HYDROLOGY OF THE NORTH FORK OF THE RIGHT FORK OF MILLER CREEK, CARBON COUNTY, UTAH, BEFORE, DURING, AND AFTER UNDERGROUND COAL MINING

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95-4025

Prepared in cooperation with the

UTAH DEPARTMENT OF NATURAL RESOURCES

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Salt Lake City, Utah
1995

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, VERTICAL DATUM AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
gallon per minute (gal/min)	0.06308	liter per second
inch (in.)	25.4	millimeter
	0.0254	meter
inch per year (in/yr)	25.4	millimeter per year
mile (mi)	1.609	kilometer
square mile (mi^2)	2.59	square kilometer

Water temperature is reported in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\,(°C) + 32.$$

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

Chemical concentration and water temperature are reported only in metric units. Chemical concentration is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is reported in microsiemens per centimeter (µS/cm) at 25 degrees Celsius.

Chemical concentration in terms of ionic interacting values is reported in milliequivalents per liter (meq/L), which is numerically equal to equivalents per million.

Hydrology of the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, Before, During, and After Underground Coal Mining

By Cecil B. Slaughter, Geoffrey W. Freethey, *and* Lawrence E. Spangler

ABSTRACT

From 1988-92 the U.S. Geological Survey, in cooperation with the Utah Division of Oil, Gas, and Mining, studied the effects of underground coal mining and the resulting subsidence on the hydrologic system near the North Fork of the Right Fork of Miller Creek, Carbon County, Utah. The subsidence caused open fractures at land surface, debris slides, and rockfalls in the canyon above the mined area. Land surface subsided and moved several feet horizontally. The perennial stream and a tributary upstream from the mined area were diverted into the ground by surface fractures where the overburden thickness above the Wattis coal seam is about 300 to 500 feet. The reach downstream was dry but flow resumed where the channel traversed the Star Point Sandstone, which forms the aquifer below the coal seams where ground-water discharge provides new base flow. Concentrations of dissolved constituents in the stream water sampled just downstream of the mined area increased from about 300 mg/L to more than 1,500 mg/L, and the water changed from primarily a magnesium calcium bicarbonate to primarily a magnesium sulfate type.

Monitored water levels in two wells completed in the perched aquifer(s) above the mine indicate that fractures from subsidence-related deformation drained the perched aquifer in the Blackhawk Formation. The deformation also could have contributed to the decrease in discharge of three springs above the mined area, but discharge from other springs in the area did not change substantially; thus, the relation between subsidence and spring discharge, if any, is not clear. No significant changes in the chemical characteristics of water discharging from springs were detected, but the dissolved-solids concentration in water collected from a perched sandstone aquifer overlying the mined coal seams increased during mining activity.

INTRODUCTION

Subsidence caused by underground longwall mining is a time-dependent deformation of the ground surface that results from readjustment of the overburden above a mined area. The magnitude and direction of vertical and horizontal ground movement depend on depth of the mined coal seam below land surface, topography above the mine, and other mining and site factors. The effect of subsidence on ground- and surface-water systems above mines is not fully understood. Changes that take place in surface-water discharge, hydraulic head in aquifers, and quality of water in streams and aquifers are poorly known in areas above mine workings where less than 500 ft of overburden exists.

The U.S. Geological Survey (USGS), in cooperation with the Utah Department of Natural Resources, Division of Oil, Gas, and Mining (UDOGM), did a study at the Cyprus Plateau Mine near Wattis in Carbon County, Utah (fig. 1), to determine how the hydrologic system is altered by land subsidence caused by underground longwall coal mining. The study began in September 1988 and ended in September 1992. The objective of the study was to determine the effects of longwall mining and the resulting land subsidence on the hydrologic system near the mine. Potential effects on the hydrologic system include changes in surface-water discharge, ground-water movement, aquifer storage, spring discharge, surface- and ground-water quality, and characteristics of the land surface. Mine personnel collected and provided data to UDOGM as part of required monitoring activities.

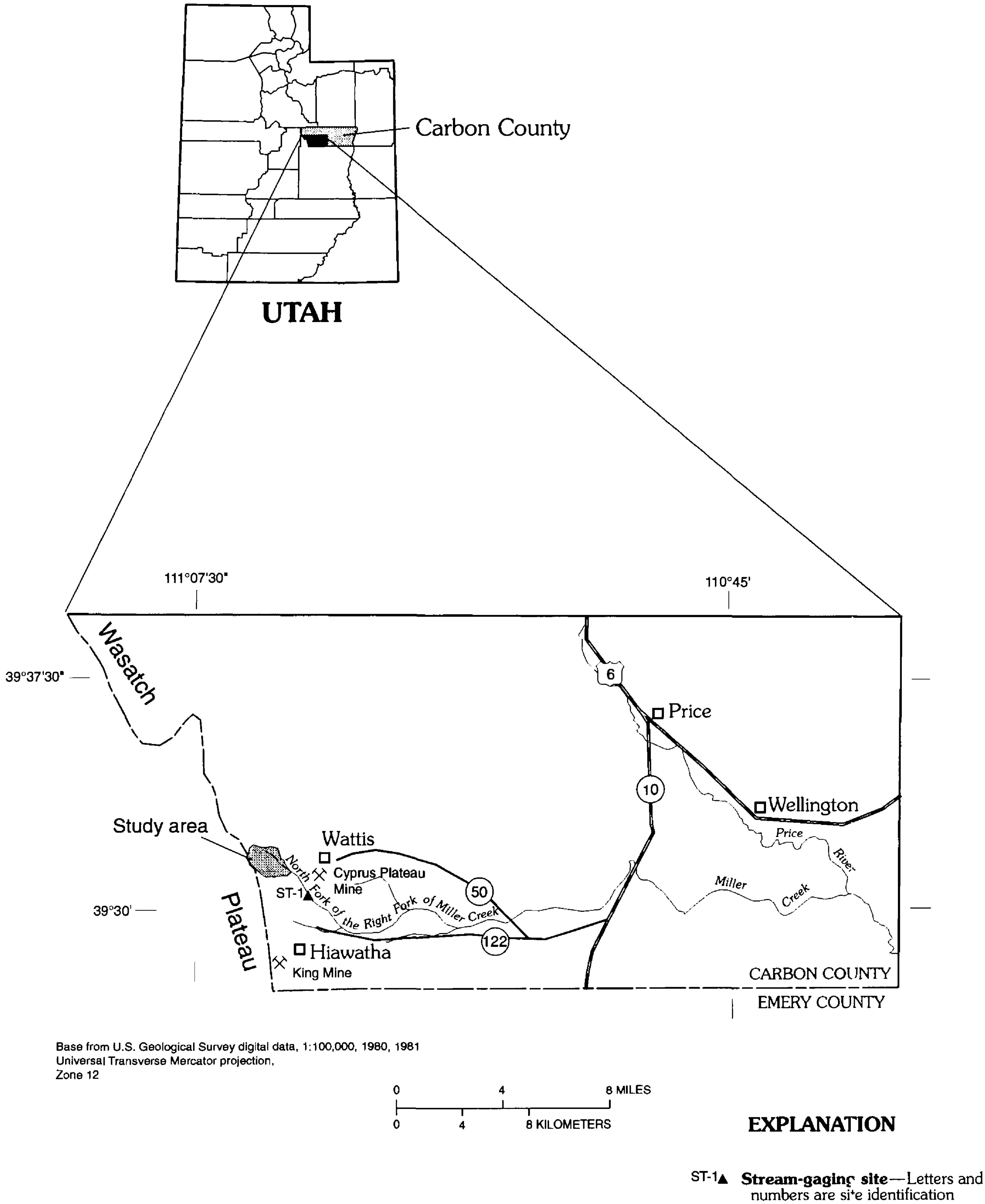


Figure 1. Location of the North Fork of the Right Fork of Miller Creek study area, Carbon County, Utah.

Purpose and Scope

This report documents the geologic, hydrologic, and geomorphic data collected before, during, and after longwall mining; describes methods used to collect and analyze the data; and presents the results of the analyses. Several aspects of data collection were limited by circumstance. Baseline hydraulic heads in the aquifers above the coal seams were not obtained because mining in the eastern part of the study area had begun several months before the installation of monitoring wells. Collection of geologic, hydrologic, and geomorphic data on the land surface above the mine was limited by the unstable condition of the steep terrain caused by ground subsidence and by the short field season caused by adverse weather typical at the high altitude of the study site.

Despite the lack of full and continuous data sets representing pre-mining, mining, and post-mining periods, the report provides previously unavailable hydrologic data that enables UDOGM to evaluate the effects of subsidence from underground mining on nearby surface-water discharge, spring discharge, water quality, and water levels in aquifers. This report provides information that has transferability to other coal mining areas with similar lithologic and hydrologic settings in the Wasatch Plateau and in the Book Cliffs of eastern Utah.

Methods of Investigation

Work done by the USGS for this report began in September 1988. All hydrologic data prior to that time and most hydrologic data after that time were collected by personnel from the Cyprus Plateau Mining Company as part of their monitoring requirements for the State of Utah. Data collection included surface-water discharge, spring discharge, and sampling of water for field and laboratory analyses. USGS personnel primarily compiled and interpreted these data for the study.

To document ground conditions prior to and during longwall mining, fractures along the stream channel and canyon slope, debris slides, and rockfalls caused by ground subsidence were mapped. Ground-anchored prisms, for siting with laser-surveying equipment, were set up by mine personnel on the north ridge, north canyon slope, and canyon floor (fig. 2). Surveys using the prisms were periodically done to document both horizontal and vertical ground movement at the land surface caused by subsidence.

Water levels were measured in two monitoring wells drilled near the stream (Wattis wells 1 and 2) and in three wells drilled from inside the mine. Water samples were collected from the wells inside the mine for water-quality analyses. Coaxial cable was cemented into a second hole drilled next to each monitoring well. A Time Domain Reflectometer (TDR) was used to periodically check the integrity of the cables. The instrument uses an electrical current to detect the location of deformities or breaks in the cable, thus giving an indication of where and when the overlying rock was deforming as a result of subsidence. The three holes inside the mine were drilled up from an access tunnel in the Third seam and were completed in a perched aquifer about 100 ft above the Third seam.

Acknowledgments

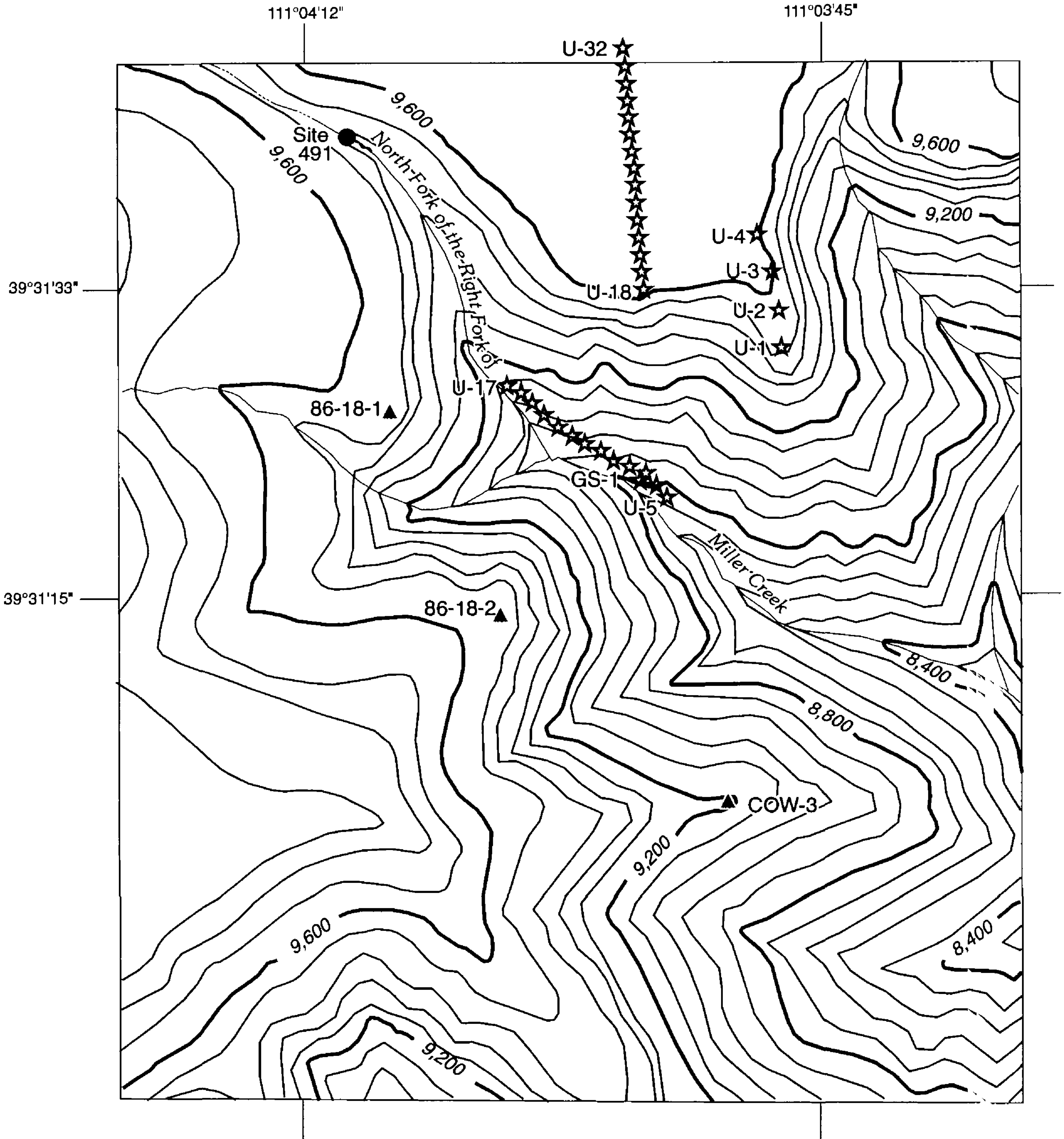
The authors would like to thank Gregory Hunt and Benjamin Grimes of the Cyprus Plateau Mining Company for their considerable contribution to the understanding of the geology in the study area, and for the time and effort they spent collecting and compiling hydrologic and water-quality data used in this study. Appreciation also is extended to William Warmack, formerly with the Utah Division of Oil, Gas, and Mining, for his diligence in measuring in-mine discharges.

DESCRIPTION OF THE STUDY AREA

The study area consists of the upper part of the drainage basin of the North Fork of the Right Fork (NFRF) of Miller Creek in Carbon County, Utah (fig. 1). The main focus of investigation is on the eastern half of the study area where coal was mined using the longwall method during 1988-91. The study area is on the east side of the Wasatch Plateau and has an area of about 1.3 mi^2. The NFRF of Miller Creek is a tributary to the Right Fork of Miller Creek. The Right Fork of Miller Creek discharges into Miller Creek, which in turn discharges into the Price River southeast of Wellington, Utah.

Coal Resources and Mining Practice

Coal has been mined in the Wasatch Plateau since the mid-1870's. Because underground mining requires that the workings be drained during extraction, the ground-water system above and adjacent to the mined areas is probably not in its original undisturbed condition. Coal had previously been mined in the area under



Base from U.S. Geological Survey digital data, 1:100,000, 1980, 1981
Universal Transverse Mercator projection, Zone 12

0 500 1,000 FEET
0 100 200 300 METERS

CONTOUR INTERVAL 80 FEET
DATUM IS SEA LEVEL

EXPLANATION

U-5☆ **Ground-anchored prism**—Letters and numbers are site identification

▲ **Survey point to determine horizontal and vertical ground movement**

● **Spring**

Figure 2. Surface topography and location of survey points in the mined area of the North Fork of the Right Fork of Miller Creek study area, Carbon County, Utah.

the west end of the NFRF of Miller Creek drainage and farther west under the Wasatch Plateau (fig. 3).

Two mineable coal seams, each between 8 and 10 ft thick, underlie the eastern part of the study area. The uppermost seam, the Wattis seam, crops out in the streambed of the NFRF of Miller Creek at an altitude of about 8,365 ft. The Wattis seam is more than 1,300 ft below land surface in the western part of the study area. The other mineable seam, the Third seam, underlies the Wattis seam by 25 to 65 ft in the study area. Overburden above the mined longwall panels in both seams ranges from about 300 ft to about 1,300 ft (fig. 4).The Hiawatha seam, about 100 ft below the Third seam, is not economically mineable in the study area.

A longwall coal-mining method was used in the eastern part of the study area by the Cyprus Plateau Mining Company at the Cyprus Plateau Mine. The method involves substantial initial development before longwall machinery is used. The initial development usually does not cause land subsidence. The development of entries for access, ventilation, and escape are necessary before coal removal begins with the longwall machinery.

Secondary entries, in groups of two or three parallel entries, were driven perpendicular to the main Cyprus Plateau Mine entry on either side of the proposed extraction area. These entries were separated by coal pillars that helped support the roof. After the secondary entries were advanced to their desired length, they were connected by an entry driven across the extraction area (longwall panel) to form the extraction face.

The longwall machine is a self-advancing hydraulic roof-support system with a coal conveyor and a digging mechanism to break or rip the coal from the face. The machine extracted coal from east to west toward the prepared main entry. The northernmost panel was extracted first; the south panel last. The longwall method is designed to support the coal face while allowing caving of the mined-out area behind the supports. Entries are developed to the south at the same time the panel to the north is being mined.

Topography and Climate

The altitude of the study area ranges from about 8,300 to 10,142 ft (fig. 3). The NFRF of Miller Creek begins perennial flow at site 491, a spring in the Castlegate Sandstone, at an altitude of about 9,450 ft. The creek flows toward the southeast and is bounded by steep slopes composed of siltstone and discontinuous sandstone outcrops.

The climate of the study area is semiarid, with precipitation increasing with altitude (Danielson and Sylla, 1983). Average annual precipitation for 1931-91 at Hiawatha, about 3.5 mi southeast of the study area, is 13.70 in/yr (fig. 5). Average annual precipitation at a station located at the headquarters of the Cyprus Plateau Mine, about 2 mi east of the study area, was about 13.79 in/yr during 1984-91. Cumulative departure from average annual precipitation for the two stations also is shown in figure 5.

Geologic and Hydrologic Setting

The study area is underlain by interbedded sandstone and siltstone that dip about 1 to 5 degrees in a southwesterly direction. Orthogonal jointing in the sandstone is common and the bedrock is extensively faulted (figs. 6 and 7). A visual inspection of the study area prior to longwall mining revealed numerous sets of north-south trending joints in the sandstone outcrops and in the rock exposed in the stream channel.

The geologic formations exposed in the study area are of Cretaceous and Tertiary age. The formations, oldest to youngest, are the Star Point Sandstone, Blackhawk Formation, Castlegate Sandstone, Price River Formation, and North Horn Formation (fig. 8).

The Star Point Sandstone generally overlies or intertongues with the underlying Mancos Shale of Cretaceous age and is the basal unit of the Mesaverde Group in the Wasatch Plateau (Spieker and Reeside, 1925). The Mesaverde Group also includes the Blackhawk Formation, Castlegate Sandstone, and Price River Formation, all of Cretaceous age. The transition from rocks of Cretaceous age to those of Tertiary age is in the North Horn Formation.

The Star Point Sandstone is made up of three prominent medium-grained sandstone units separated by shale (Clark, 1928) and is about 500 ft thick in the study area. The two upper sandstone units of the Star Point Sandstone crop out from the confluence of the NFRF of Miller Creek and the Right Fork of Miller Creek to about 500 ft upstream along the NFRF of Miller Creek. The two sandstone units form the lowermost cliffs near the confluence. The Star Point Sandstone contains an aquifer that is regional in nature and discharges to the lower reaches of the NFRF of Miller Creek. Ground water in the Star Point Sandstone generally moves in a north-northwest to south-southeast

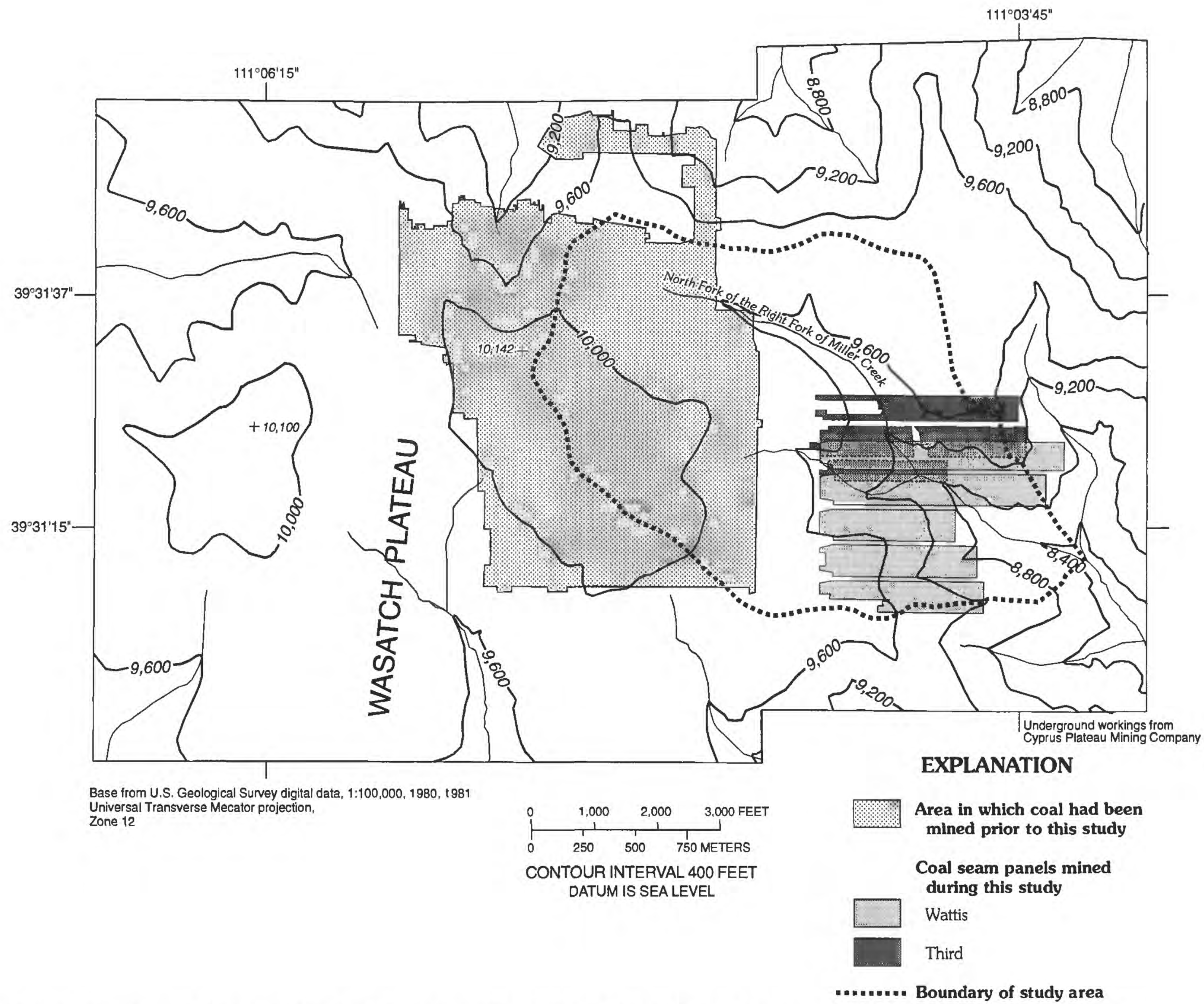
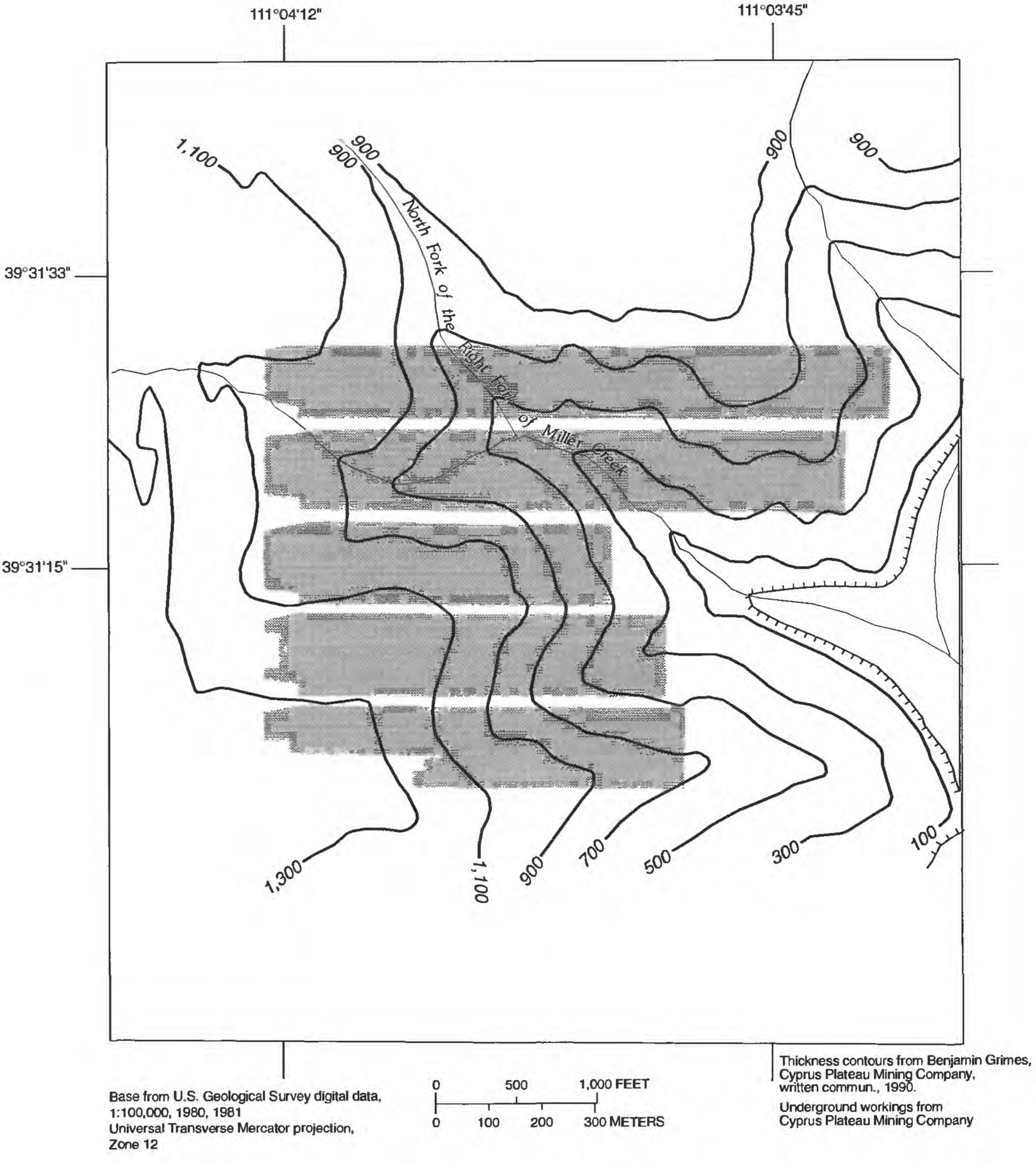


Figure 3. Areal extent of prior mine workings in relation to the study area, Carbon County, Utah.



EXPLANATION

Longwall panels in the Wattis coal seam

Outcrop of Wattis coal seam

—*900*— **Line of equal thickness of overburden**—Interval 200 feet

Figure 4. Thickness of overburden above the Wattis coal seam in part of the study area, Carbon County, Utah.

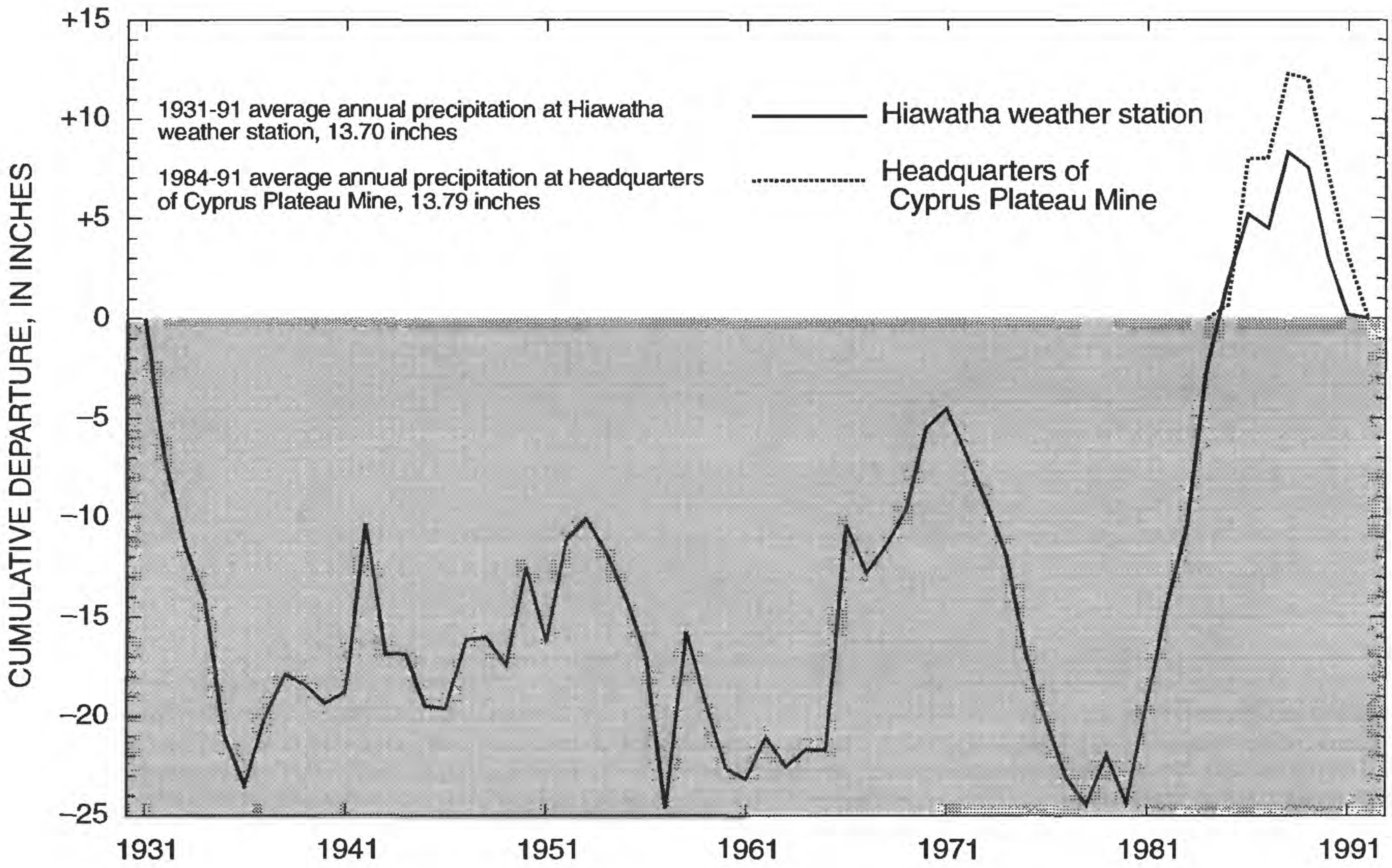


Figure 5. Cumulative departure from average annual precipitation at the Hiawatha weather station, 1931-91, and at the headquarters of the Cyprus Plateau Mine, 1984-91, Carbon County, Utah.

direction (fig. 7) (Gregory Hunt, Cyprus Plateau Mining Company, written commun., 1988).

The Blackhawk Formation forms the slope between the Star Point Sandstone and the Castlegate Sandstone. The Blackhawk Formation is composed of siltstone, sandstone, and coal beds and is about 930 ft thick in the study area. The coal beds are in the lower part of the formation. The uppermost coal bed is called the Wattis seam and the lowermost economical seam is the Third seam. The Wattis and Thirds seams are each about 8 to 10 ft thick.

The coal beds typically are underlain by sandstone similar to the Star Point Sandstone (Spieker, 1931). These sandstone units are the source of water that discharges into the Cyprus Plateau Mine, usually through bolt holes drilled into the ceiling of the entry or through seepage from the floor. The quantity of ground water that discharges into the mine usually diminishes within a short period of time after being intercepted and indicates that most of the water comes from storage in the sandstone and that recharge to these perched channel sands is slow. According to borings made during the study, there also is a perched sandstone aquifer about 50 to 60 ft above the Wattis seam in the eastern half of the study area.

Effective porosity and hydraulic-conductivity values determined from laboratory analyses of samples collected from the Blackhawk Formation elsewhere in the Wasatch Plateau show large variation, which is caused by variable lithologic character. Effective porosity values determined for fine-grained sandstone units were about 14 percent. Effective porosity values for shale and siltstone units ranged from 2 to 4 percent. Horizontal hydraulic-conductivity values ranged from $1.1x10^{-2}$ to $1.5x10^{-2}$ ft/d for the sandstone units (Lines, 1985, p. 13). Shale and siltstone units were almost impermeable ($2x10^{-7}$ ft/d). Hydraulic conductivity in fault zones is substantially larger, on the basis of communication with coal miners who have drilled into fault zones with rock-boring equipment and encountered high-pressure flows through the borings.

The Castlegate Sandstone forms a prominent cliff in the Wasatch Plateau. In the study area, the Castlegate Sandstone consists of gray, tan, and yellowish-

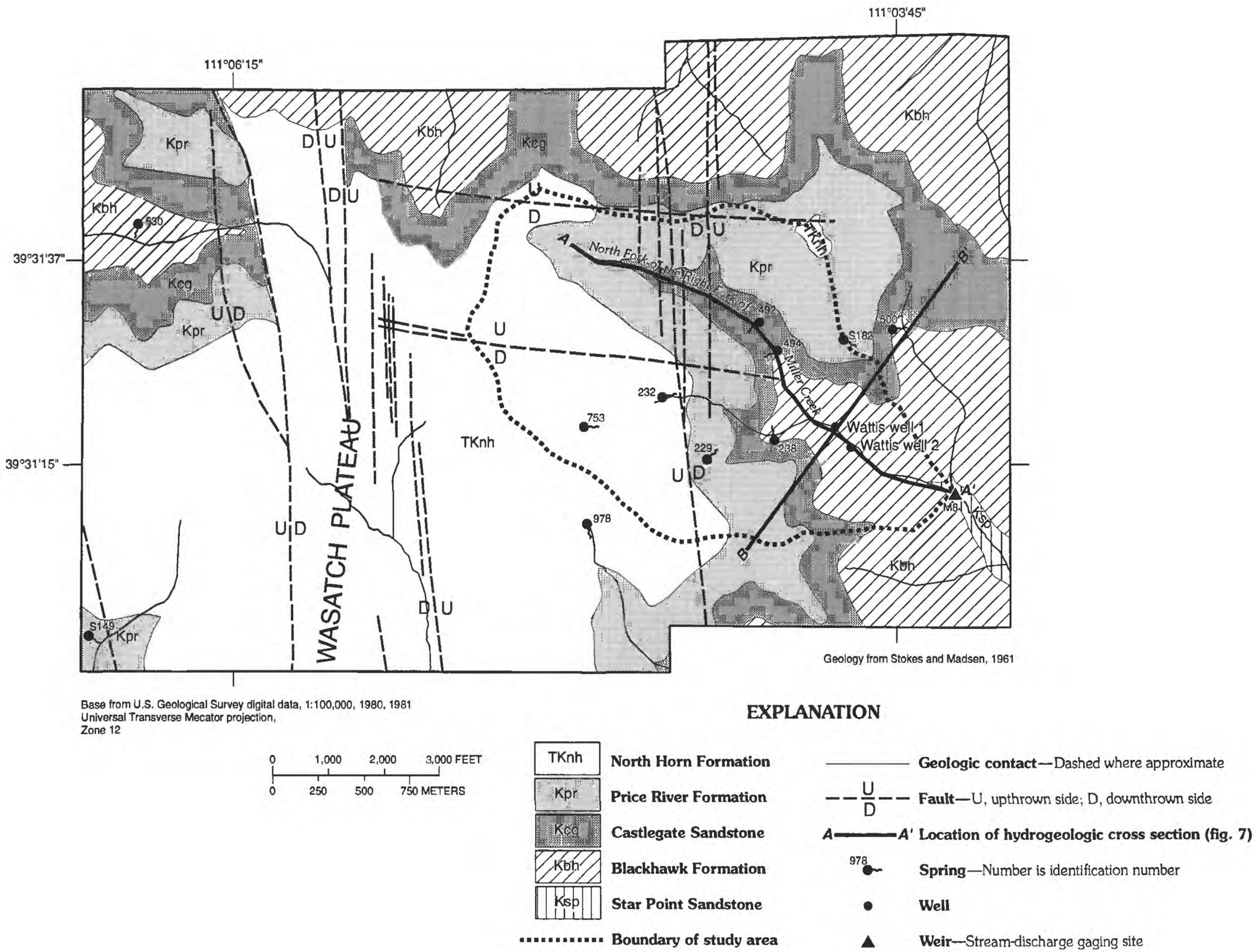


Figure 6. Location of geologic units, diagrammatic sections, and surface- and ground-water monitoring sites in and near the study area, Carbon County, Utah.

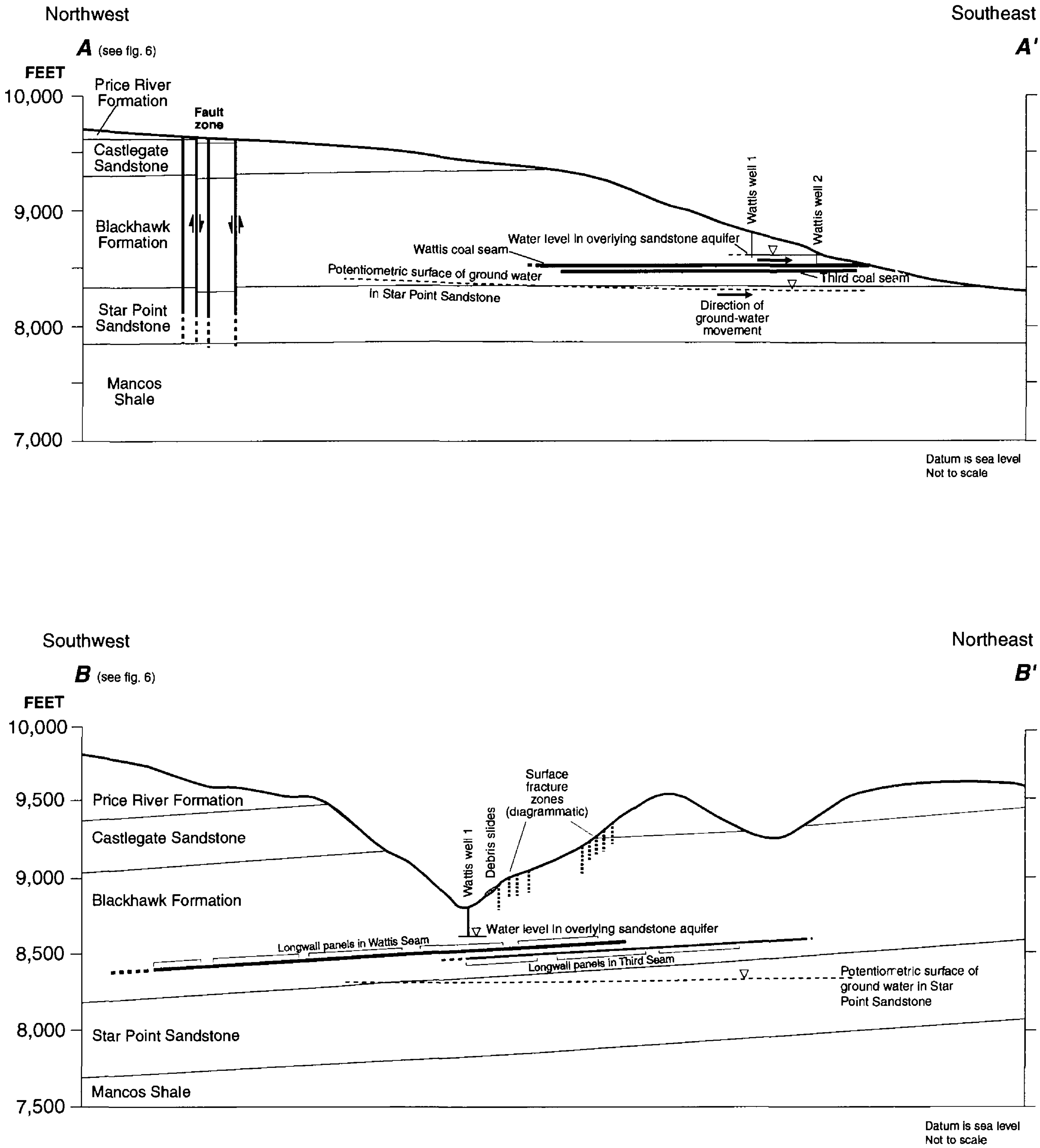


Figure 7. Generalized hydrogeologic cross sections along the North Fork of the Right Fork of Miller Creek (*A*-*A'*) and across the North Fork of the Right Fork of Miller Creek (*B*-*B'*), Carbon County, Utah. See figure 6 for lines of sections.

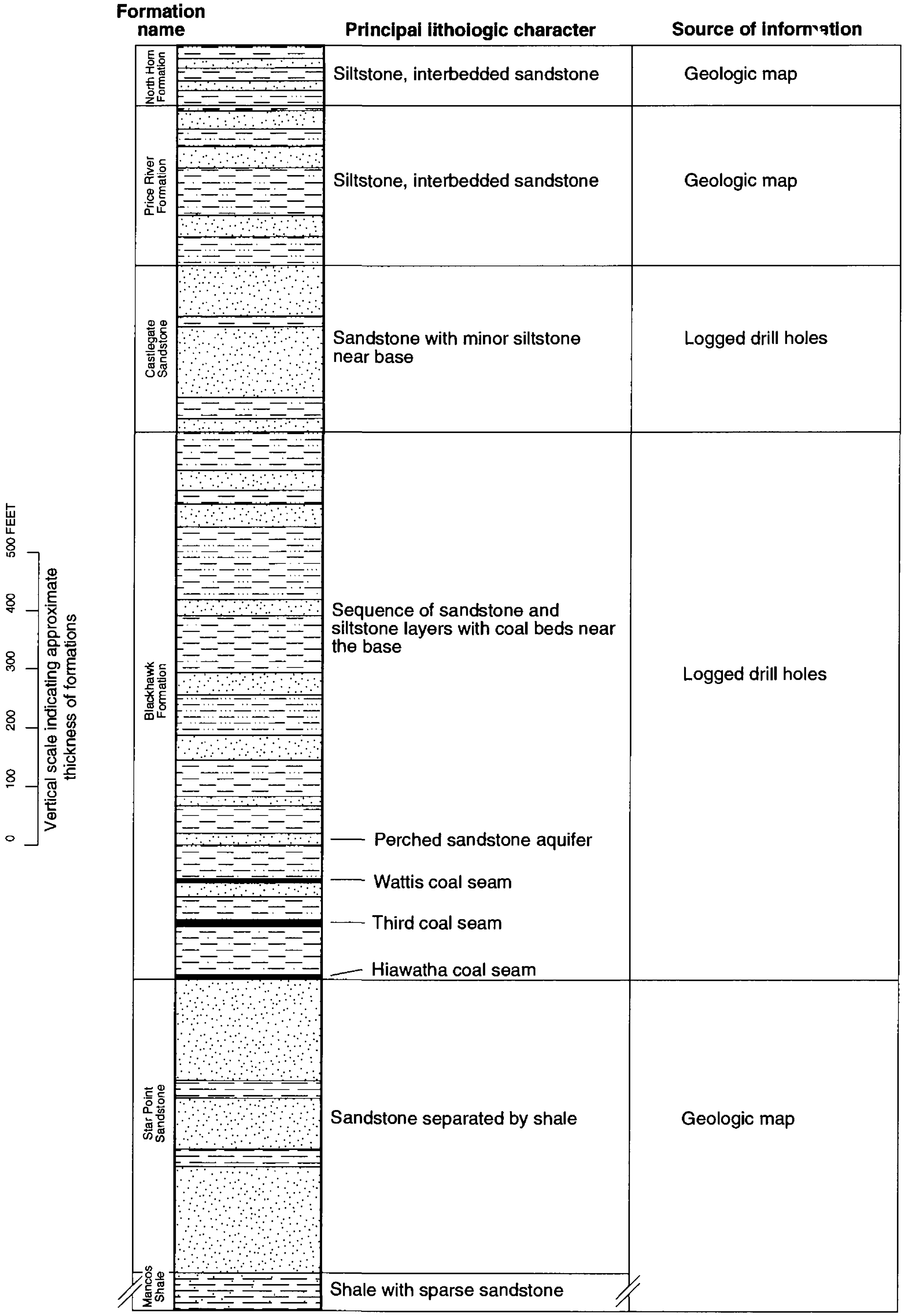


Figure 8. Composite section of geology in the study area, Carbon County, Utah (from Gregory Hunt Cyprus Plateau Mining Company, written commun., 1988).

brown sandstone about 290 ft thick. The sandstone beds are massive and are composed mostly of medium- to coarse-grained sand (Lines, 1985). Numerous springs discharge at the base of the Castlegate Sandstone. Many of the springs are perennial and provide base flow to the upper reaches of the NFRF of Miller Creek. No hydrologic-property values for or water levels in the Castlegate Sandstone are available.

The Price River Formation is composed predominantly of medium- to coarse-grained sandstone (Lines, 1985) and is about 275 ft thick in the study area. Siltstone layers overlie the sandstone layers and form gentle slopes. Numerous springs discharge from the sandstone units in the Price River Formation. No hydrologic-property values or water levels are available for this unit.

The North Horn Formation consists of variegated siltstone interbedded with sandstone (Stokes, 1964) and is about 100 ft thick in the study area. This formation, like the Price River Formation, has many springs that discharge from the sandstone units. No hydrologic-property values or water levels are available for this unit.

THE HYDROLOGIC SYSTEM BEFORE LONGWALL MINING

Hydrologic information from the eastern part of the study area has been collected by personnel from the Cyprus Plateau Mining Company since 1986 and from elsewhere near the study area since 1979 as part of the monitoring required by UDOGM. Surface-water discharge, spring discharge, water quality, and ground-control surveys were included as part of this monitoring program.

Surface-Water Discharge

Surface-water discharge was measured periodically by Cyprus Plateau Mine personnel on the NFRF of Miller Creek at the confluence of the Right Fork of Miller Creek and NFRF of Miller Creek (site ST-1), about 1 mi downstream from the study area, beginning in 1981 (fig. 9). Discharge of the stream at this location seems to be related to precipitation (fig. 5). Discharge measurements of the stream during 1981-87, a period of generally greater-than-normal precipitation in Utah, are, in general, greater than discharge measurements made during 1988-91, a period of generally less-than-normal precipitation in Utah. No effect on surface-water discharge is evident from the development of the mine entries that preceded longwall mining of the Wattis seam, which began in August 1988.

Discharge, specific conductance, pH, and temperature of the water were measured at other sites (fig. 10) on the NFRF of Miller Creek (table 1). Tributary inflows into the NFRF of Miller Creek (fig. 10) also were measured (table 2) for analysis of gains and losses in stream base flow.

Surface-Water/Ground-Water Relations

The first gain-loss study of the NFRF of Miller Creek was done in July 1986 by personnel from the Cyprus Plateau Mining Company and indicated that discharge in the NFRF of Miller Creek increased in every reach between site 491, where the creek begins at a spring, and site M-10, just downstream of the study area (fig. 11). The net gain between these two sites was about 37.5 gal/min (table 3). Actual gain in base flow might have been larger because the seepage was measured in July when riparian vegetation along the stream channel was probably transpiring ground water. Two additional gain-loss studies prior to mining were done in October 1987 and July 1988. These measurements indicated that in October 1987, base flow increased in the reach from spring site 491 to stream site M-2 but then decreased in the reach from site M-2 to site M-6, increased from M-6 to M-8, and decreased from M-8 to M-10. In July 1988, flow increased from site 491 to site M-2, decreased from M-2 to M-8, and increased from M-8 to M-10. Net gain from site 491 to site M-10 in October 1987 (16.3 gal/min) and July 1988 (20.9 gal/min) was about one-half of the gain measured in July 1986.

Ground-Water Flow

On the basis of water levels measured in wells in the Star Point Sandstone, water in the Star Point Sandstone near the eastern flank of the Wasatch Plateau moves from northwest to southeast (Gregory Hunt, Cyprus Plateau Mining Company, written commun., 1988). Water in the sandstone units within each formation above the Star Point Sandstone discharges at springs (fig. 6) that are typically near the base of the units. Despite the general dip toward the southwest, direction of ground-water flow in these sandstone units above the mine is probably also to the southeast, from the higher plateau areas toward outcrops in the stream valleys.

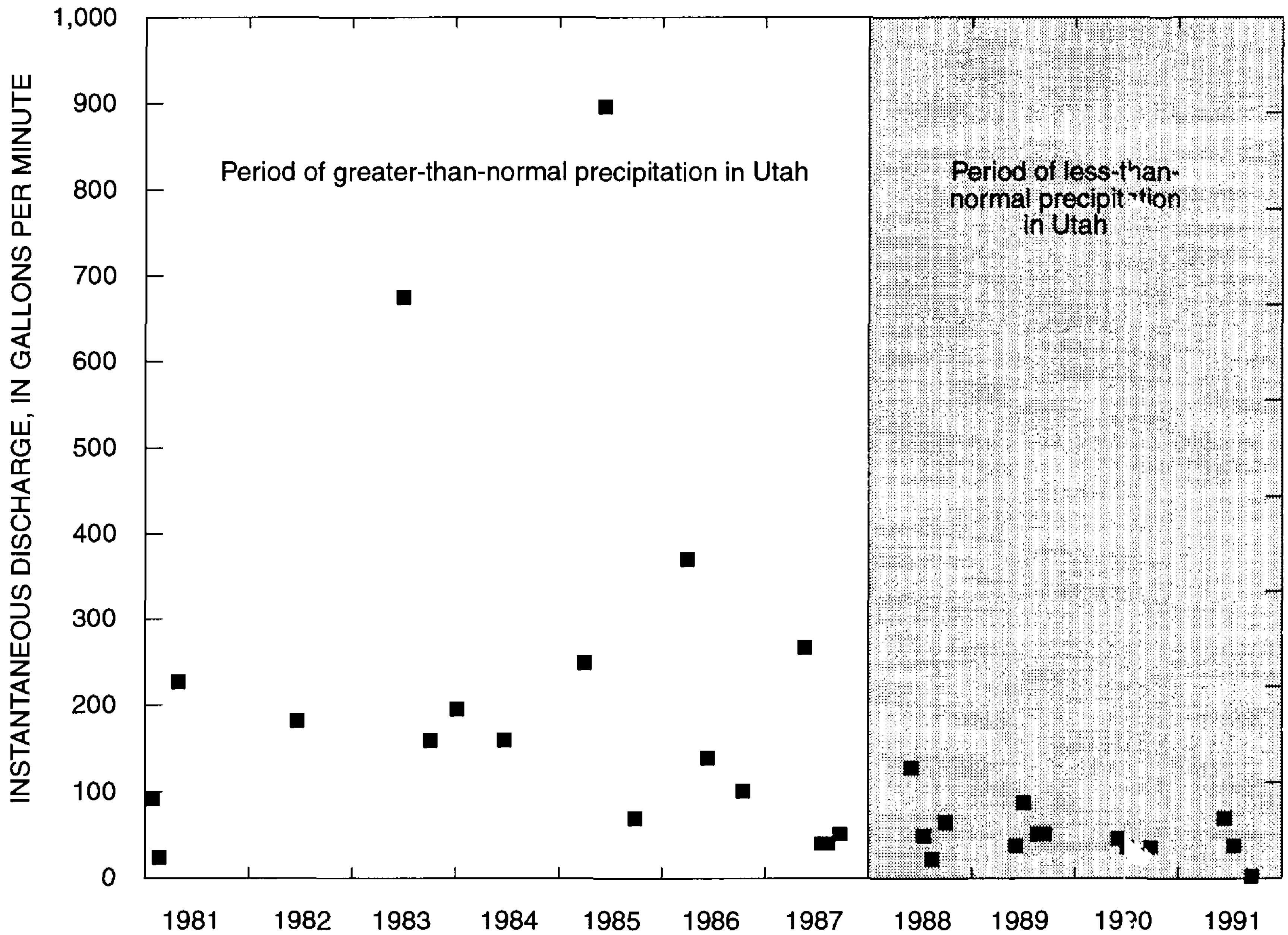


Figure 9. Variability of discharge measured at site ST-1 (figure 1) on the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 1981-91.

Spring Discharge

Discharge from springs that originate in the Blackhawk Formation, Castlegate Sandstone, Price River Formation, and North Horn Formation was measured periodically at sites in and near the study area (table 4). Of the 10 springs listed in table 4, 2 springs (530 and S149) are about 2 mi west of the study area, 3 springs (232, 753, and 978) are less than 1/2 mi west of the mined area, and 5 springs (238, 494, 500, S182, and 229) are either above or closely adjacent to the mined area. Spring 530, which discharges from the Blackhawk Formation west of the study area, showed the least variability from October 1986 through July 1988. Discharge ranged from 2.7 to 8.1 gal/min. Spring 978, which discharges from the North Horn Formation, showed the greatest variability, ranging from 1.3 to 148.1 gal/min in about 2 months. Springs generally discharge the greatest volume of ground water during the spring when snowpack begins to melt. Discharge is usually least in the fall when precipitation usually occurs as snow, which is unlikely to melt. No long-term pre-mining trends for spring discharge were evident. Discharge from springs that originate in the Price River and North Horn Formations tends to have the greatest variability, probably because these formations crop out at higher altitudes, where snowpack is greatest.

Surface- and Ground-Water Quality

Water samples were collected from the NFRF of Miller Creek at site M-8 twice prior to longwall mining by personnel from the Cyprus Plateau Mining Company. The samples were analyzed in a local laboratory for common constituents and trace elements. The results of the analyses indicated that the water in the

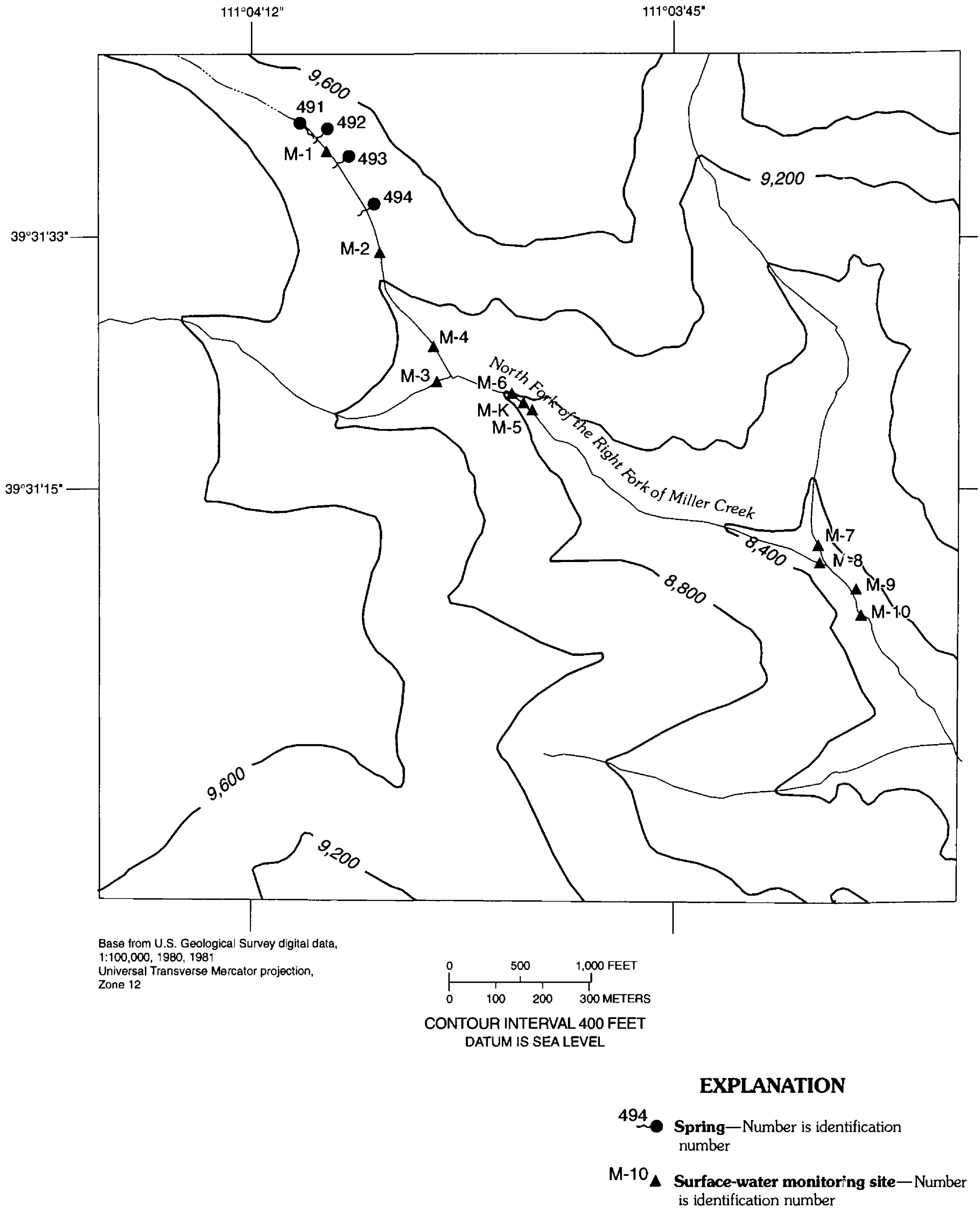


Figure 10. Location of surface-water monitoring sites and selected springs in a part of the drainage area of the North Fork of the Right Fork of Miller Creek, Carbon County, Utah.

Table 1. Discharge, specific conductance, pH, and temperature of water from the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, before longwall mining

[See fig. 10 for site location; gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; —, no data]

Site	Date	Discharge (gal/min)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)
[1]491	07-02-86	8.0	1267	7.4	—
	10-09-87	[2]3.0	—	—	—
	07-05-88	4.5	205	7.6	4.0
M-1	07-02-86	14.0	—	—	—
	10-09-87	4.3	240	7.8	3.2
	07-05-88	9.0	235	8.0	5.6
M-2	07-02-86	18.0	—	—	—
	10-09-87	20.0	360	8.5	2.6
	07-05-88	22.2	250	6.9	6.5
M-4	07-02-86	21.0	356	7.4	—
	10-09-87	20.0	440	8.6	3.4
	07-05-88	18.2	262	8.3	7.8
M-6	07-02-86	40.0	—	—	—
	10-09-87	[2]21.0	—	—	—
M-8	07-02-86	62.0	422	7.8	—
	10-09-87	25.0	220	8.9	5.8
	07-05-88	28.0	398	8.4	16.2
M-10	07-02-86	70.0	492	8.0	—
	10-09-87	25.0	525	8.8	7.0
	07-05-88	46.2	600	8.4	20.0

[1]Spring site.
[2]Estimated.

NFRF of Miller Creek is a calcium magnesium bicarbonate type and the concentration of dissolved constituents is less than 300 mg/L (table 5). The water collected in July 1988 generally contained a greater concentration of most common constituents than the sample collected in June 1988, which probably indicates that the water sampled in July contained a larger proportion of ground water than the water sampled in June. Ground water generally contains a larger concentration of dissolved constituents than surface runoff from recent precipitation.

Trace-element concentrations were about the same in both samples and included detectable concentrations of barium, chromium, iron, and manganese. Prior to mining, the concentration of dissolved solids in water sampled from springs was about the same in all formations (tables 6-9). Dissolved-solids concentration did not exceed 304 mg/L in collected samples. All samples analyzed were a magnesium bicarbonate or calcium bicarbonate type water. The concentration of dissolved magnesium was slightly greater in water from the Blackhawk Formation than in water from the Castlegate Sandstone, Price River Formation, and North Horn Formation. Most samples contained measurable concentrations of dissolved barium, boron, and total iron. A few samples contained trace elements such as aluminum, cadmium, copper, lead, nickel, selenium, and zinc. Analyses indicate that, chemically, the water from springs is virtually the same as that in the stream, except when the stream is receiving a large quantity of surface runoff.

Table 2. Discharge, specific conductance, pH, and temperature of water from spring and stream tributaries to the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, before longwall mining

[See fig. 10 for site location; gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; —, no data]

Site	Date	Discharge (gal/min)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)
			Spring sites		
492	07-02-86	2.0	1,325	7.3	—
	07-05-88	1.0	275	6.9	7.3
493	07-02-86	.5	359	6.6	—
	07-05-88	2.0	205	8.0	5.2
494	07-02-86	3.0	445	7.2	—
	10-09-87	2.0	525	8.4	5.9
	07-05-88	2.5	288	8.1	8.2
			Stream sites		
M-3	07-02-86	16.0	360	7.5	—
	10-09-87	6.0	400	8.3	2.8
	07-05-88	13.3	267	8.5	8.4
M-5	07-02-86	7.0	382	7.5	—
	10-09-87	0	—	—	—
M-7	07-02-86	4.0	567	7.6	—
	10-09-87	.7	695	8.5	11.4
	07-05-88	6.5	530	8.4	12.5
M-9	07-02-86	4.0	2,046	7.8	—
	10-09-87	.4	1,250	8.2	11.6

THE HYDROLOGIC SYSTEM DURING AND AFTER LONGWALL MINING

Longwall mining of the Wattis seam began August 2, 1988, and continued panel by panel from north to south through April 26, 1990 (fig. 12). Mining of the Third seam below the Wattis seam began in December 1990 and ended November 3, 1991, also from north to south (fig. 13). The extraction faces advanced to the west in all eight panels. The southernmost two panels of the Third seam were partially beneath the two northernmost panels of the Wattis seam (fig. 14). Overburden thickness above the mined panels in both seams ranged from 300 to more than 1,300 ft.

Surface fractures, debris slides, and rockfalls occurred soon after mining began. A survey of ground-anchored prisms in August 1990 along the NFRF of Miller Creek indicated that the ground surface had dropped a maximum of about 3.5 ft and moved horizontally about 2 ft to the west. The ground-anchored prisms along the NFRF of Miller Creek were not surveyed in 1991 because of the hazardous ground conditions above the mined area. A survey of the ground-anchored prisms on the northern rim of the canyon in September 1991 indicated that the ground surface had dropped about 6.5 ft and moved horizontally to the south about 8.5 ft at prism U-1 (fig. 2).

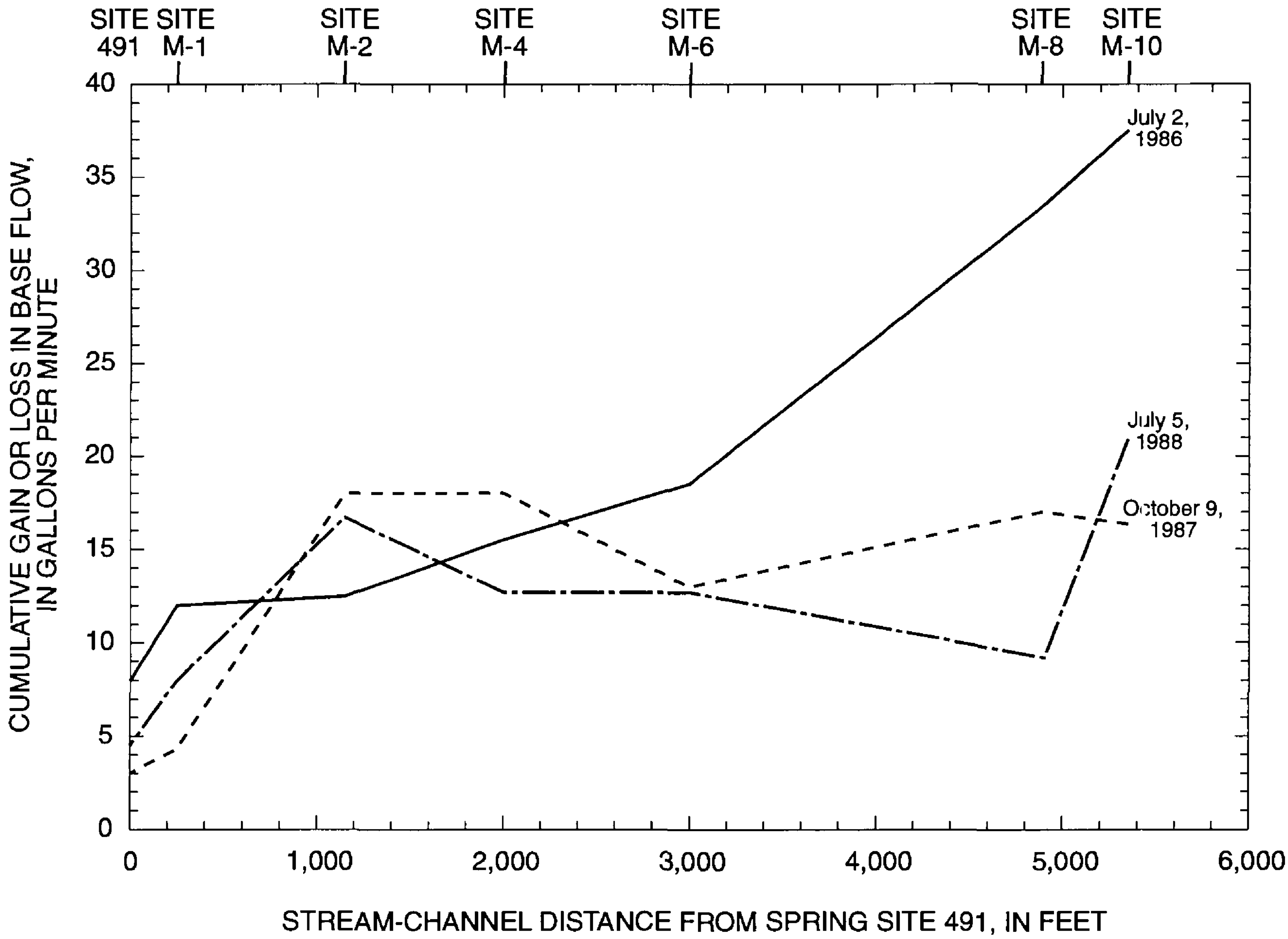


Figure 11. Gains and losses in base flow in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, before mining of the Wattis and Third coal seams.

In October 1988, two main surface fractures extended laterally across the eastern part of the north slope of the NFRF of Miller Creek canyon (fig. 14). These two fractures are sinuous in nature and generally trend in an east-west direction, parallel to the orientation of the underground barrier pillars and the mined panels. In October 1988, maximum widths of the two surface fractures (measured at the surface) were about 4 in. and 8 in. By June 1990, the maximum widths of the two surface fractures were about 1 to 5 ft and a third fracture had formed. By August 1992, after longwall mining had ceased, maximum widths of the three fractures at the surface were 8 in., 4 ft, and 7 ft.

Debris slides and rockfalls occurred during longwall mining and were usually caused by the collapse of sandstone outcrops in the Blackhawk Formation and Castlegate Sandstone. The debris slide and rockfall of greatest magnitude, about 150 ft wide, originated in the Blackhawk Formation and occurred sometime between October 19 and November 21, 1988 (during mining of the Wattis seam). Debris from the rockfall knocked down trees and scoured out a part of the canyon slope, depositing sediment, boulders, and trees into a section of the NFRF of Miller Creek just downstream from Wattis well 1 (fig. 14).

Surface-Water Discharge

In November 1988, a pressure transducer and data recorder were installed to record stage at a weir located at site M-8 on the NFRF of Miller Creek (fig. 10). Discharge of the stream was determined from a known relation between weir size and stage height behind the weir. Discharge at the weir (site M-8) generally decreased from October 1989 through December 1991 (fig. 15). The general decrease in discharge is consistent with the less-than-normal precipitation that occurred after 1987 (fig. 5).

Table 3. Discharge at, gain or loss between, and cumulative gain or loss in base flow at sites on or on tributaries to the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, before mining of the Wattis and Third coal seams

[See fig. 10 for site location; all values are in gallons per minute; —, no measurement, assumed negligible discharge]

Main channel site Tributary site	491	 492	M-1	 493	 494	M-2	M-4	 M-3	M-6	 M-5	M-8	 M-7	M-10
July 2, 1986													
Discharge	8.0	2.0	14.0	0.5	3.0	18.0	21.0	16.0	40.0	7.0	62.0	4.0	70.0
Seepage gain or loss between stream sites			4			.5	3		3		15		4
Cumulative gain or loss in base flow	8		12			12.5	15.5		18.5		33.5		37.5
October 9, 1987													
Discharge	[1]3.0	—	4.3	—	2.0	20.0	20.0	6.0	[1]21.0	—	25.0	.7	25.0
Seepage gain or loss between stream sites			1.3			13.7	0		-5		4		-.7
Cumulative gain or loss in base flow	3		4.3			18.0	18.0		13		17		16.3
July 5, 1988													
Discharge	4.5	1.0	9.0	2.0	2.5	22.2	18.2	13.3	[2]31.5	—	28.0	6.5	46.2
Seepage gain or loss between stream sites			3.5			8.7	-4		0		-3.5		11.7
Cumulative gain or loss in base flow	4.5		8			16.7	12.7		12.7		9.2		20.9

[1]Estimated from hydrographs provided by Cyprus Plateau Mining Company.
[2]Assumes no additional gain or loss from nearest upstream site.

Table 4. Discharge of water from springs in the formations above the coal seams before longwall mining, Carbon County, Utah

[See fig. 6 for site location]

Site	Date	Instantaneous discharge (gallons per minute)
	Blackhawk Formation	
530	10-10-86	7.2
	05-23-87	4.0
	07-19-87	8.1
	08-12-87	7.6
	09-22-87	7.6
	06-01-88	2.7
	07-09-88	3.1
	Castlegate Sandstone	
238	10-09-87	3.6
	06-14-88	9.9
	07-16-88	3.1
494	10-09-87	2.2
	06-14-88	8.5
	07-16-88	1.3
500	05-23-87	2.2
	07-20-87	1.8
	08-12-87	1.8
	09-22-87	1.8
	06-14-88	.9
	07-15-88	1.8
	Price River Formation	
S149	07-06-78	8.5
	06-12-85	9.9
	06-12-86	24.7
	09-30-86	4.4
	05-22-87	60.1
	07-16-87	39.9
	08-14-87	9.9
	09-23-87	3.1
	06-03-88	61.9
	07-16-88	3.6
S182	09-12-79	.9
	09-30-80	1.8
	10-22-80	.9
	11-10-80	1.3
	12-30-80	.9
	06-16-81	.9
	08-29-81	.4
	10-07-81	2.7
	06-29-83	3.1
	10-05-83	1.8
	06-21-84	3.1
	06-13-85	1.3
	Price River Formation—Continued	
S182—Continued	09-24-85	.04
	06-11-86	14.8
	10-10-86	2.7
	05-22-87	25.1
	07-19-87	4.5
	08-12-87	2.2
	09-22-87	1.3
	06-14-88	6.3
	07-15-88	2.7
229	10-10-86	.9
	05-19-87	20.2
	07-20-87	8.1
	08-12-87	5.4
	06-01-88	36.8
	07-16-88	0
	North Horn Formation	
232	06-01-88	5.8
753	09-11-79	.04
	09-30-80	.04
	10-22-80	.04
	11-10-80	.04
	06-16-81	.9
	08-29-81	.04
	10-05-83	1.0
	06-21-84	9.9
	09-21-84	.04
	06-13-85	7.2
	09-24-85	.4
	06-11-86	12.6
	10-10-86	.3
	05-19-87	14.8
	07-20-87	.9
	08-12-87	.4
	06-01-88	11.2
	07-15-88	.4
978	06-22-84	9.9
	10-10-86	4.9
	05-19-87	66.9
	07-20-87	148.1
	08-12-87	7.6
	09-22-87	1.3
	06-01-88	60.1

Table 5. Selected properties and chemical constituents in water from site M-8 on the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, before longwall mining

[See fig. 10 for location of site M-8; concentrations are dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; —, no data]

	Selected properties and common constituents												
Date	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
06-01-88	248	9.1	5.8	181	230	58	23	3	1	221	35	2	0.1
07-15-88	348	8.8	19.0	200	276	51	30	4	1	244	45	4	.2

	Trace elements											
Date	Barium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead (µg/L)	Manganese, total (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Zinc, total (µg/L)
06-01-88	30	<5	<10	<10	30	200	<20	10	<50	<20	<1	<10
07-15-88	30	<5	10	<10	20	—	—	<10	<50	<20	<1	<10

Table 6. Selected properties and chemical constituents in water from a spring (site 530) in the Blackhawk Formation, Carbon County, Utah, before longwall mining

[See fig. 6 for location of site 530; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; —, no data]

Date	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
	Selected properties and common constituents													
10-10-86	[1]564	[1]8.1	6.0	249	300	[2]66	[2]29.2	[2]5.9	[2]1.9	304	<1	40	7.4	—
05-23-87	490	8.1	5.5	—	—	—	—	—	—	—	—	—	—	—
07-19-87	440	8.3	9.0	—	—	—	—	—	—	—	—	—	—	—
08-12-87	440	8.3	7.0	267	304	71	33	6	1	326	—	27	5	.3
09-22-87	[1]491	7.8	6.2	245	294	84	31	5	1	299	—	23	5	—
06-01-88	355	7.3	7.5	263	—	85	33	5	1	321	—	25	5	.2
07-09-88	390	8.2	12.6	239	276	41	33	5	1	292	—	27	5	.1

Date	Aluminum, total (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Zinc, total (µg/L)
	Trace elements													
10-10-86	—	[2]<100	[2]100	[2]<5	<50	<20	<50	<50	<50	<10	—	<40	<5	29
05-23-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
07-19-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
08-12-87	<50	30	<20	<5	<10	20	<20	30	<20	<10	[2]<50	<20	1	<10
09-22-87	[3]<50	—	—	—	—	—	<20	50	<20	<10	<50	—	—	<10
06-01-88	[3]<50	110	120	<5	<10	[3]10	<20	210	<20	[2]<10	<50	[3]<20	[3]1	<10
07-09-88	[3]<50	60	20	<5	<10	[3]<10	20	130	<20	[2]10	<50	[3]<20	[3]1	<10

[1]Laboratory measurement.
[2]Concentration is total.
[3]Concentration is dissolved.

Table 7. Selected properties and chemical constituents in water from springs in the Castlegate Sandstone, Carbon County, Utah, before longwall mining

[See fig. 6 for site location; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data; <, less than]

		Selected properties and common constituents												
Site	Date	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L))
238	10-09-87	490	8.5	5.0	227	246	62	22	3	1	277	12	3	—
	06-14-88	232	8.5	7.2	194	220	77	13	1	1	237	16	<1	.1
	07-16-88	242	8.4	10.2	165	208	53	11	2	1	201	14	1	.1
494	10-09-87	525	8.3	5.9	196	262	61	23	4	1	239	39	4	—
	06-14-88	180	7.7	5.5	159	190	55	14	2	1	194	10	1	.1
	07-16-88	262	8.3	13.0	194	270	57	22	4	<1	237	41	3	.2
500	05-23-87	400	8.0	5.4	140	242	34	23	3	<1	249	2	2	.5
	07-20-87	380	8.0	5.6	220	256	55	22	2	1	268	2	3	.3
	08-12-87	320	8.0	8.0	218	198	64	19	3	1	266	<2	3	.2
	09-22-87	500	6.6	5.5	222	236	72	21	2	1	271	6	3	—
	06-14-88	287	8.3	9.5	216	262	75	[1]21	2	1	264	12	2	.1
	07-15-88	292	8.1	9.5	215	258	56	19	3	<1	262	14	3	.1

		Trace elements												
Site	Date	Aluminum (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium, total (µg/L)	Copper (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Zinc, total (µg/L)
238	10-09-87	<50	—	—	—	—	—	<20	30	20	<10	<50	—	—	<10
	06-14-88	<50	90	<20	<5	<10	10	<20	40	20	[1]<10	<50	<20	[1]<1	40
	07-16-88	<50	80	<20	5	<10	<10	<20	30	<20	[1]<10	<50	<20	<1	10
494	10-09-87	<50	—	—	—	—	—	<20	480	20	<10	<50	—	—	<10
	06-14-88	<50	30	<20	<5	<10	<10	40	190	20	[1]<10	<50	<20	<1	10
	07-16-88	<50	20	<20	5	<10	<10	220	<20	<20	[1]<10	<50	<20	1	10
500	05-23-87	[1]<50	20	40	7	<10	[1]10	<20	30	<20	<10	[1]<50	[1]<20	[1]<1	<10
	07-20-87	[1]300	30	20	<5	<10	[1]<10	<20	230	<20	<10	[1]<50	[1]20	[1]1	<10
	08-12-87	[1]<50	40	<20	<5	<10	[1]<10	<20	<20	<20	<10	<50	[1]<20	[1]<1	10
	09-22-87	<50	—	—	—	—	—	<20	1,440	<20	<10	<50	—	—	10
	06-14-88	<50	50	<20	<5	<10	10	<20	<20	<20	[1]<10	<50	<20	<1	<10
	07-15-88	<50	40	<20	<5	<10	<10	<20	20	<20	[1]<10	<50	<20	<1	<10

[1]Concentration is total.

Table 8. Selected properties and chemical constituents in water from springs in the Price River Formation, Carbon County, Utah, before longwall mining

[See fig. 6 for site location; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data; <, less than]

		Selected properties and common constituents													
Site	Date	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
S149	06-12-85	[1]440	[1]7.9	—	235	264	[2]80	[2]20	[2]2	[2]0.8	287	—	7	3.0	—
	06-12-86	[1]478	7.7	5.0	235	262	[2]80	[2]16	[2]2.6	[2].8	286	—	32	2.2	—
	09-30-86	400	[1]8.1	5.0	245	289	[2]80	[2]19.5	[2]2.7	[2]1	299	<1	35	2.8	—
	05-19-87	420	7.6	4.9	—	—	—	—	—	—	—	—	—	—	—
	05-22-87	415	8.0	4.2	150	274	47	17	3	1	298	—	8	<1	.5
	07-16-87	410	8.7	5.0	222	256	47	18	3	1	271	—	12	2	.4
	08-14-87	420	8.2	6.1	221	276	68	17	3	1	270	—	10	3	.2
	09-23-87	500	7.2	6.0	251	288	88	18	4	1	306	—	21	2	—
	06-03-88	268	7.2	5.5	249	—	83	16	3	1	304	—	8	2	—
	07-16-88	317	8.1	7.0	240	286	72	16	3	<1	293	—	21	2	—
S182	09-12-79	[1]365	[1]6.9	8.0	—	—	—	—	—	—	—	—	—	—	—
	09-11-80	—	—	—	158	205	[2]58.4	[2]5.76	[2]6.6	[2]9.6	192.76	—	12	2.0	.13
	09-30-80	[1]300	[1]7.1	9.0	124	195	[2]60.0	[2]5.28	[2]4.0	[2].6	151.28	—	46	3.4	—
	10-22-80	[1]380	[1]7.0	7.0	180	248	[2]59.2	[2]11.52	[2]10.8	[2]8.5	219.60	—	40	3.5	—
	11-10-80	[1]340	[1]7.2	—	182	220	[2]60.0	14.4	[2]4.0	[2].6	222.09	—	30	1.9	—
	12-30-80	[1]198	[1]7.0	4.0	178	260	[2]56.0	[2]26.4	[2]1.5	[2]8.2	217.16	—	76	.65	—
	06-16-81	[1]195	[1]7.6	—	126	150	[2]40.0	[2]10.56	[2]4.0	[2].4	153.72	—	16	4.66	—
	07-31-81	[1]360	—	—	158	185	[2]53.6	[2]12.0	[2]4.9	.4	192.76	—	26	4.77	—
	08-29-81	—	—	17.0	158	210	[2]56.0	[2]13.44	[2]3.8	[2]1.3	192.78	—	30	8.0	—
	09-24-81	[1]350	[1]7.3	—	186	228	[2]63.5	[2]13.0	[2]3.6	[2].3	226.90	—	27	3.8	—
	10-07-81	[1]360	[1]7.2	7.0	186.3	233	[2]60.5	[2]13.5	[2]5.5	.3	227.20	—	25	3.37	—
	06-29-83	[1]285	[1]6.8	8.0	114	147	[2]40.0	[2]9.0	[2]4.0	[2]1.0	139	—	12	4.0	—
	10-05-83	[1]360	[1]7.8	9.0	148	183	[2]54.0	12.0	[2]4.0	[2]1.0	181	<1	37	4.0	—
	06-21-84	[1]315	[1]7.0	7.0	145	166	[2]51.0	[2]9.0	[2]4.0	[2]1.0	177	—	10	4.0	—
	10-25-84	[1]435	[1]7.0	—	220	255	[2]71.0	[2]11.0	[2]3.0	[2]1.0	268	<1	10	8.0	—
	06-13-85	[1]270	[1]7.0	9.0	120	163	[2]52.0	[2]8.0	[2]4.0	[2].8	146	—	11	4.0	—
	09-24-85	[1]376	[1]6.6	6.0	173	235	[2]60.0	[2]14.0	[2]4.0	[2]1.0	211	<1	38	5.0	—
	06-11-86	[1]263	6.9	7.0	130	170	[2]49.0	[2]7.0	[2]3.6	[2].7	159	—	25	3.3	—
	10-10-86	[1]372	[1]8.0	16.0	155	204	[2]56.0	[2]10.9	[2]4.6	[2]2.2	189	<1	30	6.8	—
	05-22-87	220	8.2	6.5	—	—	—	—	—	—	—	—	—	—	—
	07-19-87	290	7.7	8.0	—	—	—	—	—	—	—	—	—	—	—
	08-12-87	310	7.7	8.0	—	—	—	—	—	—	—	—	—	—	—
	09-22-87	335	7.0	9.6	169	206	64	13	5	1	206	—	16	3	—
	06-14-88	195	8.2	9.6	137	184	47	9	2	1	167	—	12	2	—
	07-15-88	257	6.4	12.0	160	206	53	11	6	<1	195	—	19	4	—
229	10-10-86	[1]384	8.2	3.5	171	204	[2]58	[2]12.2	[2]1.5	[2]1.2	209	<1	25	2.4	—
	05-19-87	320	7.7	3.6	176	192	56	10	1	1	215	—	<2	<1	.5
	07-20-87	280	8.0	4.2	172	176	46	13	1	1	210	—	6	1	.3
	08-12-87	300	8.0	5.0	173	182	66	12	1	1	211	—	10	2	.2
	06-01-88	208	7.6	3.5	176	—	73	[2]10	2	1	215	—	8	1	<.1

Table 8. Selected properties and chemical constituents in water from springs in the Price River Formation, Carbon County, Utah, before longwall mining—Continued

		Trace elements													
Site	Date	Aluminum, total (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Zinc, total (µg/L)
S149	06-12-85	—	—	—	—	—	—	<50	80	—	<10	—	—	—	—
	06-12-86	—	—	—	—	—	—	<50	<50	—	<10	—	—	—	—
	09-30-86	—	[2]<100	[2]100	[2]<5	<50	<20	<50	<50	<50	<10	—	<40	<5	<5
	05-19-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	05-22-87	<50	60	30	<5	<10	<10	<20	170	<20	<10	[2]<50	<20	<1	<10
	07-16-87	1,150	80	<20	<5	<10	<10	40	1,490	20	<10	[2]<50	40	2	10
	08-14-87	540	70	<20	<5	<10	<10	<20	500	<20	<10	[2]<50	<20	1	<10
	09-23-87	[3]<50	—	—	—	—	—	<20	200	<20	<10	<50	—	—	10
	06-03-88	—	—	—	—	—	—	<20	<20	—	[2]<10	—	—	—	—
	07-16-88	—	—	—	—	—	—	40	20	—	[2]<10	—	—	—	—
S182	07-09-79	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-11-80	—	[2]50	[2]12	[2]<1	<1	10	10	65	12	[2]11	—	—	<1	10
	09-30-80	—	—	—	—	—	—	55	230	—	[2]17	—	—	—	—
	10-22-80	—	—	—	—	—	—	55	110	—	[2]18	—	—	—	—
	11-10-80	—	—	—	—	—	—	20	70	—	[2]14	—	—	—	—
	12-30-80	—	—	—	—	—	—	75	136	—	<1	—	—	—	—
	06-16-81	—	—	—	—	—	—	10	50	—	<1	—	—	—	—
	07-31-81	—	—	—	—	—	—	20	51	—	[2]<1	—	—	—	—
	08-29-81	—	—	—	—	—	—	40	69	—	[2]10	—	—	—	—
	09-24-81	—	—	—	—	—	—	16	188	—	[2]2	—	—	—	—
	10-07-81	—	—	—	—	—	—	28	87	—	[2]2	—	—	—	—
	06-29-83	—	—	—	—	—	—	<50	60	—	<10	—	—	—	—
	10-05-83	—	[2]<100	[2]130	[2]44	<50	<20	<50	<50	<50	<10	—	<40	<.3	7
	06-21-84	—	—	—	—	—	—	<50	<50	—	<10	—	—	—	—
	10-25-84	—	[2]<100	[2]230	[2]<5	<50	<20	<50	410	<50	<10	—	<40	<5	11
	06-13-85	—	—	—	—	—	—	<50	120	—	<10	—	—	—	—
	09-24-85	—	[2]<100	[2]150	[2]<5	<50	<20	90	530	<50	<10	—	<40	<5	<5
	06-11-86	—	—	—	—	—	—	140	140	—	<10	—	—	—	—
	10-10-86	—	[2]<100	[2]100	[2]<5	<50	30	130	700	<50	<10	—	—	<5	<5
	05-22-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	07-19-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	08-12-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-22-87	[3]<50	—	—	—	—	—	80	<20	<20	<10	<50	—	—	<10
	06-14-88	—	—	—	—	—	—	<20	60	—	[2]<10	—	—	—	—
	07-15-88	—	—	—	—	—	—	20	<20	—	[2]<10	—	—	—	—
229	10-10-86	—	[2]<100	[2]90	[2]<5	<50	30	<50	130	<50	<10	—	<40	<5	16
	05-19-87	<50	80	30	6	<10	<10	<20	<20	40	<10	[2]<50	<20	<1	<10
	07-20-87	100	70	20	<5	<10	<10	<20	40	<20	<10	[2]<50	30	<1	<10
	08-12-87	100	80	<20	<5	<10	<10	<20	50	<20	<10	[2]<50	<20	1	<10
	06-01-88	[3]<50	110	70	<5	[3]<10	[3]<10	<20	<20	<20	[2]<10	<50	[3]<20	[3]<1	60

[1]Laboratory measurement.
[2]Concentration is total.
[3]Concentration is dissolved.

Table 9. Selected properties and chemical constituents in water from springs in the North Horn Formation, Carbon County, Utah, before longwall mining

[See fig. 6 for site location; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data; <, less than]

Site	Date	Selected properties and common constituents: Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
232	06-01-88	170	7.4	4.8	133	—	56	[2]8	2	2	162	—	4	1	<0.1
753	09-11-79	[1]420	[1]7.5	7.0	248	270	[2]84.0	[2]9.12	[2]6.5	[2]0.96	302.56	—	10	4	—
	09-30-80	[1]390	[1]7.3	6.0	194	255	[2]67.2	[2]18.72	[2]1.9	[2].9	236.86	—	46	2.3	—
	10-22-80	[1]440	[1]7.3	3.0	258	292	[2]85.6	[2]12.0	[2]8.9	[2]4.1	314.76	—	18	5	—
	11-10-80	[1]400	—	—	268	262	[2]85.6	[2]5.28	[2]11.5	[2]1.45	329.76	—	<3	<.1	—
	06-16-81	[1]245	[1]7.8	5.0	214	235	[2]72	[2]8.64	[2]5.0	[2]1.2	261.08	—	10.5	2.58	—
	08-29-81	—	—	18.0	224	270	[2]76	[2]10.08	[2]12.0	[2]1.5	273.28	—	25	6	—
	10-05-83	[1]480	[1]7.8	7.0	239	231	[2]83	[2]12.0	[2]2.0	[2]2.0	292	<1	4	3	—
	06-21-84	[1]390	[1]7.3	—	195	203	[2]66	[2]11	[2]2	[2]1	238	—	4	2	—
	09-21-84	[1]500	[1]7.7	7.0	241	255	[2]76	[2]11	[2]2	[2]1.7	302	<1	4	4	—
	06-13-85	[1]363	[1]7.5	8.0	191	202	[2]70	[2]9	[2]2	[2].6	233	—	9	2	—
	06-11-86	[1]350	7.3	7.0	192	209	[2]67	[2]9	[2]2	[2]1.3	234	—	15	1.6	—
	10-10-86	[1]362	[1]8.0	3.0	206	229	[2]68	[2]8.5	[2]2.4	[2]7.9	251	<1	10	8.4	—
	05-19-87	340	7.2	1.6	—	—	—	—	—	—	—	—	—	—	—
	07-20-87	360	7.7	5.8	—	—	—	—	—	—	—	—	—	—	—
	08-12-87	440	7.7	11.0	—	—	—	—	—	—	—	—	—	—	—
	06-01-88	204	8.1	2.8	182	—	74	10	2	2	222	—	<2	1	—
	07-15-88	365	7.5	12.2	256	284	85	12	3	1	312	—	12	1	—
978	06-22-84	[1]410	[1]7.0	—	206	216	[2]67	[2]12	[2]3	[2]1	251	—	7	2	—
	10-10-86	[1]438	[1]8.1	5.0	218	236	[2]72	[2]12	[2]2.5	[2]1.1	266	<1	15	2.5	—
	05-19-87	360	[1]7.9	3.7	206	226	56	13	3	<1	251	—	6	<1	.5
	07-20-87	260	8.6	8.4	164	182	46	11	2	<1	200	—	2	<1	.3
	08-12-87	320	8.6	18.0	205	242	56	16	9	6	250	—	12	4	.1
	09-22-87	490	7.1	5.9	220	230	83	13	2	1	268	—	12	2	—
	06-01-88	248	7.7	4.0	194	—	84	[2]12	2	1	237	—	6	1	<.1

Table 9. Selected properties and chemical constituents in water from springs in the North Horn Formation, Carbon County, Utah, before longwall mining—Continued

		Trace elements													
Site	Date	Aluminum, total (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Man-ganese (µg/L)	Molyb-denum (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Zinc, total (µg/L)
232	06-01-88	[3]<50	60	270	<5	<10	[3]<10	80	1,040	20	[2]30	<50	[3]<20	[3]<1	10
753	09-11-79	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-30-80	—	—	—	—	—	—	33	145	—	[2]21	—	—	—	—
	10-22-80	—	—	—	—	—	—	88	168	—	[2]14	—	—	—	—
	11-10-80	—	—	—	—	—	—	840	2,300	—	[2]13	—	—	—	—
	06-16-81	—	—	—	—	—	—	10	90	—	<1	—	—	—	—
	08-29-81	—	—	—	—	—	—	50	185	—	[2]20	—	—	—	—
	10-05-83	—	[2]<100	[2]130	[2]<5	<50	<20	70	170	<50	<10	—	<40	<.3	21
	06-21-84	—	—	—	—	—	—	<50	100	—	<10	—	—	—	—
	09-21-84	—	[2]<100	[2]100	[2]<5	<50	<20	50	120	<50	<10	—	<40	<.3	20
	06-13-85	—	—	—	—	—	—	<50	<50	—	<10	—	—	—	—
	06-11-86	—	—	—	—	—	—	<50	<50	—	<10	—	—	—	—
	10-10-86	—	[2]<100	[2]70	[2]<5	<50	<20	<50	250	<50	<10	—	<40	<5	<5
	05-19-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	07-20-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	08-12-87	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	06-01-88	—	—	—	—	—	—	<20	190	—	[2]20	—	—	—	—
	07-15-88	—	—	—	—	—	—	50	90	—	[2]200	—	—	—	—
978	06-22-84	—	—	—	—	—	—	<50	<50	—	<10	—	—	—	—
	10-10-86	—	[2]<100	[2]100	[2]<5	<50	<20	<50	110	<50	<10	—	<40	<5	15
	05-19-87	70	50	30	7	<10	<10	<20	50	40	<10	[2]<50	<20	<1	<10
	07-20-87	400	30	20	6	<10	10	130	570	<20	10	[2]<50	20	<1	<10
	08-12-87	4,310	70	<20	<5	<10	10	460	6,200	<20	<10	[2]<50	<20	<1	30
	09-22-87	[3]<50	—	—	—	—	—	<20	80	<20	<10	<50	—	—	<10
	06-01-88	[3]<50	70	50	<5	<10	[3]<10	<20	<20	<20	[2]<10	<50	[3]<20	[3]<1	<10

[1]Laboratory measurement.
[2]Concentration is total.
[3]Concentration is dissolved.

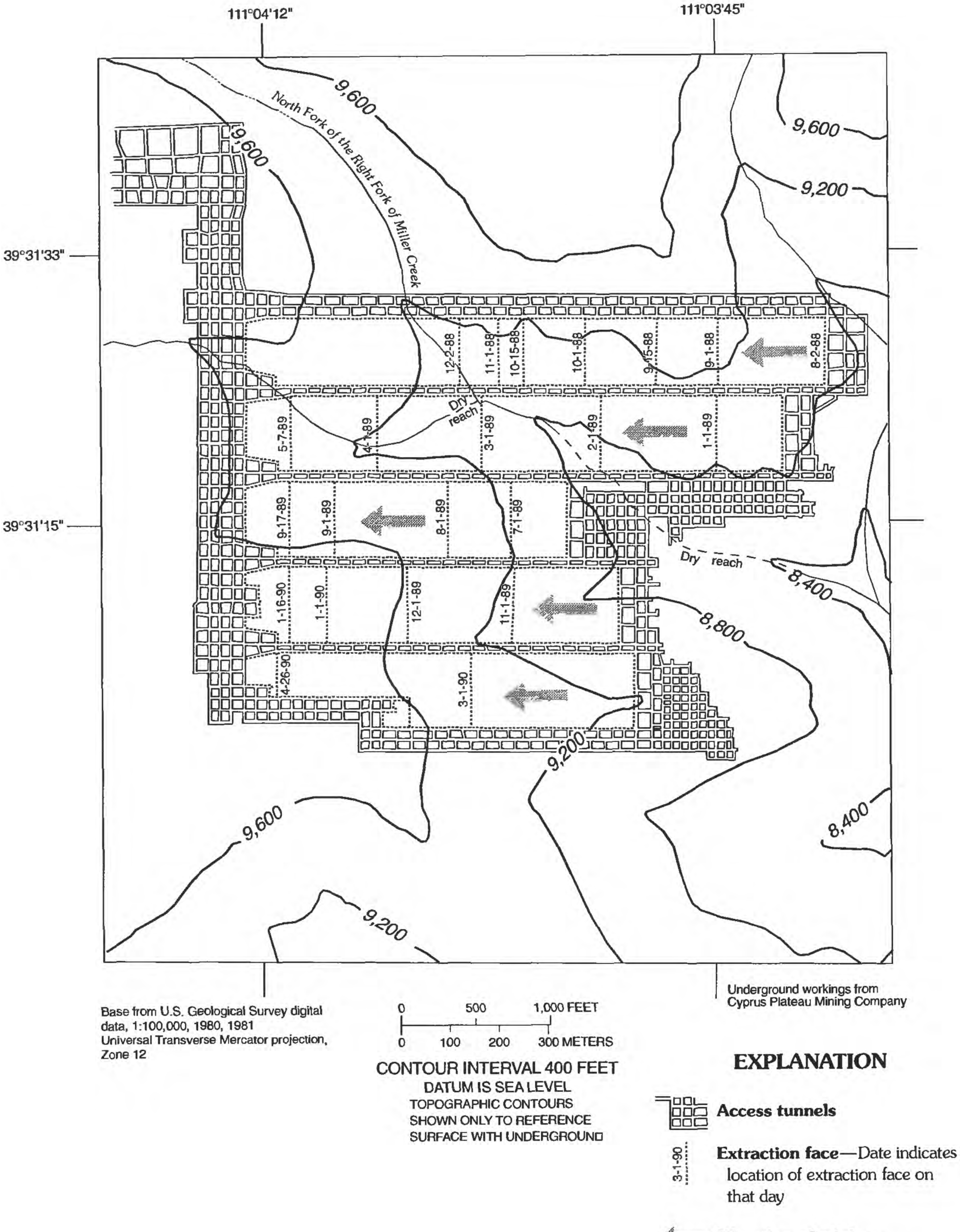
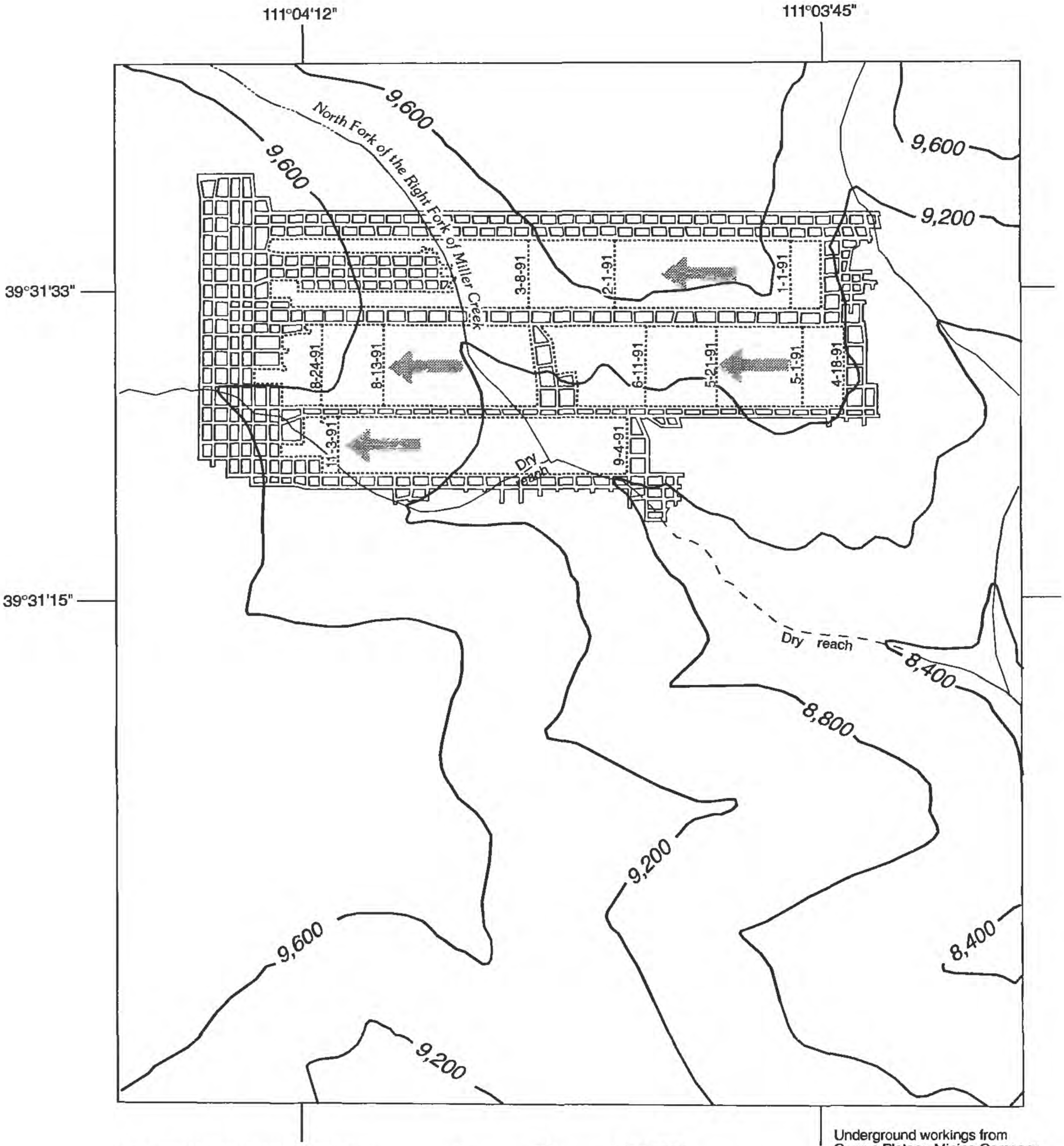


Figure 12. Longwall mining sequence of the Wattis coal seam, Carbon County, Utah.



Base from U.S. Geological Survey digital data, 1:100,000, 1980, 1981
Universal Transverse Mercator projection, Zone 12

0 500 1,000 FEET
0 100 200 300 METERS

CONTOUR INTERVAL 400 FEET
DATUM IS SEA LEVEL
TOPOGRAPHIC CONTOURS SHOWN ONLY TO REFERENCE SURFACE WITH UNDERGROUND

Underground workings from Cyprus Plateau Mining Company

EXPLANATION

Access tunnels

9-4-91 **Extraction face**—Date indicates location of extraction face on that day

Direction of mining

Figure 13. Longwall mining sequence of the Third coal seam, Carbon County, Utah.

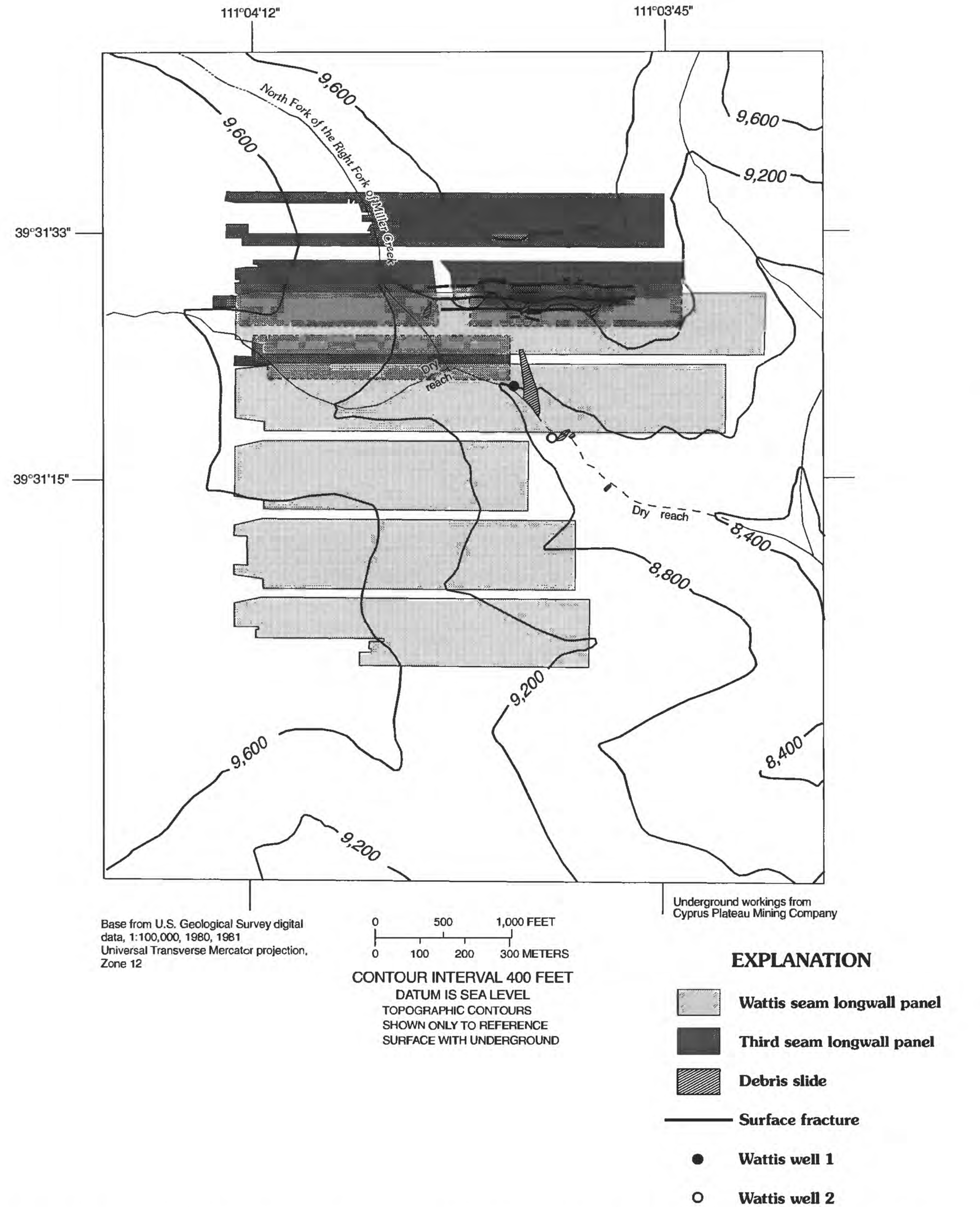


Figure 14. Approximate location of surface fractures and debris slides in relation to the mined-out longwall panels of the Wattis and Third coal seams in the eastern part of the study area, Carbon County, Utah.

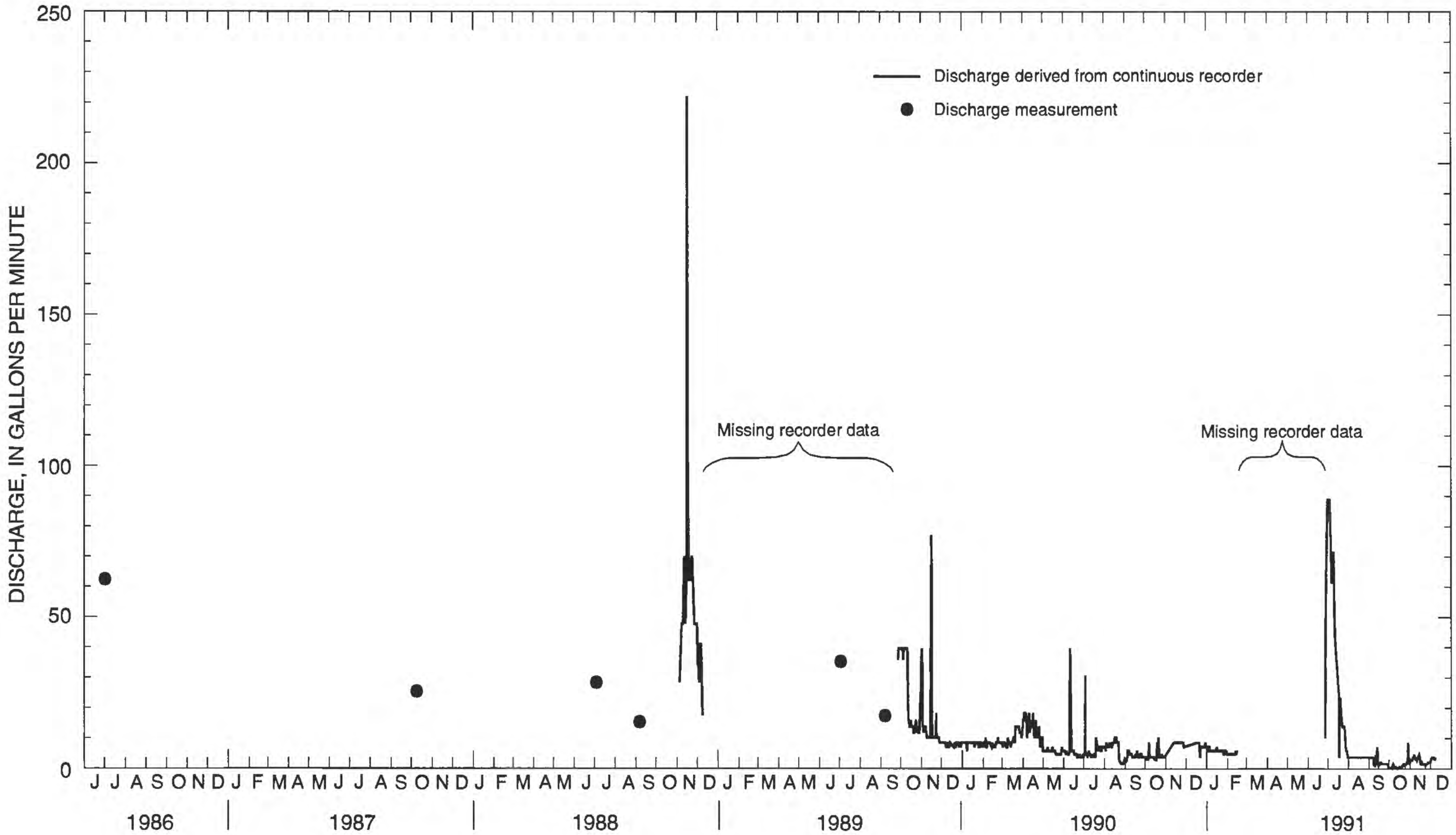


Figure 15. Discharge at site M-8 on the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 1986-91.

Surface-Water/Ground-Water Relations

Stream gain-loss studies by personnel from the Cyprus Plateau Mining Company were done in September 1988, July 1989, September 1989, July 1990, and July 1991 during longwall mining (table 10 and fig. 16). Discharge, specific conductance, pH, and temperature of the water were measured at sites on the NFRF of Miller Creek (table 11) and in tributary inflows into the NFRF of Miller Creek (table 12).

The two stream gain-loss studies done on July 5, 1988, and September 7, 1988, that bracket the beginning of the longwall mining of the Wattis coal seam (August 2, 1988) show similar reaches of gains and losses (figs. 11 and 16). Both gain-loss studies show a gain in base flow between sites 491 and M-2, a loss between sites M-2 and M-8, and a gain between sites M-8 and M-10. The gain-loss study on July 3, 1989, showed a base-flow gain between sites 491 and M-1 and a loss in base flow between sites M-1 and M-6, which was probably a direct result of the stream being diverted into an open fracture near site M-6 in January or February 1989. At site M-6 there is about 300 ft of rock overlying the Wattis coal seam. Gain in stream flow between site M-6 to site M-8 was more than 30 gal/min (fig. 16), probably a result of water from the mine being pumped back into the stream. The gain-loss study of September 7, 1989, showed similar gains and losses as the previous study, except that the stream gained instead of lost flow between sites M-8 and M-10. The gain-loss study of July 4, 1990, was done after mining of the Wattis seam was completed (April 26, 1990) and before mining of the Third seam began (December 1990) and resulted in a similar gain-loss pattern as the previous July study, except for a sizeable gain instead of a loss between sites M-1 and M-2. The gain-loss study done on July 18, 1991, indicated that the quantity of base flow lost between sites 491 and M-6 was gained between sites M-6 and M-10, although the reach showing the largest gain was between sites M-8 and M-10 and not between M-6 and M-8 as determined from the previous two July gain-loss studies (fig.16).

Water from a tributary of the NFRF of Miller Creek, at site M-3, also was diverted by open fractures sometime between January 27 and April 27, 1989. The water in the tributary stream was diverted underground beneath a sandstone outcrop in the Blackhawk Formation at a sandstone-siltstone contact. In June 1990, the water in the same tributary stream was being diverted into the subsurface about 20 ft farther upstream at another sandstone-siltstone contact. Overburden thickness above the Wattis seam at the point where water was diverted below surface in the tributary at M-3 is about 500 ft. The stream channel was dry between the point where water was being diverted below the surface and the confluence of the tributary and the NFRF of Miller Creek.

On November 22, 1988, pressure transducers and data recorders were installed to record water-level data at the two monitoring wells in the perched aquifer above the mine. A rise in the water levels in Wattis well 1 and Wattis well 2 of about 16 ft took place from about February 1 through February 13, 1989 (figs. 17 and 18), probably as a result of surface water from the stream recharging the aquifer through newly created fractures. The water level in Wattis well 1 declined about 37 ft from February 14 through February 17, 1989, probably indicating that the fractures extended from the mine to the overlying aquifer and that the aquifer was being dewatered in the vicinity of the monitoring well.

Water levels recorded for Wattis well 1 could not be independently verified with a steel tape because deformation of the rock below ground surface bent the casing several months after the well was installed. The bent casing in Wattis well 1 also prevented sampling of the ground water. Water levels in Wattis well 2 were measured with a pressure transducer and were assumed incorrect after about February 6, 1989, because the data recorder stored an unchanging water level of 38.5 ft below land surface from February 7 through April 25, 1989. A taped water-level measurement in May 1989 confirmed that the perched aquifer in the vicinity of Wattis well 2 also was dewatered.

Water began discharging from the collapsed rock behind the longwall machine at several places along Second and Third East entries during mining of the second of five panels in the Wattis coal seam (fig. 19) in greater-than-normal quantities beginning February 10, 1989. The longwall machine was directly under the stream at this time. Discharge (table 13) and chemical quality (table 14) of water from the collapsed material behind the longwall machine were periodically monitored at selected sites. Water-quality analyses of the in-mine flows at a few selected places in February 1989 (table 14) show that chemical character was similar to that of water sampled from Wattis well 2 in December 1988 and February 1989 (table 15). This evidence indicates that water entering the mine from the collapsed rock was derived primarily from water in the Blackhawk Formation. Of the samples collected in April 1989, the one from cross-cut 21 in access Third East contained larger concentrations of magnesium, cal-

Table 10. Discharge at, gain or loss between, and cumulative gain or loss in base flow at sites on or on tributaries to the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during mining of the Wattis and Third coal seams

[See fig. 10 for site location; all values are in gallons per minute; —, no measurement, assumed negligible discharge]

Main channel site	491		M-1			M-2	M-4		[1]M-6		M-8		M-10
Tributary site		492		493	494			M-3		M-5		M-7	
September 7, 1988													
Discharge	3.5	1.0	8.7	1.5	2.0	16.5	12.3	6.0	[2]18.3	—	15.0	0.5	19.2
Seepage gain or loss between stream sites			4.2			4.3	-4.2		0		-3.3		3.7
Cumulative gain or loss in base flow	3.5		7.7			12	7.8		7.8		4.5		8.2
July 3, 1989													
Discharge	4.3	2.4	12.0	.7	1.3	11.0	6.0	0	—	—	35.0	8.6	34.0
Seepage gain or loss between stream sites			5.3			-3.0	-5		-6		35		-9.6
Cumulative gain or loss in base flow	4.3		9.6			6.6	1.6		-4.4		30.6		21.9
September 7, 1989													
Discharge	4.0	1.3	15.0	.3	1.2	10.0	1.5	.3	—	—	17.0	5.0	30
Seepage gain or loss between stream sites			9.7			-6.5	-8.5		-1.8		17		8
Cumulative gain or loss in base flow	4		13.7			7.2	-1.3		-3.1		13.9		21.9
July 4, 1990													
Discharge	2.2	1.4	8.7	0	.2	30.5	3.7	0	—	—	30.5	6.1	19.7
Seepage gain or loss between stream sites			5.1			21.6	-26.8		-3.7		30.5		-16.9
Cumulative gain or loss in base flow	2.2		7.3			28.9	2.1		-1.6		28.9		12.0
July 18, 1991													
Discharge	1.0	2.2	2.2	2.2	.9	3.7	0	1.5	—	—	3.7	2.2	15.0
Seepage gain or loss between stream sites			-1			-1.6	-3.7		-1.5		3.7		9.1
Cumulative gain or loss in base flow	1		0			-1.6	-5.3		-6.8		-3.1		6.0

[1]Diversion of the stream into the subsurface through surface fractures near site M-6 began in January or February 1989.

[2]Assumes no additional gain or loss from nearest upstream site.

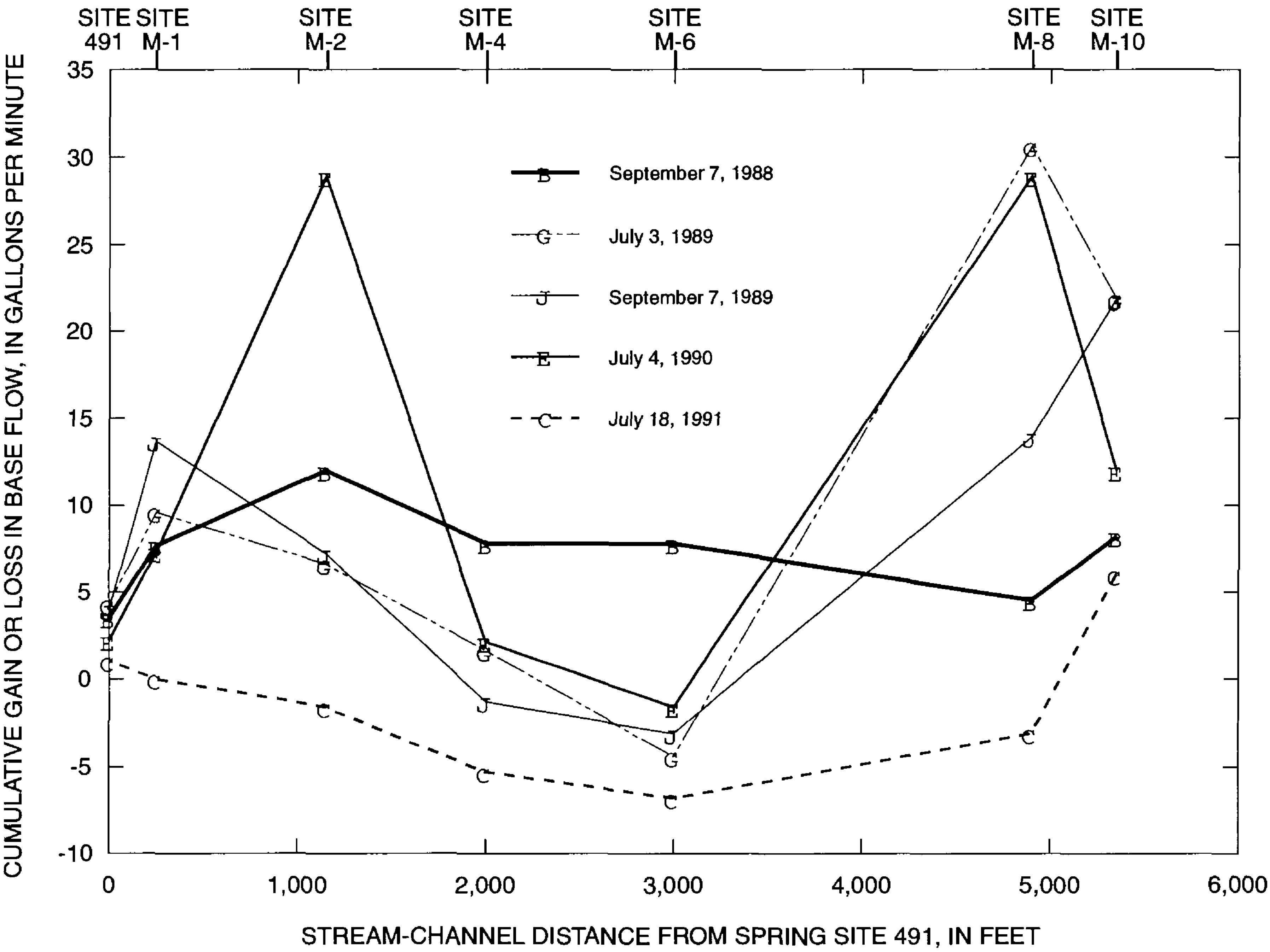


Figure 16. Gains and losses in base flow in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during mining of the Wattis and Third coal seams.

cium, and sulfate than water from Wattis well 2. This analysis indicates that water from another source was entering the mine, perhaps from another sandstone layer within the Blackhawk Formation.

The sample collected at cross-cut 12 in access Third East in April 1989 contained substantially less dissolved magnesium and sulfate, indicating that perhaps water from the overlying stream was entering the mine and contributing a substantial part to the in-mine flow at that point. Net discharge from the collapsed material increased from March through the end of May 1989, when it peaked at about 140 gal/min, and then decreased through October 1989 (fig. 20). Diversion of the stream could not have been the entire source of inflow because stream discharge was probably less than 100 gal/min during most of 1989 (figs. 9 and 15). Other sources of water could have been melting snow flowing into open fractures or the dewatering of other perched zones of saturated rock. The hydrograph of Wattis well 1 (fig. 17) indicates that the water level in the overlying aquifer declined rapidly when the aquifer was fractured, but dewatering occurred for several months after the initial water-level decline. Several attempts were made to determine if water from the NFRF of Miller Creek was contributing to ground-water discharge from the collapsed rock behind the longwall machine by using dye tracers; however, the logistics of collecting samples inside the mine made the results of the dye tracing inconclusive.

Table 11. Discharge, specific conductance, pH, and temperature of water from the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during and after longwall mining

[See fig. 10 for site location; gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Site	Date	Discharge (gal/min)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)
[1]491	09-07-88	3.5	240	8.2	5.0
	07-03-89	4.3	420	7.8	3.0
	09-07-89	4.0	460	7.4	5.0
	07-04-90	2.2	450	7.8	4.0
	07-18-91	1.0	380	7.7	5.0
M-1	09-07-88	8.7	240	8.6	5.0
	07-03-89	12.0	400	8.3	4.0
	09-07-89	15.0	420	8.1	6.0
	07-04-90	8.7	420	8.4	5.0
	07-18-91	2.2	380	8.6	8.0
M-2	09-07-88	16.5	250	8.8	6.0
	07-03-89	11.0	360	8.4	5.0
	09-07-89	10.0	410	8.2	6.0
	07-04-90	30.5	430	8.6	7.0
	07-18-91	3.7	410	8.3	8.0
M-4	09-07-88	12.3	280	9.2	8.0
	07-03-89	6.0	380	8.6	5.0
	09-07-89	1.5	410	8.3	9.0
	07-04-90	3.7	430	8.7	7.5
	07-18-91	0			
[2]M-6					
M-8	09-07-88	15.0	315	9.6	12.0
	07-03-89	35.0	1,390	8.4	14.0
	09-07-89	17.0	1,500	8.3	11.0
	07-04-90	30.5	1,810	8.3	16.0
	07-18-91	3.7	1,570	8.4	14.0
M-10	09-07-88	19.2	398	9.4	14.0
	07-03-89	34.0	1,420	8.2	15.0
	09-07-89	30.0	1,510	8.3	13.0
	07-04-90	19.7	1,650	8.4	15.0
	07-18-91	15.0	1,420	8.3	15.0

[1] Spring site.
[2] No flow after February 1989.

Table 12. Discharge, specific conductance, pH, and temperature of water from spring and stream tributaries to the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during and after longwall mining

[See fig. 10 for site location; gal/min, gallons per minute; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; —, no data]

Site	Date	Discharge (gal/min)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)
			Spring sites		
492	09-07-88	1.0	270	8.6	7.5
	06-05-89	2.2	350	7.7	5.0
	07-03-89	2.4	390	8.1	4.0
	07-11-89	1.8	380	8.2	6.0
	08-22-89	1.3	350	7.5	5.0
	09-07-89	1.3	420	7.9	6.0
	09-15-89	2.2	390	7.7	5.0
	06-04-90	1.3	390	7.5	4.0
	07-04-90	1.4	410	8.4	5.0
	07-07-90	1.8	440	8.0	5.0
	08-30-90	1.3	450	8.0	5.0
	09-18-90	.9	370	8.3	5.0
	06-13-91	4.5	390	7.3	4.0
	07-16-91	.9	420	7.8	6.0
	07-18-91	2.2	390	8.6	6.0
	09-18-91	1.3	420	8.0	7.0
	06-17-92	—	390	7.6	5.3
	06-29-92	1.0	430	7.0	5.2
493	09-07-88	1.5	230	8.7	6.0
	07-03-89	.7	410	8.2	5.0
	09-07-89	.3	450	8.0	6.0
	07-04-90	Negligible			
	06-29-92	Negligible			
494	08-19-88	1.8	290	8.3	9.0
	09-07-88	2.0	310	8.9	8.0
	06-05-89	.4	380	8.4	16.0
	07-03-89	1.3	440	8.5	5.0
	09-07-89	1.2	460	8.2	7.0
	09-15-89	.9	460	8.1	8.0
	06-04-90	1.3	450	7.7	11.0
	07-04-90	.2	460	8.6	8.0
	09-18-90	.9	450	8.3	6.0
	06-13-91	.9	450	8.3	4.0
	07-18-91	.9	500	8.4	8.0
	09-17-91	1.3	420	7.9	7.0
	06-29-92	.9	470	7.9	8.4

Table 12. Discharge, specific conductance, pH, and temperature of water from spring and stream tributaries to the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during and after longwall mining—Continued

Site	Date	Discharge (gal/min)	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)
			Stream sites		
M-3	09-07-88	6.0	265	9.1	7.9
	07-03-89	0	—	—	—
	09-07-89	.3	760	7.9	5.0
	07-04-90	0	—	—	—
	07-18-91	1.5	810	8.1	6.0
	06-29-92	0	—	—	—
M-5	07-03-89	0	—	—	—
	09-07-89	0	—	—	—
	07-04-90	0	—	—	—
M-7	09-07-88	.5	630	9.3	17.0
	07-03-89	8.6	1,530	8.6	10.0
	09-07-89	5.0	1,400	8.2	17.0
	07-04-90	6.1	1,320	8.4	11.0
	07-18-91	2.2	1,030	8.5	16.0
	06-29-92	1.5	1,220	8.6	21.1
M-9	07-03-89	6.0	2,020	8.0	10.0
	09-07-89	5.0	2,000	8.1	13.0
	07-04-90	2.0	2,110	8.4	12.0
	07-18-91	6.0	1,850	8.1	14.0
	06-29-92	3.3	2,090	8.2	17.1

Spring Discharge

Of the 13 springs periodically monitored before and after mining, 9 are inside and 4 are outside the drainage basin. Discharge at three springs, 500, 229, and S182, may have been affected by the subsidence caused by the longwall mining. Springs 229 and S182 are inside the drainage basin of the NFRF of Miller Creek, and all three springs are near the lateral extent of the longwall-mined seams. Springs 500 and S182 are on the north side of the area where the Wattis seam was mined. Both springs maintained their established pre-mining discharge pattern for about 1 year after mining of the Wattis seam began (table 16), indicating that subsidence did not affect spring discharge in the first year of mining the Wattis seam. Discharge from spring 500 ceased at least 5 months prior to mining the Third seam, and discharge from spring S182 diminished substantially about the same time and was dry after June 1991.

Spring 229 is at the west edge of the mined coal seams. Discharge from spring 229 was negligible 1 month before the beginning of mining, which is not unusual for mid-summer, but the spring never regained measurable discharge after June 1989, which is not typical even when precipitation is less than normal.

Discharge at three other springs, two near the north boundary of the mined area (sites 492 and 494) and one over the interior of the mined area (site 238), was not noticeably affected by mining-induced subsidence. The variability in discharge measured at these

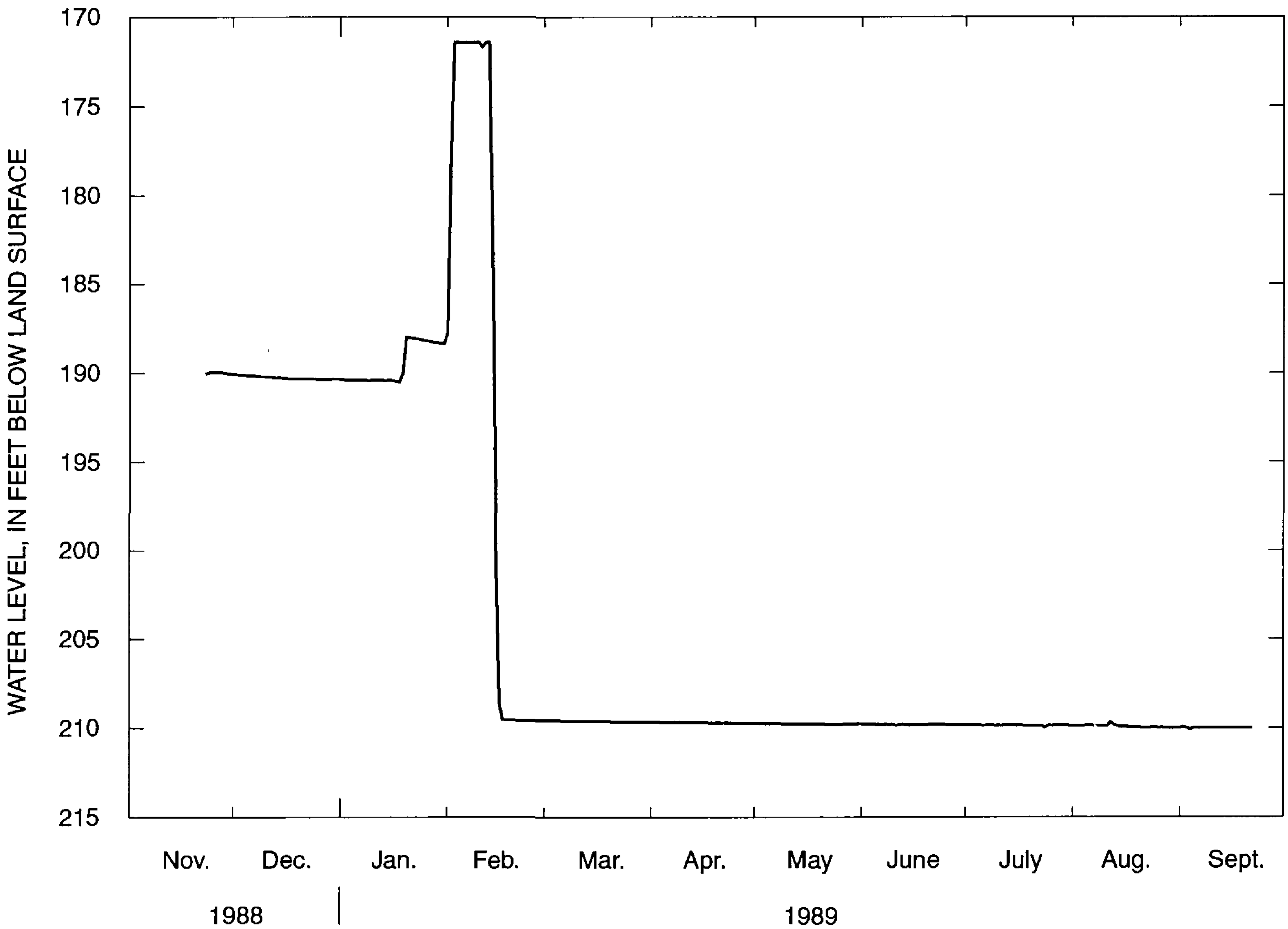


Figure 17. Water-level fluctuations in Wattis well 1, Carbon County, Utah, during longwall mining.

three springs was about the same during years of mining as during years before mining. The same was true of the discharge at sites 530, S149, 232, 753, and 978, the five springs farther west of the mined longwall panels.

The effects of mining-induced subsidence on discharge from springs in overlying formations could depend on any one, or more likely, a combination of several factors, including the location of the springs in relation to the mined panels, the vertical distance above the mined panels, the formation from which the spring is discharging, the proximity of the spring to a surface rupture, or seasonal changes in local precipitation and surface runoff during the spring. No definite conclusions regarding the effect of mining subsidence on spring discharge can be drawn from existing information.

Surface- and Ground-Water Quality

Analyses of water samples from the NFRF of Miller Creek collected during longwall mining (site M-8) indicate that the concentration of dissolved constituents in September 1988, about 1 month after longwall mining began, had not changed appreciably (from 276 mg/L in July 1988 to 310 mg/L in September 1988) (tables 5 and 17). Between September and December 1988, however, the concentration of dissolved solids increased from 310 to 779 mg/L and the type of water changed from magnesium calcium bicarbonate to magnesium sulfate (figs. 21 and 22). Dissolved-solids concentration continued to increase during mining and reached a maximum of 1,602 mg/L in July 1990.

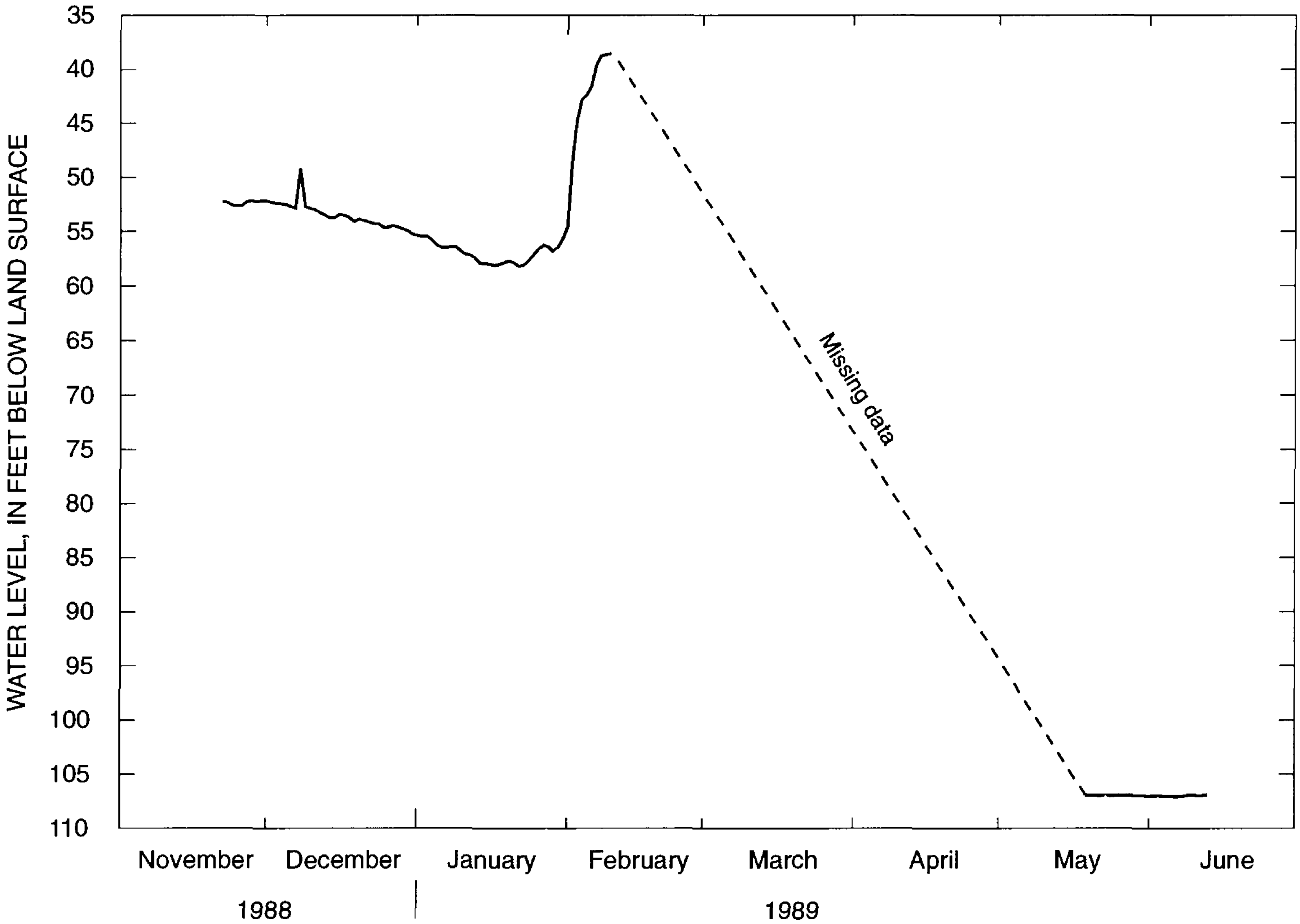


Figure 18. Water-level fluctuations in Wattis well 2, Carbon County, Utah, during longwall mining.

Several explanations of these changes are possible. A rockslide in October or November 1988 moved a substantial quantity of soil, rock, and vegetation into the creek but did not entirely block discharge. Water moving through this debris could account for part of the change in chemical composition of the water. During February 1989, water in the stream began seeping into the subsurface and changed the primary source of stream water from the Castlegate Sandstone to the Blackhawk Formation and the Star Point Sandstone. In other areas of the Wasatch Plateau, water from these two formations contains a greater concentration of magnesium and sulfate ions (Waddell and others, 1981, table 7). A third possible reason for the observed change in water quality might be related to periodic discharge of water from the mine into the stream out of a roof-collapse hole downstream from Wattis well 2. Excess water that accumulated in the mine was pumped out this hole and into the streambed from late spring 1989 to fall 1990. This water was coming into the mine primarily from the fractures in the streambed and from aquifer dewatering near Wattis well 1 and probably dissolved additional constituents as it moved through the Blackhawk Formation and the collapsed rock behind the longwall machine.

The concentration of dissolved constituents in ground water from the perched aquifer above the mine was measured three times after longwall mining began in August 1988 (December 1988, February 1989, and April 1989) (table 15). Dissolved-solids concentration decreased between December 1988 and February 1989 (554 to 489 mg/L) and increased between February 1989 and April 1989 (489 to 730 mg/L). The exact cause for these changes is not known, but the period in which the largest increase in dissolved-solids concentration occurred was the same period when mining of the Wattis coal seam under Wattis wells 1 and 2 was occurring. The water-quality change was probably

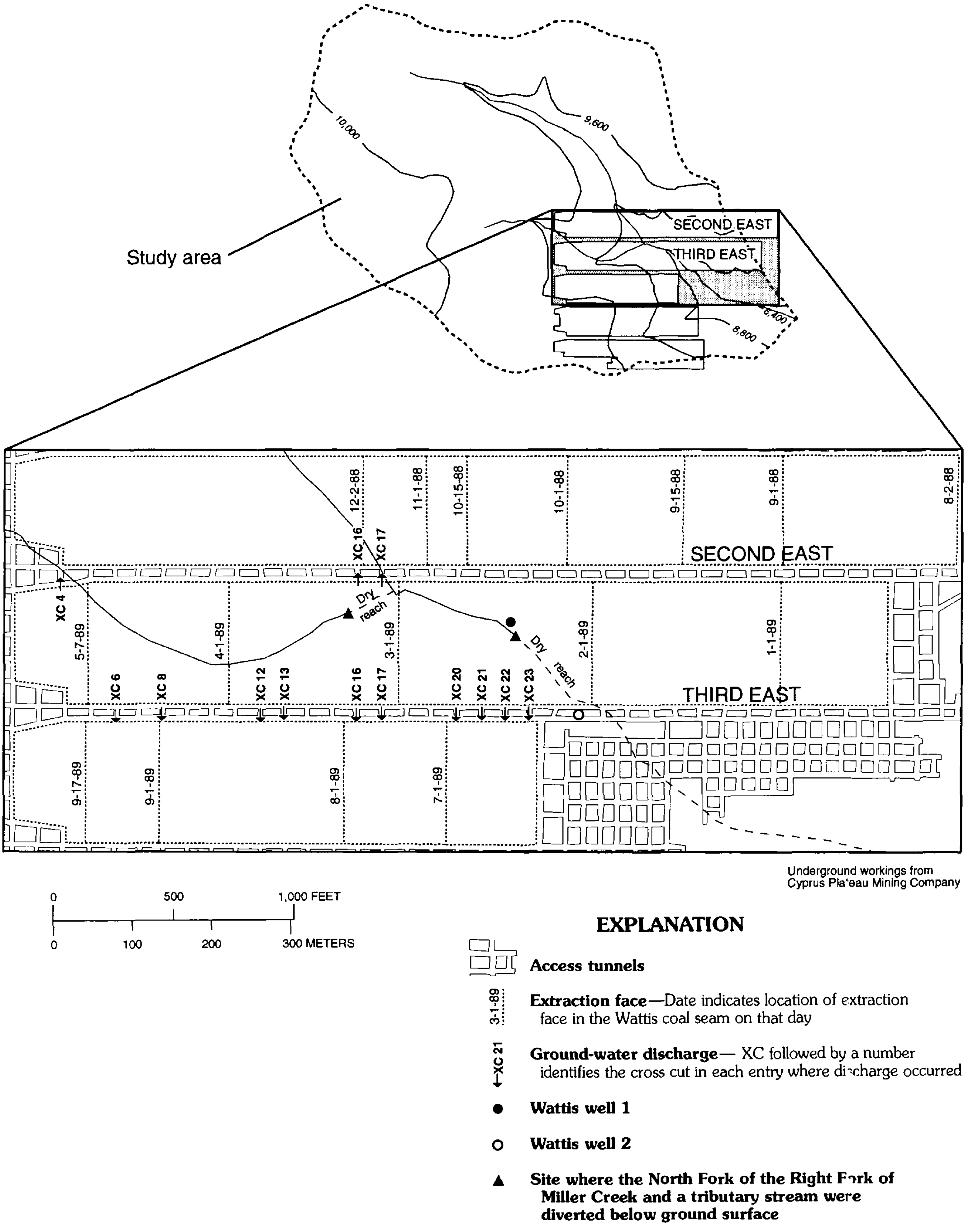


Figure 19. Location of underground sites where ground water discharged from the collapsed rock behind the longwall machine in the Wattis coal seam in the Cyprus Plateau Mine in relation to the dry reaches of the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during longwall mining.

Table 13. Discharge of water from the collapsed rock behind the longwall machine at selected sites in the Wattis coal seam, Cyprus Plateau Mine, Carbon County, Utah, during longwall mining

[Discharge in gallons per minute; see fig. 19 for site location; E, east; XC, cross cut; —, no data; Tr, trace; fldd, flooded as a result of pump malfunction or pump removal; inac, inaccessible; <, less than]

Shield: refers to water collected from the hydraulic shield of the longwall machine.
Tailgate: refers to water collected from the opposite end of the longwall machine from the conveyor access.

	Site										
Date	2nd E XC-16	3rd E XC-6	3rd E XC-12	3rd E XC-13	3rd E XC-16	3rd E XC-17	3rd E XC-21	3rd E XC-22	3rd E XC-23	Shield	Tailgate
03-22-89	1	—	—	—	0.2	1.0	2.3	Tr	Tr	—	—
03-31-89	1	—	—	1.1	.4	2.3	1.8	fldd	—	—	—
04-07-89	1	—	5.1	5.6	.6	2.7	2.7	fldd	—	10.0	—
04-11-89	1	—	fldd	2.7	.8	5.1	3.2	.8	fldd	—	—
04-21-89	inac	—	fldd	2.3	.4	.6	3.2	fldd	—	—	—
04-26-89	—	—	98.7	.4	1	.4	2.7	.8	—	—	—
05-05-89	fldd	—	76.1	2.7	.4	1.1	2.3	—	—	—	—
05-12-89	inac	—	59.3	2.7	.2	1.4	fldd	fldd	—	—	—
05-19-89	—	<1	48.6	1.4	.2	1.4	1.8	.4	—	—	81.3
05-26-89	—	<1	44.6	1.4	.2	.8	1.8	fldd	—	—	94.3
06-02-89	—	.6	38.8	1.4	.2	.8	1.8	.4	—	—	76.1
06-09-89	—	.8	31.8	1.1	.2	2.3	1.8	fldd	—	—	82.0
06-16-89	—	1.4	fldd	.8	.2	2.3	1.4	<1	—	—	84.0
06-30-89	—	1.1	fldd	.6	.2	1.8	—	—	—	—	45.6
07-07-89	—	1.1	29.2	.6	.2	1.4	—	—	—	—	46.6
07-14-89	—	.8	26.0	.6	.2	1.4	—	—	—	—	52.8
07-28-89	—	.8	29.2	.6	—	—	—	—	—	—	37.8
08-11-89	—	—	20.2	—	—	—	—	—	—	—	20.2
08-25-89	—	—	—	—	—	—	—	—	—	—	20.2
09-01-89	—	—	—	—	—	—	—	—	—	—	20.2
09-29-89	—	—	—	—	—	—	—	—	—	—	9.0
10-20-89	—	—	—	—	—	—	—	—	—	—	11.9

related to faster than normal ground-water flow between strata of different lithologic character enhanced by the formation of open vertical subsidence fractures.

The quality of water discharging from 11 monitored springs did not vary substantially from the premining to the post-mining period. Water from all the springs remained a magnesium calcium bicarbonate type (tables 18-21), although slight decreases in bicarbonate and slight increases in sulfate did take place in at least four springs (sites 530, 238, 492, and 978). Quality of the water from selected springs in the North Horn and Price River Formations varied seasonally, with concentrations typically greater in the fall than in the spring. Seasonal variation was less noticeable in water from the Castlegate Sandstone and Blackhawk Formation. Total iron in water from all formations sometimes increased by one to two orders of magnitude from one sampling to the next. The reason for these fluctuations is unknown, but the fluctuations are probably not related to mining subsidence because the time of variation in iron at each spring has no correlation with the mining activity.

SUMMARY

The U.S. Geological Survey, in cooperation with the Utah Department of Natural Resources, Division of Oil, Gas, and Mining, evaluated the response of the existing hydrologic system and the natural processes associated with this system to land subsidence caused by underground coal mining in the drainage basin of the North Fork of the Right Fork of Miller Creek, Carbon

Table 14. Selected properties and chemical constituents in water discharging from the collapsed rock behind the longwall machine in the Cyprus Plateau Mine, Carbon County, Utah, during longwall mining

[See fig. 19 for site location; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; XC, cross cut; <, less than; —, no data]

Site	Date	Selected properties and common constituents: Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L as SiO_2)
Second East entry															
XC 16	02-28-89	890	8.0	7.0	312	560	90	63	4.7	11	381	230	4.3	0.4	4.7
XC 17	02-28-89	910	7.4	7.0	232	621	110	57	4.2	6.3	283	300	4.8	.3	6.1
Third East entry															
XC 21	02-28-89	910	8.0	6.0	213	619	97	65	5.4	9.1	261	310	5.8	.4	4.4
	04-26-89	1,310	7.9	7.5	194	1,036	159	122	<1	10.0	237	638	5.0	.3	—
XC 12	04-26-89	600	8.2	8.0	247	344	78	41	<1	6.0	302	97	3.0	.4	—

Site	Date	Trace elements: Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
Second East entry																		
XC 16	02-28-89	37	0.5	1	5	8	10	8	140	10	41	21	20	40	—	2,200	6	65
XC 17	02-28-89	29	.5	1	5	30	10	130	1,200	10	40	48	20	90	—	690	6	140
Third East entry																		
XC 21	02-28-89	32	.5	2	5	20	10	4	40	10	45	9	80	100	—	1,300	6	7
	04-26-89	<10	—	<5	<10	—	<10	<20	<20	[1]<20	—	[1]<10	<50	150	10	—	—	[1]20
XC 12	04-26-89	30	—	<5	<10	—	<10	<20	200	[1]<20	—	[1]40	<50	60	5	—	—	[1]<10

[1]Concentration is total.

Table 15. Selected properties and chemical constituents in water from Wattis well 2 in the Blackhawk Formation, Carbon County, Utah, during longwall mining

[See fig. 6 for location of Wattis well 2; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; —, no data]

Date	Selected properties and common constituents													
	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L as SiO_2)
12-19-88	854	7.7	6.0	318	554	92	64	7.0	5.2	388	190	5.1	0.2	9.4
02-28-89	770	8.1	6.0	250	489	70	58	7.2	5.4	305	200	5.6	.2	7.1
04-27-89	1,050	8.0	7.0	297	730	104	92	<1	5.0	363	346	6.0	.3	—

Date	Trace elements																
	Barium (mg/L)	Beryllium (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Cobalt (mg/L)	Copper (mg/L)	Iron (mg/L)	Iron, total (mg/L)	Lead (mg/L)	Lithium (mg/L)	Manganese (mg/L)	Molybdenum (mg/L)	Nickel (µg/L)	Selenium (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
12-19-88	25	0.5	1	5	3	10	13	530	10	41	20	10	10	—	400	6	61
02-28-89	22	.5	3	5	3	10	16	300	10	41	5	10	10	—	380	6	35
04-27-89	<10	—	<5	<10	—	<10	<20	890	[1]<20	—	[1]30	<50	<20	1	—	—	[1]20

[1]Concentration is total.

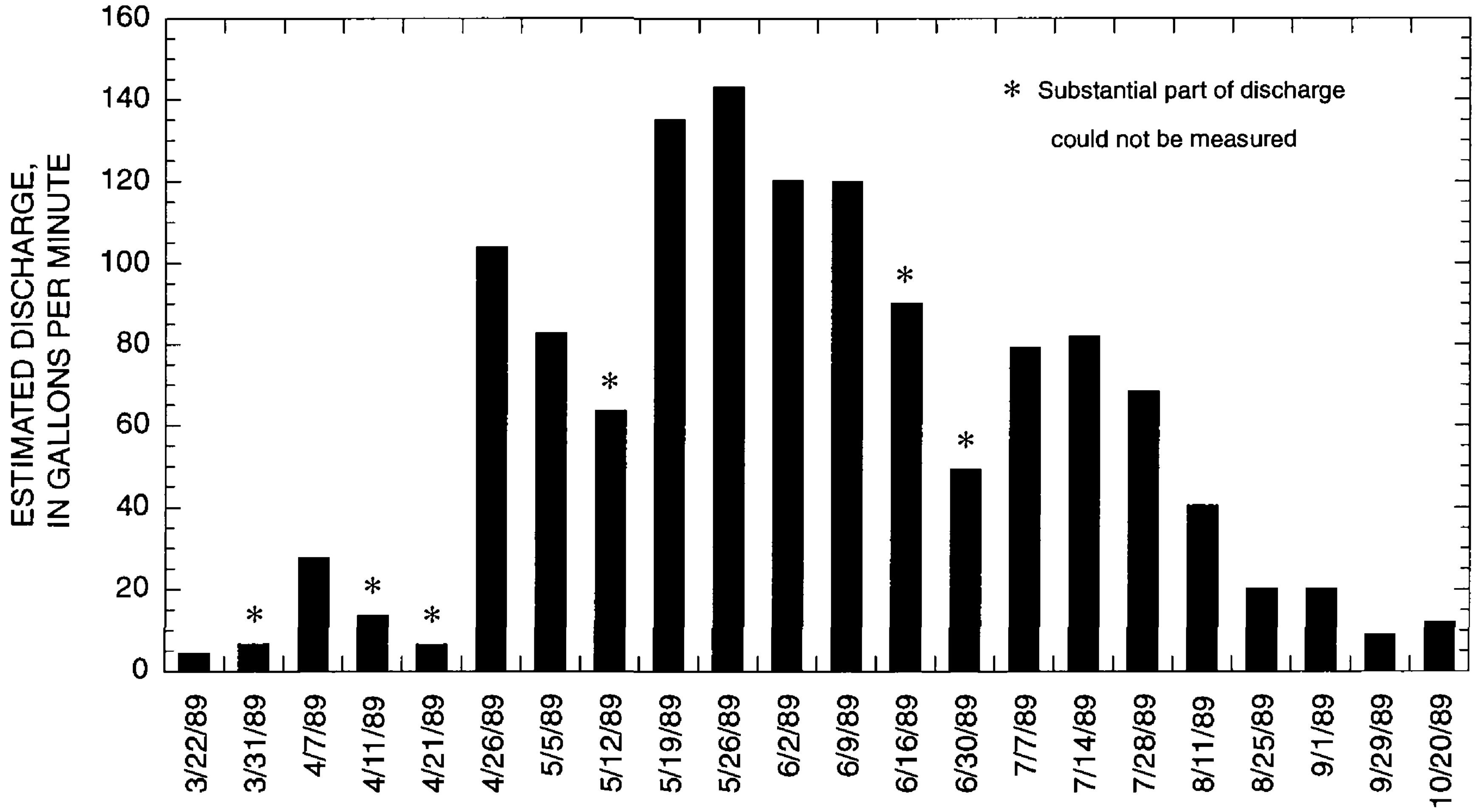


Figure 20. Variation in estimated discharge from the collapsed rock behind the longwall machine during mining of the Wattis coal seam in the Cyprus Plateau Mine, Carbon County, Utah, after the North Fork of the Right Fork of Miller Creek began entering the subsurface through open fractures.

County, Utah. The objective of the study was to determine the effects of longwall mining and the resulting land subsidence on ground-water movement, aquifer storage, ground-water quality, surface-water discharge, spring discharge, surface-water quality, water quality of springs, and the characteristics of the land surface.

Longwall mining of the Wattis seam in the Cyprus Plateau Mine in Carbon County, Utah, began August 2, 1988, and ended April 26, 1990, and mining of the Third seam began in December 1990 and ended November 3, 1991. Surface fractures, debris slides, and rockfalls occurred soon after mining began. Surface-movement surveys indicate that the ground surface above the longwall panels dropped a maximum of about 6.5 ft and moved horizontally to the south a maximum of about 8.5 ft. Surface fractures were created by the subsidence and generally trended east-west, parallel to the orientation of the underground barrier pillars. After mining ceased, the width of the largest opening at land surface was 7 ft. One rockfall caused by the subsidence resulted in debris being deposited in the North Fork of the Right Fork of Miller Creek.

Disturbance of the rock above the mine was sufficient to create two diversions of water into the subsurface through fractures, one on the North Fork of the Right Fork of Miller Creek and the other on a tributary. At the points where the streams entered the subsurface, thickness of overlying rock above the mined Wattis seam ranged from about 300 to 500 ft. The North Fork of the Right Fork of Miller Creek remained dry down the valley to where the Star Point Sandstone begins providing base flow for the stream.

Water levels in two monitoring wells in the perched aquifer above the mine rose about 16 ft before declining to below the bottom of the wells. The rise probably was caused by surface water entering the perched aquifer through open fractures at land surface. The decline is thought to be because the fractures eventually formed open conduits between the mine and the aquifer, allowing the aquifer to drain into the mine cavity. The timing of the water-level decline corresponds to an increase in the quantity of water that discharged into the mine from the collapsed rock behind the longwall machine.

Variation in discharge of the 13 monitored springs indicates a tentative correlation between the area where subsidence occurs and the effect of subsidence on discharge from springs. Three springs near the

Table 16. Discharge of water from springs in the formations above the coal seams during and after longwall mining, Carbon County, Utah

[See fig. 6 for site location]

Site	Date	Discharge (gallons per minute)
	Blackhawk Formation	
530	08-13-88	4.9
	09-03-88	5.8
	06-06-89	3.1
	07-11-89	3.1
	08-22-89	3.1
	09-14-89	3.1
	06-02-90	3.1
	08-22-90	.9
	10-03-90	2.2
	06-11-91	4.4
	07-16-91	4.5
	08-13-91	.4
	09-17-91	1.8
	Castlegate Sandstone	
238	08-19-88	2.7
	09-05-88	5.8
	06-05-89	8.5
	07-11-89	3.6
	08-22-89	3.6
	09-15-89	3.6
	05-30-90	12.1
	07-06-90	3.6
	08-22-90	3.1
	09-24-90	4.9
	06-11-91	18.0
	07-15-91	13.5
	08-13-91	4.5
	09-18-91	2.7
[1]492	06-05-89	2.2
	07-11-89	1.8
	08-22-89	1.3
	09-15-89	2.2
	06-04-90	1.3
	07-07-90	1.8
	08-30-90	1.3
	09-18-90	.9
	06-13-91	4.5
	07-16-91	.9
	08-13-91	1.3
	09-18-91	1.4
494	08-19-88	1.8
	09-05-88	1.8
	06-05-89	.4
	09-15-89	.9
	06-04-90	1.3
	Castlegate Sandstone—Continued	
494—Continued	09-18-90	.9
	06-13-91	.9
	09-17-91	1.3
	06-29-92	.9
500	08-19-88	1.3
	09-05-88	1.8
	06-06-89	.4
	07-11-89	2.7
	08-22-89	.4
	06-04-90	0
	07-06-90	0
	08-30-90	0
	09-24-90	0
	06-11-91	0
	07-16-91	0
	08-14-91	0
	09-17-91	0
	05-19-92	0
	Price River Formation	
S149	08-20-88	5.8
	09-10-88	4.0
	06-05-89	12.1
	07-11-89	4.5
	08-22-89	2.7
	09-14-89	1.8
	05-30-90	34.1
	07-07-90	5.8
	08-22-90	1.3
	09-24-90	4.5
	06-12-91	107.8
	07-15-91	22.4
	09-17-91	2.7
	05-19-92	38.0
S182	08-19-88	1.8
	09-05-88	1.3
	06-05-89	1.8
	07-11-89	.7
	08-22-89	.4
	09-15-89	.4
	06-04-90	2.2
	07-02-90	1.3
	08-30-90	.4
	10-03-90	.4
	06-11-91	0
	07-15-91	0
	08-14-91	0
	05-20-92	0

Table 16. Discharge of water from springs in the formations above the coal seams during and after longwall mining, Carbon County, Utah—Continued

Site	Date	Discharge (gallons per minute)
	Price River Formation—Continued	
S229	08-20-88	0
	09-05-88	0
	06-05-89	2.2
	07-11-89	0
	08-22-89	0
	09-15-89	0
	05-30-90	0
	07-06-90	0
	08-22-90	0
	09-24-90	0
	07-15-91	0
	08-14-91	0
	09-18-91	0
	North Horn Formation	
232	09-03-88	0
	06-05-89	3.1
	07-11-89	0
	08-22-89	0
	09-15-89	0
	05-30-90	3.6
	07-06-90	.4
	08-22-90	.4
	09-24-90	0
	06-12-91	9.0
	07-15-91	.4
	08-13-91	0
	09-18-91	0
	North Horn Formation—Continued	
753	08-19-88	0
	09-05-88	0
	06-05-89	.4
	05-30-90	.4
	07-02-90	.4
	08-30-90	0
	09-24-90	0
	06-12-91	13.5
	07-15-91	0
	08-13-91	0
	09-18-91	.4
	05-19-92	2.5
978	08-19-88	5.8
	09-05-88	3.6
	06-06-89	12.1
	07-11-89	5.8
	08-22-89	1.3
	09-15-89	.9
	05-30-90	20.2
	07-02-90	9.0
	08-30-90	2.7
	10-03-90	1.3
	06-12-91	50.3
	07-16-91	9.0
	08-13-91	4.5
	09-18-91	2.7
	05--1992	4.3

[1]Spring was added to sampling schedule after longwall mining began.

lateral extent of the mined area generally decreased in discharge, but three other springs also near the lateral extent of the mined area showed negligible change in typical discharge; thus, no definite conclusions regarding the effect of mining subsidence on spring discharge can be drawn from existing information.

Analyses of water samples from the North Fork of the Right Fork of Miller Creek collected during longwall mining indicate that the concentration of dissolved constituents increased from 310 to 779 mg/L between September and December 1988 and that the type of water changed from magnesium calcium bicarbonate to magnesium sulfate. Dissolved-solids concentration continued to increase during mining and reached a maximum concentration of 1,602 mg/L in July 1990.

The dissolved-solids concentration of water collected from Wattis well 2 increased during the period when mining of the Wattis coal seam was under the well and is probably related to the rapid movement of ground water between formations through vertical fractures caused by subsidence. No substantial changes in quality occurred in water discharging from springs in the Blackhawk Formation, Castlegate Sandstone, Price River Formation, and North Horn Formation as a result of longwall mining. Chemical analyses of ground water before and after mining show that magnesium, calcium, and bicarbonate are the primary ions in the ground water and that the magnitude of these concentrations has not changed.

Table 17. Selected properties and chemical constituents in water from the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during and after longwall mining

[See fig. 10 for site location; concentration is dissolved unless otherwise noted; M-8, sampling site at the weir on the North Fork of the Right Fork of Miller Creek;
M-K, sampling site near Wattis well 1 on North Fork of the Right Fork of Miller Creek; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data; <, less than]

Site	Date	Selected properties and common constituents: Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L as SiO_2)
M-8	09-30-88	330	9.3	6.8	228	310	67	36	4	1	278	0	64	4	0.1	—
	[1]12-20-88	1,130	8.4	1	344	779	120	100	6.7	2.7	386	17	340	5.7	.2	7.7
M-K	04-26-89	1,430	8.4	1	324	1,204	131	152	<1	3	358	18	673	4	.2	—
M-8	04-27-89	1,450	8.5	7	436	1,098	131	157	7	5	445	42	535	12	.4	—
	06-06-89	1,600	8.4	7	388	1,280	110	194	10	5	473	0	652	10	.4	—
	07-03-89	1,390	8.4	14	266	1,050	123	120	9	8	325	0	552	9	.5	—
	09-15-89	1,470	8.4	10	336	1,196	164	140	8	8	400	5	624	7	.2	—
	05-30-90	1,660	7.2	8	366	1,434	159	182	10	6	422	12	757	11	.3	—
	07-04-90	1,810	8.3	16	273	1,602	144	170	9	5	390	11	801	11	—	—
	08-22-90	1,750	8.5	10	—	—	—	—	—	—	—	—	—	—	—	—
	09-18-90	1,640	8.3	8	370	1,566	147	220	54	8	451	—	871	12	—	—
	06-12-91	1,760	7.1	15	292	1,280	148	166	32	6	356	—	803	12	—	—
	07-16-91	1,660	8.1	17	284	1,594	131	185	11	7	336	5	868	11	—	—
	09-17-91	1,740	8.4	10	331	1,492	156	190	29	6	379	12.5	862	13	.2	—
	05-22-92	1,710	8.3	10.3	294	1,352	134	169	10	6	278	16	770	10	—	—

Table 17. Selected properties and chemical constituents in water from the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, during and after longwall mining—Continued

		Trace elements																
Site	Date	Barium (µg/L)	Beryllium (µg/L)	Cadmium (µg/L)	Chromium (µg/L)	Cobalt (µg/L)	Copper (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel (µg/L)	Selenium (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc, total (µg/L)
M-8	09-30-88	20	—	<5	<10	—	<10	<20	20	—	—	<10	<50	<20	<1	—	—	10
	[1]12-20-88	42	.5	1	5	3	10	10	650	10	33	3	10	10	—	330	6	4
M-K	04-26-89	10	—	<5	<10	—	<10	<20	520	<20	—	<10	<50	20	3	—	—	<10
M-8	04-27-89	<10	—	<5	<10	—	<10	<20	30	<20	—	<10	<50	<20	<1	—	—	<10
	06-06-89	30	—	<5	<10	—	<10	<20	<20	—	—	<10	<50	<20	<1	—	—	<10
	07-03-89	40	—	<5	<10	—	<10	<20	<20	—	—	<10	<50	<20	3	—	—	<10
	09-15-89	180	—	<5	<10	—	10	<20	30	—	—	<10	<50	30	2	—	—	30
	05-30-90	20	—	<10	<10	—	<10	<20	80	—	—	<10	<50	<20	<1	—	—	<10
	09-17-91	<20	—	<5	<10	—	<10	<20	<20	—	—	<10	<50	<20	<.1	—	—	<20
	05-22-92	—	—	—	—	—	—	<20	<20	—	—	<10	—	—	—	—	—	—

[1]A landslide depositing rock and vegetative debris into the stream occurred near Wattis well 1 between October and December 1988.

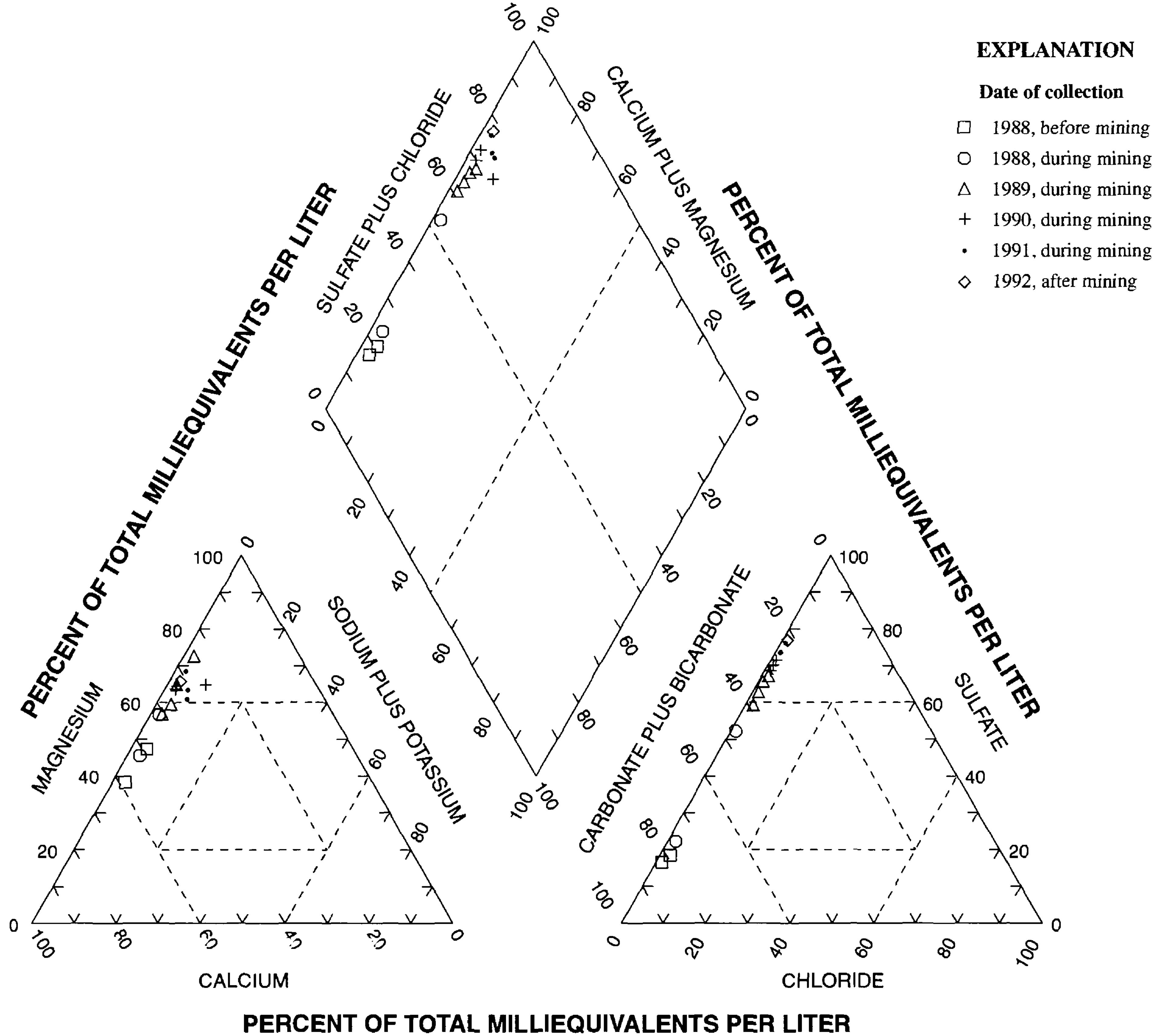


Figure 21. Chemical composition of water collected at site M-8 on the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, before, during, and after longwall mining.

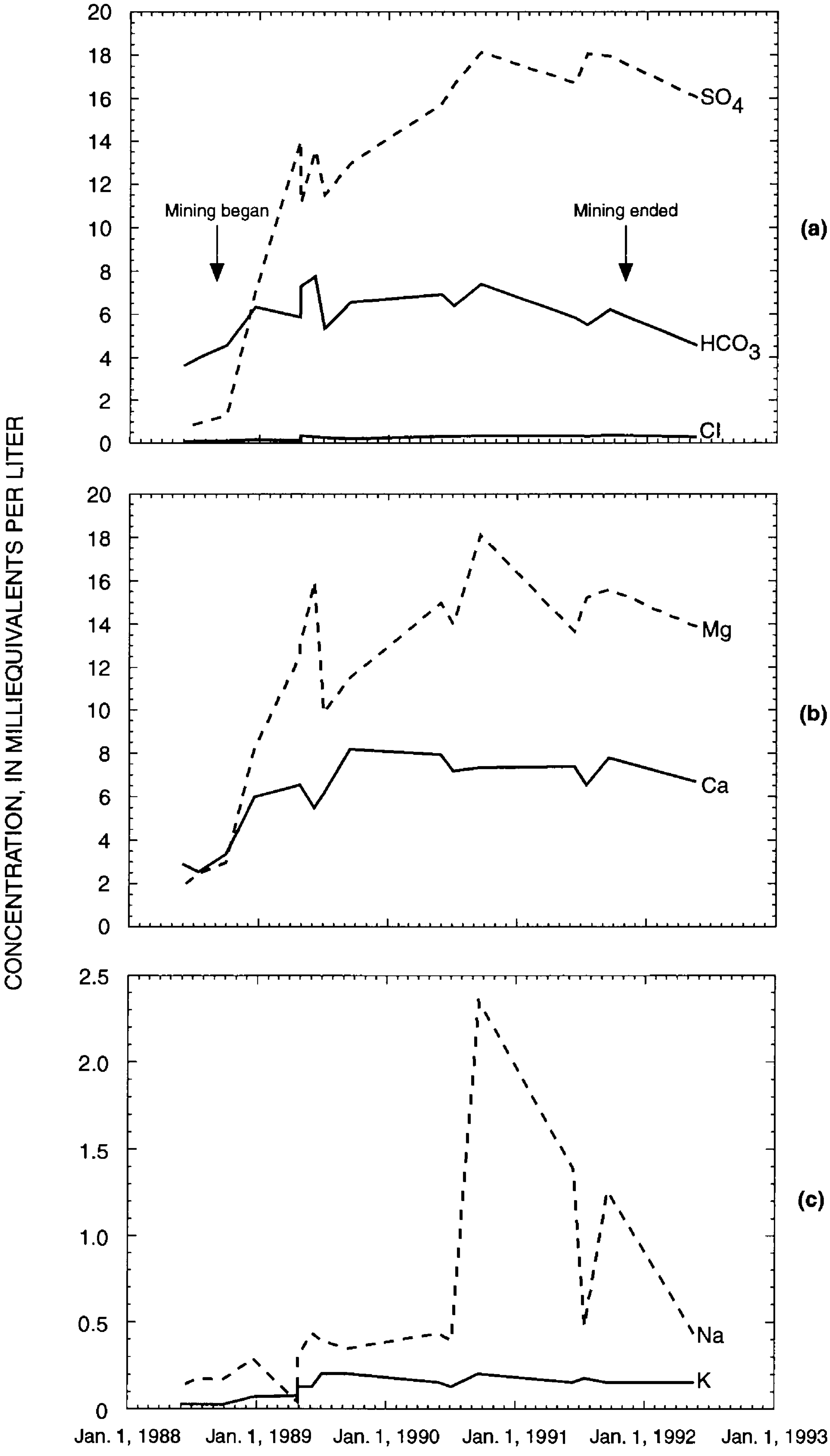


Figure 22. Variation in concentration of (a) chloride (Cl), bicarbonate (HCO_3), and sulfate (SO_4), (b) calcium (Ca) and magnesium (Mg), and (c) sodium (Na) and potassium (K) in water from site M-8 on the North Fork of the Right Fork of Miller Creek, Carbon County, Utah.

Table 18. Selected properties and chemical constituents in water from a spring (site 530) in the Blackhawk Formation, Carbon County, Utah, during and after longwall mining

[See fig. 6 for site location; concentration is dissolved unless otherwise noted; μS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; μg/L, micrograms per liter; —, no data; <, less than]

Date	Selected properties and common constituents														
	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
08-13-88	329	8.3	11.0	—	—	—	—	—	—	—	—	—	—	—
09-03-88	230	7.7	13.0	262	308	70	33	5	1	320	—	21	6	.1
06-06-89	540	8.4	8.3	240	298	61	30	4	1	293	—	27	5	—
07-11-89	580	7.5	12.0	248	328	64	33	5	1	303	—	29	5	—
08-22-89	590	8.1	9.0	—	—	—	—	—	—	—	—	—	—	—
09-14-89	540	8.0	8.0	262	294	70	31	5	<1	320	—	25	3	—
06-02-90	560	7.5	6.0	270	344	70	30	5	<1	324	2.4	39	4	—
09-17-91	560	8.2	10	266	300	69	28	4	<1	266	0	21	3	.1
06-17-92	568	8.05	8.3	218	304	63	—	5	<1	218	0	56	4	—

Date	Trace elements													
	Aluminum, total (μg/L)	Barium (μg/L)	Boron (μg/L)	Cadmium (μg/L)	Chromium, total (μg/L)	Copper, total (μg/L)	Iron (μg/L)	Iron, total (μg/L)	Lead, total (μg/L)	Manganese (μg/L)	Molybdenum (μg/L)	Nickel, total (μg/L)	Selenium, total (μg/L)	Zinc, total (μg/L)
08-13-88	—	—	—	—	—	—	—	—	—	—	—	—	—	—
09-03-88	[1]<50	40	<20	<5	<10	[1]<10	<20	<20	<20	[2]<10	<50	[1]<20	[1]1	<10
06-06-89	—	—	—	—	—	—	<20	50	—	<10	—	—	—	—
07-11-89	—	—	—	—	—	—	<20	70	—	<10	—	—	—	—
08-22-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
09-14-89	—	—	—	—	—	—	<20	80	—	<10	—	—	—	—
06-02-90	—	—	—	—	—	—	<20	70	—	<10	—	—	—	—
09-17-91	<50	—	30	<0.5	<10	<10	<30	13	20	<10	<50	<20	<.1	<10
06-17-92	—	—	—	—	—	—	<20	30	—	<10	—	—	—	—

[1]Concentration is dissolved.
[2]Concentration is total.

Table 19. Selected properties and chemical constituents in water from springs in the Castlegate Sandstone, Carbon County, Utah, during and after longwall mining

[See fig. 6 for site location; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data; <, less than]

		Selected properties and common constituents													
Site	Date	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
238	08-19-88	235	8.7	10.0	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	245	8.3	8.0	188	200	63	13	1	2	229	—	4	2	<.1
	06-05-89	320	8.5	4.0	124	202	42	9	1	1	151	—	12	1	.1
	07-11-89	360	8.5	9.0	160	202	61	13	2	1	195	—	16	1	<.1
	08-22-89	380	8.3	7.0	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	400	8.3	8.0	184	208	56	12	2	1	220	2	8	<1	.1
	05-30-90	400	7.2	6.0	187	226	63	10	2	1	221	3.6	2	2	—
	09-18-91	420	7.9	5	182	224	61	12	2	1	182	0	25	<1	.1
	06-11-91	370	7.2	5	188	176	58	10	1	1	176	12	10	2	—
	06-17-92	407	7.38	5	184	218	73	9	1	1	184	0	45	<1	—
494	08-19-88	290	8.2	9.0	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	280	7.7	6.4	200	264	67	25	3	<1	244	—	41	4	.1
	06-05-89	380	8.3	16.0	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	460	8.1	8.0	—	—	—	—	—	—	—	—	—	—	—
	06-04-90	450	7.7	11.0	—	—	—	—	—	—	—	—	—	—	—
	07-18-91	500	8.41	8	—	—	—	—	—	—	—	—	—	—	—
[1]492	06-05-89	350	7.7	5.0	148	220	43	17	2	<1	181	—	10	3	.2
	07-11-89	380	8.2	6.0	176	232	56	18	3	1	215	—	16	2	<.1
	08-22-89	350	7.5	5.0	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	390	7.7	5.0	186	204	45	18	3	<1	227	—	6	1	.1
	06-04-90	390	7.5	4.0	190	200	53	19	3	<1	232	0	6	2	.2
	09-18-91	420	8.0	7.0	186	224	50	18	2	<1	186	0	12	2	.2
	06-13-91	390	7.33	4.0	194	250	50	20	7	<1	178	16	27	1	—
	06-17-92	389	7.57	5.3	186	200	50	19	3	<1	186	0	33	2	—
500	08-19-88	280	7.6	9.0	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	290	8.4	7.5	213	236	59	21	2	1	260	—	<2	2	<.1
	06-06-89	690	7.7	6.0	190	234	56	19	2	1	232	—	8	3	.2
	07-11-89	540	7.6	7.0	216	268	73	22	2	1	264	—	16	2	—
	08-22-89	490	7.5	6.0	—	—	—	—	—	—	—	—	—	—	—
	Dry in 1990, 1991, and 1992														

Table 19. Selected properties and chemical constituents in water from springs in the Castlegate Sandstone, Carbon County, Utah, during and after longwall mining—Continued

		Trace elements													
Site	Date	Aluminum, total (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Man-ganese (µg/L)	Molyb-denum (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Zinc, total (µg/L)
238	08-19-88	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	[2]<50	70	<20	<5	<10	[2]<10	40	1,360	<20	[3]30	<50	[2]<20	[2]<1	10
	06-05-89	[2]<50	90	<20	<5	<10	[2]<10	30	960	<20	<10	<50	[2]<20	[2]<1	<10
	07-11-89	260	40	<20	<5	<10	[2]10	<20	270	<20	<10	<50	[2]<20	[2]<1	<10
	08-22-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	[2]<50	260	<20	8	<10	[2]<10	<20	1,020	<20	<10	<50	[2]<20	[2]<1	30
	05-30-90	—	—	—	—	—	—	30	580	—	<10	—	—	—	—
	06-11-91	—	—	—	—	—	—	<2	<5	—	<1	—	—	—	—
	09-18-91	5		8	2	<.5	<1	<1	7	71	2	<1	5	2	.13
	06-17-92	—	—	—	—	—	—	<2	<2	—	<1	—	—	—	—
494	08-19-88	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	[2]<50	10	<20	<5	<10	[2]<10	<20	470	<20	[3]10	<50	[2]20	[2]2	20
	06-05-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	07-18-92	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	06-29-92	—	—	—	—	—	—	—	—	—	—	—	—	—	—
[1]492	06-05-89	<50	20	20	<5	<10	[2]<10	<20	200	<20	<10	<50	[2]<20	[2]<1	20
	07-11-89	<50	10	<20	<5	<10	[2]<10	<20	240	<20	<10	<50	[2]<20	[2]<1	30
	08-22-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	<50	190	<20	<5	<10	[2]10	<20	320	<20	<10	<50	[2]<20	[2]<1	10
	06-04-90	[2]<50	20	<20	<10	<10	[2]<10	<20	130	<20	<10	<50	[2]<20	[2]<1	10
	06-13-91	—	—	—	—	—	—	<2	<2	—	<1	—	—	—	—
	09-18-91	11		2	<2	<.5	<1	<1	18	46	<2	<1	5	2	.11
	06-17-92	—	—	—	—	—	—	<2	<8	—	<1	—	—	—	—
500	08-19-88	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	[2]<50	30	<20	<5	<10	[2]<10	<20	50	<20	[3]<10	<50	220	[2]<1	10
	06-06-89	[2]<50	30	<20	<5	<10	[2]<10	<20	20	<20	[3]<10	<50	[2]<20	[2]<1	<10
	07-11-89	—	—	—	—	—	—	<20	250	—	<10	—	—	—	—
	08-22-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Dry in 1990, 1991, and 1992														

[1] Spring was added to sampling schedule after longwall mining began.
[2] Concentration is dissolved.
[3] Concentration is total.

Table 20. Selected properties and chemical constituents in water from springs in the Price River Formation, Carbon County, Utah, during and after longwall mining

[See fig. 6 for site location; concentration is dissolved unless otherwise noted; µS/cm microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data; <, less than]

		Selected properties and common constituents													
Site	Date	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Cerbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)
S149	08-20-88	318	7.5	6.0	—	—	—	—	—	—	—	—	—	—
	09-10-88	330	9.0	8.0	248	294	95	20	3	1	303	—	91	2
	06-05-89	460	7.3	5.0	—	—	—	—	—	—	—	—	—	—
	07-11-89	520	7.5	6.0	—	—	—	—	—	—	—	—	—	—
	08-22-89	520	7.2	6.0	—	—	—	—	—	—	—	—	—	—
	09-14-89	510	7.3	6.0	—	—	—	—	—	—	—	—	—	—
	05-30-90	410	7.0	7.0	—	—	—	—	—	—	—	—	—	—
	05-19-92	552	7.58	5.1	258	322	90	19	3	1	258	0	54	1
	06-12-92	500	7.19	4	240	324	70	13	2	1	220	20	14	3
	09-17-92	490	8.2	7	246	298	79	16	3	<100	246	0	19	1
S182	08-19-88	260	7.3	11.5	—	—	—	—	—	—	—	—	—	—
	09-05-88	270	7.6	11.5	169	208	57	13	3	1	206	—	23	4
	06-05-89	230	7.1	9.0	118	202	38	9	3	<1	144	—	10	4
	07-11-89	360	7.5	11.0	156	222	57	12	4	2	190	—	21	3
	08-22-89	350	7.5	6.0	—	—	—	—	—	—		—	—	—
	09-15-89	400	7.9	7.0	164	206	56	13	4	<1	200	—	21	2
	06-04-90	340	6.1	6.0	145	226	50	10	4	<1	177	0	14	3
229	06-05-89	340	7.0	4.0	130	214	46	6	1	<1	159	—	6	1

		Trace elements													
Site	Date	Aluminum, total (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Manganese (µg/L)	Molybdenum (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Zinc, total (µg/L)
S149	09-10-88	—	—	—	—	—	—	<20	20	—	[1]10	—	—	—	—
	06-12-91	—	—	—	—	—	—	<20	<20	—	<10	—	—	—	—
	09-17-91	<50	70	20	<5	<10	<10	60	310	<20	<10	<50	<20	<1	<10
	05-19-92	—	—	—	—	—	—	<20	<20	—	<10	—	—	—	—
S182	09-05-88	—	—	—	—	—	—	30	30	—	[1]<10	—	—	—	—
	06-05-89	—	—	—	—	—	—	30	50	—	<10	—	—	—	—
	07-11-89	—	—	—	—	—	—	<20	30	—	<10	—	—	—	—
	09-15-89	—	—	—	—	—	—	<20	40	—	<10	—	—	—	—
	06-04-90	—	—	—	—	—	—	30	130	—	<10	—	—	—	—
	07-02-90	—	—	—	—	—	—	<20	50	—	<10	—	—	—	—
	10-03-90	—	—	—	—	—	—	<20	50	—	<10	—	—	—	—
229	06-05-89	—	—	—	—	—	—	<20	30	—	<10	—	—	—	—
	06-11-91	—	—	—	—	—	—	<20	<20	—	[1]<10	—	—	—	—

[1]Concentration is total.

Table 21. Selected properties and chemical constituents in water from springs in the North Horn Formation, Carbon County, Utah, during and after longwall mining

[See fig. 6 for site location; concentration is dissolved unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data; <, less than]

		Selected properties and common constituents													
Site	Date	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Alkalinity (mg/L as $CaCO_3$)	Dissolved solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
232	06-05-89	380	7.2	4.0	150	168	54	8	1	1	183	—	10	2	0.2
	05-30-90	280	6.8	6.0	192	208	58	8	2	1	234	0	2	2	.1
	07-06-90	350	7.9	8.0	168	188	65	9	2	1	205	—	12	2	.1
	08-22-90	310	7.8	14.0	—	—	—	—	—	—	—	—	—	—	—
	06-12-91	300	7.2	4.0	134	200	47	8	6	2	154	5	29	2	—
	07-15-91	370	—	20.0	206	206	74	5	2	<1	251	—	<2	1	—
	06-17-92	360	7.1	5.1	170	198	65	8	2	1	170	0	35	<1	—
753	06-05-89	370	7.6	6.0	166	242	62	9	1	1	203	—	<2	1	—
	08-22-89	420	8.2	6.0	—	—	—	—	—	—	—	—	—	—	—
	05-30-90	370	7.5	2.0	202	226	71	9	2	2	246	0	2	2	—
	07-02-90	440	8.0	8.0	238	234	81	11	1	1	290	—	33	1	—
	06-12-91	390	7.2	4.0	186	192	58	8	1	2	207	10	10	3	—
	09-18-91	500	7.9	6.0	254	282	82	24	2	1	310	—	2	2	<.1
	05-19-92	425	7.7	7.1	220	230	75	10	1	1	220	0	37	<1	—
978	08-19-88	260	7.2	7.0	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	215	7.6	7.0	240	244	79	15	2	1	293	—	12	2	—
	06-06-89	430	7.4	5.0	216	228	69	12	2	1	264	—	6	2	—
	07-11-89	450	7.4	7.0	216	262	79	15	3	1	261	—	8	1	—
	08-22-89	430	7.2	7.0	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	480	7.3	7.0	230	248	74	15	2	<1	281	—	10	1	—
	05-30-90	430	7.9	5.0	224	258	78	13	2	<1	273	0	6	2	—
	07-02-90	460	7.8	6.0	225	232	74	13	2	1	275	—	25	2	—
	08-30-90	480	7.5	6.0	—	—	—	—	—	—	—	—	—	—	—
	10-03-90	380	7.1	4.0	233	250	86	13	3	<1	284	—	16	1	—
	06-12-91	510	7.2	3.0	208	308	68	13	6	<1	234	10	21	3	—
	07-16-91	440	7.1	6.0	224	242	77	10	3	<1	273	—	6	2	—
	09-18-91	460	7.8	8.0	222	260	69	25	4	<1	271	—	16	<1	<.1
	05-19-92	478	7.3	4.7	230	258	74	13	2	1	230	0	41	<1	—

Table 21. Selected properties and chemical constituents in water from springs in the North Horn Formation, Carbon County, Utah, during and after longwall mining—Continued

		Trace elements													
Site	Date	Aluminum, total (µg/L)	Barium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium, total (µg/L)	Copper, total (µg/L)	Iron (µg/L)	Iron, total (µg/L)	Lead, total (µg/L)	Man-ganese (µg/L)	Molyb-denum (µg/L)	Nickel, total (µg/L)	Selenium, total (µg/L)	Zinc, total (µg/L)
232	06-05-89	[1]170	80	<20	<5	<10	[1]<10	60	1,920	<20	<10	<50	[1]<20	[1]<1	10
	05-30-90	160	60	30	<10	[1]<10	[1]<10	130	560	<20	<10	<50	[1]<20	[1]<1	10
	07-06-90	[1]<50	60	<20	<10	—	[1]<10	20	1,030	<20	<10	<50	[1]<20	[1]1	10
	06-12-91	—	—	—	—	—	—	30	230	—	[2]<10	—	—	—	—
	07-15-91	—	—	—	—	—	—	<20	20	—	[2]<10	—	—	—	—
	06-17-92	—	—	—	—	—	—	<20	22	—	<10	—	—	—	—
753	06-05-89	—	—	—	—	—	—	<20	160	—	<10	—	—	—	—
	08-22-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	05-30-90	—	—	—	—	—	—	<20	90	—	<10	—	—	—	—
	07-02-90	—	—	—	—	—	—	<20	50	—	<10	—	—	—	—
	06-12-91	—	—	—	—	—	—	<20	<20	—	—	—	—	—	—
	09-18-91	<50	80	<20	<5	<10	<10	300	310	<20	180	<50	<20	[1]<1	10
	05-19-92	—	—	—	—	—	—	<20	<20	—	<10	—	—	—	—
978	08-19-88	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-05-88	—	—	—	—	—	—	30	730	—	[1]20	—	—	—	—
	06-06-89	—	—	—	—	—	—	<20	<20	—	<10	—	—	—	—
	07-11-89	—	—	—	—	—	—	<20	<20	—	<10	—	—	—	—
	08-22-89	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	09-15-89	—	—	—	—	—	—	50	840	—	<10	—	—	—	—
	05-30-90	—	—	—	—	—	—	<20	70	—	<10	—	—	—	—
	07-02-90	—	—	—	—	—	—	<20	60	—	<10	—	—	—	—
	10-03-90	—	—	—	—	—	—	<20	<20	—	<10	—	—	—	—
	06-12-91	—	—	—	—	—	—	<20	<20	—	—	—	—	—	—
	07-16-91	—	—	—	—	—	—	<20	<20	—	—	—	—	—	—
	09-18-91	—	50	30	—	—	<10	30	50	<20	<10	<50	<20	[1]<1	<10
	05-19-92	—	—	—	—	—	—	<20	<20	—	<10	—	—	—	—

[1] Concentration is dissolved.
[2] Concentration is total.

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