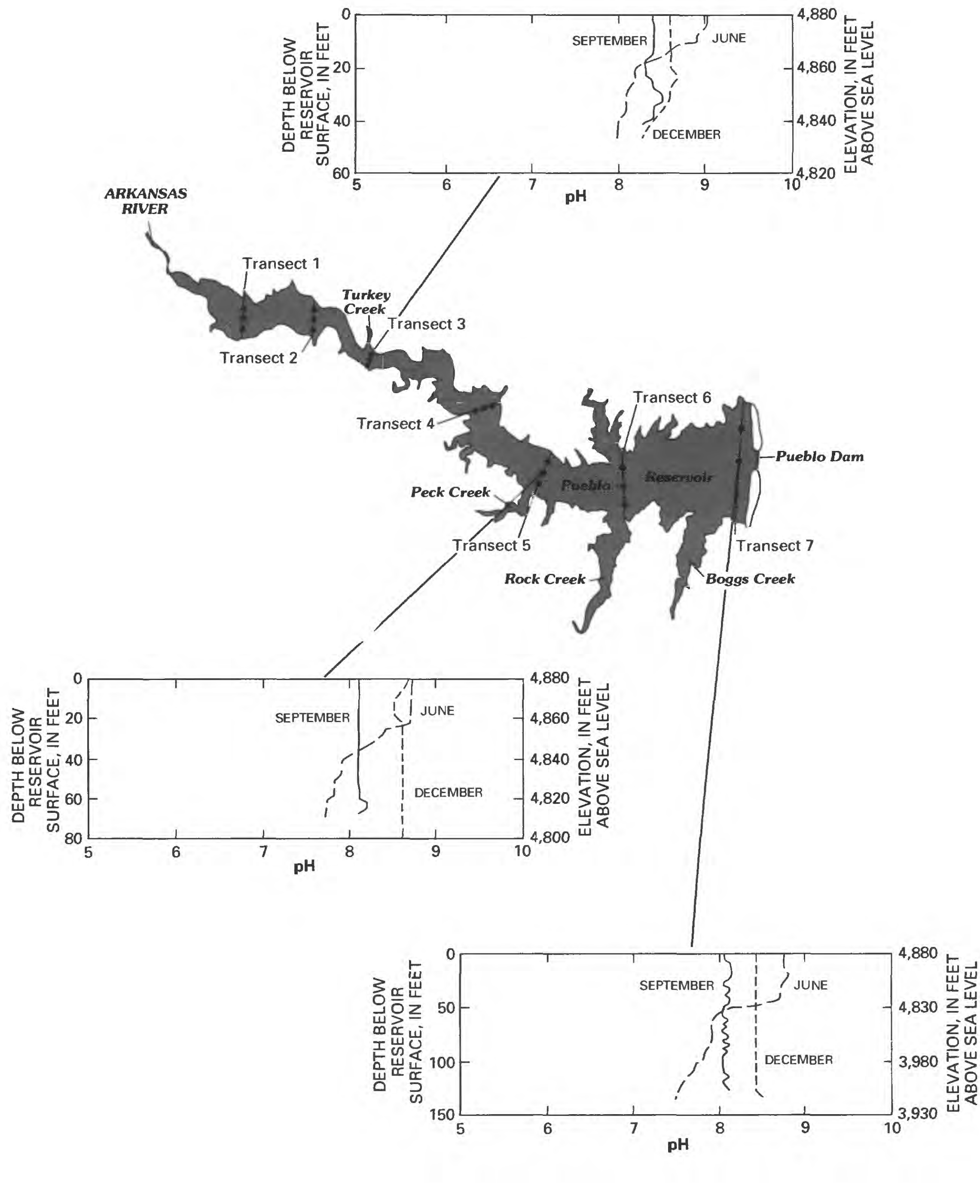
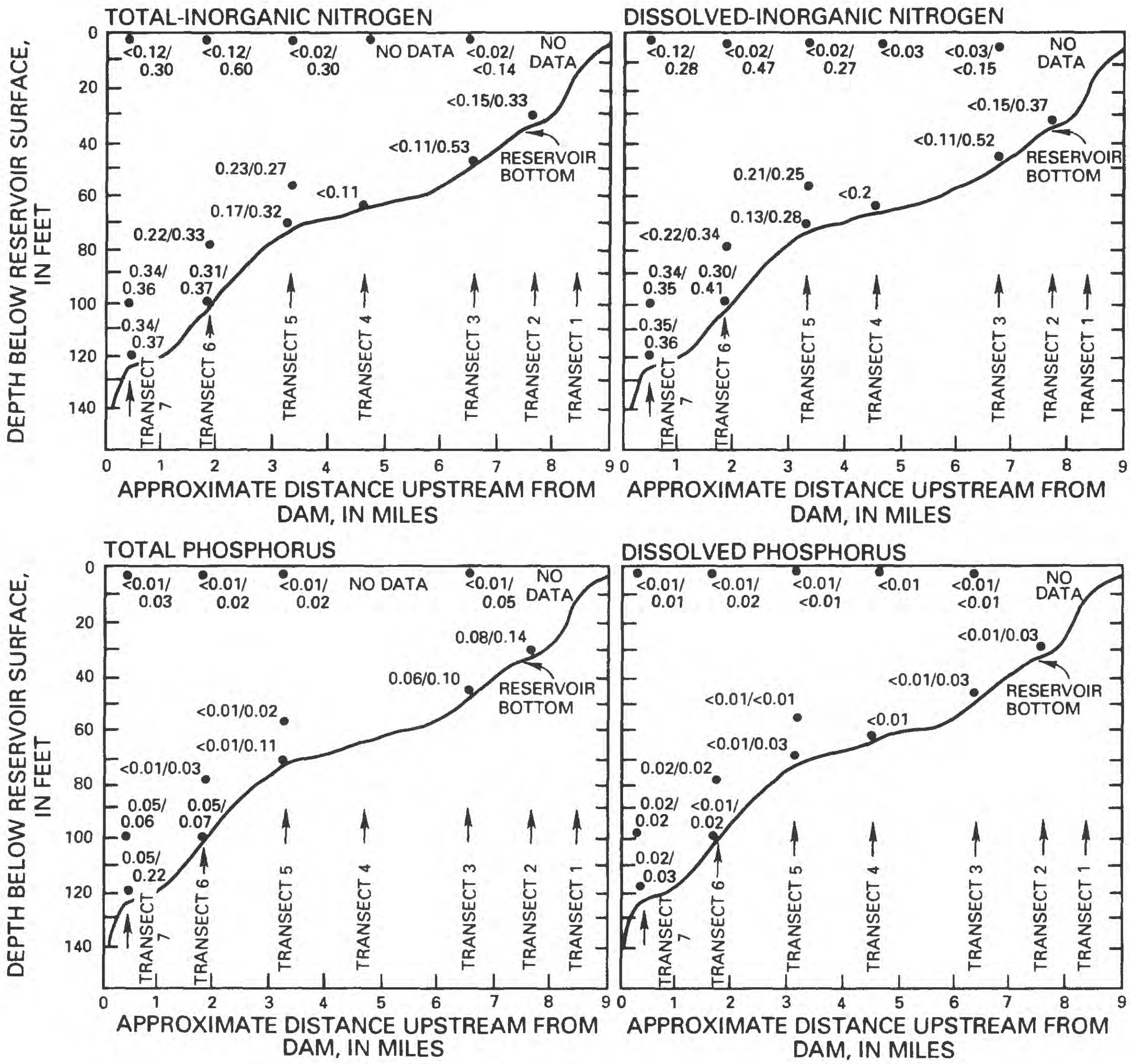


Figure 15.--Selected pH profiles of Pueblo Reservoir at transects 3, 5, and 7 for June, September, and December 1985.



EXPLANATION

0.02/0.02 UPPER NUMBER IS MINIMUM CONCENTRATION LOWER NUMBER IS MAXIMUM CONCENTRATION A SINGLE NUMBER INDICATES ONLY ONE ANALYSIS-- Concentration is in milligrams per liter

● SAMPLE DEPTH

Figure 16.--Minimum and maximum concentrations of total-inorganic nitrogen, dissolved-inorganic nitrogen, total phosphorus, and dissolved phosphorus in Pueblo Reservoir, July through September 1985.

bottom ranged from less than 0.11 to 0.53 mg/L, and had an average concentration of about 0.3 mg/L. Goldman and Horne (1983) indicate that total-inorganic-nitrogen concentrations less than 0.1 mg/L may limit phytoplankton growth, whereas concentrations greater than 0.4 mg/L would not limit growth. A comparison of total-inorganic nitrogen and dissolved-inorganic-nitrogen concentrations (fig. 16) indicate that nearly all the total-inorganic nitrogen is dissolved.

Areal and vertical variations of minimum and maximum total-inorganic-nitrogen and dissolved-inorganic-nitrogen concentrations during the summer of 1985 in Pueblo Reservoir are shown in figure 16. The inorganic-nitrogen concentrations of samples collected near the reservoir surface varied more than inorganic-nitrogen concentrations of samples collected near the reservoir bottom. The minimum concentrations of inorganic nitrogen measured near the reservoir surface were less than the minimum inorganic-nitrogen concentrations measured near the reservoir bottom, probably as the result of biological uptake in the euphotic zone.

Total-phosphorus and dissolved-phosphorus concentrations in Pueblo Reservoir during the summer of 1985 also are shown in figure 16. Total-phosphorus concentrations ranged from less than 0.01 to 0.05 mg/L, with an average of about 0.02 mg/L near the reservoir surface, and ranged from less than 0.01 to 0.22 mg/L, with an average of about 0.07 mg/L near the reservoir bottom. The largest total-phosphorus concentrations measured at each transect occurred near the reservoir bottom, possibly as a result of phosphorus associated with underflow of Arkansas River water or from settling of dead algal cells. Dissolved-phosphorus concentrations ranged from less than 0.01 to 0.02 mg/L near the reservoir surface; the dissolved-phosphorus concentrations ranged from less than 0.01 to 0.03 mg/L near the reservoir bottom, indicating that the particulate phosphorus concentrations in Pueblo Reservoir are much greater than soluble-phosphorus concentrations. Particulate phosphorus in a lake includes bacterial, plant, and animal phosphorus as well as the phosphorus adsorbed to the suspended sediment. Phytoplankton only are able to use phosphorus in the phosphate form for growth (Goldman and Horne, 1983). The orthophosphate in the euphotic zone was rapidly consumed by phytoplankton, as indicated by concentrations that generally were less than the analytical detection level (0.01 mg/L). The total-orthophosphate concentrations near the reservoir bottom were considerably greater than near the reservoir surface and ranged from less than 0.01 to 0.06 mg/L near the reservoir bottom because of the lack of biological uptake.

Major Chemical Constituents

The major chemical constituents are calcium, magnesium, potassium, sodium, bicarbonate, carbonate, chloride, fluoride, and sulfate. These constituents are used by plants as nutrients, but unlike nitrogen and phosphorus, the concentrations usually are sufficient enough not to become limiting to plant growth. Concentrations of major chemical constituents are affected by the minerals and the solubility of the minerals in rocks that occur in the drainage basin upstream from the reservoir, irrigation-return flows, waste materials discharged to the Arkansas River upstream from the reservoir, precipitation, and evaporation.

Concentrations of major chemical constituents near the reservoir surface at transect 7 and near the reservoir bottom at transect 2 for the summer of 1985 are shown in figure 17. Between July and August, concentrations of calcium, magnesium, sodium, bicarbonate, chloride, and sulfate more than doubled near the reservoir bottom, whereas concentrations of these constituents changed very little near the reservoir surface at transect 7. The variations in ion concentrations at transects 2 and 7 were consistent with changes in specific conductance that occurred with depth and demonstrate the effects of chemical stratification for specific ions. The changes in concentrations of specific ions probably result largely from variations in concentrations of the ions in the Arkansas River upstream from the reservoir.

Trace Elements

Trace elements occur in relatively small concentrations and usually are expressed in micrograms per liter. Concentrations of selected trace elements analyzed from water samples collected during the summer of 1985 near the reservoir bottom at transect 2 and near the reservoir surface at transect 7 are summarized in table 3. These data indicate that most of the trace elements are suspended rather than dissolved; the trace elements are sorbed to the sediment particles (and organic particulates) and, therefore, are transported with sediment entering the reservoir. As the sediment settles to the reservoir bottom, trace elements are removed from the water. Reducing conditions commonly occur in the bottom sediments where the water filling the void spaces between sediment particles contains little or no dissolved oxygen. These conditions result in dissolution and mobilization of trace elements which then migrate upward. As trace elements reach the surface of the reservoir sediments, the trace elements are oxidized by dissolved oxygen in the reservoir water and precipitate on the upper sediment particles (Britton and Wentz, 1980). If dissolved oxygen becomes depleted in the lower strata of the reservoir, reducing conditions may cause large concentrations of trace elements to be released quickly to the reservoir water.

During August and September 1985, concentrations of total recoverable iron were 4,100 μg/L and 2,800 μg/L near the reservoir bottom at transect 2. The recommended criterion for aquatic life is 1,000 μg/L (U.S. Environmental Protection Agency, 1976). Dissolved-manganese concentrations also exceeded public water-supply standards near the reservoir bottom at transect 2 during July and September. Concentrations of other trace elements were less than established water-quality standards for Pueblo Reservoir (Colorado Department of Health, 1982).

Biological Constituents

Lakes contain a large variety of organisms. During 1985, the distribution and abundance of phytoplankton and zooplankton were measured. Plankton is the community of suspended or floating organisms that drift with water currents. The plant portion of the plankton are called phytoplankton and commonly are referred to as algae. Zooplankton are the animal part of the plankton.

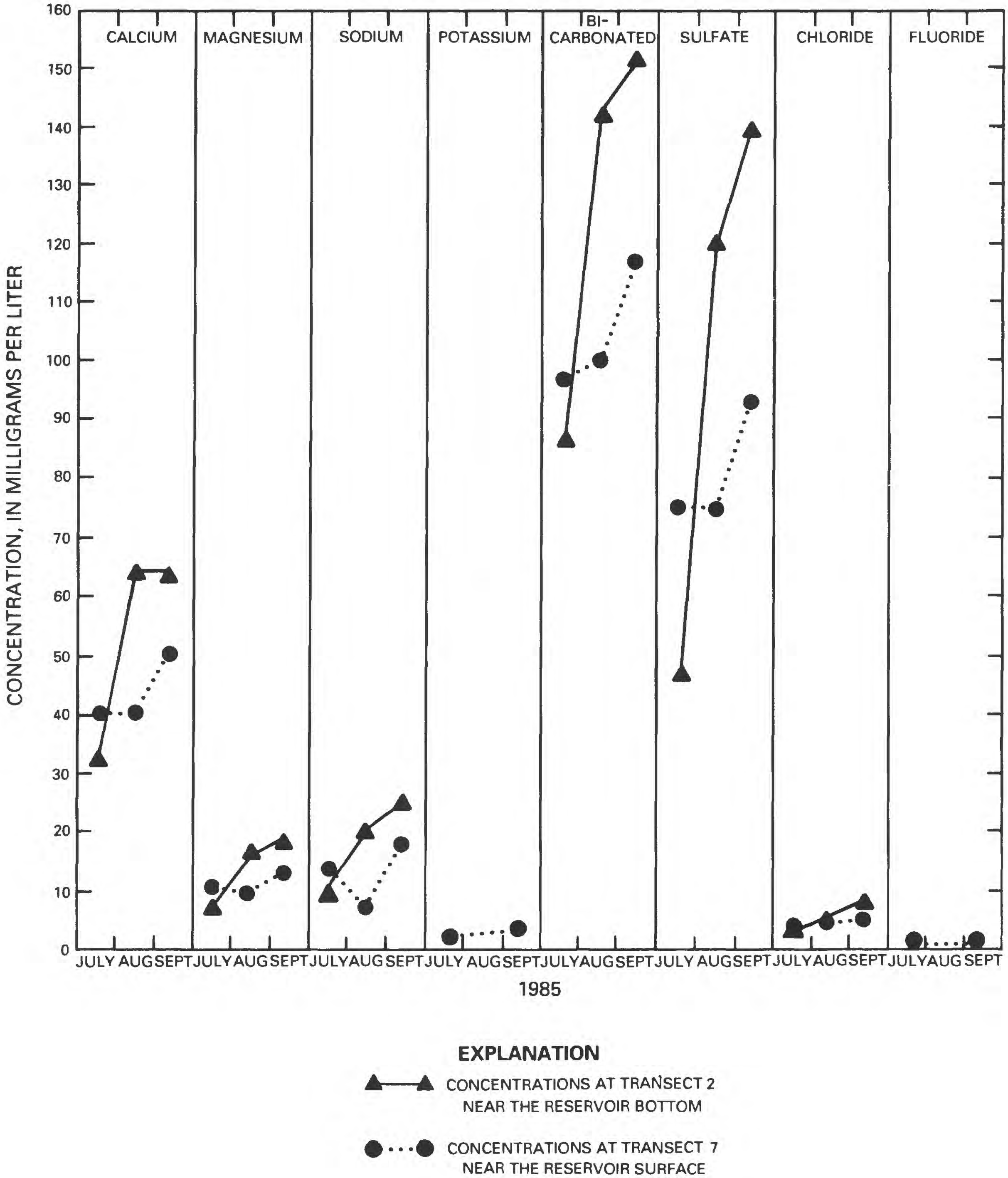


Figure 17.--Concentrations of major chemical constituents near the reservoir surface at transect 7 and near the reservoir bottom at transect 2, July through September 1985.

Table 3.--*Summary of selected trace-element data for Pueblo Reservoir, summer 1985*

[--, missing data]

Constituent	Number of analyses	Concentrations, in micrograms per liter: Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
	[1]*Transect 2*		*July 15, 1985*			
Barium, dissolved	3	51	1	50	51	0
Barium, total	0	--	--	--	--	--
Copper, dissolved	3	2	1	1	2	0
Copper, total	0	--	--	--	--	--
Iron, dissolved	3	13	8	6	21	4
Iron, total	0	--	--	--	--	--
Manganese, dissolved	3	75	3	72	77	1
Manganese, total	0	--	--	--	--	--
Nickel, dissolved	2	3	1	2	3	1
Nickel, total	0	--	--	--	--	--
Selenium, dissolved	3	1	0	1	1	0
Selenium, total	0	--	--	--	--	--
Zinc, dissolved	3	11	3	9	14	2
Zinc, total	0	--	--	--	--	--
	[1]Transect 2		August 15, 1985			
Barium, dissolved	3	66	6	62	73	3
Barium, total	3	233	58	200	300	33
Copper, dissolved	3	2	1	2	3	0
Copper, total	3	7	1	6	8	1
Iron, dissolved	3	4	1	3	5	1
Iron, total	3	4,133	723	3,300	4,600	418
Manganese, dissolved	3	24	6	19	31	4
Manganese, total	3	113	21	90	130	12
Nickel, dissolved	3	2	0	2	2	0
Nickel, total	3	11	1	10	12	1
Selenium, dissolved	3	2	1	2	3	0
Selenium, total	3	3	0	3	3	0
Zinc, dissolved	3	5	2	3	6	1
Zinc, total	3	33	6	30	40	3

Table 3.--*Summary of selected trace-element data for Pueblo Reservoir, summer 1985*--Continued

Constituent	Number of analyses	Concentrations, in micrograms per liter				
		Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
	[1]Transect 2	September 25, 1985				
Barium, dissolved	3	83	15	72	100	9
Barium, total	3	100	0	100	100	0
Copper, dissolved	3	2	1	1	2	0
Copper, total	3	7	2	6	9	1
Iron, dissolved	3	19	27	4	50	15
Iron, total	3	2,800	173	2,700	3,000	100
Manganese, dissolved	3	52	4	49	56	2
Manganese, total	3	123	6	120	130	3
Nickel, dissolved	3	6	1	5	7	1
Nickel, total	3	8	3	6	11	2
Selenium, dissolved	3	3	0	3	3	0
Selenium, total	3	2	0	2	2	0
Zinc, dissolved	3	12	16	3	30	9
Zinc, total	3	37	6	30	40	3
	[2]Transect 7	July 19, 1985				
Barium, dissolved	3	52	1	51	52	0
Barium, total	2	100	0	100	100	0
Copper, dissolved	3	4	1	3	4	0
Copper, total	2	4	1	3	4	1
Iron, dissolved	3	6	3	4	10	2
Iron, total	2	60	0	60	60	0
Manganese, dissolved	3	2	1	1	2	0
Manganese, total	2	20	0	20	20	0
Nickel, dissolved	3	6	6	3	13	3
Nickel, total	2	11	8	5	16	6
Selenium, dissolved	3	3	0	3	3	0
Selenium, total	2	3	0	3	3	0
Zinc, dissolved	3	11	2	9	12	1
Zinc, total	2	10	0	10	10	0

Table 3.--*Summary of selected trace-element data for Pueblo Reservoir, summer 1985*--Continued

Constituent	Number of analyses	Concentrations, in micrograms per liter: Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
Transect 7[2] August 27, 1985						
Barium, dissolved	--	--	--	--	--	--
Barium, total	3	100	0	100	100	0
Copper, dissolved	3	2	1	1	2	0
Copper, total	3	3	1	2	3	0
Iron, dissolved	3	30	17	20	50	10
Iron, total	1	30	--	30	30	--
Manganese, dissolved	3	10	0	10	10	0
Manganese, total	3	10	0	10	10	0
Nickel, dissolved	3	2	1	1	2	0
Nickel, total	3	7	3	5	10	2
Selenium, dissolved	3	3	0	3	3	0
Selenium, total	3	3	0	3	3	0
Zinc, dissolved	3	17	6	10	20	3
Zinc, total	3	13	6	10	20	3
Transect 7[2] September 30, 1985						
Barium, dissolved	3	64	4	60	67	2
Barium, total	3	100	0	100	100	0
Copper, dissolved	3	1	0	1	1	0
Copper, total	3	3	0	3	3	0
Iron, dissolved	3	5	1	4	6	1
Iron, total	3	333	12	320	340	7
Manganese, dissolved	3	16	0	16	16	0
Manganese, total	3	57	6	50	60	3
Nickel, dissolved	3	2	0	2	2	0
Nickel, total	3	3	1	3	4	0
Selenium, dissolved	3	3	0	3	3	0
Selenium, total	3	3	0	3	3	0
Zinc, dissolved	3	11	3	9	14	1
Zinc, total	3	30	10	20	40	6

[1]Water samples collected at transect 2 were collected near the reservoir bottom.

[2]Water samples collected at transect 7 were collected near the reservoir surface.

Phytoplankton

Phytoplankton or algae are common and normal inhabitants of surface water and are encountered in every water supply that is exposed to sunlight (Palmer, 1977). Phytoplankton, though usually inconspicuous, are extremely important in lakes because phytoplankton are the primary producers of organic matter and oxygen on which most aquatic animals depend. Phytoplankton provide a source of food for herbivorous zooplankton and fish. Thus, algae often are an asset in raw water. However, numerous water problems may result as the abundance of algae increases or the occurrence of certain kinds of algae increases. Extensive accumulations of algae at or near the lake surface are called algal blooms. Algal blooms may occur when there are sufficient nutrients available, when there are warm water temperatures, and when there is adequate sunlight. When algae die as a result of overproduction that depletes the available nutrients needed for growth and reproduction, the dissolved oxygen may become depleted, which may result in fish kills or in severe mortality of certain aquatic insects. Decomposing phytoplankton can cause an unpleasant odor; the fishy smell associated with very productive water is actually the odor of decomposing algae (McCoy, 1982). Excessive concentrations of algae can be troublesome because they clog screens, produce slime, and produce poor taste and bad odor, particularly as anaerobic decomposition occurs.

The groups of algae that occurred in Pueblo Reservoir during the summer and fall of 1985 were diatoms, green algae, blue-green algae, cryptomonads, golden-brown algae, euglenoids, and dinoflagellates. Diatoms, green algae, blue-green algae, and cryptomonads comprised the majority of the phytoplankton. The average concentrations of phytoplankton collected from the euphotic zone in Pueblo Reservoir varied from more than 41,000 cells/mL during July to about 11,000 cells/mL during October 1985 (fig. 18). During July and August, blue-green algae comprised about 70 percent of the phytoplankton in the reservoir. During September, blue-green algae comprised about 50 percent of the phytoplankton and, during October, diatoms comprised the greatest percentage.

The distribution and concentrations of the major algal groups for July and September 1985 are shown in figures 19 and 20. During July, the greatest concentrations occurred at transect 3 where more than 100,000 cells/mL of algae were measured. During September, the greatest concentrations occurred at transect 2 where more than 50,000 cells/mL were measured. During July, blue-green algae were the dominant algal group throughout the reservoir (fig. 19). But in September, blue-green algae comprised the greatest percentage of phytoplankton at transects 1, 2, 3, and 4, and diatoms comprised the greatest percentage of phytoplankton at transects 5, 6, and 7 (fig. 20).

The large concentrations of phytoplankton, especially the blue-green algae, could cause substantial water-quality problems if specific conditions occur. Given the right conditions--warm water, large rate of algal respiration, low light levels, and small quantities of oxygen entering the reservoir from either the Arkansas River or the atmosphere--the overabundance of phytoplankton could cause substantial oxygen depletion in Pueblo Reservoir in a relatively short period of time.

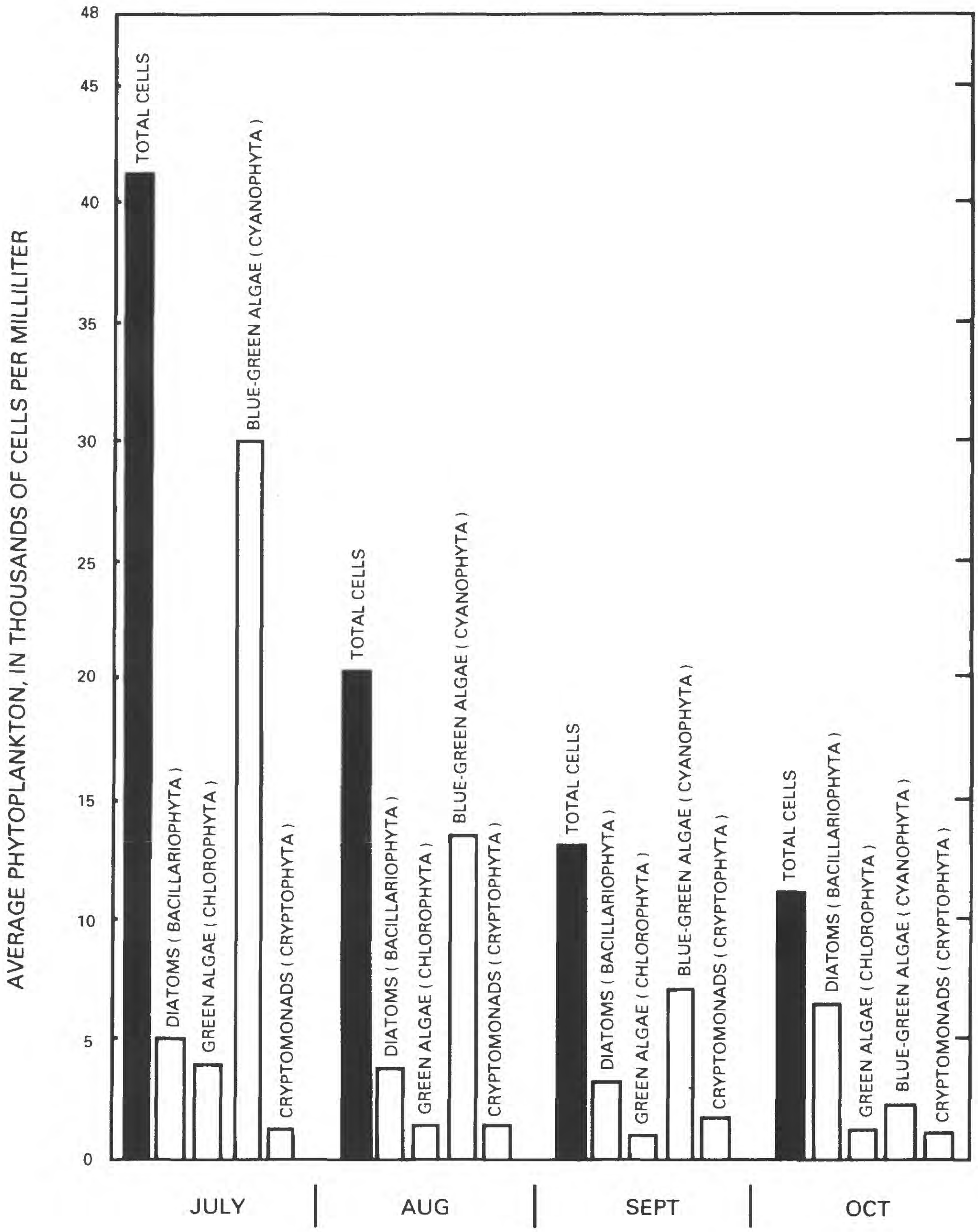


Figure 18.--Monthly variations in average concentration of total phytoplankton and major algal groups in Pueblo Reservoir, 1985.

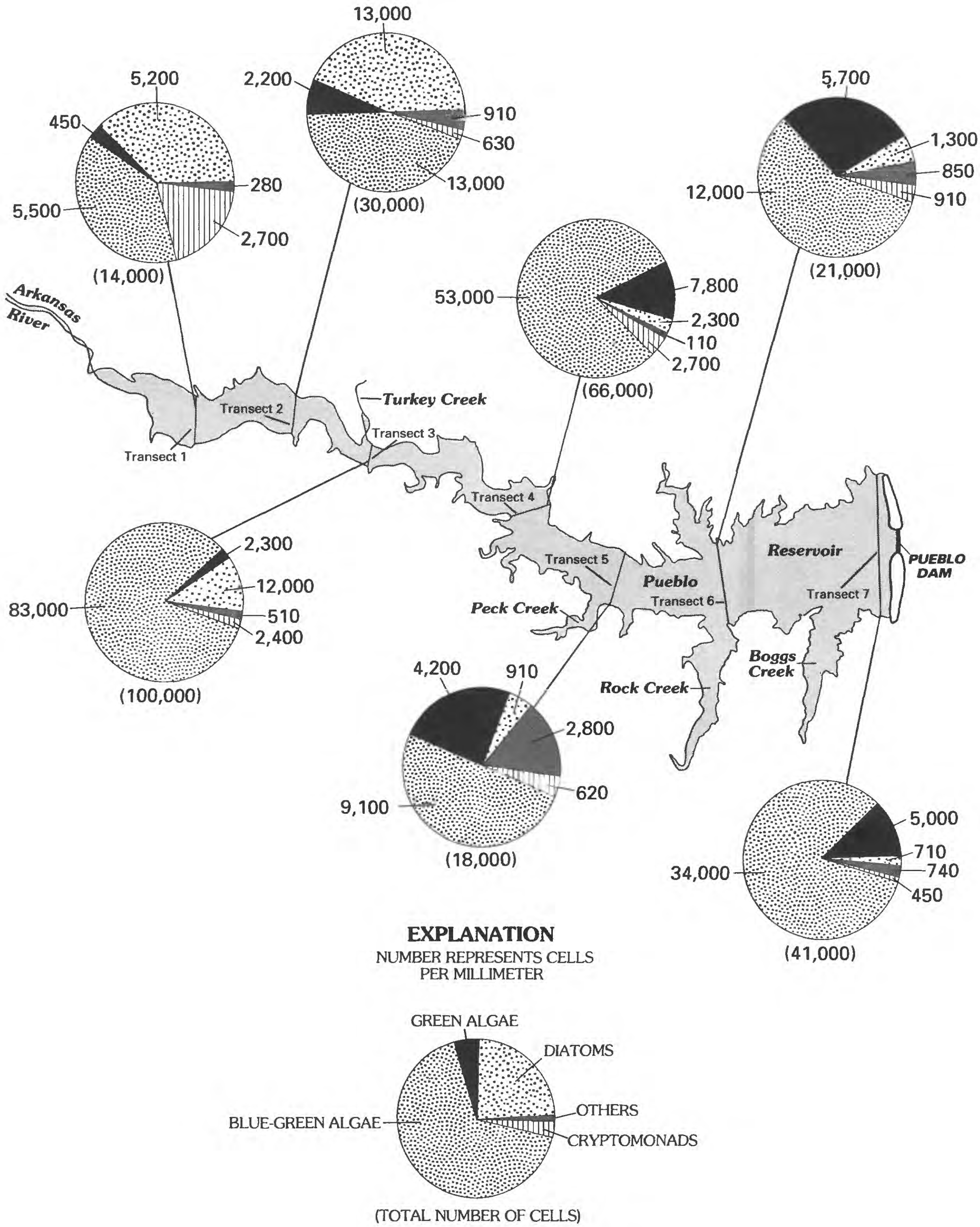


Figure 19.--Distribution and concentration of the major algal groups in Pueblo Reservoir, July 1985.

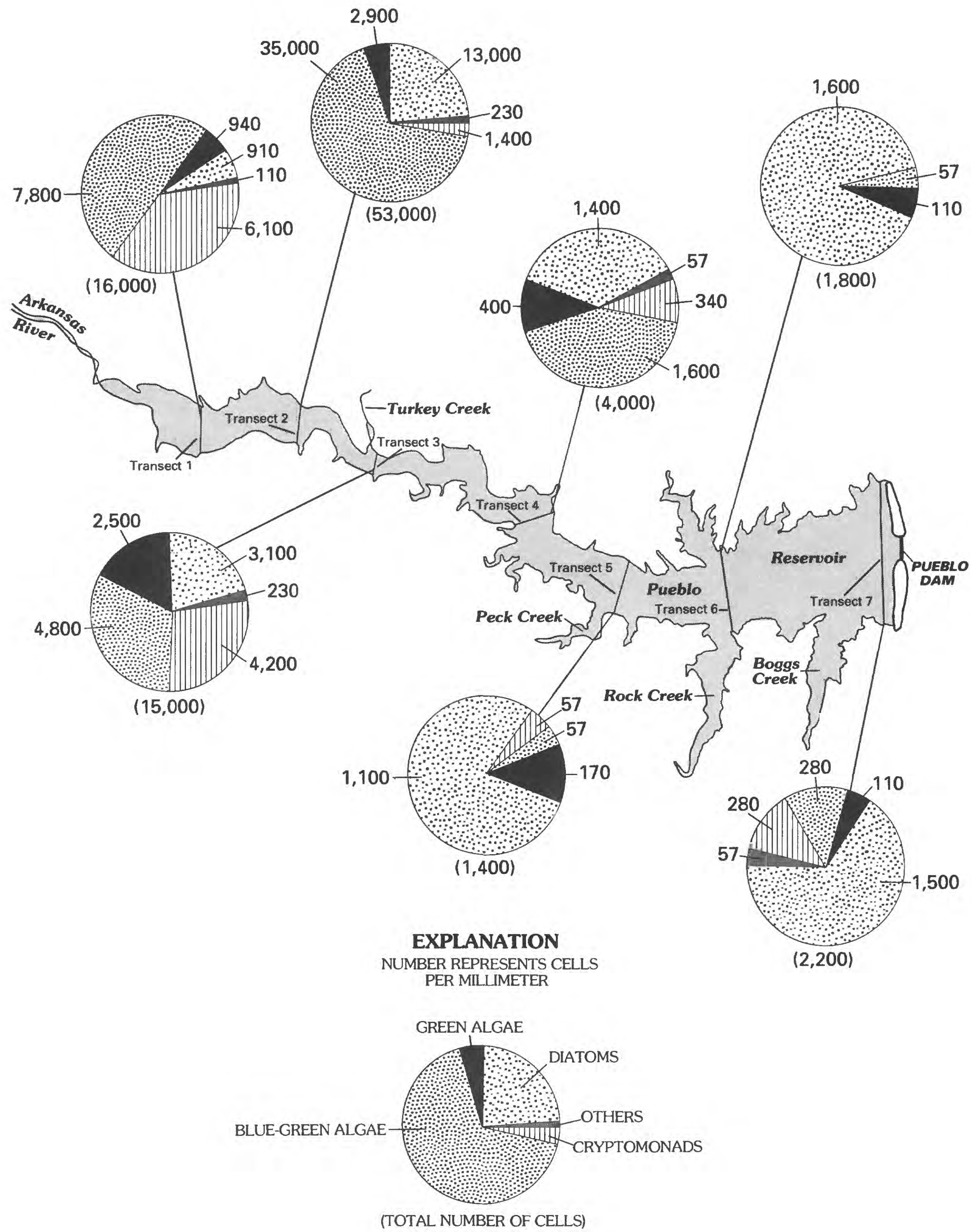


Figure 20.--Distribution and concentration of the major algal groups in Pueblo Reservoir, September 1985.

Zooplankton

Zooplankton are the animal part of the plankton and are an important source of food for fish. Some zooplankton are strong swimmers, while others have weak powers of locomotion. A daily, vertical migration of zooplankton is common (Britton and others, 1975). Zooplankton feed on bacteria, algae, and other zooplankton. Zooplankton grazing on phytoplankton may limit algal populations.

Zooplankton densities (organisms per cubic meter) in Pueblo Reservoir are shown in figure 21. Zooplankton densities ranged from a few thousand organisms per cubic meter at transects 1 and 2 to about 80,000 organisms per cubic meter at transect 5 during August.

SUMMARY AND CONCLUSIONS

Pueblo Reservoir is the farthest upstream, main-stem reservoir constructed on the Arkansas River and drains an area of 4,669 mi^2, of which about 94 percent drains into the Arkansas River upstream from the reservoir. This reconnaissance study provides a better understanding of the reservoir and quality of water entering Pueblo Reservoir and makes a preliminary assessment of some of the water-quality characteristics of the reservoir.

During the 1985 sampling period, Pueblo Reservoir was stratified, and underflow from the Arkansas River occurred that resulted in stratification of the water in the reservoir with respect to specific conductance. Concentrations of dissolved solids decreased markedly below the thermocline during June. Later in the summer, circulation deepened the thermocline, and dissolved-solids concentrations increased substantially below the thermocline. The variations in specific conductance that occurred in the reservoir generally coincided with variations in specific conductance measured at station 07097000, Arkansas River at Portland. During the 1985 water year, the maximum daily mean specific conductance at Arkansas River at Portland was 540 μS/cm and occurred during January 1985; the minimum daily mean specific conductance of 140 μS/cm occurred during June 1985.

Dissolved-oxygen profiles made during the summer of 1985 indicated that substantial depletion of dissolved-oxygen concentrations occurred in the lower strata of Pueblo Reservoir. The minimum dissolved-oxygen concentration of 0.1 mg/L occurred during August near the reservoir bottom at transect 7 (nearest the dam). During fall and winter, much smaller changes in dissolved-oxygen concentrations occurred between the reservoir surface and reservoir bottom because of mixing and decreased biological activity in the reservoir. Mixing caused dissolved oxygen to be transported throughout the water column.

The pH of Pueblo Reservoir typically ranged from about 7.5 to 9 during the 1985 sampling period. The pH was largest near the reservoir surface as the result of photosynthesis and smallest near the bottom where organic matter was decomposing. During fall and winter, less change in pH occurred with depth because of mixing and decreased biological activity in the reservoir.

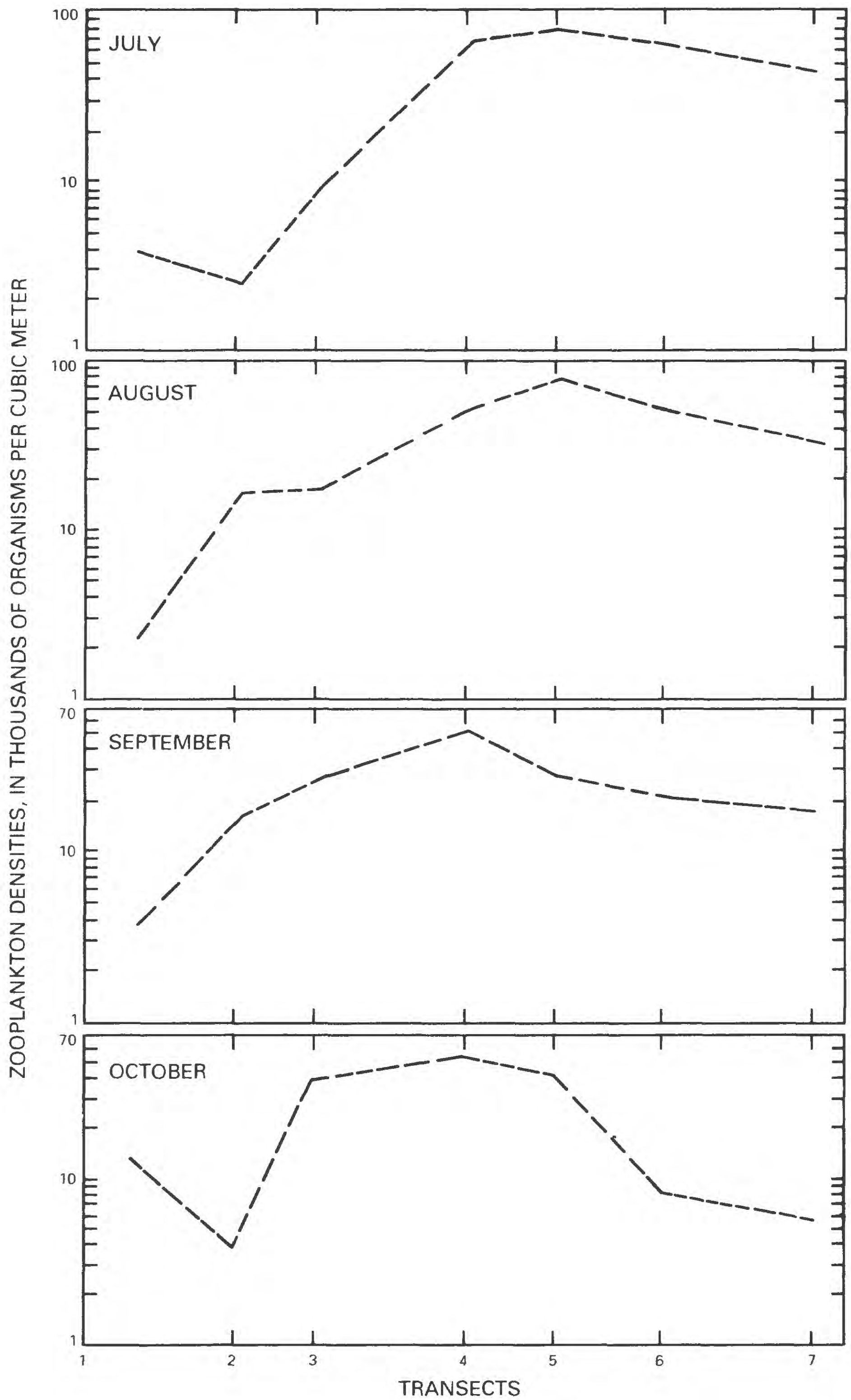


Figure 21.--Distribution of zooplankton densities in Pueblo Reservoir, July through October 1985.

Concentrations of nitrogen and phosphorus were measured during the summer of 1985 at multiple locations and depths in the reservoir. Total-nitrogen concentrations at Pueblo Reservoir ranged from less than 0.2 to 1.2 mg/L and had an average concentration of 0.6 mg/L. The predominant nitrogen form was organic nitrogen, which, as in the Arkansas River, comprised about 60 percent of the total nitrogen. The average total-inorganic-nitrogen concentration near the reservoir surface was about 0.2 mg/L; near the reservoir bottom, the average concentration was about 0.3 mg/L. Concentrations of total phosphorus ranged from less than 0.01 to 0.05 mg/L near the reservoir surface and ranged from less than 0.01 to 0.22 mg/L near the reservoir bottom. Concentrations of total phosphorus were largest near the reservoir bottom.

Concentrations of major ions in samples collected near the reservoir bottom at transect 2 varied greatly during the summer of 1985, whereas the concentrations of the ions changed very little in samples collected near the reservoir surface at transect 7 (nearest the dam) during the summer of 1985. Variations in ion concentrations were consistent with changes in specific conductance that occurred with depth and demonstrate the effects of chemical stratification and inflow on concentrations of specific ions. Dissolved-solids concentrations at the Arkansas River at Portland, as indicated by specific-conductance measurements, usually are largest from January to March and smallest during June and July.

Concentrations of most trace elements generally were small and were less than the established water-quality standards for Pueblo Reservoir. However, in 1985, concentrations of total iron occasionally exceeded the aquatic-life standard (1,000 μg/L) near the reservoir bottom at transect 2, and dissolved-manganese concentrations exceeded the standard for public water supply near the reservoir bottom at transect 2. Trace elements that occurred in the largest concentrations at the Arkansas River at Portland are barium, iron, manganese, strontium, and zinc. Trace elements primarily occur in association with suspended material.

Diatoms, green algae, blue-green algae, and cryptomonads comprised the majority of the phytoplankton in Pueblo Reservoir in the summer and fall of 1985. The maximum average concentration of phytoplankton was 41,000 cells/mL and occurred in July. Blue-green algae dominated from June to September; diatoms dominated in October. The average concentrations of phytoplankton drastically decreased from July to October. Zooplankton densities ranged from a few thousand organisms/m^3 at transects 1 and 2 to about 80,000 organisms/m^3 at transect 5 during August.

A list of potential inbasin contaminants and transportation-related contaminants was compiled and included in the section in the back of the report titled "Supplemental Information Related to Potential Contaminants to Pueblo Reservoir." Currently (1986), the greatest threat of contamination in the upper Arkansas River basin probably is from metal mines that discharge to the streams in the vicinity of Leadville. Flammable liquids, combustible liquids, and flammable gases accounted for 71 percent of the hazardous materials and 71 percent of the loads terminated in Colorado. Flammable liquids, combustible liquids, corrosives, oxidizers, and petroleum materials frequently are transported by rail. Depending on the specific compounds, location, and quantity of material spilled, a spill could pose a threat to the quality of water in Pueblo Reservoir.

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SUPPLEMENTAL INFORMATION RELATED TO POTENTIAL CONTAMINANTS TO PUEBLO RESERVOIR

Potential contaminants to Pueblo Reservoir include inbasin contaminants and transportation-related contaminants. Contaminants that enter waterways in the upper Arkansas River basin may degrade the quality of water in the Arkansas River, which in turn may affect the quality of water in Pueblo Reservoir. Locations of potential sources of contaminants are shown on plate 1 and were compiled from Colorado Department of Health discharge permits. Numerous wastewater treatment plants and metal mines discharge water into the Arkansas River or tributary streams. Because the basin is not densely populated, discharges from wastewater treatment plants are small, and the effects on stream quality are diminished as stream flows dilute the wastewater. However, municipal and industrial wastewater may have greater affects on water quality in the river, and, therefore, on water quality in the reservoir in the future if: (1) Water use in the basin changes, (2) water exchanges occur, (3) streamflows diminish, or (4) substantial municipal and industrial growth occurs. Currently (1986), the greatest threat of contamination in the basin probably is from the metal mines that discharge to the streams in the vicinity of Leadville.

As the number of shipments of hazardous materials increases throughout Colorado and throughout the basin, the chance of accidental transportation-related spills increases. Ten billion pounds of hazardous materials are transported on Colorado highways each year in about 50,000 shipments (Florence Phillips, attorney, Governor's office, written commun., 1986). During 1984, 3,354 shipments of hazardous materials were transported from the State by rail, and 10,192 shipments by rail terminated in the State (Association of American Railroads, written commun., 1986).

Identification of the types of hazardous materials transported throughout the State and the upper Arkansas River basin and the frequency at which they are being transported has been difficult. Required placards placed on the vehicles indicate the category of hazardous materials, such as flammable liquid, or solid, flammable or nonflammable gas, poison gas, explosives, irritant, or corrosive. However, according to a disaster services official, laws governing placarding of motor vehicles are extensively violated and disaster services personnel occasionally have to deal with unauthorized mixed loads. A statewide, hazardous-material transportation survey by the Colorado State Port of Entry Division from August 26 to August 30, 1985, determined that 6 percent of the surveyed vehicles that haul hazardous materials violated Federal placarding requirements (Port of Entry Division, Department of Revenue, written commun., 1986).

Numerous contacts with Federal, State, railroad, and motor-vehicle officials, civil defense agencies, Port of Entry Division, Colorado State Patrol, County disaster services agents, and hazardous-materials response teams indicate that detailed information on the transportation and frequency of shipments is unavailable. Some officials have indicated that every type of material listed in the "Code of Federal Regulations, [Title] 49, Transportation, Parts 100 to 177," Office of the Federal Register (1984), is transported through Colorado and through the Arkansas River basin, with the exception of nuclear warheads. County disaster-services officials indicate that motor vehicles causing the greatest concern have been petroleum tankers.

Information presented in three reports provides an indication of the types of materials frequently transported. The 1-week survey by the Colorado State Port of Entry Division noted that 477 trucks transported hazardous materials through southeastern Colorado. It was not known how many of the loads were transported through the upper Arkansas River basin. The survey concluded that the percentage of the total loads carrying hazardous materials had increased from 5.5 percent in 1984 to 6.8 percent in 1985. Flammable liquids, combustible liquids, and flammable gases accounted for 71 percent of the hazardous materials and 71 percent of the loads terminated in Colorado.

The top 25 hazardous materials transported by rail in the United States during 1984 are shown in table 4 and indicate that flammable liquids, combustible liquids, corrosives, oxidizers, and petroleum materials frequently are shipped. Older records of hazardous materials transported by rail through El Paso County indicate that the same classes of hazardous materials were being transported during 1978 as during 1984. Specific materials included ammonium nitrate, gasoline, caustic soda, hydrochloric acid, and phosphorus pentasulfide. Classes of hazardous materials that are transported in Colorado are flammable liquids and solids including combustibles, nonflammable gases, oxidizers, corrosives, and other regulated materials.

Because of the increase in shipments of hazardous materials through Colorado and the Arkansas River basin, the potential for accidental spills has increased. Depending on the specific compounds and the location and the quantity of the spill in the Arkansas River, water-quality problems could occur in Pueblo Reservoir and affect municipal, industrial, or recreational use. Water-quality problems could range from minor inconveniences to major disturbances that have the potential to affect human health.

Table 4.--*Top 25 hazardous materials transported by rail in the United States during 1984*

[Data from Association of American Railroads, written commun., 1986; --, commodity not ranked in the top 25 for a particular year]

Commodity	Volume[1] 1984	Rank 1984	1983	1982	1981	1980
Liquified petroleum gas------	105,975	1	1	1	1	1
Caustic soda-----------------	72,287	2	2	2	2	2
Trailers and containers on flat cars-----------------	99,341	3	3	4	4	3
Sulfuric acid----------------	47,544	4	4	5	5	6
Fuel Oil---------------------	42,217	5	3	3	4	4
Anhydrous ammonia------------	44,857	6	7	6	5	5
Chlorine---------------------	44,035	7	6	7	7	7
Phosphoric acid--------------	29,285	8	9	9	9	--
Ammonium nitrate-------------	22,754	9	8	8	8	8
Methanol---------------------	21,784	10	11	11	12	12
Vinyl chloride monomer-------	18,002	11	10	10	10	10
Hydrochloric acid------------	12,664	12	12	12	13	13
Combustible liquid not otherwise specified--------	9,630	13	--	--	--	--
Crude oil--------------------	8,842	14	13	13	11	11
Gasoline---------------------	8,513	15	--	23	14	--
Petroleum naptha-------------	7,868	16	--	--	--	--
Styrene monomer inhibited----	7,594	17	22	23	22	22
Carbon dioxide refrigerated liquid--------------------	7,197	18	16	15	18	18
Carbolic acid or phenol------	6,502	19	14	17	17	17
Acids, chemical and other----	6,375	20	--	--	--	--
Petroleum naptha-------------	6,317	21	--	--	--	--
Petroleum naptha-------------	6,093	22	--	--	--	--
Adiptic acid-----------------	5,851	23	--	--	--	--
Ethylene oxide---------------	5,469	24	17	16	16	16
Hexamethylene diamine--------	5,011	25	19	18	23	23

	Number of carloads of hazardous materials 1984	1983	1982	1981	1980
Total--top 25	652,007	566,096	497,323	570,590	594,657
Total--all hazardous materials	915,516	827,303	720,685	818,411	847,299

[1]Volume is number of carloads of hazardous materials.

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