QUALITY OF WATER IN AN INACTIVE URANIUM MINE AND

ITS EFFECTS ON THE QUALITY OF WATER IN BLUE CREEK,

STEVENS COUNTY, WASHINGTON, 1984-85

By S. S. Sumioka

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 89-4110

Tacoma, Washington
1991

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

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ILLUSTRATIONS

CONVERSION FACTORS

For the convenience of readers who may prefer to use metric units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	by	to obtain metric unit
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
square feet per day (ft^2/d)	0.0929	square meters per day (m^2/d)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km^2)
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	1,234	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
tons per day (tons/d)	0.9072	megagram per day (Mg/d)

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.

degree Fahrenheit (°F) to degree Celsius (°C): $°C = 5/9 (°F - 32)$

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ABSTRACT

An inactive uranium mine in Stevens County, northeastern Washington State, contributes highly mineralized water to Blue Creek. Water also accumulates in unused pits and a retention pond within the mine, but the pits presently (1985) do not contribute surface runoff to Blue Creek.

From September 1984 through August 1985, the basin received 934 acre-feet of precipitation. The quantities of water that left the basin were 188 acre-feet as streamflow, about 1 acre-foot as ground-water discharge, 47 acre-feet as evaporation from the pits and retention pond, and 637 acre-feet as evapotranspiration losses. The volume of water in the pits and retention pond increased by 81 acre-feet. A comparison of water entering and leaving the basin indicates a residual of about 20 acre-feet more water leaving the basin than entering. This could be the result of errors in measurement or estimation, in combination with unmeasured changes in basin storage. It was assumed that because of below-normal precipitation during the year of study, the measured runoff was also below normal.

Chemical analyses of water samples from the pits and the retention pond, within the mine, indicated that these waters were highly mineralized and contained significant concentrations of aluminum, cadmium, copper, iron, manganese, nickel, nitrate-nitrogen, sulfate, zinc, radium-226, and uranium. The concentrations were smallest in pit 4, at the upgradient end of the mine, and largest in the retention pond, at the downgradient end of the mine.

Water leaving the mine basin as ground-water discharge and from a small surface-drainage network also was mineralized, and contained cadmium, manganese, nickel, nitrate-nitrogen, and sulfate in concentrations that exceeded U.S. Environmental Protection Agency maximum allowable standards for drinking water or for the well-being of freshwater aquatic life. Several samples of water from the mine drainage stream contained suspended-solids concentrations in excess of U.S. Environmental Protection Agency standards for uranium-mine effluents. Concentrations of radium-226 and uranium in water leaving the mine basin were relatively large, but did not exceed U.S. Environmental Protection Agency or U.S. Nuclear Regulatory Commission standards for uranium-mine effluents. The addition of water from the mine basin to Blue Creek increased concentrations of almost all constituents in water samples collected from Blue Creek downstream of the mine drainage stream, compared with samples collected upstream of the mine drainage stream. Concentrations of most constituents were smaller near the mouth of Blue Creek, but still larger than those upstream of the mine drainage stream.

Procedures for monitoring and a list of suggested water-quality constituents and characteristics for monitoring also are presented, should a future monitoring program be implemented to determine annual chemical loads entering Blue Creek from the mine basin.

Data indicated that bromide and iodide ions, and possibly a fluorescent dye, would be most suitable for a future study to determine ground-water flow paths in the vicinity of the retention pond.

INTRODUCTION

An inactive, open-pit uranium mine on the Spokane Indian Reservation, in Stevens County, Washington, is located about 40 miles northwest of Spokane, Wash. (fig. 1). About 900 acres of land were leased from the Spokane Indian Tribe for mining. Water discharging from the mine area enters Blue Creek, a tributary of the Spokane River arm of Franklin D. Roosevelt (FDR) Lake, a part of the Coulee Dam National Recreational Area.

The U.S. Bureau of Land Management and the U.S. Bureau of Indian Affairs are concerned about the quality of surface water within the mine and the effects that water discharging from the mine area might have on Blue Creek. The water coming from the mine area is highly mineralized, and there is a possibility that highly mineralized water accumulating within the mine might overflow, reach Blue Creek, and cause significant water-quality changes.

Background

Uranium was discovered at the mine site in 1954, and mining operations started in 1956. Except from 1962 through 1969, mining was continuous until 1982, when operations were halted. The mine has remained inactive since then.

During periods of mining, ore to be transported to the mill, overburden, waste material, and protore (a low-grade uranium ore) were stored in several onsite dumps and piles. As mining progressed, the upper reaches of a small stream draining the central part of the mine (Central drain in fig. 2) was gradually covered by overburden and waste, but water continued to flow in the channel, issuing from the base of the overburden and waste covering the channel (fig. 3). In 1978, a yellow-white precipitate appeared in the Central drain, extending from the toe of the southernmost waste dump to a point downgradient of the confluence with two other streams (West and East drains in fig. 2) draining the mine area. A chemical analysis of the precipitate showed it to be a mixture of "aluminous salts and gypsum" that contained between 3- and 6-percent uranium oxide (U_3O_8) (Cramer-Bornemann and Seymour, 1979; Council of Energy Resource Tribes, 1980). To prevent this mineralized water from entering Blue Creek and, subsequently, the Spokane River arm of FDR Lake, the mine operator constructed a clay-lined retention pond behind an earthen dam immediately downgradient from the southernmost waste dump (fig. 3). The dam has retarded the flow from the waste dump, but a small amount (about 0.01 ft^3/s on November 19, 1980) of highly mineralized water (6,010 mg/L (milligrams per liter) dissolved solids on November 19, 1980) continues to issue from a seep at the toe of the dam and flow southward. Since 1982, water also has accumulated in two pits on the mine site (see fig. 2). Water in pit 4 and the retention pond periodically is pumped into pit 3, a larger and deeper excavation, to prevent overflow into the drainage channels.

This study was made in cooperation with the U.S. Bureau of Indian Affairs and the U.S. Bureau of Land Management. James LeBret, U.S. Bureau of Indian Affairs, participated in the planning and provided much help during the course of the study.
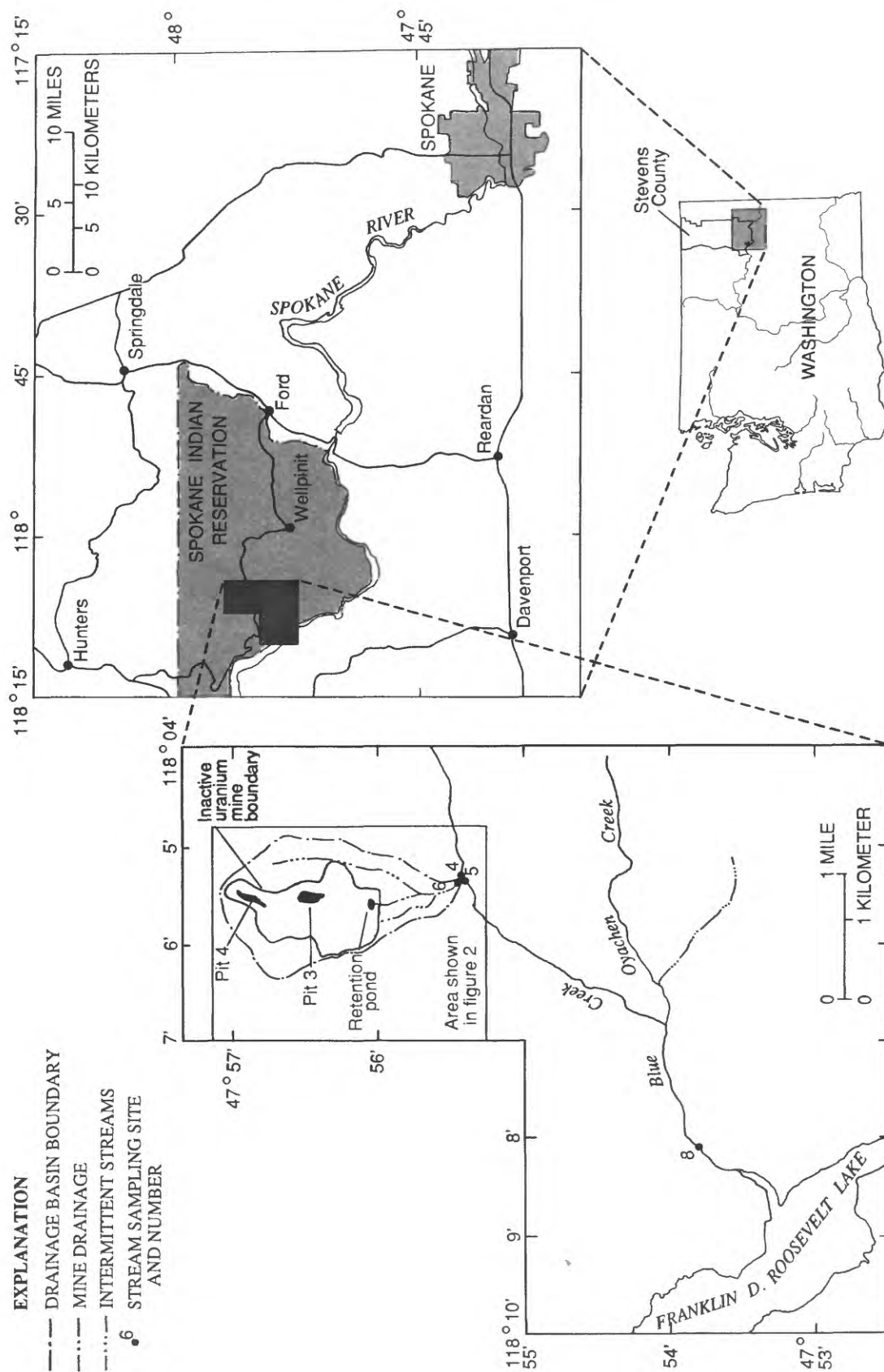
Figure 1.--Location of the inactive uranium mine and stream-sampling sites.

EXPLANATION

—··— DRAINAGE BASIN BOUNDARY

—···— MINE DRAINAGE

····· INTERMITTENT STREAMS

•⁶ STREAM SAMPLING SITE
     AND NUMBER
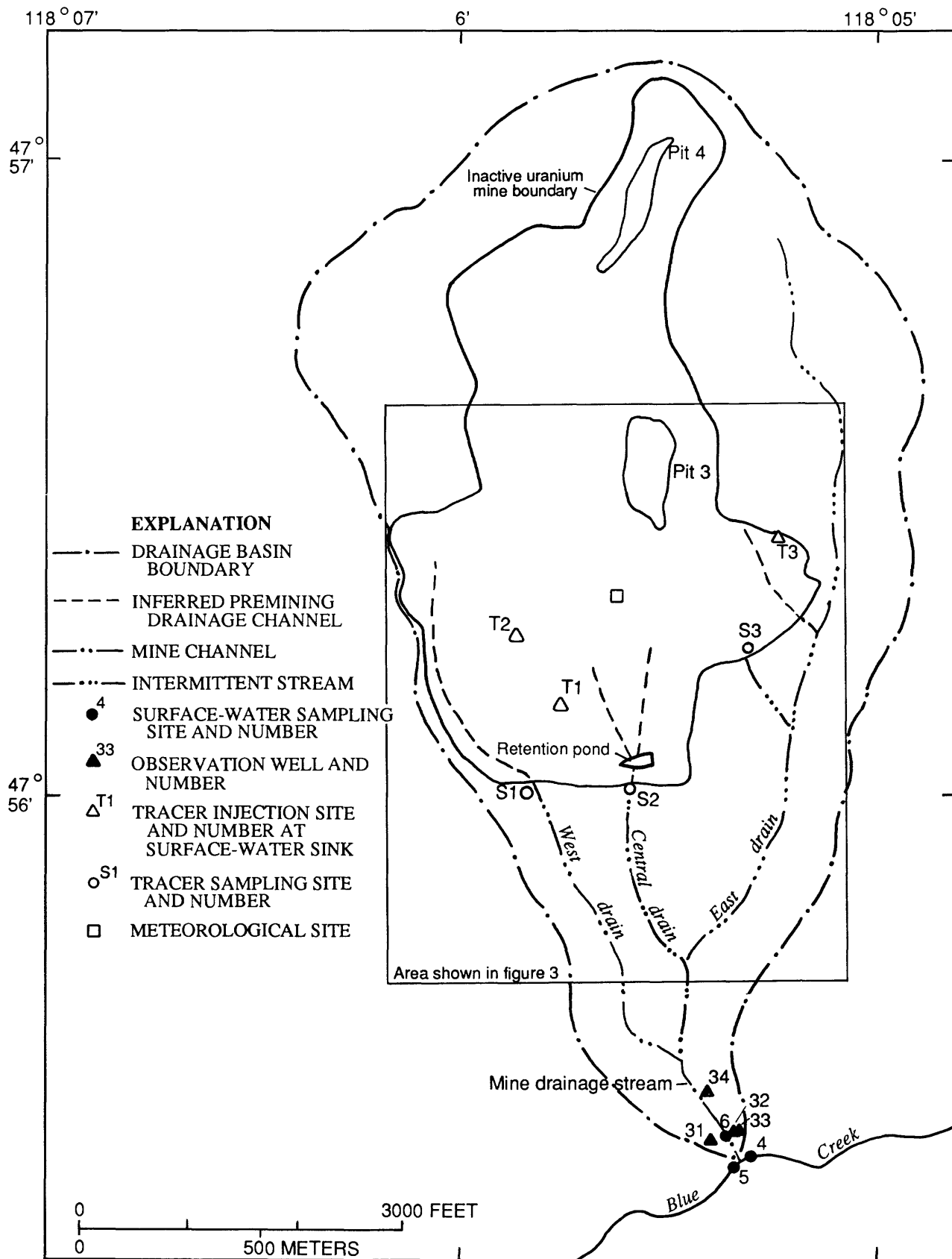
Figure 2.--Location of sampling and tracer-injection sites in and near the inactive uranium mine, and inferred pre-mining drainage channels. See figure 1 for location.
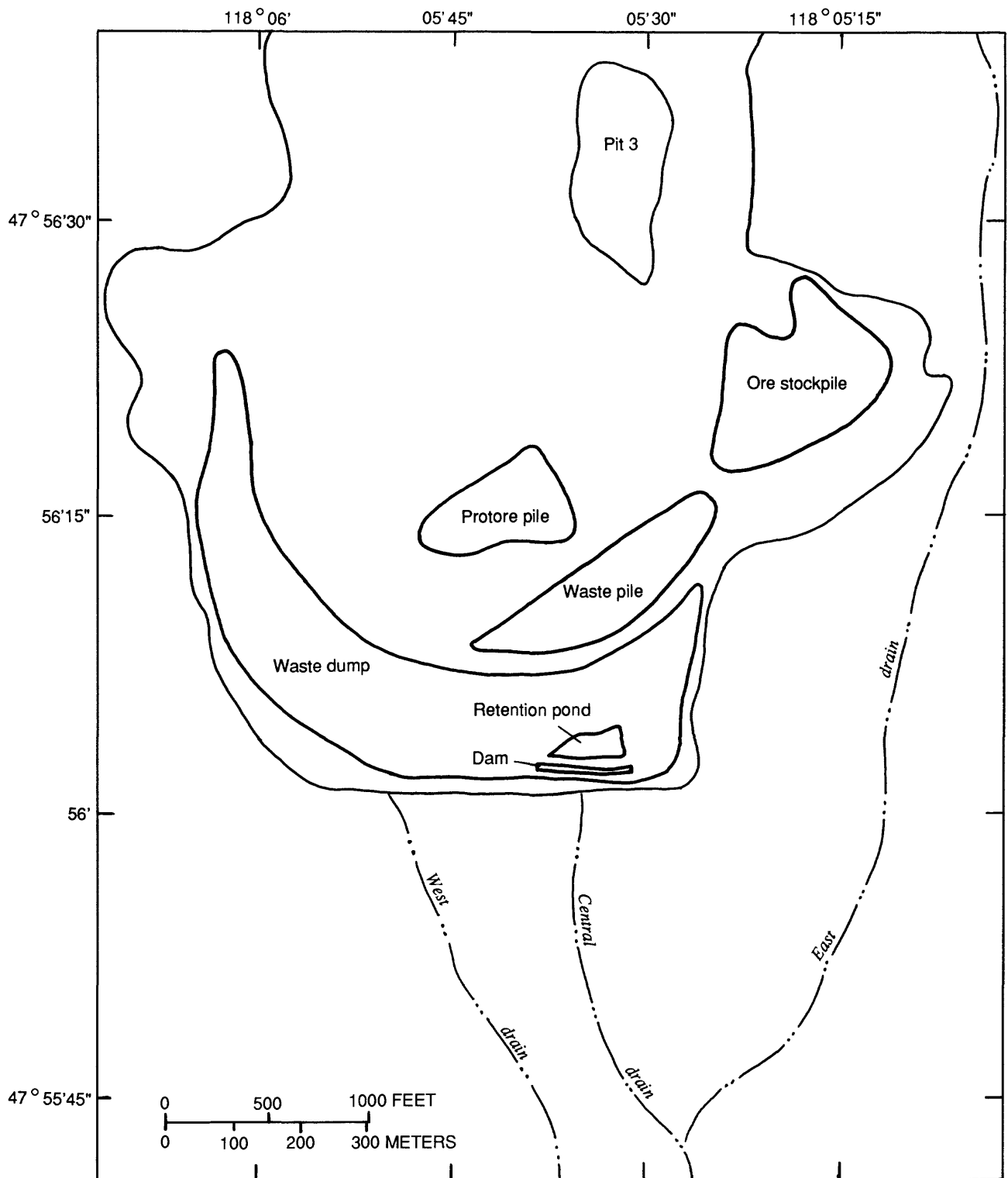
Figure 3.--Location of retention dams, waste dumps, protore pile, and ore stockpile at the inactive uranium mine. See figure 2 for location.

Purpose and Scope

The purpose of this report is to present the results of a study done to determine (a) the monthly and annual water budgets and probable variation in runoff for the drainage basin in which the mine is located; (b) if precipitation is the source of low pH water found in pit 3 and the retention pond; (c) the quality of water in pits 3 and 4, the retention pond, streamflow from the basin, Blue Creek upstream and downstream of the point the drainage enters, and near the mouth of Blue Creek; (d) the quality of ground water discharged from the basin into Blue Creek; and (e) the daily mean values of discharge, water temperature, specific conductance, and pH for mine drainage from the basin, Blue Creek upstream and downstream of the mine drainage, and near the mouth of Blue Creek. This report also describes a potential water-quality monitoring program that would allow the determination of annual loads of selected chemical constituents entering Blue Creek from the mine basin and information about the type of ground-water tracers and procedures needed to examine flow paths near the retention pond.

This report is based on data collected from the pits, the retention pond, a meteorological station at the mine, and ground and surface waters near the mine. Data collection for this report started in May 1984 and continued through July 1985. Analyses of samples from pit 4, collected in August 1983, also are included in the report. The section of the report that discusses the tracer study is based on a single set of water samples collected from a surface-water sink in the mine (T1, fig. 2) and from several springs issuing from the downgradient boundary of the mine (S1, S2, and S3, fig. 2).

Description of the Study Area

Although about 900 acres of land were leased from the Spokane Indian Tribe for mining, only about 320 acres of land actually have been disturbed by mining activity. The disturbed area is restricted to a single drainage basin that covers about 830 acres. This basin is drained by three small streams that converge near the downgradient (southern) end of the basin to form what is called the mine drainage stream in this report (fig. 2) and enter Blue Creek about 3.5 miles upstream from its mouth.

The study area has a continental climate, characterized by warm, dry summers and clear, cold winters. Precipitation from spring through fall occurs as rain, whereas in winter most precipitation is in the form of snow. Precipitation at Wellpinit, about 7 miles east of the mine, averaged 19.4 inches per year for the period 1951 to 1980 (U.S. Department of Commerce, 1983).

The oldest rocks in the mine basin are metasedimentary phyllites and calc-silicate hornfels of Precambrian age. These rocks have been intruded by granite, predominantly porphyritic quartz monzonite of Cretaceous age, in the western and southern parts of the basin. The porphyritic quartz monzonite also is the predominant rock type in the remainder of the Blue Creek basin. Quaternary alluvium, consisting of coarse sand and gravel, covers the porphyritic quartz monzonite along Blue Creek, downgradient of the mine basin. Unconsolidated material in the mine basin consists primarily of weathered metasedimentary and granitic rocks.

Ore deposits are found in the metasedimentary rock, near its contact with the porphyritic quartz monzonite. Near-surface ore is in the form of autunite and meta-autunite, whereas deep ore bodies are composed of uraninite and coffinite and are associated with pyrite and marcasite. The geology and uranium mineralization of the area are discussed in more detail by Becraft and Weis (1963), Nash and Lehrman (1975), and Nash (1977).

Land is used in the mine area as rangeland for cattle and habitat for resident populations of deer and elk. Vegetation in the area consists primarily of ponderosa pine and bluebunch wheat grass. Snowberry and spirea are found in the stream valleys.

Acknowledgments

DATA COLLECTION

Data from September 1984 through August 1985 were used to determine the water budget. The pits and the retention pond were sampled in May and September of 1984, and pit 4 also was sampled in August 1983. Daily mean values of streamflow were determined from June 1984 through September 1985. Water-quality sampling of the mine drainage stream, Blue Creek, and ground water began in July 1984 and occurred monthly through July 1985.

Sites

The site numbers used in this report were assigned previously by the mine operator as part of a surface- and ground-water monitoring network. For this study, only a few of those sites were used, and they are discussed in downgradient order.

Pits 4 and 3 and the retention pond are within the mine boundary (fig. 1), and samples collected from these sites were used to characterize the quality of accumulated surface water in the mine. Pits 4 and 3 were open pits during mining operations and were the sites of the most recent mining activity. All older pits in the mine have been filled with overburden and waste. Sites 4, 6, 5, and 8 are stream sites outside the disturbed area (fig. 1). Site 4 is on Blue Creek, just upstream of the point where the mine drainage stream enters. Site 6 is on the mine drainage stream. Sites 5 and 8 are on Blue Creek, just downstream of the point where the mine drainage stream enters and near FDR Lake, respectively. Sites 34, 31, 32, and 33 (fig. 2) are observation wells downgradient of the mine. Samples from a surface-water sink and several springs (T1, and S1, S2, and S3, respectively, in fig. 2) were collected and analyzed to determine which tracing agents could be used to study ground-water flow patterns near the retention pond.

Pit 4 is the northernmost pit at the mine. The floor of the pit is about 450 feet below land surface at its deepest point. The water-surface area was about 6 acres in October 1984, and the volume of water was estimated to be about 150 acre-feet. The southern rim of the pit was raised 40 to 50 feet with fill during 1982 to prevent water from overflowing because of rising water levels.

Pit 3 is located near the center of the mine. The floor of the pit is about 550 feet below land surface. The water-surface area in October 1984 was about 9 acres, and the estimated volume was 360 acre-feet.

The retention pond is at the extreme southern boundary of the disturbed area, immediately downgradient of the southernmost waste dump. The top of the dam is about 30 feet above the bottom of the pond. The surface area in October 1984 was just over 1 acre, with a volume of about 15 acre-feet.

Site 4 is a surface-water site on Blue Creek, about 70 feet upstream of the point where surface drainage from the mine basin enters. The channel of Blue Creek is 2 to 3 feet wide at this point, and water depth averages about 0.4 foot during base-flow conditions. The streambed consists of coarse sand, gravel, and cobbles. Bedrock is exposed on the right bank and in the streambed. Shrubs and trees encroach to near the edge of water.

Site 6 is a surface-water site on the unnamed stream that drains the mine basin and is located about 300 feet upstream of the point where it enters Blue Creek. The stream channel is 1 to 2 feet wide, and the water depth is about 0.1 foot deep during base-flow periods. The streambed is primarily medium-to-coarse sand and fine gravel. Vegetation is present on the banks, but is less dense than that found at sites 4 or 5. Bedrock is not exposed in the channel or along the banks, but is visible on the nearby hill slopes. At this site, surface-water and ground-water drainage divides converge to form a constriction where both surface-water and ground-water discharge from the basin could be monitored.

Site 5 is a surface-water site on Blue Creek, about 30 feet downstream of the point where surface drainage from the mine basin enters. The stream channel is about 3 feet wide, and the average water depth during base-flow conditions is about 0.3 foot. The streambed is composed primarily of coarse sand, gravel, and some cobbles. The banks are thickly vegetated, and there are no signs of bedrock.

Site 8 is a surface-water site on Blue Creek, about 1,000 feet upstream of where backwater from FDR Lake is encountered and about 3.5 miles downstream of site 5. The stream channel is about 5 feet wide, and water depth averages about 0.2 foot during base-flow conditions. The streambed is composed of coarse sand, gravel, and cobbles. Vegetation on the banks is chiefly grass with a few shrubs.

Site 34 is an observation well about 500 feet north and upgradient of surface-water site 6. The total depth of the well is 11 feet, 2.5 feet of which is in bedrock. It is cased to 6 feet with 4-inch-diameter polyvinyl chloride (PVC) pipe and screened with slotted PVC from 6 to 11 feet.

Site 31 is an observation well near site 6, about 50 feet west of the stream channel. The total depth of the well is 9 feet, 2 feet of which is in bedrock. The well is cased with 4-inch-diameter PVC pipe to a depth of 4 feet and screened with slotted PVC from 4 to 9 feet.

Site 32 is an observation well near site 6, about 10 feet east of the stream channel. The total depth of the well is 18 feet, 1 foot of which is in bedrock. It is cased to 13 feet with 4-inch-diameter PVC pipe and screened with slotted PVC from 13 to 18 feet.

Site 33 is an observation well about 20 feet east and upgradient of site 32. The total depth of the well is 9 feet, 2 feet of which is in bedrock. It is cased with 4-inch-diameter PVC pipe to 4 feet and screened with slotted PVC from 4 to 9 feet.

The meteorological station was established about 800 feet south of the center of and overlooking the southern lip of pit 3. The station is located near the center of the mine area at an elevation of about 2,800 feet.

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Procedures

The meteorological station was equipped according to National Weather Service guidelines (U.S. Department of Commerce, 1972) with a wet/dry precipitation collector and a Class-A evaporation pan. Precipitation as rain and snow was collected in a propane-heated, tipping-bucket precipitation gage, and the amount of precipitation was recorded continuously in 0.01-inch increments on a strip-chart. Rain also was collected in an automated wet/dry precipitation sampler to obtain samples for pH determinations. The pH of snow was determined from samples of snow on the ground collected near the meteorological station. These samples were melted and analyzed within 24 hours of collection. The wet/dry collector was checked weekly, and if sufficient quantities of water were present, the pH of the sample was determined. During late fall and winter when most of the precipitation occurred, however, mud and snow on the roads in the mine prevented field personnel from reaching the site, and thus only a small number of samples were collected. Values for free-water-surface evaporation were obtained from the amount of water determined to have evaporated from the evaporation pan and adjusted with published pan-to-lake coefficients.

Flow rates in Blue Creek (sites 4 and 8) and in the mine-drainage channel (site 6) were determined from continuous (15-minute interval) digital recordings of water levels in the streams and from a rating table established for each site. The rating tables were developed from the monthly discharge measurements and corresponding water levels at the time of the measurements (Rantz and others, 1982). Ice in the stilling wells and gage pools during the winter (November through February) caused the loss of some gage-height records. Daily stream discharge during this period was estimated using the monthly discharge measurements, weather records from the onsite meteorological station, and, to replace any missing weather data, records from the National Weather Service station at Wellpinit, Wash.

The quantity of ground water leaving the basin was estimated from monthly measurements of water levels in observation wells 31, 32, 33, and 34, and a value for hydraulic conductivity obtained from a slug test (Bouwer and Rice, 1976) conducted in 1980 (N. P. Dion, U.S. Geological Survey, written commun., 1982). Wells 32 and 34 were used to determine the hydraulic gradient in the alluvial aquifer, and wells 31, 32, and 33 were used to determine the wetted cross-sectional area of the aquifer near site 6.

Changes in the volume of water stored in pits 4 and 3 and the retention pond were determined from staff-gage readings of water levels in the pits and retention pond. Water-surface elevations were converted to water volumes by using aerial photographs and contour maps provided by the U.S. Bureau of Indian Affairs.

Ground-water quality was determined from samples collected monthly from the well at site 32. The well was bailed using a PVC bailer until the specific conductance of the water in successive bailers was stable. When this occurred, indicating that water that had been standing in the casing had been removed, a peristaltic pump was used to collect the sample.

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Sampling for water quality in the pits and the retention pond was done on a seasonal basis. Samples were collected both during spring when the waters were well mixed and during late summer when maximum thermal stratification existed. Temperature and dissolved-oxygen concentrations in the water column were determined at 2- to 5-foot intervals using a dissolved-oxygen meter. The temperature and dissolved-oxygen profiles were used to select two to five sampling depths. A Van Dorn-type sampler was used to collect samples from the selected depths. The specific conductance, pH, and alkalinity of these samples were determined in the field. In addition, chemical analyses were performed on two to three of these samples. Water transparency was measured in the pits and retention pond using an 8-inch-diameter Secchi disk.

Stream-water quality was determined from samples collected monthly at sites 4, 5, 6, and 8; a single grab sample was collected from the center of flow at each site. Water was assumed to be well mixed in these small, shallow streams, justifying the collection of a single sample. Sites 4, 5, 6, and 8 each were equipped with a three-parameter mini-monitor to obtain a continuous record of water temperature, specific conductance, and pH. These data were recorded hourly on a digital recorder separate from the gage-height recorder.

The monthly water-quality samples were analyzed in the field for temperature, specific conductance, pH, alkalinity, and acidity. Dissolved-oxygen concentrations were determined using a dissolved-oxygen meter. The samples then were processed, preserved, and shipped to the U.S. Geological Survey Central Laboratory in Arvada, Colo., for the determination of major ions, trace metals, and radionuclides. Samples were collected, field measurements made, and samples were preserved according to procedures described in technical publications of the U.S. Geological Survey (Thatcher and others, 1977; Skougstad and others, 1979).

Other sources of data included U.S. Geological Survey streamflow data from streams draining areas similar to the mine area, for which long-term records exist, and precipitation records from the National Weather Service station in Wellpinit and from the mine operator.

WATER BUDGET

Water enters the basin only as precipitation. During field reconnaissance of the topography and geology of the basin, it was concluded that the surface-water divide is probably a good approximation of the ground-water divide. It is assumed, therefore, that interbasin ground-water flow is negligible. Water leaves the basin as streamflow, ground-water discharge, evaporation from the water surfaces of pits 3 and 4 and the retention pond, evaporation from the land surface, and transpiration from plants. Some of the precipitation may be detained temporarily in the basin as storage in the pits and the retention pond, in the unconsolidated material, and, during the winter months, as snow.

Monthly and annual estimates of water entering and leaving the basin were calculated for the 12-month period September 1984 through August 1985. These values were entered into the following water-budget equation:

$$Ppt = SW + GW + EFWS + \Delta V + ET + R, \qquad (1)$$

where:

Ppt = water entering the basin as precipitation, in acre-feet;
SW = water leaving the basin as surface runoff, in acre-feet;
GW = water leaving the basin as ground water in the unconsolidated material, in acre-feet;
$EFWS$ = water leaving the basin by evaporation from free-water surface of the pits and retention pond, in acre-feet;
ΔV = change in volume of water in the pits and retention pond, in acre-feet;
ET = evapotranspiration from soil surfaces and plants, in acre-feet; and
R = residual, in acre-feet.

The equation was solved for R, which represents changes in storage in the basin and errors in all the other quantities. The monthly residuals, therefore, reflect changes in soil moisture, ground-water storage, and snow storage. On an annual basis, the changes in storage are assumed to be zero, and the residual primarily represents errors in the other quantities.

The recorded precipitation in the basin for the 12-month period (fig. 4) was 13.5 inches. If the same amount fell everywhere in the basin, the quantity of water entering the basin would be 934 acre-feet (table 1). During the same period, precipitation at Wellpinit was 9.2 inches, which is only 47 percent of the long-term average of 19.4 inches at Wellpinit. This suggests that precipitation in the mine basin also was less than might be expected in an average 12-month period.

Total surface-water discharge from the mine basin, as measured at site 6, was 188 acre-feet (table 1). The discharge hydrograph for the period for site 6 is presented in figure 5. Periods of high flow occurred in November 1984, in response to rainfall, and in March and April 1985, primarily due to snowmelt.
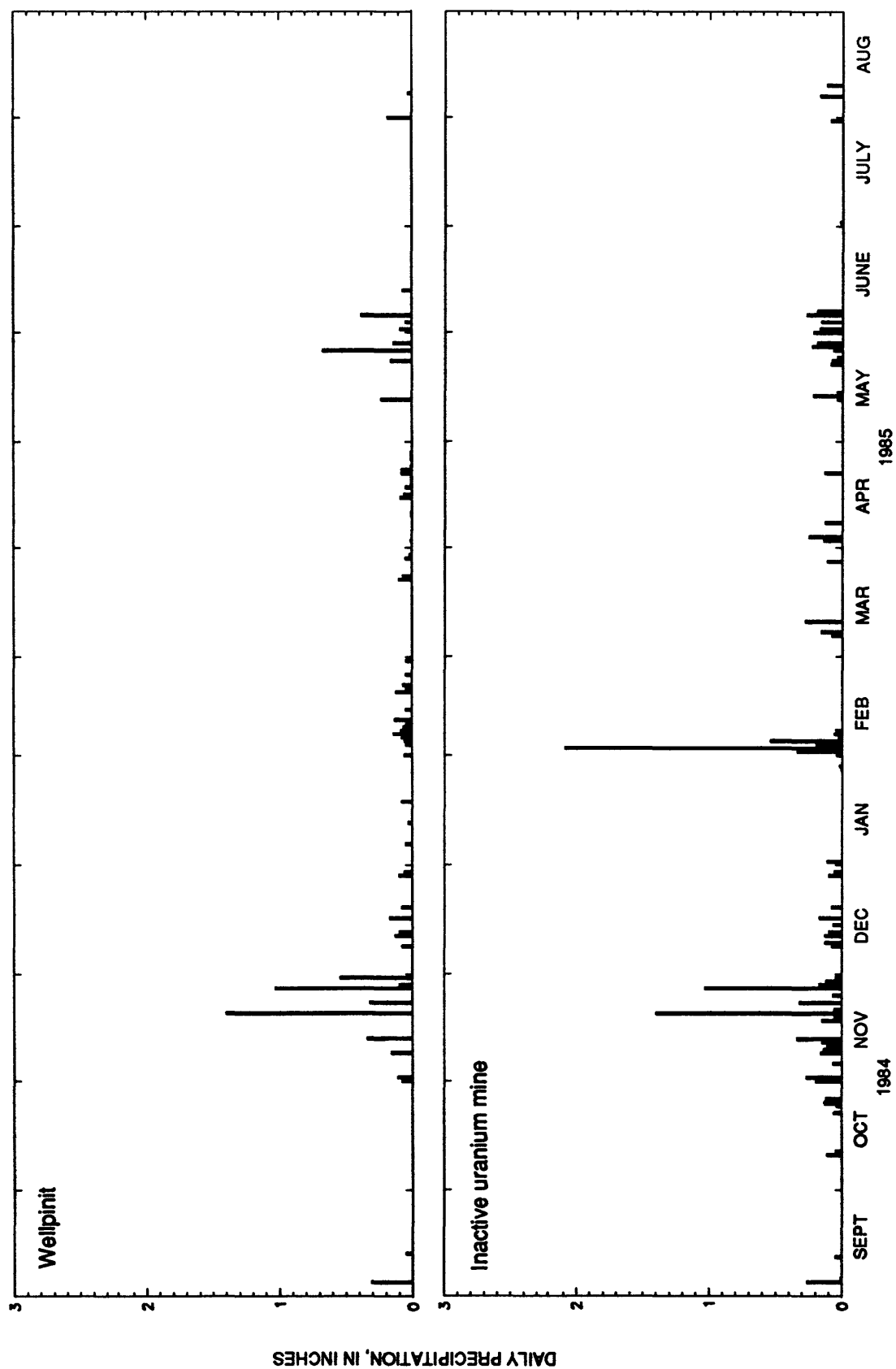
Figure 4.--Daily precipitation recorded at Wellpinit and the inactive uranium mine, September 1984 through August 1985.

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Table 1.--Monthly and annual water budgets for the mine basin, September 1984 through August 1985

[All units in acre-feet; --, analysis or measurement not done]

Component	1984				1985								Annual
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Total
Measured input:													
Precipitation	19	35	338	64	10	232	44	45	50	69	8	20	934
Measured and calculated outflow:													
Surface-water discharge	7	8	14	18	9	8	38	36	20	15	9	6	188
Ground-water discharge	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	1.2
Free-water-surface evaporation[1]	5.3	2.0	--	--	--	--	--	3.9	5.8	7.7	14	8.3	47
Storage pits and retention pond[2]	0	1	19	5	4	14	35	5	4	1	-4	-3	81
Evapotranspiration[3]	27	29	54	35	35	35	83	98	97	91	27	26	637
Sum of outputs	39.4	40.1	87.1	58.1	48.1	57.1	156.1	143	126.9	114.8	46.1	37.4	954.2
Residual[4]	-20.4	-5.1	250.9	5.9	-38.1	174.9	-112.1	-98	-76.9	-45.8	-38.1	-17.4	-20.2

[1] The monthly values of free-water-surface evaporation were obtained by multiplying the recorded monthly pan evaporation by the following coefficients: 0.8 for September and October; 0.7 for June, July, and August; and 0.6 for April and May (Rowher, 1931; Young, 1947; Kohler, 1954; and Ficke, 1972). Estimates not computed for winter months.

[2] Positive numbers indicate that the total volume of water increased; negative numbers indicate that the total volume of water decreased.

[3] This component includes all evaporation losses from the basin, except for free-water-surface evaporation. These values were obtained using a method modified from Jensen and Haise, 1963 (H. H. Bauer, U.S. Geological Survey, written commun., 1986).

[4] This component includes changes in soil moisture storage, snow storage, and ground-water storage, and errors associated with the measurement, calculation, or estimation of the other components.

BLUE CREEK UPSTREAM OF MINE DRAINAGE (SITE 4)

MINE DRAINAGE (SITE 6)

BLUE CREEK NEAR MOUTH (SITE 8)

DISCHARGE, IN CUBIC FEET PER SECOND
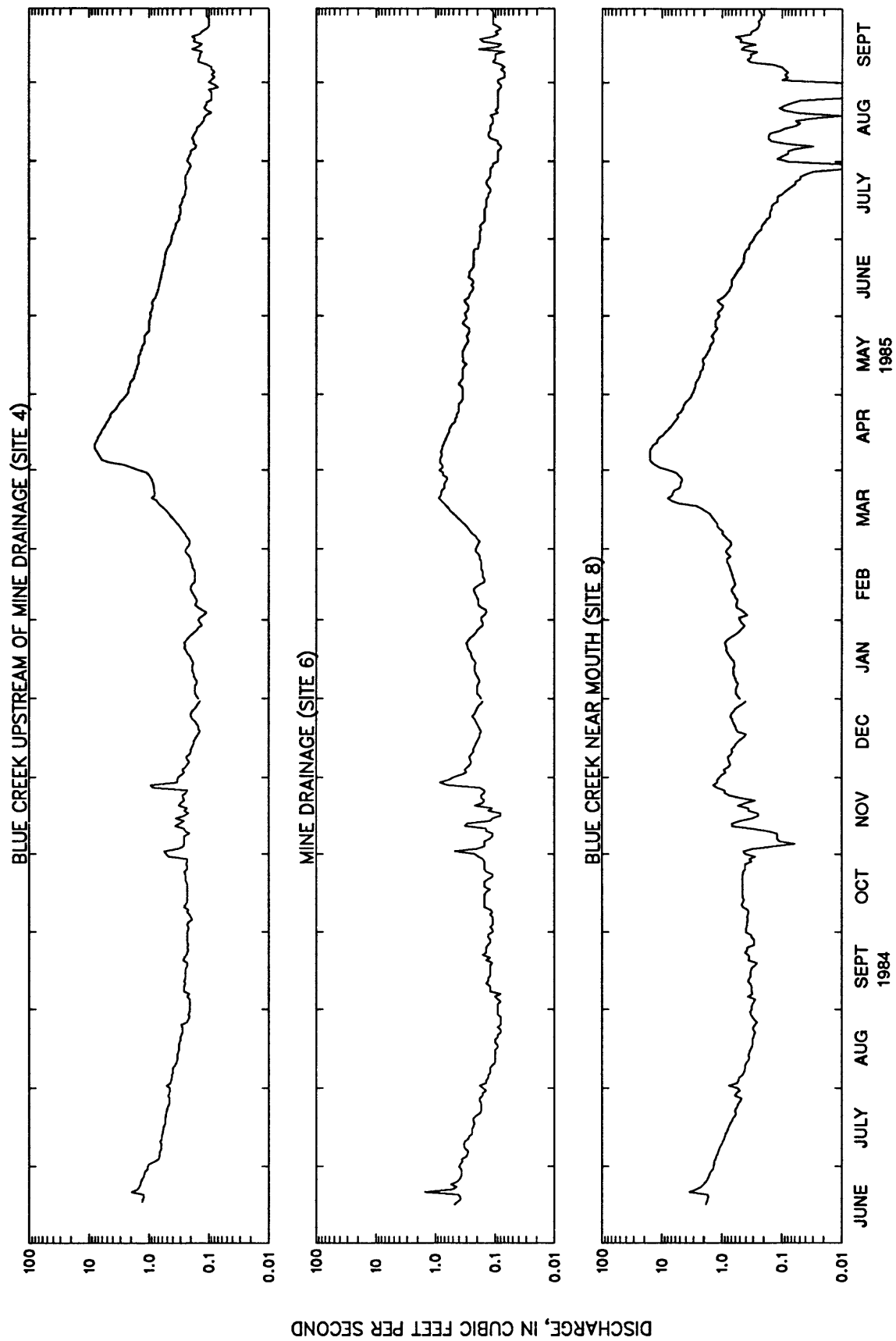
Figure 5.--Daily mean discharge at sites 4, 6, and 8, June 1984 through September 1985.

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The computed monthly values of ground-water discharge (table 1) indicate that ground water leaving the basin near site 6 was constant during the 12-month period and totaled only 1.2 acre-feet. Ground-water discharge was calculated using the equation:

$$Q = KIA, \tag{2}$$

where,

Q = discharge, in cubic feet per day;
K = hydraulic conductivity, in feet per day;
I = hydraulic gradient, in feet per foot; and
A = wetted cross-section area at site 6, in square feet.

Values used to compute ground-water discharge from the basin are presented in table 2. The daily discharges presented in table 2 were used to calculate an average daily discharge for each month, which in turn was used to determine the discharge for each month. The assumption that the discharge values in table 2 could be used to determine the monthly flow was made because there was relatively little variation in flow from measurement to measurement, and because the resultant monthly totals made up a small percentage of the water budget.

Table 2.--Values used to compute ground-water discharge from the mine basin

Date	Hydraulic conductivity, K, in feet per day	Hydraulic gradient, I, in feet per foot	Wetted cross-section area, A, in square feet	Discharge, Q	
				cubic feet per day	acre-feet per day
1984					
Sept. 24	1.92	0.0600	708	81.56	0.00187
Oct. 22	1.92	.0599	721	82.92	.00190
Nov. 26	1.92	.0593	730	83.11	.00191
Dec. 18	1.92	.0595	728	83.17	.00191
1985					
Jan. 28	1.92	.0597	726	83.22	.00191
Mar. 21	1.92	.0593	799	90.97	.00209
Apr. 29	1.92	.0597	749	85.85	.00197
May 20	1.92	.0600	734	84.86	.00194
June 24	1.92	.0601	719	82.97	.00194
July 22	1.92	.0608	692	80.78	.00185
Aug. 29	1.92	.0607	643	74.94	.00172

The evaporation from the pits and retention pond for the 12-month period was about 35 inches. This is equivalent to about 47 acre-feet of free-water-surface evaporation from the 16-acre total surface area of the pits and retention pond. Pan evaporation was measured daily during ice-free periods and totaled into monthly values. The monthly pan-evaporation values were multiplied by coefficients to obtain monthly evaporation values for the pits and retention pond, and the monthly values were added to obtain annual evaporation. Three different monthly coefficients were applied to the pan-evaporation data because of differences in heat exchange through the sides and bottom of the pan with respect to the sides and bottom of the pits and retention pond: 0.6 for April and May, 0.7 for June through August, and 0.8 for September and October. In general, pan coefficients are larger in late summer and early fall when the surface temperature of natural water bodies are highest and evaporation from them would approach that of an evaporation pan (Kohler, 1954; Perry and Corbett, 1956; Winter, 1981; and Farnsworth and others, 1982). The monthly pan coefficients used for the mine basin water budget were computed as the average of coefficients derived from other studies. The following table presents reported coefficients used to obtain the average coefficient applied to evaporation data in this study.

	Rowher (1931)	Young (1947)	Kohler (1954)	Ficke (1972)	Average
April	0.60	0.66	0.39	0.70	0.59
May	.63	.68	.44	.74	.62
June	.69	.77	.62	.74	.70
July	.69	.74	.68	.73	.71
August	.71	.78	.77	.72	.74
September	.82	.87	.93	.66	.82
October	.72	.93	.90	.64	.80

Storage in the pits and retention pond increased by 81 acre-feet during the study. Most of the increases were in response to snowmelt runoff and spring rains; however, ground water probably enters and leaves the pits and retention pond during the entire year, as indicated by the fact that the floor of the pits and the retention pond are below the water table (Cramer-Bornemann and Seymour, 1979).

A total of 637 acre-feet (9.2 inches) of water was lost from the mine basin through evapotranspiration for the study period. For the purposes of this study, evapotranspiration is defined as the evaporation from water, soil, snow, ice, plant, and other surfaces, plus transpiration (Veihmeyer, 1964). The calculation of evapotranspiration values was based on radiation methods proposed by Jensen and Haise (1963) and modifications of those methods by H. H. Bauer (U.S. Geological Survey, written commun., 1986).

The monthly residuals range from -112 to 251 acre-feet; the negative residuals indicate that more water left the basin than entered, and the positive residuals indicate that more water entered the basin than left. Even though it was not possible to separate errors from changes in storage, some general statements can be made concerning the residuals. Some part of the large positive residuals in November 1984 and February 1985 represent

precipitation retained in the basin as soil moisture or snow. During spring and early summer (March through June 1985), much of the stored water left the basin as increased streamflow due to snowmelt and increased evapotranspiration due to spring plant growth, resulting in relatively large negative residuals. Evaporative processes, principally evapotranspiration, but also free-water-surface evaporation, accounted for most of the water lost in September 1984 and July and August 1985. In October and December 1984, the residuals indicate that there was little change in storage in the basin. The negative residual in January 1985 resulted from the small amount of precipitation for the month, whereas water leaving the basin was about the same as in December and February. The annual residual of -20.2 acre-feet is about 2 percent of the precipitation entering the basin. Assuming that, for the study period, the change in storage is zero, the annual residual represents the error in the determination of the annual water budget.

A detailed error analysis was beyond the scope of this report; however, some unknown part of each monthly residual was due to errors in measurement and (or) calculation of monthly quantities. Nevertheless, the residuals still can be explained reasonably in terms of changes in storage.

An attempt was made to determine the yearly and monthly variability in surface outflow from the mine basin. Information on the variability of flow would be useful in the design and operation of impoundments or treatment facilities for the mine drainage.

The total streamflow from the mine basin for the water-budget period was probably less than normal, because precipitation in the basin was also less than normal. Quantitative estimates of the year-to-year variability in runoff could not be made because of the lack of long-term streamflow data.

The discharge hydrograph for the mine drainage stream (mine drainage, site 6 in fig. 5) and values for surface-water discharge (table 1) indicate that two months (March and April) accounted for almost 40 percent of the streamflow for the study period. Discharge data from Mill Creek, near Colville, Wash., about 50 miles from the mine and for which long-term records exist, were compared with discharge data from the mine drainage stream. Because of differences in basin characteristics, however, particularly drainage areas and land use in the basins, it was not possible to assume that variations in mean monthly discharge in Mill Creek are representative of the mine drainage stream.

QUALITY OF WATER IN MINE AND ITS EFFECTS ON BLUE CREEK

The following sections describe the results of field and laboratory analyses of samples of precipitation (field pH only), of water from the pits and retention pond, of water leaving the mine basin as surface water, and in the receiving stream, and ground water, downgradient of the mine.

pH of Precipitation

Samples of rain and snow falling in the mine were collected and analyzed to determine if precipitation is the source of low pH water found within the mine. Because of inaccessibility of the site during the fall and winter, mechanical problems with the sampler, and the small amount of precipitation in the area during the study, only four samples were collected and analyzed (two rain samples in September 1984 and August 1985, and two snow samples in December 1984 and January 1985).

The measured pH of the rain samples was 7.2 units in September 1984 and 7.1 units in August 1985. The pH of distilled water in equilibrium with atmospheric carbon dioxide is 5.6 units. The high pH values of the rain samples indicate that dust particles in the atmosphere, derived from exposed carbonate rock, may be causing a buffering effect.

The pH of the two snow samples was 5.3 units in December 1984 and 4.5 units in January 1985. The reason for the low pH values is not known. For comparison, data on snow chemistry of the Cascade-Sierra Nevada Mountains show a median pH of snow samples of 5.6 units (Laird and others, 1986). Snow and associated snowmelt may contribute to the low pH values observed in the retention pond. However, pH values in the retention pond are also low during periods of no precipitation, indicating another source of low pH water.

Mine Pits and Retention Pond

A comparison of the field data and analytical results of water samples collected from the pits and the retention pond indicates that the water increases in mineralization downgradient through the mine. However, this downgradient relation between the pits and the retention pond is not straightforward, because water is periodically pumped from pit 4 and the retention pond to prevent their overflowing, and placed in pit 3. Therefore, the water quality in pit 3, to some degree, reflects the addition of water from pit 4 and the retention pond. The amount of water added to pit 3 from pit 4 and the retention pond is relatively small when compared with the volume of water already in pit 3. The temperature and dissolved-oxygen profiles (see figs. 6-8) observed in the pits and the retention pond indicate that these bodies of water may not have annual temperature and oxygen cycles typical of natural lakes in this climate. A sampling schedule encompassing periods before, during, and after turnover would have provided a better understanding of these cycles. The ability of the water to mix vertically, which is dependent on the breakup of temperature, and in some cases chemical, stratification, will affect the distribution and concentration of many constituents in the water column, especially oxygen, trace metals, and nutrients.
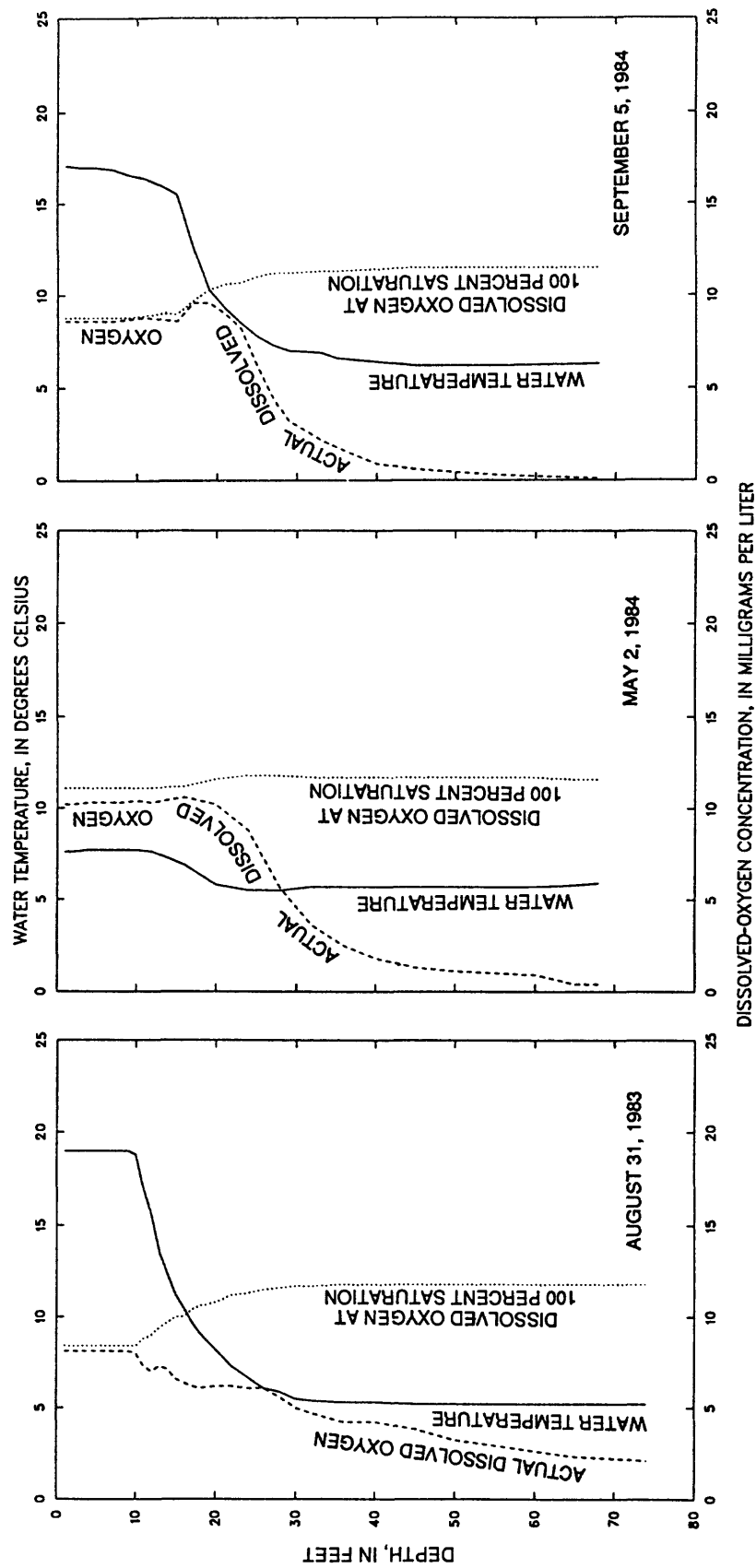
Figure 6.--Temperature and dissolved-oxygen profiles from pit 4 at the inactive uranium mine.
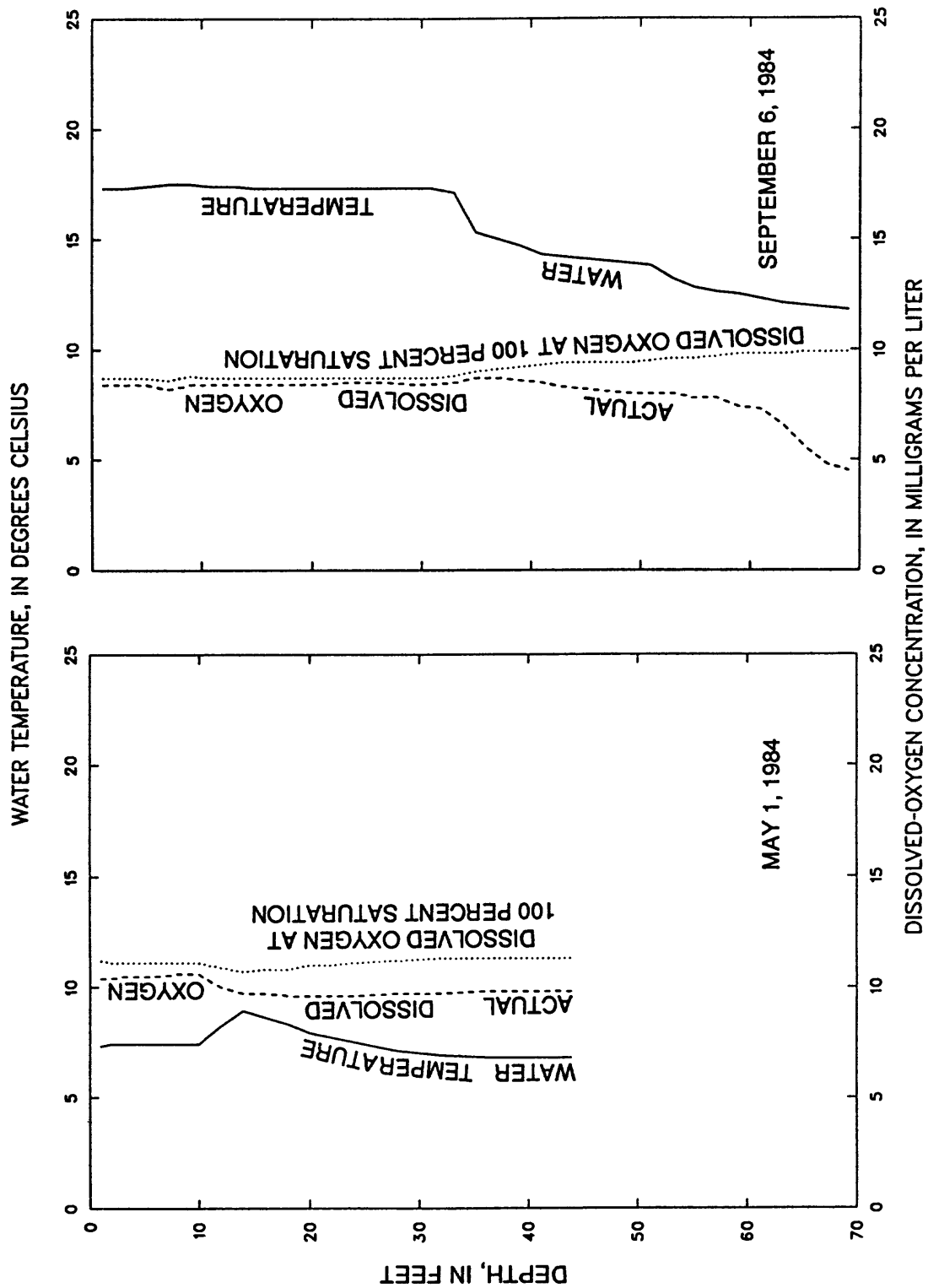
Figure 7.--Temperature and dissolved-oxygen profiles from pit 3 at the inactive uranium mine.
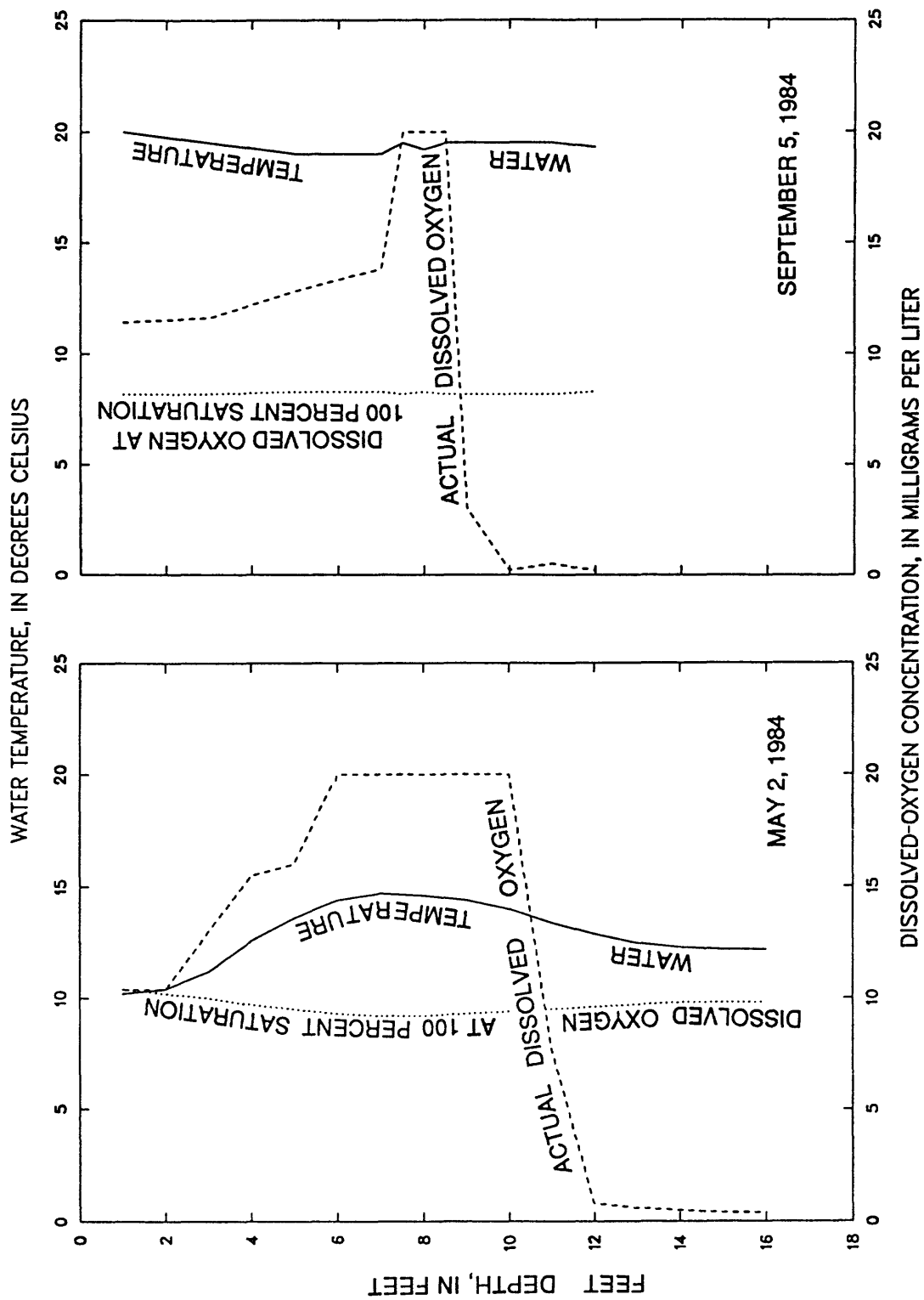
Figure 8.--Temperature and dissolved-oxygen profiles from the retention pond at the inactive uranium mine.

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The results of chemical analyses of water samples from the pits and retention pond were compared to U.S. Environmental Protection Agency (EPA) criteria for drinking water, and the well-being of freshwater aquatic life (U.S. Environmental Protection Agency, 1986), and limits for uranium-mine effluents (U.S. Environmental Protection Agency, 1984), and U.S. Nuclear Regulatory Commission (NRC) standards for protection from radiation hazards (U.S. Nuclear Regulatory Commission, 1984). Even though these waters are not used for domestic purposes, drinking-water criteria provide a frame of reference for many of the constituents.

Because pit 4 is upgradient of most of the disturbed areas in the mine, the opportunity to receive highly mineralized water is considerably less than for pit 3 and the retention pond. The dissolved-solids concentrations of samples from pit 4 ranged from 763 mg/L to 1,330 mg/L; dissolved-solids concentrations from pit 3 (2,330 mg/L to 3,150 mg/L) and from the retention pond (12,300 mg/L to 15,700 mg/L) for the same sampling periods were larger. However, concentrations of nitrate-nitrogen in all samples from pit 4 exceeded EPA criteria for drinking water (U.S. Environmental Protection Agency, 1986); nitrate-nitrogen concentrations in pit 3 and the retention pond were elevated (7.0-8.9 mg/L in pit 3 and 2.4-9.7 mg/L in the retention pond), but did not exceed the EPA drinking-water criterion. It was assumed that the large concentrations of nitrate-nitrogen were due to the leaching of explosives residues from the surrounding area. No other readily apparent anthropogenic source of nitrogen is present in the area (for example, agriculture or livestock operations) and nitrate-containing minerals have not been reported to occur in the area. Concentrations of manganese, nickel, and sulfate in all samples from the pits and the retention pond exceeded EPA drinking-water criteria. The uranium concentration of most samples from the pits and retention pond exceeded the maximum limit for uranium-mine effluent (U.S. Environmental Protection Agency, 1984). Radium-226 concentrations in all samples exceeded EPA criteria for drinking water; in addition, samples from pit 3 in September 1984 and all samples from the retention pond exceeded NRC standards for protection from radiation hazards (U.S. Nuclear Regulatory Commission, 1984).

Pit 4

Water-quality data for pit 4 were collected three times during the study (August 31, 1983, and May 1 and September 5, 1984). The Secchi-disk transparency increased from 7 feet in August 1983 to 9 and 12 feet for the two visits in 1984. However, the differences in Secchi-disk transparency may have been due to factors other than increasing water clarity. The intensity and angle of incident light and smoothness of the water surface also affect Secchi-disk visibility in water. Cloud cover was estimated for the August 1983 and May 1984 visits at 80 and 100 percent, respectively, and for the September 1984 visit at less than 5 percent.

The water-temperature profile made in August 1983 (fig. 6) indicates that thermal stratification was well established, with the metalimnion, the region of the water column with the steepest temperature gradient, between 10 and 30 feet below the water surface. In May 1984, pit 4 was stratified only weakly. The temperature profile in September 1984 was similar to that of August 1983, but with the metalimnion between 20 and 30 feet below the water surface. The latter two profiles were similar to those of typical temperate-climate lakes during late summer.

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Dissolved-oxygen deficits were found in the hypolimnion during all three visits, but especially in May and September 1984. Deficit is common during periods of thermal stratification, but was unexpected in May. This seemingly anomalous profile may have resulted from the rapid depletion of dissolved oxygen as a result of oxidation-reduction processes in bottom water near the time of spring turnover, from incomplete mixing during periods of turnover, or both.

Measurements of pH and specific conductance from water samples collected from pit 4 are presented in table 3. The relatively high pH (7.6) observed near the surface in August 1983 most likely resulted from a loss of dissolved carbon dioxide from the water, causing a shift in the carbonate/bicarbonate equilibrium reactions,

$$CO_2 + H_2O \rightleftarrows H_2CO_3 \rightleftarrows H^+ + HCO_3^- \rightleftarrows 2H^+ + CO_3^{-2}. \qquad (3)$$
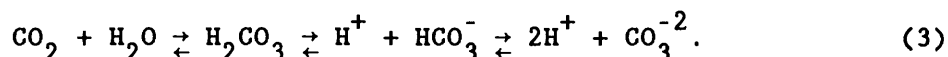
The result is a decrease in hydrogen ion concentration and a rise in pH. Photosynthetic activity is one possible means of removing carbon dioxide from the water.

Table 3.--Values of pH and specific conductance of water samples from pit 4

Sampling depth, in feet	pH, in units	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
August 31, 1983		
3	7.6	1,210
16	6.9	1,350
25	6.9	1,550
50	6.8	1,580
73	6.9	1,600
May 1, 1984		
3	6.9	933
12	6.9	1,120
32	6.8	1,440
50	6.7	1,470
65	7.0	1,550
September 5, 1984		
3	7.0	1,070
12	7.1	1,070
21	7.0	1,410
40	6.9	1,550
67	6.8	1,600

The pH of a system also can be raised through the removal of hydrogen ions from the water by the reaction between water and carbonate-bearing rock (eq. 4), or by the reaction of water and such minerals as albite, present in the quartz monzonite (eq. 5):

$$CaCO_3 + H^+ \rightarrow Ca^{+2} + HCO_3^- , \quad \text{and;} \qquad (4)$$
$$\text{(calcite)}$$

$$2NaAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2Na^+. \quad (5)$$
(albite) (kaolinite)
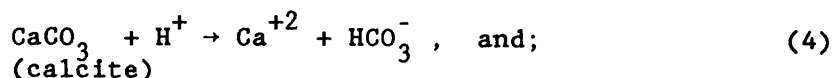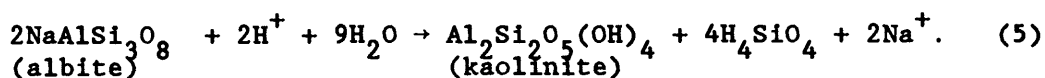
The specific-conductance values of samples from pit 4 ranged from 933 to 1,600 μS/cm (microsiemens per centimeter). A definite increase with depth was noted during all visits (table 3). The possibility that water in pit 4 does not mix during spring and fall turnover cannot be dismissed. Even though the temperature was equal throughout the water column, a density gradient due to dissolved substances may retard mixing.

Concentrations of major cations and anions also were observed to increase with depth each time the pit was sampled (table 4). The predominant ions were calcium and sulfate. Nitrate-nitrogen concentrations, obtained by subtracting nitrate-nitrogen concentrations from nitrite-plus-nitrate concentrations, ranged from 14 to 30 mg/L for all samples. These nitrate concentrations are not considered toxic to freshwater aquatic life, but may be harmful to warmblooded animals if ingested (U.S. Environmental Protection Agency, 1986).

Table 4.--Results of chemical analyses of water samples from pit 4 for selected common constituents

[Results in milligrams per liter unless otherwise specified; μS/cm, microsiemens per centimeter; --, analysis or measurement not done; <, below detection level; $^\circ$C, degree Celsius]

Constituent or characteristic	August 31, 1983			May 1, 1984			September 6, 1984		
	Depth, in feet			Depth, in feet			Depth, in feet		
	3	16	73	3	32	65	3	21	67
Specific conductance, μS/cm at 25 $^\circ$C	1,210	1,350	1,600	933	1,440	1,550	1,070	1,410	1,600
pH, units	7.6	6.9	6.9	6.9	6.8	7.0	7.0	7.0	6.8
Temperature, $^\circ$C	19	10.5	5.2	7.6	5.2	5.8	17.0	9.3	6.3
Oxygen, dissolved	8.1	6.4	2.1	10.2	3.6	.4	8.6	9.0	.1
Oxygen demand, chemical	--	--	--	12	--	11	30	50	40
Hardness, as CaCO$_3$	650	660	850	450	740	800	540	660	810
Acidity, total as CaCO$_3$	--	--	--	--	--	--	--	--	--
Calcium, dissolved	200	200	260	130	220	240	160	200	250
Magnesium, dissolved	36	39	49	28	43	47	33	39	45
Sodium, dissolved	30	33	41	23	36	39	27	33	39
Potassium, dissolved	3.3	3.2	3.9	2.4	3.6	4.0	3.1	3.4	4.0
Alkalinity, total as CaCO$_3$	30	35	53	27	45	58	27	35	60
Sulfate, dissolved	560	610	770	430	710	780	460	580	740
Chloride, dissolved	1.4	1.4	1.7	1.0	1.4	1.5	1.0	1.0	1.4
Fluoride, dissolved	.5	.4	.3	.3	.3	.3	.3	.2	.2
Silica, dissolved	22	20	19	20	19	19	24	22	19
Solids, dissolved, residue at 180 $^\circ$C	966	1,050	1,320	763	1,230	1,330	826	1,010	1,290
Solids, suspended, residue at 105 $^\circ$C	--	--	--	2	3	<2	6	8	4
Nitrite, dissolved as N	--	--	--	.03	<.01	<.01	.10	.04	<.01
Nitrite plus nitrate, dissolved as N	19	23	30	16	28	29	14	20	27
Phosphorus, hydrolyzable + ortho, total as P	--	--	--	<.01	<.01	<.01	<.01	<.01	.01

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Concentrations of trace metals (table 5), except for dissolved manganese and dissolved nickel, did not exceed EPA criteria for drinking water or for the well-being of freshwater aquatic life. Concentrations of dissolved beryllium in two samples were found to be in the "at risk" range for cancer (footnote d, table 6). Concentrations of dissolved radium-226 in all samples collected in May 1984 exceeded the criteria for drinking water and were generally uniform throughout the water column (tables 5 and 6). Concentrations of dissolved radium-226 in the August 1983 and September 1984 samples increased with depth; generally only the near-surface samples did not exceed the EPA criterion for drinking water (tables 5 and 6). Dissolved-uranium concentrations in all samples collected in May 1984 would have exceeded the EPA limits for uranium-mine effluents if the water had entered the surface-water drainage system. Only the near-surface samples from August 1983 and September 1984 were within the EPA limits for dissolved uranium in uranium-mine effluents (tables 5 and 6).

Table 5.--<u>Results of chemical analyses of water samples from pit 4 for selected trace metals</u>

[Results in micrograms per liter unless otherwise specified; pCi/L, picoCuries per liter; --, analysis or measurement not done; <, below detection level]

Constituent	August 31, 1983 Depth, in feet			May 1, 1984 Depth, in feet			September 6, 1984 Depth, in feet		
	3	16	73	3	32	65	3	21	67
Aluminum, dissolved	<100	<100	<100	<100	<100	<100	<100	<100	<100
total recoverable	--	--	--	--	110	100	<100	<100	<100
Beryllium, dissolved	--	--	--	2	<.5	<1	<1	<1	1
Cadmium, dissolved	1	<1	<1	<1	<1	<1	<1	<1	<1
total recoverable	--	--	--	<1	<1	<1	34	7	3
Copper, dissolved	1	1	<1	<2	<1	<1	1	<1	<1
total recoverable	--	--	--	4	5	4	5	4	3
Iron, dissolved	<3	<3	3	4	55	21	<3	<3	<3
total recoverable	--	--	--	50	60	70	30	40	30
Manganese, dissolved	1,300	2,900	3,000	1,900	3,000	3,300	1,200	2,400	3,100
total recoverable	--	--	--	2,100	2,900	3,200	1,700	2,400	3,100
Nickel, dissolved	61	85	82	57	67	63	38	52	58
total recoverable	--	--	--	75	90	84	56	58	51
Strontium, dissolved	700	780	1,000	5,000	8,800	9,600	590	790	950
Zinc, dissolved	23	50	50	46	55	42	16	30	45
total recoverable	--	--	--	60	50	40	30	30	30
Radium-226, dissolved, pCi/L	1.7	5.2	8.3	7.0	7.5	6.5	1.0	2.6	6.7
Uranium, natural, dissolved	3,900	6,200	8,400	4,300	10,000	8,000	1,700	5,000	8,600

Table 6.--Criteria, limits, and standards for drinking water, the well-being of freshwater aquatic life, and uranium-mine effluents of the U.S. Environmental Protection Agency (EPA, 1984 and 1986); and the U.S. Nuclear Regulatory Commission (NRC, 1984)

[mg/L, milligrams per liter; μg/L, micrograms per liter; pCi/L, picoCuries per liter; --, not listed; >, greater than; <, less than]

Constituent or characteristic	Drinking water/ esthetics, EPA (1986)	Freshwater aquatic life, EPA (1986)	Uranium-mine effluent	
			EPA (1984) 24-hour maximum	NRC (1984)
pH, units	5-9	6.5-9.0	6-9	--
Oxygen, dissolved, mg/L	--	>8.0 [a]	--	--
Oxygen demand, chemical, mg/L	--	--	200	--
Alkalinity, total as CaCO$_3$, mg/L	--	>20	--	--
Sulfate, dissolved, mg/L	250	--	--	--
Chloride, dissolved, mg/L	250	--	--	--
Solids, dissolved, mg/L	500 [b]	10,000	--	--
Solids, suspended, mg/L	--	(c)	--	--
Nitrate-nitrogen, dissolved, mg/L	10	<90	30	--
Beryllium, dissolved, μg/L	(d)	--	--	--
Cadmium, dissolved, μg/L	10	--	--	--
Cadmium, total recoverable, μg/L	--	(e)	--	--
Copper, dissolved, μg/L	1,000	--	--	--
Copper, total recoverable μg/L	--	(e)	--	--
Iron, dissolved, μg/L	300	1,000	--	--
Manganese, dissolved, μg/L	50	--	--	--
Nickel, dissolved, μg/L	13.4 [f]	--	--	--
Nickel, total recoverable, μg/L	--	(e)	--	--
Zinc, dissolved, μg/L	5,000 [f]	--	1,000	--
Zinc, total recoverable, μg/L	--	(e)	--	--
Radium-226, dissolved, pCi/L	3 [b]	--	10	30
Uranium, dissolved, μg/L	--	--	4,000	44,000

[a] For salmonid fish, the instantaneous concentration to be achieved at all times.

[b] U.S. Department of Health, Education, and Welfare (1962).

[c] Should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life.

[d] Concentrations corresponding to risk of cancer of 1 in 100,000, 1,000,000, and 10,000,000 are 6.8, 0.68, and 0.068 μg/L, respectively.

[e] Standards, in micrograms per liter, based on hardness of water, in milligrams per liter as CaCO$_3$; value should not exceed standard more than once every 3 years:

Cadmium: 4-day average $= e^{(0.7852(\ln hardness)-3.49)}$; 1-hour average $= e^{(1.128(\ln hardness)-3.828)}$

Copper: 4-day average $= e^{(0.8545(\ln hardness)-1.465)}$; 1-hour average $= e^{(0.9422(\ln hardness)-1.464)}$

Nickel: 4-day average $= e^{(0.846(\ln hardness)+1.1645)}$; 1-hour average $= e^{(0.846(\ln hardness)+3.3612)}$

Zinc: 4-day average $= e^{(0.8473(\ln hardness)+0.7614)}$; 1-hour average $= e^{(0.8473(\ln hardness)+0.8604)}$

Example: Site 6, July 24, 1984: hardness = 1,600 mg/L as CaCO$_3$, total recoverable cadmium = 12 μg/L

Standard (1-hour average) $= e^{(1.128(\ln 1,600)-3.828)} = e^{(1.128(7.3778)-3.828)} = e^{(8.322-3.828)} = e^{4.94} = 89$ μg/L.

[f] U.S. Environmental Protection Agency, 1980.

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Water-quality data for pit 3 were collected twice during the study, on May 1 and September 6, 1984. Although the deepest part of the pit was not sampled in May, the temperature and dissolved-oxygen profiles (fig. 7) indicate that the conditions at 45 feet were probably similar to those that would have been found at greater depths.

Secchi-disk transparencies in May and September were 15 and 24 feet, respectively, indicating greater light transmission than in pit 4. The transparency data indicate that, even though the water was highly colored, the quantity of suspended material was low.

The water-temperature profile from May (fig. 7) shows a stratum of slightly warmer water about 15 feet below the surface. This profile may have developed because of a depression in temperature of near-surface water, or the inflow of warmer water at this level. The water-temperature profile for September (fig. 7) shows only a slight degree of stratification; at this time of year, maximum thermal stratification would be expected. The relatively high water transparency, strong winds, and high air temperatures probably combined to produce a thick epilimnion.

The water in pit 3 was well oxygenated in May (fig. 7) and the dissolved-oxygen profile was as expected, given the temperature profile. In September, the dissolved-oxygen concentration decreased slightly near the bottom, but was still larger than expected for late summer (almost 5 mg/L). The presence of dissolved oxygen in the bottom water may have been because of mixing of the water column or the inflow of oxygenated water.

Water samples collected and analyzed from selected depths in pit 3 indicate that the pH was relatively uniform with depth and between seasons (table 7). Specific conductance increased with depth and was greater in September than in May, but varied with depth more in May than in September (table 7).

Table 7.--Values of pH and specific conductance of water samples from pit 3

Sampling depth, in feet	pH, in units	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
May 1, 1984		
3	4.6	2,220
10	4.6	2,220
20	4.7	2,870
32	4.7	2,870
42	4.7	2,870
September 6, 1984		
3	4.5	3,000
25	4.5	3,000
45	4.5	3,050
55	4.5	3,050
67	4.6	3,150

All pH values measured in pit 3 were between 4.5 and 4.7, well below the 6.5 minimum value set by EPA for the protection of freshwater aquatic life (U.S. Environmental Protection Agency, 1986). The most likely cause of the low pH values is the inflow of runoff from the surrounding area that has been in contact with sulfide minerals in waste piles or exposed rock, resulting in acidic water as those minerals become oxidized.

Specific-conductance values were high during both visits. The lower values obtained in May, compared with those in September, likely were due to dilution from greater quantities of snowmelt runoff prior to the May visit. The volume of water increased in pit 3 by about 31 acre-feet from March to May 1985. Assuming similar conditions existed in 1984, a similar increase in volume could have occurred. The uniformity of pH and specific-conductance values in September, along with the temperature and dissolved-oxygen profiles, indicates that some mixing of upper and lower water layers had taken place.

Tables 8 and 9 summarize the results of chemical analyses of samples for common constituents and trace metals, respectively, from pit 3. Concentrations of major cations and anions in all samples are generally large; as in pit 4, calcium and sulfate predominated. Calcium concentrations in all samples ranged from 240 to 370 mg/L. Sulfate concentrations ranged from 1,500 to 2,200 mg/L, six to nine times the maximum concentrations recommended by EPA for drinking water. Other constituents present in large concentrations included magnesium (110 to 170 mg/L), sodium (59 to 160 mg/L), and nitrate-nitrogen (7.0 to 8.9 mg/L). The high degree of mineralization is probably the result of contact between acidic water, produced during the oxidation of pyrites or other sulfide minerals, and the subsequent dissolution of other rock minerals disturbed and exposed during the course of mining.

Large concentrations of several trace metals in pit 3 water (table 9) probably are due also to the reaction between acidic water and the surrounding minerals. Beryllium was present in all the samples at concentrations that present a risk of cancer (see footnote d, table 6). Cadmium, copper, nickel, and zinc were found in concentrations exceeding the EPA criteria for the well-being of freshwater aquatic life (U.S. Environmental Protection Agency, 1986). No criteria have been established for aluminum, but concentrations as small as 150 μg/L (micrograms per liter) at pH 5 are harmful to certain species of fish, according to studies by Haines (1981). Thus, the concentrations of dissolved aluminum found in pit 3 (20,000 μg/L at 42 feet depth in May 1984, and 41,000 μg/L at 45 feet in September 1984) could be considered harmful to fish if released into the environment. Dissolved manganese concentrations also were elevated (61,000 μg/L at 3 feet in May 1984, and 85,000 μg/L at 67 feet in September 1984). The actual toxicity of these trace metals to fish may be reduced because of the large hardness values (greater than 1,100 mg/L for all samples) of the water (U.S. Environmental Protection Agency, 1980).

The results of analyses of water samples from pit 3 for selected radionuclides (table 9) indicate that radium-226 is present in concentrations exceeding the criterion for drinking water (see table 6 for criteria). Uranium concentrations exceeded the maximum limit set for uranium-mine effluents. The significant decrease in dissolved-uranium concentrations from May to September 1984 cannot be explained, but the slight differences in pH and dissolved-oxygen concentrations in May and September may contribute to the differences in uranium concentration. Hem (1985) suggested that the oxidation state of uranium ions is the primary control on their solubility in water.

Table 8.--Results of chemical analyses of water samples from pit 3
for selected common constituents

[Results in milligrams per liter unless otherwise specified; μS/cm, microsiemens per centimeter; --, analysis or measurement not done; <, below detection level; °C, degree Celsius]

Constituent or characteristic	May, 1 1984			September 6, 1984		
	Depth, in feet			Depth, in feet		
	3	20	42	3	45	67
Specific conductance, μS/cm at 25 °C	2,220	2,870	2,870	3,000	3,050	3,150
pH, units	4.6	4.7	4.7	4.5	4.5	4.6
Temperature, °C	7.4	7.9	6.8	17.3	14.1	11.9
Oxygen, dissolved	10.5	9.6	9.8	8.4	8.2	4.8
Oxygen demand, chemical	82	--	83	140	140	140
Hardness, as $CaCO_3$	1,100	1,300	1,300	1,300	1,100	1,600
Acidity, total as $CaCO_3$	--	--	--	2.5	2.5	2.0
Calcium, dissolved	240	270	270	290	250	370
Magnesium, dissolved	130	150	150	130	110	170
Sodium, dissolved	59	160	160	120	120	130
Potassium, dissolved	2.6	3.0	3.2	3.3	3.1	3.3
Alkalinity, total as $CaCO_3$	<1	<1	<1	--	--	--
Sulfate, dissolved	1,500	1,800	1,900	2,000	2,200	2,200
Chloride, dissolved	3.3	5.4	5.4	3.8	4.0	4.0
Fluoride, dissolved	1.2	1.1	1.1	1.4	1.5	1.6
Silica, dissolved	23	20	19	22	20	17
Solids, dissolved, residue at 180 °C	2,330	2,870	2,910	3,050	3,110	3,150
Solids, suspended, residue at 105 °C	12	3	7	1	1	1
Nitrite, dissolved as N	<.01	<.01	<.01	<.01	<.01	<.01
Nitrite plus nitrate, dissolved as N	7.7	8.9	8.7	7.7	7.0	8.0
Phosphorus, hydrolyzable + ortho, total as P	<.01	.01	.01	<.01	<.01	<.01

The Retention Pond

Water-quality samples from the retention pond were collected twice during the study, May 2 and September 5, 1984. Secchi-disk transparencies were almost identical for both visits: 3.5 feet in May and 3.8 feet in September.

The water column was not thermally stratified during either visit and temperatures were fairly high, ranging from 10 to 14 °C in May, and 19 to 20 °C in September (fig. 8). During May, there was a zone of water between about 3 and 10 feet that was warmer than the surface or bottom. The water temperatures in May were higher than in pits 3 and 4, probably because the pond is fairly shallow, is located on the southern side of the waste pile, and is not shaded by vegetation or high banks.

Table 9.--Results of chemical analyses of water samples from pit 3
for selected trace metals

[Results in micrograms per liter unless otherwise specified; pCi/L, picoCuries
per liter; --, analysis or measurement not done]

| | May 1, 1984 | | | September 6, 1984 | | |
| | Depth, in feet | | | Depth, in feet | | |
Constituent	3	20	42	3	45	67
Aluminum, dissolved	30,000	--	20,000	35,000	41,000	40,000
total recoverable	31,000	--	20,000	30,000	36,000	31,000
Beryllium, dissolved	20	10	20	30	30	20
Cadmium, dissolved	40	41	22	100	100	100
total recoverable	43	42	39	50	60	60
Copper, dissolved	210	150	150	--	300	300
total recoverable	220	160	170	230	240	190
Iron, dissolved	150	110	100	180	130	100
total recoverable	190	100	90	130	110	90
Manganese, dissolved	61,000	65,000	67,000	80,000	84,000	85,000
total recoverable	61,000	65,000	64,000	76,000	80,000	81,000
Nickel, dissolved	1,100	970	860	--	1,000	--
total recoverable	1,200	1,100	830	1,100	1,000	1,000
Strontium, dissolved	1,600	2,000	2,000	1,700	1,800	1,800
Zinc, dissolved	2,400	1,800	1,800	2,800	3,100	2,800
total recoverable	2,500	1,800	1,800	2,700	2,900	2,600
Radium-226, dissolved, pCi/L	23	22	20	38	33	47
Radon-222, dissolved, pCi/L	--	--	--	--	--	1,240
Uranium, natural, dissolved	16,000	14,000	14,000	4,300	3,700	4,500

On both sampling dates, unusually large dissolved-oxygen concentrations were measured near mid-depth and small concentrations were measured near the bottom (fig. 8). The small concentrations near the bottom probably were due to the presence of oxidizable material (both organic and inorganic). The reason for the large concentration near mid-depth is unknown; however, one possibility is algal photosynthesis.

All pH values (table 10) were below the minimum set by EPA (U.S. Environmental Protection Agency, 1986) for the well-being of freshwater aquatic life (6.5) and by EPA (U.S. Environmental Protection Agency, 1984) for uranium-mine effluents (6.0; see table 6). The apparent source of the low pH water is the inflow of ground water that has been in contact with acid-producing metallic sulfides, as evidenced by increased concentrations of trace metals and sulfate, and a large chemical-oxygen demand (see table 11).

The specific-conductance values were large and increased with depth, even though the pond is shallow. The large conductivity values probably result from concentration by evaporation and from the inflow of highly mineralized ground water.

Concentrations of major cations and anions were large (table 11), as evidenced by the large values of specific conductance. Magnesium and sulfate were the predominant ions in May and September, but calcium concentrations also were large.

Aluminum, manganese, and zinc concentrations were large, equaling or exceeding 470,000, 500,000, and 26,000 μg/L, respectively (table 12). Concentrations of beryllium, cadmium, copper, and iron were also large, at times as large as 240, 550, 7,000, and 5,900 μg/L, respectively.

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Table 10.--<u>Values of pH and specific conductance</u>
<u>of water samples from the retention pond</u>

Sampling depth, in feet	pH, in units	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius
	May 2, 1984	
3	3.7	7,130
8	3.5	8,630
12	3.8	9,630
	September 5, 1984	
3	3.6	8,600
7	3.7	8,700
11	3.7	9,200

Table 11.--<u>Results of chemical analyses of water samples from the retention pond</u>
<u>for selected common constituents</u>

[Results in milligrams per liter unless otherwise specified; μS/cm, microsiemens per centimeter; --, analysis or measurement not done; <, below detection level; °C, degree Celsius]

Constituent or characteristic	May 2, 1984 Depth, in feet		September 5, 1984 Depth, in feet	
	3	12	3	11
Specific conductance, μS/cm at 25 °C	7,130	9,630	8,600	9,200
pH, units	3.7	3.8	3.6	3.7
Temperature, °C	11.2	12.9	19.5	19.5
Oxygen, dissolved	13.0	.8	11.6	.5
Oxygen demand, chemical	670	850	--	--
Hardness, as $CaCO_3$	4,400	5,700	5,600	5,800
Acidity, total as $CaCO_3$	76	96	41	41
Calcium, dissolved	440	480	590	490
Magnesium, dissolved	810	1,100	1,000	1,100
Sodium, dissolved	37	72	45	50
Potassium, dissolved	4.4	4.3	4.9	4
Alkalinity, total as $CaCO_3$	<1	<1	--	--
Sulfate, dissolved	8,000	10,000	10,000	12,000
Chloride, dissolved	4.4	5.6	2.8	2.8
Fluoride, dissolved	11	12	<.1	<.1
Silica, dissolved	84	91	99	79
Solids, dissolved, residue at 180 °C	12,300	15,600	15,200	15,700
Solids, suspended, residue at 105 °C	21	41	18	26
Nitrite, dissolved as N	<.1	<.1	<.01	<.01
Nitrite plus nitrate, dissolved as N	4.3	2.4	9.7	7
Phosphorus, hydrolyzable + ortho, total as P	.01	.01	.01	.01

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Table 12.--Results of chemical analyses of water samples from the
retention pond for selected trace metals

[Results in micrograms per liter unless otherwise specified; pCi/L,
picoCuries per liter; --, analysis or measurement not done; <, below
detection level]

| Constituent | May 2, 1984 | | September 5, 1984 | |
| | Depth, in feet | | Depth, in feet | |
	3	12	3	11
Aluminum, dissolved	490,000	710,000	510,000	470,000
total recoverable	540,000	720,000	660,000	640,000
Beryllium, dissolved	180	240	110	130
Cadmium, dissolved	<1	--	500	500
total recoverable	<1	550	450	500
Copper, dissolved	2	3,300	3,300	3,500
total recoverable	2,800	3,500	7,000	7,000
Iron, dissolved	4,300	4,800	3,200	4,500
total recoverable	4,700	5,900	3,100	4,500
Manganese, dissolved	500,000	630,000	630,000	640,000
total recoverable	530,000	650,000	600,000	610,000
Nickel, dissolved	56	--	11,000	11,000
total recoverable	9,900	7,800	25,000	18,000
Strontium, dissolved	950	930	920	890
Zinc, dissolved	26,000	33,000	33,000	34,000
total recoverable	28,000	34,000	32,000	34,000
Radium-226, dissolved, pCi/L	55	48	63	61
Uranium, natural, dissolved	160,000	180,000	160,000	180,000

Concentrations of radium-226 ranged from 48 pCi/L (picoCuries per liter)
in May 1984 to 63 pCi/L in September 1984. Concentrations of uranium ranged
from 160,000 to 180,000 μg/L for both visits.

A comparison of selected water-quality data from pit 4, pit 3, and the
retention pond is shown in table 13. The data were collected from 3 feet
below the water surface on September 5 and 6, 1984, in the three bodies of
water.

Streams

Water temperature, specific conductance, and pH were recorded hourly, at
the four stream sites (4, 6, 5, and 8), and daily mean values were computed
for water temperature and specific conductance. The daily mean values are
shown in figures 9 and 10. Maximum and minimum pH values are shown in figure
11. The results of other field measurements and chemical analyses of water
samples from the same sites are shown in tables 14 through 21.

Daily mean water temperatures were greater than 10 °C from mid-May to mid-
September (fig. 9) at all sites. Values of 0 °C were recorded in December,
January, and February. It is not known if the mine drainage stream or Blue
Creek ever became solidly frozen, but surface ice was present from November
through February at all sites.
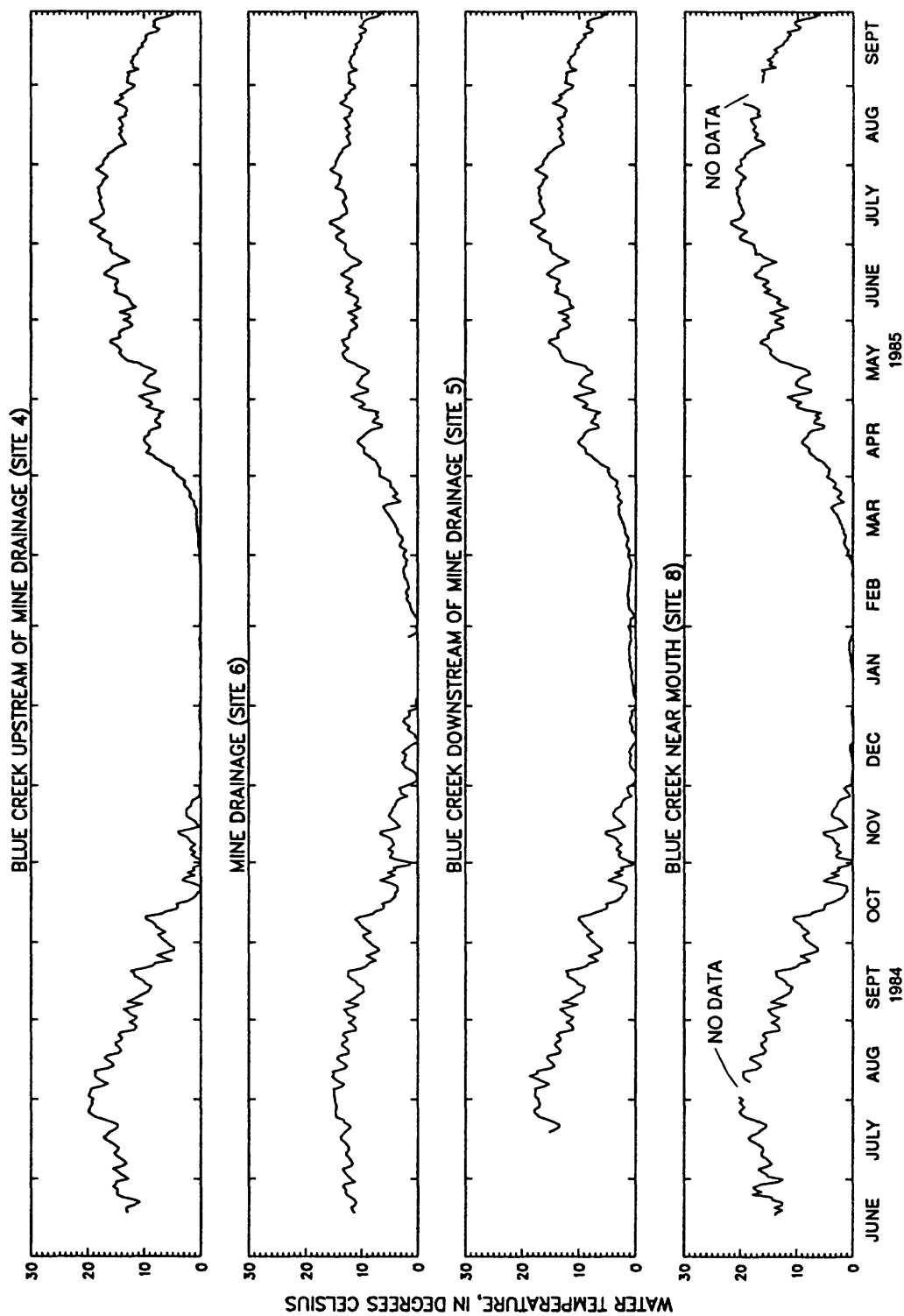
Figure 9.--Daily mean values of water temperature at sites 4, 6, 5, and 8,
June 1984 through September 1985. See figure 1 for location of sites.

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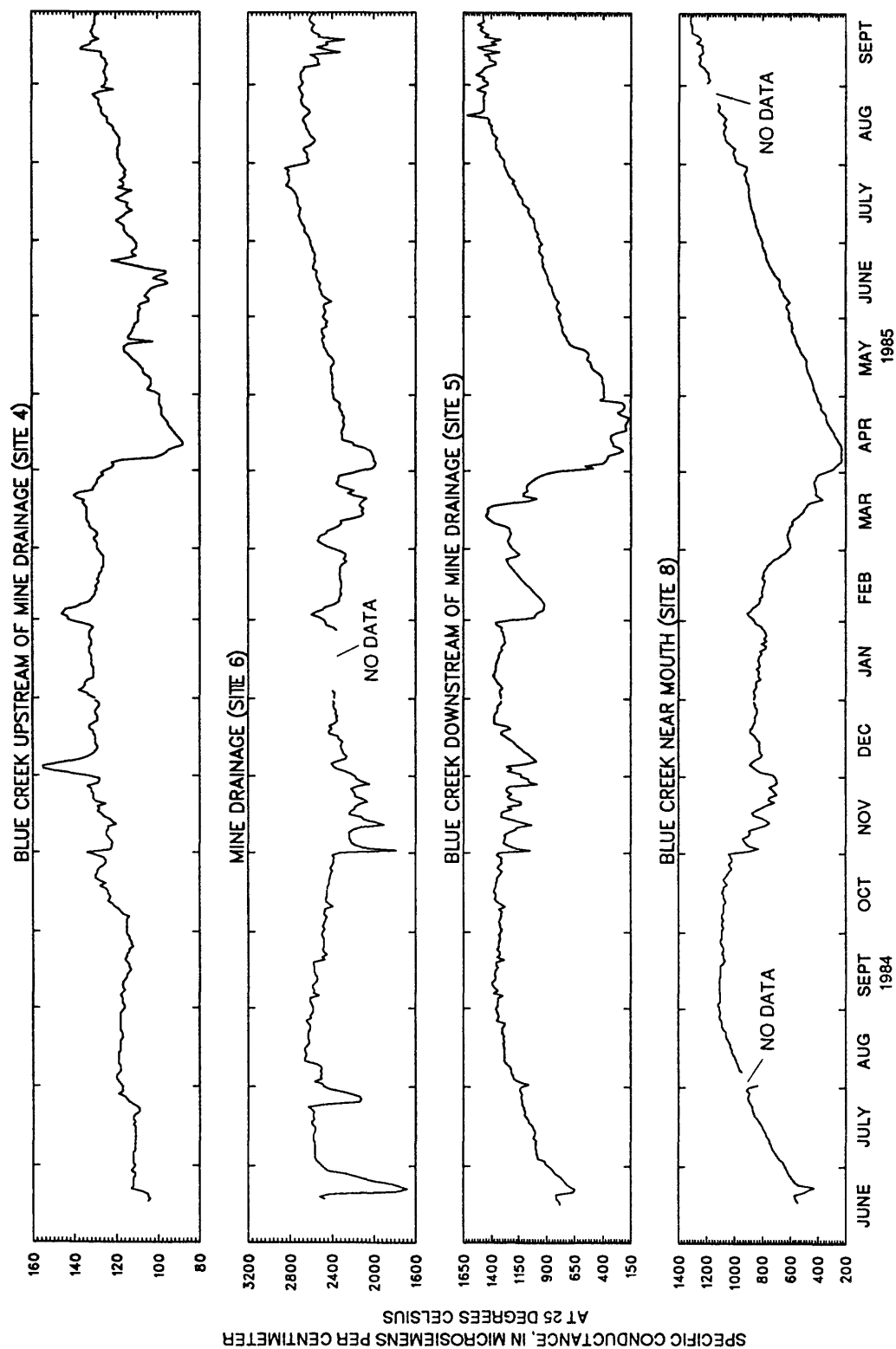
Figure 10.--Daily mean values of specific conductance at sites 4, 6, 5, and 8, June 1984 through September 1985. See figure 1 for location of sites.

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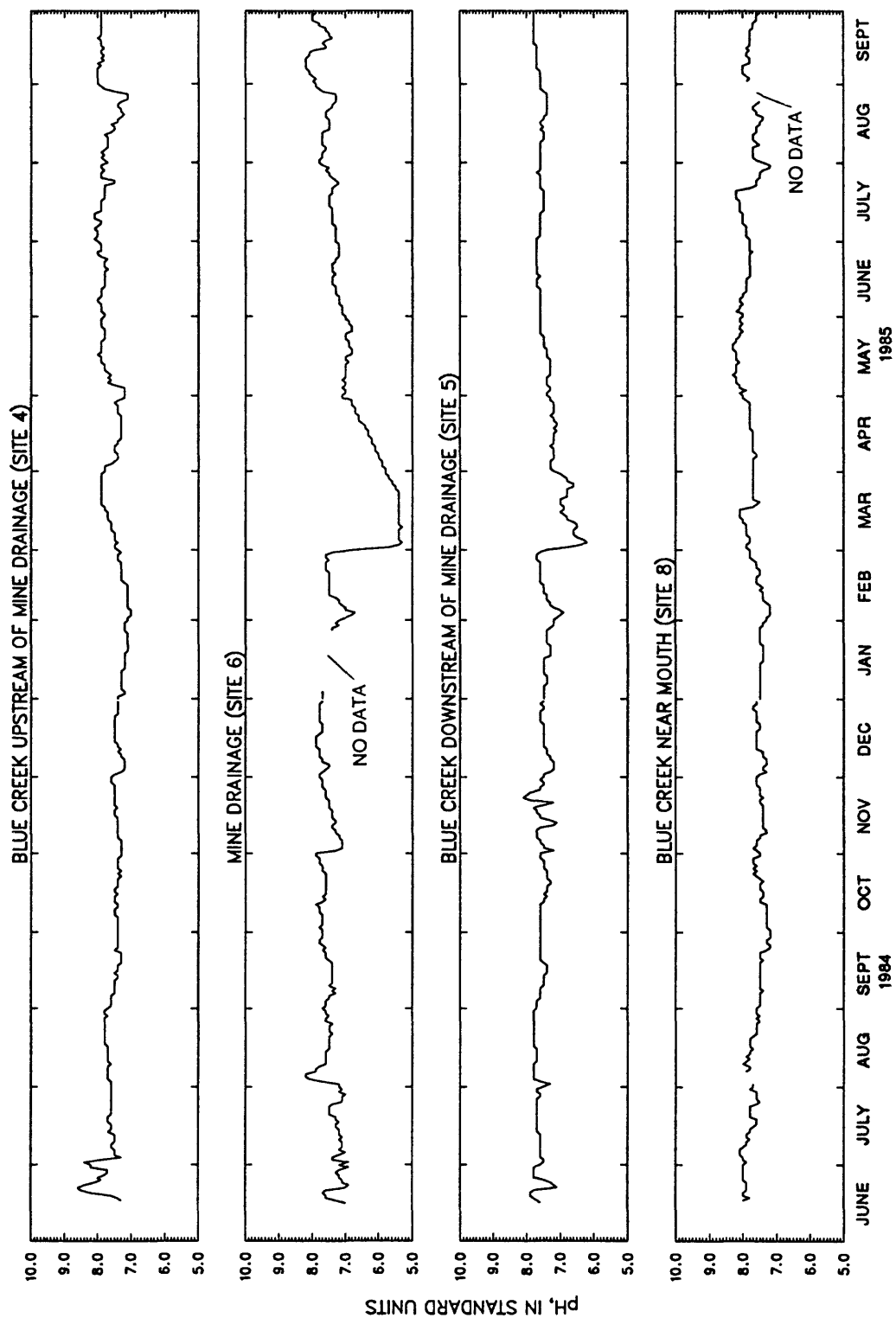
Figure 11.--Daily mean values of pH at sites 4, 6, 5, and 8, June 1984 through September 1985.
See figure 1 for location of sites.

Table 13.--Selected water-quality data collected at 3-foot depth from pit 4, pit
3, and the retention pond, September 5 and 6, 1984

[Results in micrograms per liter unless otherwise specified; mg/L, milligrams per
liter; μS/cm, microsiemens per centimeter; pCi/L, picoCuries per liter; --,
analysis or measurement not done; <, below detection level; °C, degree Celsius]

Constituent or characteristic	Pit 4	Pit 3	Retention pond
Specific conductance (μS/cm at 25 °C)	1,070	3,000	8,600
pH (units)	7.0	4.5	3.6
Hardness, as CaCO$_3$ (mg/L)	540	1,300	5,600
Nitrite plus nitrate, dissolved as N (mg/L)	14.0	7.7	9.7
Sulfate (mg/L)	460	2,000	10,000
Solids, dissolved (mg/L)	826	3,050	15,200
Aluminum, dissolved	<100	35,000	510,000
Cadmium, dissolved	<1	100	500
Iron, dissolved	<3	180	3,200
Manganese, dissolved	1,200	60,000	630,000
Nickel, dissolved	38	--	11,000
Zinc, dissolved	16	2,800	33,000
Radium-226, dissolved, pCi/L	1.0	38	63
Uranium, dissolved	1,700	4,300	160,000

Graphs of daily mean specific conductance at the stream sites are shown in
figure 10. The specific conductance at site 4 was relatively uniform, ranging
from 100 to 160 μS/cm, with the exception of a significant decrease in early
April 1985 caused by the increased flow in Blue Creek from snowmelt (see fig.
5). The specific conductance of the mine drainage was usually 10 to 20 times
that of Blue Creek upstream of the mine drainage. Specific conductances of
Blue Creek downstream of the mine drainage stream and near its mouth, although
greater than upstream of the mine drainage stream, were lower than in the mine
drainage stream, a reflection of the mixing of these two streams.

For much of the study period, daily mean pH values in Blue Creek and the
mine drainage stream were between 7.0 and 8.0 (fig. 11). However, low daily
mean pH values (below 6.0) were recorded in the mine drainage during March and
early April, probably in response to snowmelt runoff. The addition of mine
drainage to and the dilution by Blue Creek can be seen in the pH values for
Blue Creek downstream of the mine drainage stream (site 5). The effects of
the mine drainage stream on the pH of Blue Creek near its mouth (site 8) are
not readily apparent.

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Table 14.--Results of chemical analyses of water samples from Blue Creek upstream of the mine drainage stream (site 4) for selected common constituents

[Results in milligrams per liter unless otherwise specified; ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter; --, analysis or measurement not done; <, below detection level; °C, degree Celsius]

Constituent or Characteristic	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Discharge, instantaneous, ft³/s	0.53	0.23	--	0.25	0.24	0.15	--	0.20	0.93	2.78	1.32	0.54	0.22
Specific conductance, µS/cm at 25 °C	112	120	117	136	136	132	131	125	134	100	116	115	113
pH, units	7.6	7.8	7.4	7.4	7.6	7.5	7.2	7.4	7.9	7.5	7.8	7.7	7.9
Temperature, °C	16.0	13.6	5.9	0.1	1.1	0.0	0.1	0.1	1.3	6.5	11.8	12.3	16.2
Oxygen, dissolved	8.8	9.2	11.6	12.5	12.6	12.4	12.7	13.5	12.1	11.1	9.3	10.3	9.1
Oxygen demand, chemical	33	30	10	<10	16	20	17	12	79	15	21	16	27
Hardness, as CaCO3	44	47	41	51	53	58	54	53	60	38	44	44	47
Acidity, total as CaCO3	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcium, dissolved	13	14	12	15	16	17	16	16	18	11	13	13	14
Magnesium, dissolved	2.8	3.0	2.7	3.3	3.2	3.7	3.3	3.2	3.7	2.5	2.7	2.7	2.9
Sodium, dissolved	6.4	6.2	5.4	6.3	6.1	6.7	6.4	5.8	6.3	5.9	6.1	6.5	6.3
Potassium, dissolved	5.5	2.1	2.1	2.1	1.9	1.9	1.8	1.6	1.9	1.9	1.9	2.1	2.4
Alkalinity, total as CaCO3	57	59	59	78	61	54	59	57	61	42	52	54	59
Sulfate, dissolved	11	5.9	5.5	8.1	8.5	11	7.6	8.5	9.9	11	8.2	5.0	4.6
Chloride, dissolved	1.5	.9	1.0	1.2	1.0	1.2	1.1	1.5	1.3	1.1	1.0	1.1	1.1
Fluoride, dissolved	.1	.1	.1	.1	.1	.1	.2	.1	.1	.1	.1	.1	.1
Silica, dissolved	40	36	33	35	34	38	36	35	37	40	39	39	39
Solids, dissolved, residue at 180 °C	104	96	104	98	96	99	105	108	97	104	93	100	98
Solids, suspended, residue at 105 °C	4	<1	9	1	16	9	2	12	10	12	25	17	8
Nitrite, dissolved as N	.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Nitrite plus nitrate, dissolved as N	.14	<.10	<.10	<.10	1.4	.32	.24	.26	.30	<.10	<.10	<.10	.17
Phosphorus, hydrolyzable + ortho, total as P	.10	.11	.08	.06	.07	.07	.05	.06	.10	.15	.14	.12	.08

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Table 15.--Results of chemical analyses of water samples from the mine drainage stream (site 6) for selected common constituents

[Results in milligrams per liter unless otherwise specified; ft³/s, cubic feet per second; μS/cm, microsiemens per centimeter; --, analysis or measurement not done; °C, degree Celsius]

Constituent or characteristic	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Discharge, instantaneous, ft³/s	0.17	0.16	--	0.16	0.17	0.19	--	0.17	0.89	0.34	0.32	0.18	0.17
Specific conductance, μS/cm at 25 °C	2,600	2,630	2,540	2,510	2,220	2,460	2,360	2,230	2,030	2,380	2,450	2,520	2,730
pH, units	7.4	7.5	7.7	7.6	7.6	7.6	7.4	7.4	5.4	6.8	6.9	7.3	7.4
Temperature, °C	16.1	14.5	8.8	5.1	3.4	0.0	2.0	1.9	6.6	10.8	13.2	11.8	15.4
Oxygen, dissolved	8.8	9.1	10.6	11.3	11.8	12.6	12.3	12.0	11.7	9.4	8.8	9.8	9.5
Oxygen demand, chemical	71	100	80	59	67	55	71	35	14	95	67	64	65
Hardness, as CaCO3	1,600	1,600	1,530	1,440	1,440	1,490	1,370	1,420	2,060	1,440	1,550	1,540	1,670
Acidity, total as CaCO3	--	--	--	--	--	--	24	33	92	91	54	--	42
Calcium, dissolved	380	360	350	330	330	350	300	320	260	330	340	320	370
Magnesium, dissolved	160	170	160	150	150	150	150	150	140	150	170	180	180
Sodium, dissolved	41	44	44	44	41	40	42	39	34	40	35	38	48
Potassium, dissolved	7.0	7.3	7.5	7.5	6.2	6.7	6.4	6.4	5.7	6.0	6.6	7.0	7.8
Alkalinity, total as CaCO3	72	55	73	78	84	77	72	73	8	29	51	63	46
Sulfate, dissolved	1,700	1,600	1,500	1,600	1,400	1,500	1,300	1,400	1,400	1,600	1,700	1,600	1,900
Chloride, dissolved	3.3	3.5	.7	3.4	3.3	3.4	3.1	3.1	2.6	2.8	3.0	3.2	3.5
Fluoride, dissolved	.7	.6	.5	.4	.4	.4	.6	.6	.9	.8	.8	.7	.6
Silica, dissolved	47	51	53	55	53	49	49	49	45	46	45	47	50
Solids, dissolved, residue at 180 °C	2,660	2,700	2,520	2,410	2,270	2,390	2,340	2,290	2,060	2,460	2,490	2,550	2,750
Solids, suspended, residue at 105 °C	54	12	24	5	16	24	21	33	340	62	7	58	24
Nitrite, dissolved as N	.15	.27	.11	.09	.06	.04	.05	.06	.04	.05	.04	.04	.05
Nitrite plus nitrate, dissolved as N	23	23	21	19	18	18	16	16	14	14	15	7.5	17
Phosphorus, hydrolyzable + ortho, total as P	.03	.03	.03	.02	.03	.03	.02	.03	.18	.01	.05	.04	.02

Table 16.--Results of chemical analyses of water samples from Blue Creek downstream of the mine drainage stream (site 5) for selected common constituents

[Results in milligrams per liter unless otherwise specified; ft³/s, cubic feet per second; μS/cm, microsiemens per centimeter; --, analysis or measurement not done; <, below detection level; °C, degree Celsius]

Constituent or characteristic	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Discharge, instantaneous,[1] ft³/s	--	--	--	--	--	--	--	0.44	2.36	3.52	1.66	0.59	0.39
Specific conductance, μS/cm at 25°C	1,060	1,320	1,430	1,390	1,320	1,360	1,320	1,280	1,060	475	689	945	1,160
pH, units	7.6	7.8	7.6	7.2	7.6	7.4	7.2	7.6	6.9	7.3	7.5	7.8	7.7
Temperature, °C	15.0	13.1	5.8	1.3	2.0	0.0	0.6	1.2	4.0	7.9	13.3	10.9	17.3
Oxygen, dissolved	9.0	9.1	11.5	12.4	12.9	12.7	12.8	13.1	11.5	10.8	9.0	9.8	9.5
Oxygen demand, chemical	36	40	50	34	35	<10	48	22	12	58	25	22	37
Hardness, as CaCO₃	556	730	730	730	651	780	659	660	630	220	353	514	642
Acidity, total as CaCO₃	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcium, dissolved	130	170	170	170	150	180	150	160	140	50	82	120	150
Magnesium, dissolved	56	74	74	74	67	80	69	63	68	23	36	52	65
Sodium, dissolved	17	22	23	25	23	25	22	17	19	9.8	13	16	18
Potassium, dissolved	3.9	4.2	4.8	4.5	3.9	4.1	3.8	3.4	3.5	2.4	2.8	3.5	4.2
Alkalinity, total as CaCO₃	54	55	67	71	74	67	63	65	37	37	49	52	54
Sulfate, dissolved	530	710	750	750	640	730	770	610	600	190	300	460	590
Chloride, dissolved	1.8	1.8	2.5	2.2	2.2	2.2	2.0	2.0	1.8	1.2	1.3	1.5	1.7
Fluoride, dissolved	.4	.3	.3	.3	.3	.2	.3	.3	.5	.2	.3	.3	.3
Silica, dissolved	41	41	41	42	41	45	40	37	39	40	41	43	42
Solids, dissolved residue at 180°C	870	1,160	1,250	1,190	1,060	1,160	1,100	1,040	949	293	530	773	976
Solids, suspended residue at 105°C	21	9	22	4	20	14	20	22	174	52	48	24	16
Nitrite, dissolved as N	.40	.12	.05	.04	.03	.02	.02	.02	.02	<.01	.01	.01	.02
Nitrite plus nitrate, dissolved as N	6.6	9.3	5.4	9.9	8.9	8.2	8.3	7.5	6.8	5.7	1.8	2.8	4.2
Phosphorus, hydrolyzable + ortho, total as P	.05	.07	.06	.04	.04	.05	.04	.05	<.01	.17	.13	.10	.08

[1]Instantaneous discharge was not measured prior to February 25, 1985.

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Table 17.--Results of chemical analyses of water samples from Blue Creek near its mouth (site 8) for selected common constituents

[Results in milligrams per liter unless otherwise specified; ft^3/s, cubic feet per second; μS/cm, microsiemens per centimeter; --, analysis or measurement not done; <, below detection level; °C, degree Celsius]

Constituent or characteristic	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 19	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Discharge, instantaneous, ft^3/s	0.69	0.26	--	0.40	1.02	0.55	--	0.83	7.49	5.82	2.39	0.67	0.15
Specific conductance, μS/cm at 25 °C	855	1,110	1,140	1,100	790	870	760	712	342	401	539	755	900
pH, units	7.8	7.6	7.4	7.4	7.6	7.5	7.5	7.7	7.6	7.7	8.3	7.8	8.0
Temperature, °C	14.8	13.5	5.3	0.2	2.1	0.0	0.0	0.1	3.5	5.7	12.9	12.8	19.3
Oxygen, dissolved	9.6	10.2	12.0	13.3	12.8	12.5	13.5	13.4	11.8	10.4	10.0	10.0	11.5
Oxygen demand, chemical	26	<10	<10	<10	18	55	20	<10	20	41	21	13	26
Hardness, as CaCO$_3$	423	581	614	569	387	452	402	370	202	168	263	415	494
Acidity, total as CaCO$_3$	--	--	--	--	--	--	--	--	--	--	--	--	--
Calcium, dissolved	100	140	150	140	92	110	98	92	48	41	64	100	120
Magnesium, dissolved	42	56	58	53	37	43	38	34	20	16	25	40	47
Sodium, dissolved	15	19	20	19	16	17	15	12	9.6	8.8	11	14	17
Potassium, dissolved	3.4	4.3	4.1	3.9	2.9	3.0	2.7	2.5	2.1	2.2	2.6	3.1	3.7
Alkalinity, total as CaCO$_3$	56	50	48	56	64	58	57	54	49	49	52	56	54
Sulfate, dissolved	400	550	570	580	340	390	360	300	170	130	210	360	430
Chloride, dissolved	1.6	1.7	1.9	2.2	2.1	2.0	1.8	1.7	1.4	1.3	1.2	1.6	1.5
Fluoride, dissolved	.3	.3	.3	.3	.3	.3	.3	.3	.3	.2	.3	.3	.3
Silica, dissolved	37	36	36	35	36	39	38	35	37	37	39	39	37
Solids, dissolved, residue at 180 °C	668	906	946	908	589	676	603	545	293	282	399	600	753
Solids, suspended, residue at 105 °C	14	9	--	1	9	5	6	6	80	25	13	27	5
Nitrite, dissolved as N	.01	.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Nitrite plus nitrate, dissolved as N	3.8	5.0	5.5	5.7	3.5	4.2	3.7	3.2	1.5	1.0	1.4	2.2	.62
Phosphorus, hydrolyzable + ortho, total as P	.02	.03	.01	.02	.04	.05	.03	.04	.12	.10	.05	.02	.02

Table 18.--<u>Results of chemical analyses of water samples from Blue Creek upstream of the mine drainage stream (site 4) for selected trace metals</u>

[Results in micrograms per liter unless otherwise specified; pCi/L, picoCuries per liter; --, analysis or measurement not done; <, below detection level]

Constituent	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Aluminum, dissolved	300	<100	<100	<100	<100	<100	<100	200	200	800	200	200	200
total recoverable	300	300	100	100	400	--	300	300	2,500	4,400	2,600	1,300	600
Beryllium, dissolved	<1	<1	<1	2	--	<.5	<.5	.8	<.5	<.5	<.5	<.5	<.5
Cadmium, dissolved	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
total recoverable	1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1
Copper, dissolved	3	1	1	<1	<1	<1	1	3	3	1	1	1	3
total recoverable	3	3	5	3	2	2	5	5	6	3	7	4	2
Iron, dissolved	350	290	240	190	170	100	29	150	120	400	150	180	160
total recoverable	420	450	410	400	610	670	400	410	2,000	2,700	1,500	1,300	980
Manganese, dissolved	6	15	14	87	17	35	10	4	11	19	16	18	15
total recoverable	20	20	40	100	30	40	10	20	80	40	20	40	50
Nickel, dissolved	<1	3	2	1	3	4	4	4	<1	<1	2	3	1
total recoverable	7	3	6	7	14	12	18	4	11	1	8	35	9
Strontium, dissolved	90	100	86	95	96	100	92	96	93	71	84	85	95
Zinc, dissolved	4	28	12	5	5	14	9	4	15	10	11	6	12
total recoverable	10	30	10	90	<10	10	30	10	240	30	<10	10	20
Radium-226, dissolved, pCi/L	.1	.1	<.1	<.2	<.1	<.9	<.9	<.6	<.1	.2	.2	.2	.1
Radon-222, dissolved, pCi/L	36	25	54	60	67	76	4	64	--	26	22	27	105
Uranium, natural, dissolved	2.1	2.0	3.1	3.1	2.4	3.1	2.8	3.0	4.2	2.3	3.4	2.6	2.2

Table 19.--Results of chemical analyses of water samples from the mine drainage stream (site 6) for selected trace metals

[Results in micrograms per liter unless otherwise specified; pCi/L, picoCuries per liter; --, analysis or measurement not done; <, below detection level]

Constituent	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Aluminum, dissolved	<100	100	300	200	200	200	200	200	1,500	<100	<100	100	300
total recoverable	5,200	1,800	1,100	100	700	1,300	2,700	2,700	23,000	11,000	6,400	4,100	1,700
Beryllium, dissolved	<10	<10	<10	<10	<10	<10	<10	<10	<10	10	<10	10	<10
Cadmium, dissolved	13	12	13	13	11	10	14	12	17	14	15	15	20
total recoverable	12	9	21	12	11	10	14	12	15	16	11	15	16
Copper, dissolved	6	8	8	3	4	3	4	6	51	14	7	6	6
total recoverable	36	17	20	8	8	8	24	15	100	48	40	45	13
Iron, dissolved	20	30	100	50	60	30	100	20	40	80	30	30	30
total recoverable	470	80	190	90	220	410	140	130	--	240	120	420	120
Manganese, dissolved	39,000	42,000	39,000	39,000	36,000	35,000	37,000	35,000	36,000	40,000	35,000	35,000	37,000
total recoverable	39,000	38,000	41,000	38,000	34,000	33,000	36,000	35,000	38,000	40,000	35,000	37,000	36,000
Nickel, dissolved	520	190	490	420	170	500	530	570	600	570	600	560	690
total recoverable	580	600	500	800	400	550	810	570	650	860	--	600	640
Strontium, dissolved	2,700	1,600	1,500	1,300	1,200	1,300	1,300	1,300	1,100	1,500	1,400	1,500	1,600
Zinc, dissolved	540	610	580	560	510	600	630	580	1,100	930	690	670	700
total recoverable	710	740	660	620	420	610	670	670	1,400	1,100	960	830	800
Radium-226, dissolved, pCi/L	3.4	3.4	2.4	1.5	1.9	2.3	2.3	1.6	3.0	3.6	3.5	2.7	2.8
Radon-222, dissolved, pCi/L	43	38	63	55	63	149	75	88	--	60	65	--	70
Uranium, natural, dissolved	950	740	480	300	310	430	660	570	1,200	910	1,200	1,080	810

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Table 20.--Results of chemical analyses of water samples from Blue Creek downstream of the mine drainage stream (site 5) for selected trace metals

[Results in micrograms per liter unless otherwise specified; pCi/L, picoCuries per liter; --, analysis or measurement not done; <, below detection level]

Constituent	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Aluminum, dissolved	<100	<100	100	100	<100	<100	<100	100	<100	500	<100	<100	100
total recoverable	1,400	900	800	200	600	1,000	1,300	900	10,000	5,900	2,900	1,500	900
Beryllium, dissolved	<.5	<1	2	2	<.5	<.5	<.5	2.7	<.5	<.5	<.5	<.5	<.5
Cadmium, dissolved	3	5	5	6	5	9	4	3	6	<1	1	3	3
total recoverable	5	5	6	5	5	4	7	<1	5	2	2	4	3
Copper, dissolved	1	5	4	1	3	1	3	2	8	9	4	3	3
total recoverable	12	8	9	5	4	6	11	7	8	10	22	8	6
Iron, dissolved	5	54	34	40	29	8	8	16	11	220	31	17	6
total recoverable	380	230	380	220	380	520	310	290	4,700	2,800	1,300	740	650
Manganese, dissolved	12,000	17,000	18,000	18,000	16,000	17,000	15,000	13,000	16,000	4,600	7,200	10,000	--
total recoverable	11,000	15,000	18,000	18,000	15,000	16,000	16,000	15,000	19,000	4,700	6,800	10,000	12,000
Nickel, dissolved	140	200	200	210	70	250	220	230	240	77	110	140	200
total recoverable	200	300	250	220	190	--	150	220	260	96	130	140	190
Strontium, dissolved	530	690	660	640	610	720	580	560	530	220	340	470	580
Zinc, dissolved	120	250	280	270	230	300	260	260	430	82	100	150	190
total recoverable	260	300	320	290	240	300	300	260	510	150	190	230	260
Radium-226, dissolved, pCi/L	1.0	1.2	1.1	.6	.7	.7	<.9	<.6	1.3	1.4	.6	.6	.7
Radon-222, dissolved, pCi/L	39	29	72	--	68	89	111	78	--	28	47	37	30
Uranium, natural, dissolved	400	360	250	150	140	180	370	280	430	160	290	239	210

Table 21.--Results of chemical analyses of water samples from Blue Creek near its mouth (site 8) for selected trace metals

[Results in micrograms per liter unless otherwise specified; pCi/L, picoCuries per liter; --, analysis or measurement not done; <, below detection level]

Constituent	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 19	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Aluminum, dissolved	<100	<100	<100	<100	<100	<100	<100	<100	100	100	<100	<100	<100
total recoverable	300	200	<100	<100	200	100	<100	<100	4,800	3,400	1,200	900	300
Beryllium, dissolved	<.5	<1	<1	<1	<1	<.5	<.5	.8	<.5	<.5	<.5	<.5	<.5
Cadmium, dissolved	1	<1	1	<1	2	1	<1	<1	<1	<1	<1	<1	<1
total recoverable	2	1	1	1	1	<1	<1	<1	3	<1	1	1	1
Copper, dissolved	<1	2	2	2	2	2	<1	<1	2	3	1	2	2
total recoverable	5	4	16	3	2	<1	3	4	10	5	8	6	3
Iron, dissolved	<3	7	4	<3	9	15	9	7	54	64	10	6	<3
total recoverable	180	140	110	60	160	110	100	120	3,200	1,800	570	640	180
Manganese, dissolved	1,700	95	110	520	1,500	780	870	520	2,300	2,100	1,900	590	170
total recoverable	1,600	110	140	530	1,400	780	900	620	2,900	2,300	2,000	1,300	330
Nickel, dissolved	20	17	11	16	28	20	26	24	30	39	26	20	6
total recoverable	42	16	20	23	49	25	52	37	60	47	34	39	16
Strontium, dissolved	460	620	620	540	400	450	390	360	210	180	270	400	510
Zinc, dissolved	22	20	16	26	28	44	37	31	40	59	16	14	11
total recoverable	70	20	20	50	20	40	40	30	160	70	60	300	80
Radium-226, dissolved, pCi/L	<.1	.2	<.1	<.1	<.1	<.9	<.9	<.6	<.1	.2	<.1	.2	.2
Radon-222, dissolved, pCi/L	--	47	66	63	40	37	45	--	--	11	19	32	38
Uranium, natural, dissolved	140	93	110	110	92	120	120	100	130	120	--	165	100

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The alkalinity of Blue Creek upstream of the mine drainage stream also remained relatively uniform for the study period (table 14). The effect of the addition of snowmelt from the mine basin on Blue Creek can be seen in the alkalinity values determined for the mine drainage stream (site 6; table 15) and in Blue Creek (sites 4 and 5; tables 14 and 16) for March and April 1985. Samples collected from the mine drainage stream in winter and early spring also contained detectable quantities of base-neutralizing substances (reported as acidity in table 15).

Dissolved-oxygen concentrations were relatively large at all sites, ranging from about 9 to 13.5 mg/L (tables 14-17). The mine drainage stream consistently had the smallest dissolved-oxygen concentration, and Blue Creek near its mouth consistently had the largest dissolved-oxygen concentration among the four sites.

The mine drainage also caused a change in the proportions of major ions present in Blue Creek between the three sites. Calcium and bicarbonate (expressed as alkalinity) were the predominant cation and anion in samples collected at Blue Creek upstream of the mine drainage stream. In samples collected from the mine drainage stream, the major cation was also calcium, but the percentage of magnesium present was greater than in Blue Creek upstream of the mine drainage stream. The predominant anion in the mine drainage stream was sulfate. Water in Blue Creek downstream of the mine drainage stream was similar in chemical composition to the mine drainage (calcium-sulfate), but with decreased concentrations. The composition of water in Blue Creek near the mouth was about the same as that of Blue Creek downstream of the mine drainage stream; however, the concentrations were decreased even more, mostly as a result of dilution. To summarize, water in Blue Creek changed from calcium-bicarbonate type upstream of the mine drainage stream to calcium-sulfate type downstream of the mine drainage stream.

The effects of the mine drainage were seen also in the concentrations of nitrate-nitrogen. At Blue Creek upstream of the mine drainage stream, the nitrate-nitrogen concentrations were less than 1.5 mg/L, indicating that even during periods of high flow, little nitrogen reaches upper Blue Creek. Nitrate concentrations in samples of mine drainage with the exception of the sample collected in June 1985, were all more than 10 mg/L. Concentrations of nitrate in Blue Creek downstream of the mine drainage stream (ranging from 1.8 to 9.9 mg/L) were greater than in Blue Creek upstream of the mine drainage and near its mouth. This indicates that nitrates from the mine basin are being carried into the surface drainage by rain and snowmelt runoff, but they are diluted downstream of the mine drainage stream. Concentrations of total phosphate phosphorus were generally small (tables 14-17) but, at times, were greater than 0.1 mg/L, which could lead to excessive plant growth (U.S. Environmental Protection Agency, 1986).

Dissolved- and suspended-solids concentrations in Blue Creek and the mine drainage stream reflect the activities in their respective basins. In Blue Creek upstream of the mine drainage stream, dissolved- and suspended-solids concentrations were small, ranging from 93 to 108 mg/L and less than 1 to 25 mg/L, respectively. The dissolved-solids concentrations in the mine drainage were about 20 times that in Blue Creek upstream of the mine drainage stream, and the suspended-solids concentrations were about 10 times as great. Several samples from the mine drainage stream contained suspended-solids concentrations (table 15) exceeding the EPA limit for uranium-mine effluent (U.S. Environmental Protection Agency, 1984) (table 6). Blue Creek downstream of

the mine drainage stream showed the effects of mine drainage, in that concentrations of both dissolved and suspended solids were about 10 times the concentrations in Blue Creek upstream of the mine drainage stream. Throughout the study, concentrations of suspended solids in Blue Creek upstream of the mine drainage stream were less than in the mine drainage or Blue Creek downstream of the mine drainage stream.

Trace-metal concentrations in Blue Creek upstream of the mine drainage were generally small (table 18), and at times were below the detection level of the analytical methods used for their determinations. During and after snowmelt (generally March through May), concentrations of total recoverable aluminum and iron were greater than at other times of the year (table 18). The concentrations of total recoverable aluminum (100 to 4,400 μg/L) were large enough to be potentially damaging to freshwater aquatic life (Haines, 1981). The concentrations of total recoverable zinc in March (240 μg/L) also exceeded the EPA criterion for the well-being of freshwater aquatic life (U.S. Environmental Protection Agency, 1986).

Most trace-metal concentrations in the mine drainage did not exceed EPA criteria for drinking water and for the protection of freshwater aquatic life (tables 19 and 6). However, two samples contained beryllium in the "at risk" range (footnote d, table 6) and all samples contained manganese and nickel concentrations exceeding drinking-water criteria. The chemical data indicate that some trace metals (aluminum, copper, and iron) are present mostly in suspended form (or associated with suspended-sediment particles) and that others (cadmium, manganese, nickel, and zinc) are present mostly in dissolved form.

As in the case of the major ions, the inflow of mine drainage caused increased concentrations of several trace metals in Blue Creek. Concentrations of aluminum, cadmium, and copper in Blue Creek downstream of the mine drainage stream were two to six times as great as in Blue Creek upstream of the mine drainage stream. Concentrations of manganese, nickel, and zinc in Blue Creek downstream of the mine drainage were 10 to 500 times as great as upstream. In terms of water-quality standards (U.S. Environmental Protection Agency, 1986), these elements were present in quantities that could be considered harmful to man and aquatic life if long-term exposure were to occur. Concentrations of most trace metals in Blue Creek near its mouth (table 21), even though larger than concentrations found upstream of the mine drainage stream, were much smaller than concentrations immediately downstream of the mine drainage stream. Smaller-than-expected concentrations of dissolved iron were found at site 5 (table 20) in July 1984, September 1981 through March 1985, and June 1985, relative to concentrations at sites 4 and 6 (tables 18 and 19). A possible reason for these anomalous results is that some process related to the filtering of the samples in the field may have resulted in a loss of dissolved iron from the samples from site 5. A review of total recoverable iron concentrations from sites 4, 6, and 5 (tables 18, 19, and 20) shows that concentrations at site 5 reflect the mixing of Blue Creek and mine drainage waters.

The inflow of mine drainage caused an increase in concentrations of uranium and radium-226 in Blue Creek (tables 18 and 20). The magnitudes of the increases ranged from about 60 to 200 times for uranium and about 3 to 10 times for radium-226. Uranium concentrations in the mine drainage ranged from 300 to 1,200 μg/L, and were 150 to 300 times that in Blue Creek upstream of the mine drainage stream. Downstream of the mine drainage stream, uranium

concentrations ranged from 140 to 430 μg/L, 70 to 100 times as great as upstream. Nevertheless, the concentrations of uranium in the mine drainage stream (table 19) were less than the maximum allowable for uranium-mine effluents (table 6). Radium-226 concentrations in the mine drainage ranged from 1.5 to 3.6 pCi/L. The largest concentrations occurred in July and August 1984 and March through May 1985. If these samples represent continuous and long-term concentrations, then the maximum 30-day limit set by EPA (U.S. Environmental Protection Agency, 1984) for uranium-mine effluents was exceeded. Uranium and radium-226 concentrations in Blue Creek near its mouth were about half the concentrations found in Blue Creek downstream of the mine drainage stream.

In general, concentrations of most constituents in Blue Creek decreased downgradient from where the mine drainage stream entered. Concentrations near the mouth of Blue Creek, however, were still higher than concentrations found upstream of the mine drainage stream.

<u>Ground Water</u>

The results of field measurements and chemical analyses of ground-water samples collected during the study from the observation well at site 32 were compared with water-quality criteria (table 6) and are shown in tables 22 and 23. The maximum temperature measured was 12.3 °C in July 1985, and the minimum temperature was 5.1 °C, measured in February 1985. Specific-conductance values ranged from 1,140 to 1,640 μS/cm. Relatively uniform pH values were measured during the study, ranging from 6.4 to 7.0 units. Alkalinity ranged from 93 to 110 mg/L. The chemical oxygen demand was generally low (<10 to 35 mg/L) for all samples.

The predominant cation in all samples was calcium, and the predominant anion was sulfate. This is typical of runoff from mine areas where pyrite (FeS_2) occurs in exposed host rock and spoils. Pyrite oxidizes to produce hydrogen and sulfate ions as contact water infiltrates and percolates to the water table, as shown by the overall reaction (Barnes and Romberger, 1968),

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{-2}. \qquad (6)$$
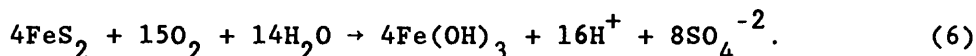
The hydrogen ions, in turn, release calcium and other cations from surrounding rock minerals. The dissolved-solids concentrations were fairly large, ranging from 1,070 to 1,500 mg/L, indicating a high degree of mineralization.

Nitrate-nitrogen concentrations were moderate (5.1 to 7.1 mg/L), and probably much of the nitrate was leached from explosives residues remaining in overburden and waste-material piles within the mine. Orthophosphate concentrations were small (0.01 to 0.08 mg/L).

In general, trace-metal concentrations (table 23) were small. Comparison of dissolved and total concentrations of trace metals indicates that most are present either as ore particulates or attached to other particles. However, three samples (January, February, and March 1985) contained large levels of dissolved cadmium (59, 57, and 24 μg/L, respectively). All of these values exceeded the EPA (U.S. Environmental Protection Agency, 1986) criterion for drinking water (table 6). The source of cadmium is not known; cadmium was not detected in chemical analyses of the metasedimentary rocks in the area (Nash and Lehrman, 1975).

Table 22.--Results of chemical analyses of water samples from observation well at site 32 for selected common constituents

[Results in milligrams per liter unless otherwise specified; μS/cm, microsiemens per centimeter; <, below detection level; °C, degree Celsius]

Constituent or Characteristic	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Specific conductance, μS/cm at 25°C	1,140	1,220	1,300	1,290	1,580	1,580	1,590	1,560	1,630	1,600	1,490	1,640	1,570
pH, units	6.6	6.7	7.0	6.7	6.8	6.8	6.8	6.8	6.6	6.6	6.4	6.6	6.8
Temperature, °C	10.1	12.1	10.8	10.2	8.2	6.0	5.7	5.1	5.7	6.7	7.9	9.7	12.3
Oxygen demand, chemical	17	30	20	<10	34	35	14	13	28	25	<10	10	24
Hardness, as CaCO3	989	715	673	806	856	960	947	1,010	1,000	989	989	981	952
Calcium, dissolved	210	210	200	240	250	280	270	300	290	280	280	290	280
Magnesium, dissolved	46	46	42	50	56	63	66	62	67	70	64	62	61
Sodium, dissolved	20	19	17	20	20	22	22	18	22	23	22	23	23
Potassium, dissolved	3.8	3.8	3.8	3.9	3.7	4.0	3.9	4.1	3.8	3.8	3.9	4.1	4.2
Alkalinity, total as CaCO3	110	110	107	101	99	98	100	103	100	98	95	95	93
Sulfate, dissolved	610	630	630	770	800	860	900	780	840	880	870	860	800
Chloride, dissolved	2.5	2.1	2.1	2.2	2.4	2.4	2.3	3.1	2.4	2.5	2.4	2.4	2.7
Fluoride, dissolved	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2	.2
Silica, dissolved	43	44	42	43	42	45	44	40	42	43	42	45	44
Solids, dissolved, residue at 180°C	1,080	1,070	1,130	1,210	1,330	1,410	1,450	1,470	1,460	1,500	1,460	1,400	1,300
Solids, suspended, residue at 105°C	20	10	117	<1	43	1	6	17	6	9	12	13	10
Nitrite, dissolved as N	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	.11
Nitrite plus nitrate, dissolved, as N	5.1	5.2	6.8	6.1	6.9	6.6	7.1	6.8	6.8	6.9	6.9	6.3	6.5
Phosphorus, hydrolyzable + ortho, total as P	.04	.03	.08	.02	.04	.02	.02	.04	.02	.01	.05	.03	.03

Table 23.--Results of chemical analyses of water samples from observation well at site 32 for selected trace metals

[Results in micrograms per liter unless otherwise specified; pCi/L, picoCuries per liter; --, analysis or measurement not done; <, below detection level]

Constituent	1984						1985						
	July 24	Aug. 27	Sept. 24	Oct. 22	Nov. 26	Dec. 18	Jan. 28	Feb. 25	Mar. 21	Apr. 29	May 20	June 24	July 22
Aluminum, dissolved	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
total recoverable	700	800	2,700	<100	900	--	<100	200	<100	100	200	300	100
Beryllium, dissolved	<1	<1	<1	2.0	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5	<.5
Cadmium, dissolved	<1	<1	3	1	7	9	59	57	24	<1	2	3	10
total recoverable	<1	<1	1	3	10	10	90	70	18	3	2	18	45
Copper, dissolved	3	1	2	<1	3	<1	<1	4	2	<1	<1	4	1
total recoverable	5	4	9	7	6	<1	7	17	3	1	9	6	8
Iron, dissolved	<3	4	3	4	4	<3	8	4	6	<3	4	<3	11
total recoverable	970	720	2,300	90	720	20	10	180	20	100	190	320	230
Manganese, dissolved	46	9	13	7	73	16	16	75	24	10	9	3	90
total recoverable	80	60	240	40	130	20	<10	50	50	60	20	70	200
Nickel, dissolved	<1	1	2	<1	4	<1	3	4	<1	<1	<1	4	4
total recoverable	10	2	5	9	18	6	19	7	13	8	6	12	29
Strontium, dissolved	750	800	720	850	930	1,000	1,000	990	1,000	1,000	1,000	990	980
Zinc, dissolved	26	3	11	17	34	19	21	66	11	18	13	9	19
total recoverable	50	<10	30	30	20	20	80	60	<10	20	10	40	30
Radium-226, dissolved, pCi/L	.9	.8	.8	.8	1.0	1.3	1.0	1.0	.9	.9	.9	.8	.7
Radon-222, dissolved pCi/L	5,580	6,200	8,390	--	6,730	4,780	4,360	2,290	8,860	8,100	6,450	7,440	
Uranium, natural, dissolved	27	30	31	25	24	27	35	35	37	35	36	33	30

Concentrations of uranium, radium-226, and radon-222 (table 23) reflect the presence of uranium ore and minerals in the study area. Concentrations of dissolved uranium and radium-226 ranged from 24 to 37 μg/L and 0.7 to 1.3 pCi/L, respectively, slightly greater than normal (Hem, 1985). However, the concentrations were below EPA and NRC (U.S. Environmental Protection Agency, 1984, and U.S. Nuclear Regulatory Commission, 1984) limits (see table 6). Radon-222 concentrations ranged from 2,290 to 8,860 pCi/L; however, there are no standards for radon in water by which to compare these values.

A comparison of selected water-quality analyses from surface waters (mine drainage stream and Blue Creek) and ground water (observation well at site 32) is presented in tables 24 and 25 for common constituents and trace metals, respectively. These data indicate that concentrations in ground water of several constituents are as large or larger than concentrations in the mine drainage stream (site 6). Because the discharge from the ground-water system is much less than from the mine drainage stream, however, the effect on Blue Creek is not as evident.

Table 24.--Median concentrations of selected common chemical constituents from surface-water sites and the observation well at site 32

[Results in milligrams per liter unless otherwise specified; μS/cm, microsiemens per centimeter; --, analysis or measurement not done; <, below detection level; ^{o}C, degree Celsius]

Constituents	Surface-water sites				Observa-tion well
	Site 4	Site 6	Site 5	Site 8	Site 32
Specific conductance μS/cm at 25 $^{\circ}$C	120	2,460	1,280	790	1,570
pH, units	7.6	7.4	7.6	7.6	6.7
Oxygen, dissolved	11.6	10.6	11.5	11.8	--
Oxygen demand, chemical	17	67	35	20	20
Hardness, as CaCO$_3$	47	1,530	651	415	960
Calcium, dissolved	14	330	150	100	270
Magnesium, dissolved	3	150	67	40	62
Sodium, dissolved	6.3	41	19	15	22
Potassium, dissolved	1.9	6.7	3.9	3.0	3.9
Alkalinity, total as CaCO$_3$	59	72	55	54	100
Sulfate, dissolved	8.2	1,600	610	360	1,400
Chloride, dissolved	1.1	3.2	1.8	1.7	2.4
Fluoride, dissolved	.1	.6	.3	.3	.2
Silica, dissolved	37	49	41	37	43
Solids, dissolved, residue at 180 ^{o}C	99	2,460	1,040	603	800
Solids, suspended, residue at 105 ^{o}C	9	24	20	9	10
Nitrite, dissolved as N	<.01	.05	.02	<.01	9
Nitrite plus nitrate, dissolved as N	.14	17	6.8	3.5	6.8
Phosphorus, hydrolyzable + ortho, total as P	.08	.03	.05	.03	.03

Table 25.--Median concentrations of selected trace metals from surface-water
sites and the observation well at site 32

[Results in micrograms per liter unless otherwise specified;
pCi/L, picoCuries per liter; <, below detection level]

| Constituents | Surface-water sites | | | | Observa-tion well |
	Site 4	Site 6	Site 5	Site 8	Site 32
Aluminum, dissolved	200	200	<100	<100	<100
total recoverable	350	2,700	1,000	200	200
Beryllium, dissolved	<.5	<10	<.5	<.5	<.5
Cadmium, dissolved	<1	13	4	<1	3
total recoverable	<1	12	5	1	10
Copper, dissolved	1	6	3	2	1
total recoverable	3	20	8	4	6
Iron, dissolved	170	30	29	7	4
total recoverable	610	165	380	160	190
Manganese, dissolved	15	37,000	16,000	780	16
total recoverable	40	37,000	15,000	900	60
Nickel, dissolved	2	530	200	20	1
total recoverable	8	600	195	37	9
Strontium, dissolved	93	1,400	580	400	990
Zinc, dissolved	10	610	250	26	18
total recoverable	10	710	260	50	30
Radium-226, dissolved, pCi/L	.1	2.7	.8	.1	.9
Radon-222, dissolved, pCi/L	45	65	68	39	6,730
Uranium, natural, dissolved	2.8	740	250	115	31

The U.S. Bureau of Indian Affairs and the U.S. Bureau of Land Management expect to be involved with further activities in and around the mine in the future. Possible elements of future work plans include continued water-quality monitoring and the determination of ground-water flow paths in the vicinity of the retention pond.

Continued Water-Quality Monitoring

The Bureau of Indian Affairs and the Bureau of Land Management could continue to monitor water-quality constituents and characteristics so that the loads of selected chemical constituents entering Blue Creek from the mine basin can be calculated. Data from this monitoring program could be used to estimate loads of selected constituents entering Blue Creek from the mine drainage stream.

Chemical discharge, or load, usually is calculated as tons per day (tons of chemical constituents transported per day), and is determined by using the following equation (Porterfield, 1972):

$$Q_L = Q_W \times C \times k , \qquad (7)$$

where

Q_L = load, in tons per day;
Q_W = stream discharge, in cubic feet per second;
C = concentration of constituent, in milligrams per liter; and
k = constant used in converting the units of stream discharge and constituent concentration to tons per day.

If the above units for Q_W and C are used, k is equal to 0.0027.

The value Q_L obtained from this equation is only an estimate of the daily load, because Q_W is often an instantaneous or daily mean value and C is usually the concentration of the constituent from a single sample. To obtain an estimate of the load for longer periods, Q_L can be multiplied by the number of days in the period of interest. However, the accuracy of this estimate is less than that of the daily load value, particularly if water discharge and (or) concentration varies significantly during the period. Better estimates can be obtained if several discharge measurements and water-quality sampling visits are made during the period of interest. The number of discharge measurements and water-quality samples required depends on how accurate an estimate is required. Table 26 illustrates the computation of the annual dissolved-solids load from the mine drainage stream, using data collected during this study.

Table 26.--Computation of the annual dissolved-solids load from the
mine drainage stream

Date	Q_W instantaneous discharge, in cubic feet per second	x	C dissolved solids concentration, in milligrams per liter	x	k conversion factor	=	Q_L load, in tons per day
1984							
July 24	0.17	x	2,660	x	0.0027	=	1.2
Aug. 27	.16	x	2,700	x	.0027	=	.44
Sept. 24	a .12	x	2,520	x	.0027	=	.82
Oct. 22	.16	x	2,410	x	.0027	=	1.0
Nov. 26	.17	x	2,270	x	.0027	=	1.0
Dec. 18	.19	x	2,390	x	.0027	=	1.2
1985							
Jan. 28	a .21	x	2,340	x	.0027	=	1.3
Feb. 25	.17	x	2,290	x	.0027	=	1.1
Mar. 21	.89	x	2,060	x	.0027	=	5.0
Apr. 29	.34	x	2,460	x	.0027	=	2.3
May 20	.32	x	2,490	x	.0027	=	2.2
June 24	.18	x	2,550	x	.0027	=	1.2
SUM					(tons/d)		18.76

Average daily load: $\dfrac{18.6 \text{ tons/d}}{12}$ = 1.6 tons/d

Annual load: 1.6 tons/d x 365 d/yr = 584 tons/yr

a Estimated discharge; obtained from digital record of gage height.

The minimum number of samples from the mine drainage stream required to obtain reliable estimates of annual loads is 12, one per month. Monthly measurements and samples need to be sufficient to account for the range in discharge and water quality that would be encountered in the mine drainage stream. As stated previously, if more accurate estimates of annual loads are required, more samples would need to be collected during the year. The sampling is to be made at equal time intervals to avoid biasing the estimate of the annual load toward periods of high or low discharge.

An alternative method for computing loads is to construct transport curves, in which the chemical load of a constituent is plotted as a function of instantaneous water discharge. This curve then can be used to obtain an estimate of chemical load for any length of time for which total water discharge is known. Although this method may appear to be more useful, several aspects of curve construction and use should be considered. To obtain valid estimates of chemical load, the curve must be based on data (both chemical concentration and discharge) collected over a wide range of flow magnitudes to define adequately the discharge hydrograph and its associated chemical loads (for example, a more intensive sampling program). Also, some error may be introduced when daily values of discharge are used with a curve constructed using instantaneous discharges. The magnitude of this type of error is not known, but it may be large for small rivers (Verhoff and others, 1980). More extensive discussions of this curve method may be found in reports by Porterfield (1972) and Verhoff and others (1980).

A review of water-level records and chemical analyses of samples from the ground-water system (observation well at site 32) indicates that ground-water discharge and quality vary less over time than do surface drainage discharge and quality. Therefore, bimonthly or quarterly sampling is probably sufficient to determine how much of the annual chemical load is carried by ground water.

Field measurements and the suite of analytical constituents need to be chosen so that not only can annual loads be determined, but the results of the chemical analyses can be compared with those from the present (1985) study. The following characteristics or constituents are needed in any future sampling program:

Acidity	Oxygen, dissolved
Alkalinity	pH
Aluminum	Potassium
Cadmium	Radium-226
Calcium	Silica
Chloride	Sodium
Copper	Solids, dissolved
Fluoride	Solids, suspended
Iron	Specific conductance
Lead	Strontium
Magnesium	Sulfate
Manganese	Uranium
Nickel	Water temperature
Nitrate-nitrogen	Zinc

This list includes those constituents found in most analytical schemes, and allows for comparison of data from the monitoring program with historical data. Trace metals and radionuclides included on the list have been found in large concentrations in the study area, therefore monitoring changes in concentration and load is necessary.

Flow Paths Near the Retention Pond

Further study at the mine could include determining ground-water flow paths in the vicinity of the retention pond and identifying specific sources in the mine that contribute water to the springs emerging at the downgradient boundary of the mine. A part of the present (1984-85) study was to evaluate ground-water tracers and procedures that could be used as part of a ground-water study at the mine. Criteria used to evaluate substances for use as tracers were small background concentration, onsite detection methods, low cost, low toxicity, and chemical and biological stability.

A water sample was collected from a surface-water sink in the mine and from three springs issuing from the downgradient boundary of the mine (sites T1, S1, S2, and S3, respectively; fig. 2). Two other surface-water sinks (T2 and T3 in fig. 2) have been identified by James LeBret (geologist, U.S. Bureau of Indian Affairs, Wellpinit, Wash., oral commun., 1984); however, no water

was present when these sites were visited. The concentrations of several ions (bromide, chloride, iodide, and lithium) and ethanol (as dissolved organic carbon) were determined in the water samples to establish background levels of these potential tracers. The following table presents the results of these analyses.

Constituent	Concentration, in milligrams per liter, at selected sampling sites			
	T1	S1	S2	S3
Bromide	<0.004	0.011	0.007	0.004
Chloride	4.4	12.4	6.0	7.4
Iodide	.06	.14	.034	.019
Lithium	3.9	.28	.26	.09
Dissolved organic carbon	4.0	2.1	2.0	3.0

These data indicate that bromide and iodide ions could be used as tracers because of their small background concentrations. An added advantage is that concentrations of bromide and iodide can be determined in the field using electrometric instruments with ion-selective electrodes. Chloride was rejected for use because of its large background concentration. Lithium was rejected because onsite detection is not possible for this element. Ethanol was eliminated because, not only was it present in relatively large concentrations, but also because it is subject to microbial degradation. Other types of tracers, such as other ionic substances (nitrate-nitrogen, sulfate, or ammonia), stable and radioactive isotopes, gases, other hydrophilic organic substances (benzoate), and fluorocarbons were rejected because of difficulties in handling and detection, high cost, or large background concentrations (Davis and others, 1980).

Tracer injections simultaneously made at the three suspected recharge areas (T1, T2, and T3 in fig. 2) with three different tracers would reduce the time and costs of conducting this study. By a process of elimination, fluorescent dyes appear to be the best choice for the third tracer. There are a number to choose from, and onsite detection is possible with portable fluorometers. The choice of a specific dye is dependent on soil type, subsurface material, and the pH and background fluorescence of native water. These characteristics were not determined during the present study.

Planning the sampling frequency needs to take into account the possibility that the tracer may appear at the discharge points from within a few days to weeks after injection. One possible sampling frequency is twice per day for the first 10 to 14 days, and weekly thereafter for 3 or 4 weeks or until the tracers are identified in the springs.

SUMMARY AND CONCLUSIONS

An inactive uranium mine in northeastern Washington State contributes highly mineralized water to Blue Creek. Water enters the mine basin as precipitation and leaves the basin as surface runoff, ground-water discharge, and evapotranspiration. There is no known surface-water inflow, and ground-water inflow is assumed to be negligible.

The water budget for the 12-month period September 1984 through August 1985 indicates that 934 acre-feet of water entered the basin as precipitation. The water leaving the basin included 188 acre-feet as surface-water discharge, about 1 acre-foot as ground-water discharge near site 6; 47 acre-feet as evaporation from the pits and retention pond; and about 637 acre-feet as evapotranspiration from soil surfaces and plants. Eighty-one acre-feet remained in the basin as storage in the pits and retention pond. The residual, representing change in storage and errors associated with the measurement, calculation, or estimation of the other water-budget components, was about 20 acre-feet of water for the 12-month period.

About 40 percent of the annual streamflow from the basin occurred in March and April. The total annual streamflow was less than what would be expected in an "average" year, on the basis of precipitation data.

The pH values of two rain samples were 7.2 and 7.1, and of two snow samples were 5.3 and 4.5. The reason for the difference is unknown.

The mineralization of accumulated surface water within the mine boundary increases in a downgradient direction. The mineralization of water in pit 4, at the upgradient end of the mine, was less than that of the other two surface-water bodies: pH values were near neutral, and trace-metal concentrations, except for manganese and nickel, were small. Concentrations of radium-226 and uranium were elevated.

In pit 3, located near the center of the mine, pH values were below the minimum standards for the well-being of freshwater aquatic life. Concentrations of sulfate, beryllium, cadmium, copper, manganese, nickel, and zinc exceeded EPA criteria for drinking water and the well-being of freshwater aquatic life. In addition, radium-226 and uranium concentrations exceeded EPA limits for uranium-mine effluents.

Concentrations of most constituents in the retention pond, located at the downgradient end of the mine, were greater than in either pits 3 or 4. The constituents that exceeded EPA criteria were the same as those in pit 3, plus iron.

The relation of surface-water quality to location in the mine was affected to some unknown degree by the periodic pumping of water from pit 4 and the retention pond into pit 3.

The effects of the mine drainage on Blue Creek were seen in the relative concentrations of many constituents upstream and downstream of the point where the mine drainage enters. The predominant ions in Blue Creek upstream of the mine drainage were calcium and bicarbonate, whereas the predominant ions in mine drainage and Blue Creek downstream from the mine drainage (sites 5 and 8) were calcium and sulfate. Nitrate-nitrogen, dissolved and suspended solids, trace-metal and radionuclide concentrations in Blue Creek upstream of the mine drainage (site 4) were generally small. With the addition of highly mineralized water from the mine area, concentrations of nitrate-nitrogen, solids, aluminum, cadmium, copper, manganese, nickel, strontium, zinc, radium-226, and uranium increased as much as 500 times. Uranium and radium-226 concentrations in the drainage were elevated, but still within maximum limits for uranium-mine effluents. Near the mouth of Blue Creek (site 8), about 3.5 miles downstream of where the mine drainage stream enters Blue Creek, concentrations of most constituents were larger than upstream of the mine drainage.

In ground water leaving the mine basin, the predominant ions were calcium and sulfate. Dissolved-solids concentrations exceeded 1,000 mg/L in all samples. Nitrate-nitrogen concentrations were moderate, possibly because of explosive residues in overburden and waste material. Dissolved cadmium was detected in three samples at concentrations exceeding the EPA criterion for drinking water. The source of the cadmium was not determined. Radionuclide concentrations in the samples reflected contact with uranium minerals. Uranium and radium-226 concentrations were elevated slightly, but still within NRC standards for uranium-mine effluents.

A potential monitoring program was described to collect surface-water-quality and water-discharge data so that annual loads of selected constituents from the mine basin could be determined. Sampling frequency would be monthly for surface water leaving the mine basin and bimonthly or quarterly sampling for ground water. The suite of constituents and characteristics would include acidity, alkalinity, aluminum, cadmium, calcium, chloride, copper, fluoride, iron, lead, magnesium, manganese, nickel, nitrate-nitrogen, dissolved oxygen, pH, potassium, radium-226, silica, sodium, dissolved and suspended solids, specific conductance, strontium, sulfate, uranium, water temperature, and zinc.

Data from a limited sampling program indicate that bromide, iodide, and, possibly, a fluorescent dye would be the best tracers to use to determine ground-water flow paths in the vicinity of the retention pond. The criteria used in selecting tracers were background concentrations and the availability of field methods for detection.

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