Hydrologic conditions and water-quality conditions following underground coal mining in the North Fork of the Right Fork of Miller Creek drainage basin, Carbon and Emery Counties, Utah, 2004–2005

Prepared in Cooperation with the
BUREAU OF LAND MANAGEMENT

Scientific Investigations Report 2007-5026

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of Miller Creek drainage area, Carbon and Emery Counties, Utah.
Taken by C.D. Wilkowske on September 16, 2004.

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U.S. Geological Survey

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in)	25,400	micrometer (µm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Precipitation rate	
inches per year (in/yr)	0.003861	centimeters per year (cm/yr)
	Volume	
ounce, fluid (fl. oz)	0.02957	liter (L)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Latitude, degrees north, and longitude, degrees west are referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water is reported either in milligrams per liter (mg/L), micrograms per liter (µg/L), or milliequivalents per liter (meq/L).

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By C.D. Wilkowske, and J.L. Cillessen, U.S. Geological Survey; and P.N. Brinton, U.S. Bureau of Land Management

Abstract

In 2004 and 2005, the U.S. Geological Survey, in cooperation with the Bureau of Land Management, reassessed the hydrologic system in and around the drainage basin of the North Fork of the Right Fork (NFRF) of Miller Creek in Carbon and Emery Counties, Utah. The reassessment occurred 13 years after cessation of underground coal mining that was performed beneath private land at shallow depths (30 to 880 feet) beneath the NFRF of Miller Creek. This study is a follow-up to a previous USGS study of the effects of underground coal mining on the hydrologic system in the area from 1988 to 1992. The previous study concluded that mining related subsidence had impacted the hydrologic system through the loss of streamflow over reaches of the perennial portion of the stream, and through a significant increase in dissolved solids in the stream. The previous study also reported that no substantial differences in spring-water quality resulted from longwall mining, and that no clear relationship between mining subsidence and spring discharge existed.

During the summers of 2004 and 2005, the USGS measured discharge and collected water-quality samples from springs and surface water at various locations in the NFRF of Miller Creek drainage basin, and maintained a streamflow-gaging station in the NFRF of Miller Creek. This study also utilized data collected by Cyprus–Plateau Mining Corporation from 1992 through 2001.

Of thirteen monitored springs, five have discharge levels that have not returned to those observed prior to August 1988, which is when longwall coal mining began beneath the NFRF of Miller Creek. Discharge at two of these five springs appears to fluctuate with wet and dry cycles and is currently low due to a drought that occurred during 1999–2004. Discharge at two other of the five springs did not increase with increased precipitation during the mid-1990s, as was observed at other monitored springs. This suggests that flowpaths to these springs may have been altered by land subsidence caused by underground coal mining. Analysis of possible impacts to the fifth spring were inconclusive due to a lack of data collected during the mid-1990s. Discharge at eight other monitored springs in the study area appears to be controlled mainly by climatic fluctuations and was generally near the value measured prior to 1988. Discharge at one of these eight springs is significantly greater than that measured during the longwall mining period. Concentrations of magnesium, calcium, sulfate, and dissolved solids at one undermined spring were elevated in relation to other springs in the study area. Dissolved-solids concentration at this spring ranged from 539–709 milligrams per liter. Dissolved-solids concentration for all other springs in the study area ranged from 163 to 360 milligrams per liter and was near the median value measured prior to longwall mining beneath the NFRF of Miller Creek drainage basin.

Baseflow measured at a streamflow-gaging station on the NFRF of Miller Creek located downstream of the mined area during the summer of 2004 was near 5 gallons per minute. Baseflow in 2005 increased to 7–8 gallons per minute, due to increased precipitation. This is slightly greater than the range of baseflow measured near the end of the longwall mining period which was approximately 3–5 gallons per minute.

Seepage investigations carried out in the summer of 2004 and 2005 along the NFRF of Miller Creek showed a net loss of surface flow along the studied reach. Specific areas within the study reach had streamflow losses prior to longwall mining; however, the study reach as a whole was observed to gain in discharge when measured in 1986–1988, immediately before longwall mining began. The area where the greatest loss in discharge from the NFRF of Miller Creek occurred corresponds to an area where overburden (material overlying a deposit of useful geological materials or bedrock) is between 210 and 700 feet thick. Overburden thickness at the place where the streambed first dried up was approximately 600 feet thick. In 2004, approximately 1,600 feet of the streambed of the NFRF of Miller Creek was dry. Only 300 feet of the streambed was dry during the wetter year of 2005. Prior to longwall mining, no dry reaches were observed, though seepage loss was documented. Average discharge measured at a tributary to the NFRF of Miller Creek has increased from 1.6 gallons per minute measured during longwall mining to 7.2 gallons per minute measured in 2004–2005. During both years of this study, the lower reach of the stream regained flow from this tributary and from seepage gains.

Water quality in the lower reach of the NFRF of Miller Creek downstream of the longwall-mined area showed significantly higher concentrations of magnesium, calcium, sulfate, and strontium, in relation to water in the upper reach of the NFRF of Miller Creek and to the springs sampled in the area.

Dissolved-solids concentration measured in the lower reach of the stream in 2004 and 2005 ranged from 1,880 to 2,220 milligrams per liter, while sulfate concentrations ranged from 1,090 to 1,320 mg/L. The maximum contaminant level for drinking water in the State of Utah for dissolved solids and sulfate is 2,000 and 1,000 mg/L respectively. Concentrations of these ions are slightly greater than those measured during and just following mining beneath the NFRF of Miller Creek drainage basin, but are significantly higher than those measured prior to mining. With the exception of strontium, dissolved metal concentrations in the NFRF of Miller Creek were similar to those measured in area springs. Values of pH in the creek and at all spring sites were near neutral. Qualitative observations of the creek bottom suggest that mining-related activities have had little effect on vegetative growth.

Introduction

The effects of underground coal-mining-related land subsidence on overlying hydrologic systems generally are complex and poorly understood, particularly when the depth of overburden is shallow (less than 500 ft). From 1988 to 1992, the U.S. Geological Survey (USGS) in cooperation with the Utah Department of Natural Resources, Division of Oil, Gas, and Mining (UDOGM), studied the effects of underground coal mining and the resulting land subsidence on the hydrologic system near the North Fork of the Right Fork (NFRF) of Miller Creek in Carbon and Emery Counties, Utah (*fig. 1*). This initial study was documented in a USGS report by Slaughter and others (1995). From 2004 to 2005, the USGS, in cooperation with the Bureau of Land Management (BLM), conducted a study that reassessed the hydrologic system 13 years after the completion of longwall mining. This study compared hydrologic conditions in 2004–2005 to those observed prior to longwall mining underneath the NFRF of Miller Creek, and to those reported during 1988–1992 by Slaughter and others (1995). This study provides additional data on the long-term effects of longwall coal mining conducted at shallow-to-moderate depths (50 to 1,000 ft) of overburden on surrounding hydrologic systems. Overburden refers to material overlying a deposit of useful geological materials or bedrock. Results will assist the BLM and UDOGM in managing and understanding the effects of mining in this and other watersheds.

Background

Longwall mining essentially involves complete removal of coal from large, rectangular (longwall) blocks or “longwall panels.” The rectangular longwall panel is “blocked out” by excavating passageways around its perimeter using traditional room and pillar methods. This process is known as “development mining.” The coal is removed from the longwall blocks by a coal-cutting machine that runs back and forth along the face of the panel, taking a cut of coal with each pass (*fig. 2*). The cut coal falls onto a conveyor running along the entire length of the panel and is transported from the mine. During coal removal, the roof in the mined area is supported by hydraulic, movable roof supports. As the coal-cutting machine advances, the supports are moved to prop up the freshly exposed roof. The roof is allowed to collapse behind the supports as they are advanced toward the coal panel face (Energy Information Administration, 1995). In addition to full-extraction mining by longwall methods, areas originally mined by room-and-pillar methods can also be completely extracted.

Coal Mining in the Study Area

In the study area, coal was removed from the Wattis seam and from the Third seam, which underlies the Wattis seam by less than 100 ft (Slaughter and others, 1995). The coal was removed using both longwall-mining and conventional room-and-pillar methods. The mining below the NFRF of Miller Creek drainage basin took place between August 1988 and November 1991. The Wattis Seam was mined by longwall methods in this area from August 1988 to early April 1990, and the underlying Third Seam was longwall mined from late December 1990 to November 1991.

Prior to and following coal extraction from beneath the NFRF of Miller Creek drainage basin, mining occurred in a number of adjacent areas (*fig. 3*). The locations and sequence of mining were determined from mine-working maps (Cyprus–Plateau Mining Corporation, 1986; 1990; 1993a, b; 1995). During the 1950s, the Wattis Mine was developed in the Wattis Seam in an area east of the NFRF of Miller Creek using room-and-pillar methods which included some full-extraction mining. During the 1970s and 1980s, the U.S. Fuel Company operated the King No. 4 Mine (or Hiawatha Mine) using full-extraction room and pillar methods in the Wattis Seam directly to the south and southwest of the NFRF of Miller Creek. The latest known mining in this area occurred in early 1987. From 1981 to 1985, the Cyprus–Plateau Mining Corporation mined a group of longwall panels in the central and north-central portion of the study area. Other room-and-pillar mining to the north of these panels occurred from 1989 to 1991, concurrent with the mining beneath the NFRF of Miller Creek drainage basin. Two groups of multiple adjacent longwall panels located over 1 mile to the west and southwest of the study area also were mined from 1990 to the mid-1990s. Mining of the Third Seam, primarily by partial extraction room-and-pillar mining methods, took place in the area directly to the north of the NFRF of Miller Creek prior to 1990.

Underground-mine leases issued by the BLM on public-owned land generally require at least 500 ft of overburden for longwall-coal mining beneath perennial streams (Jeff McKenzie, Bureau of Land Management, oral commun., 2006). Mining occurred beneath the NFRF of Miller Creek at depths shallower than 500 ft, and was conducted under privately owned land. Mining in the Wattis seam removed blocks that were up

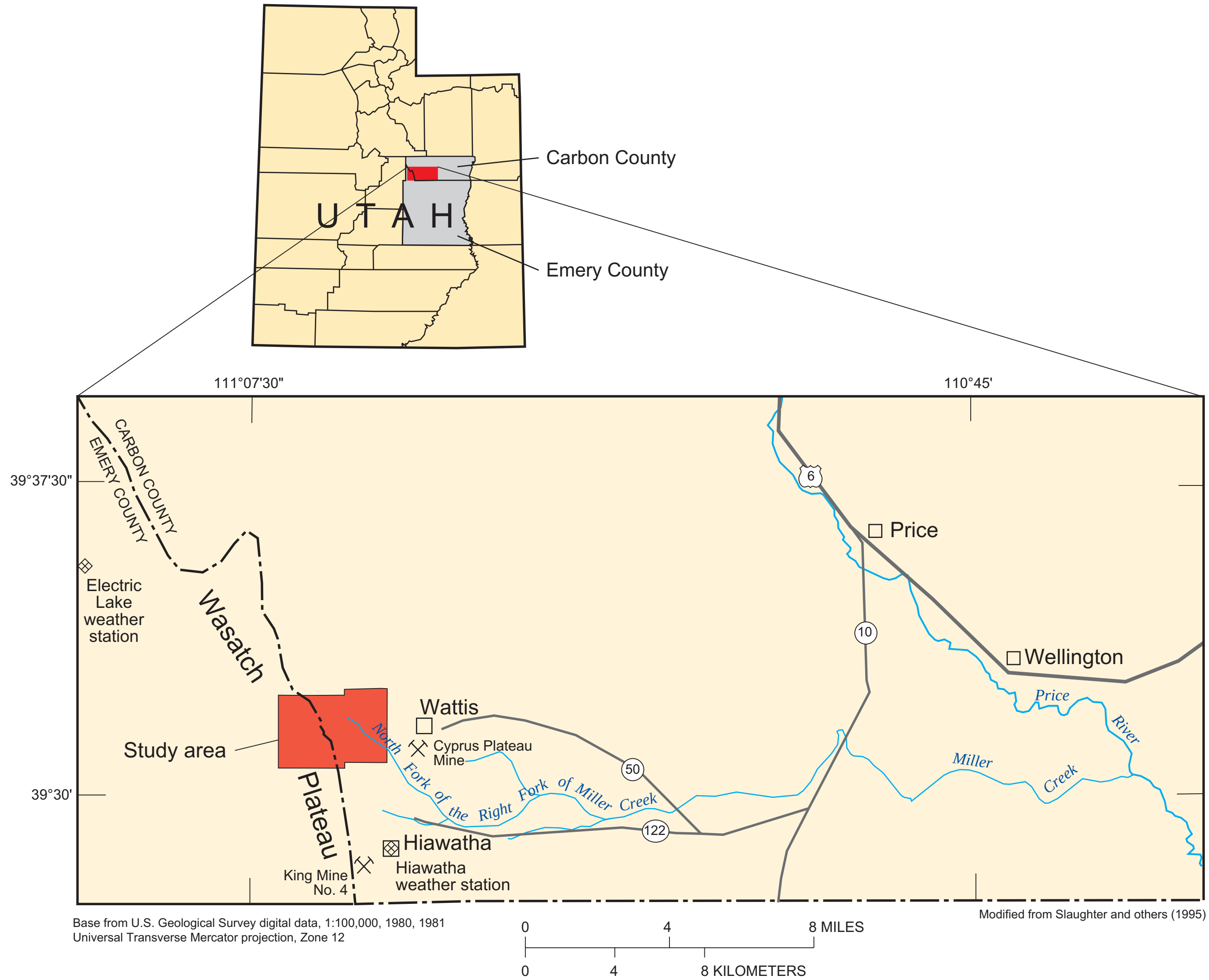


Figure 1. Location of the North Fork of the Right Fork of Miller Creek study area, Carbon and Emery Counties, Utah.

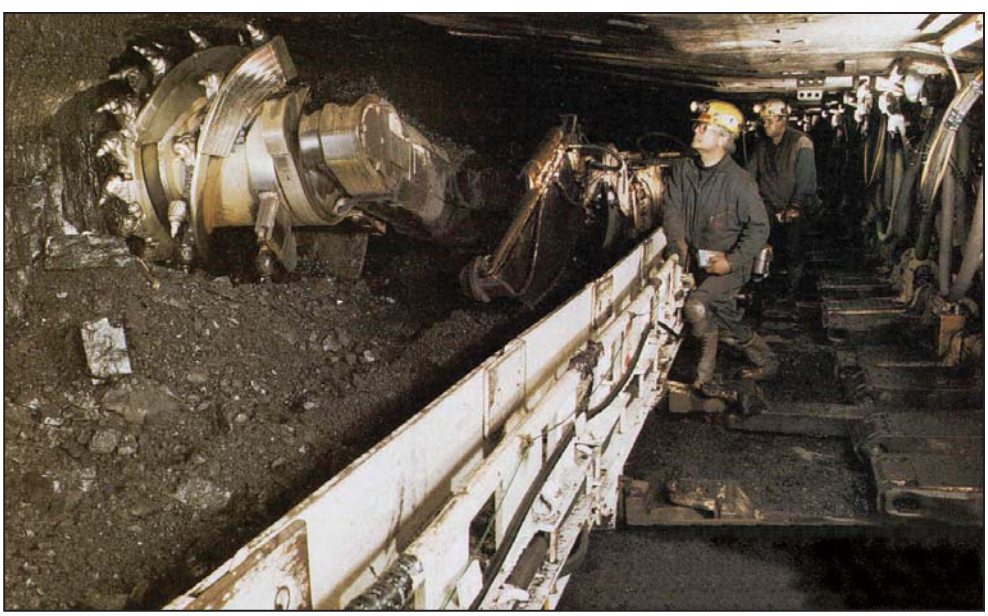

Photograph by Energy Information Administration, 1995

Figure 2. A longwall coal mining machine mining coal.

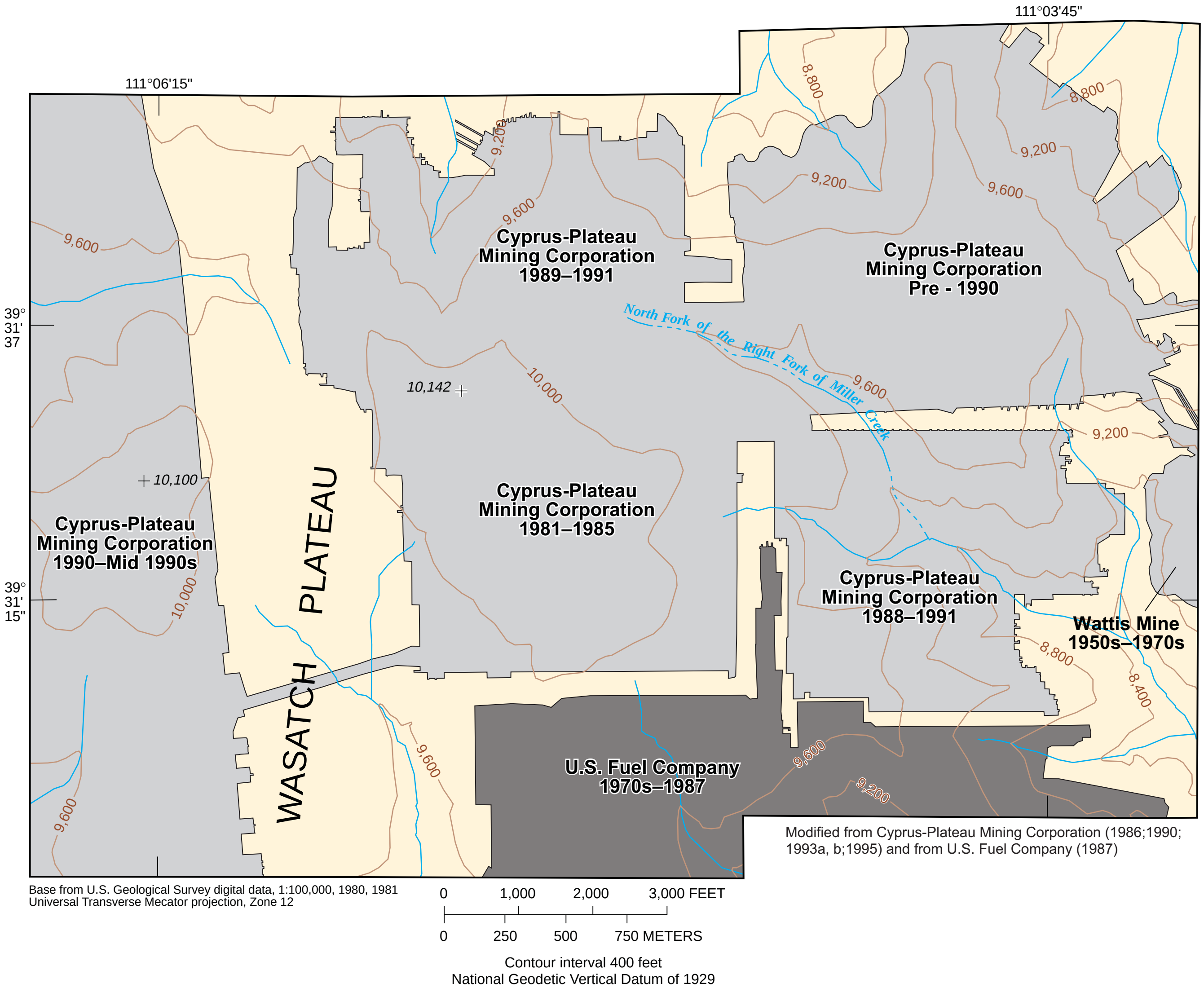
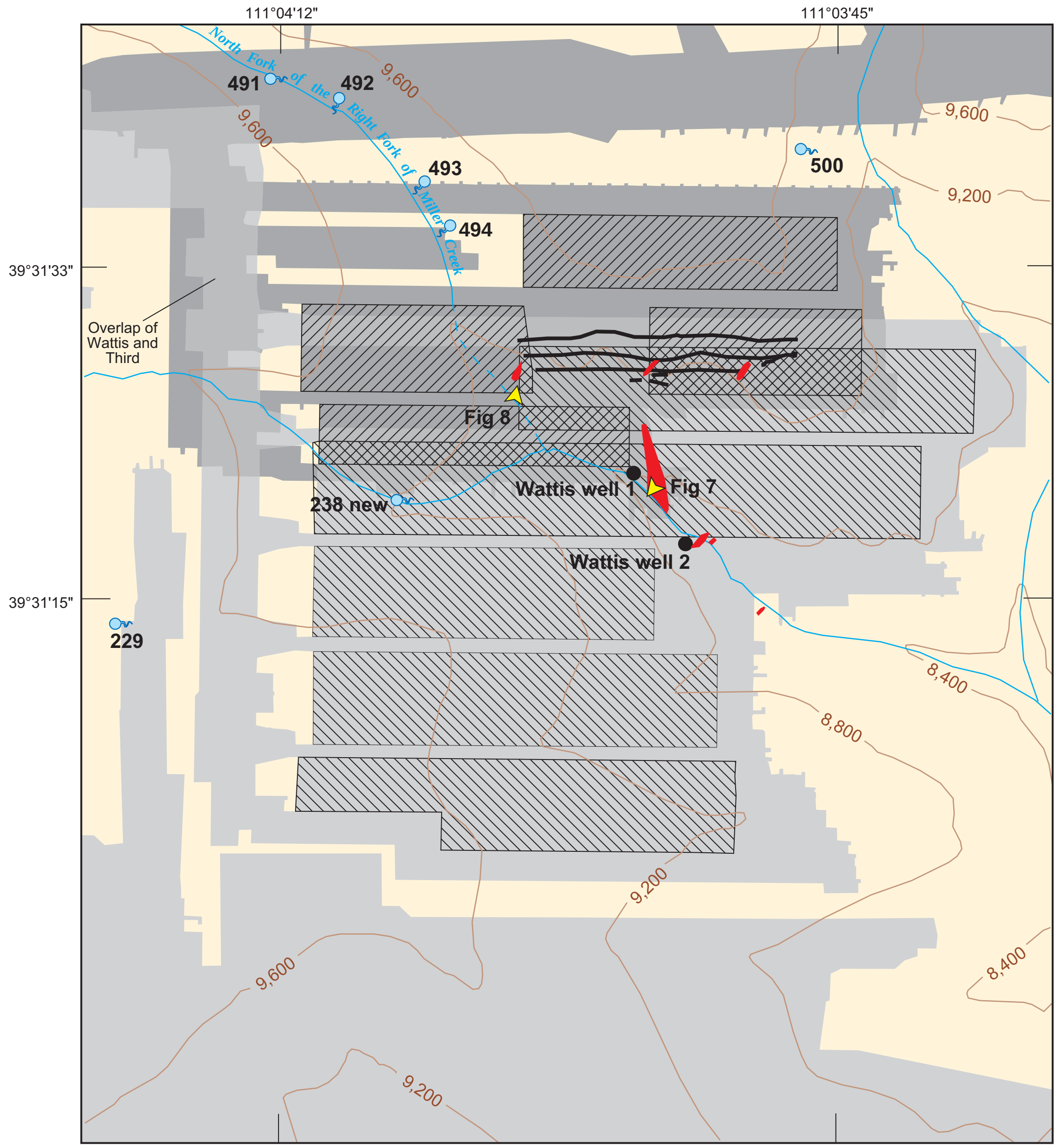


Figure 3. Areal extent of underground coal mining in the North Fork of the Right Fork of Miller Creek drainage basin, Carbon and Emery Counties, Utah, 1981-present.

to 500 ft wide and 4,000 ft long (*fig. 4*). As part of the permitting process, Cyprus–Plateau Mine personnel were required to monitor the hydrologic system in and around the mined area. Data that were collected in compliance with this permit from 1988 through June 1992 were published in Slaughter and others (1995). Data collected from July 1992 through 2001 by Cyprus–Plateau Mine were submitted to UDOGM and are published in this report.

Soon after mining began underneath the NFRF of Miller Creek in 1988, land surface in the study area started to subside. As of September 1991, land surface dropped as much as 6.5 ft vertically and moved as much as 8.5 ft horizontally in the area surveyed by Slaughter and others (1995). The vertical motion was a direct result of the subsidence and collapse of the mine roof caused by the removal of coal. The horizontal motion was due to rotational slumping of blocks from cliff faces at land surface. This movement opened fractures at the land surface, and caused debris slides and rockfalls in the canyon above the mined area (*fig. 4*). Debris from a large rock fall knocked over trees and removed soil from part of the canyon slope. This rock fall deposited sediment, boulders, and trees into a section of the NFRF of Miller Creek. The largest surface fractures were backfilled by the Cyprus–Plateau Mining Corporation; however, some of the water in the NFRF of Miller Creek was diverted through fractures into the subsurface. Monitoring wells in a perched aquifer over the mine showed a water-level rise followed by water-level declines that coincided with the subsidence. Water also began discharging into the mine in greater-than-normal quantities. Seepage studies done in the NFRF of Miller Creek during and after longwall mining indicated that water was being lost along certain parts of the drainage. The location of the seepage loss coincided with the area where longwall mining took place beneath the stream (Slaughter and others, 1995). The seepage investigation also indicated that the stream gained water at a location further downstream.



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

Modified from from Cyprus-Plateau Mining Corporation (1986; 1990; 1993 a, b; 1995)

0 500 1,000 FEET
0 100 200 300 METERS

CONTOUR INTERVAL 400 FEET
National Geodetic Vertical Datum of 1929

EXPLANATION

Longwall coal seam panels
- Wattis
- Third

Extent of mining
- Wattis
- Third

Debris slide

Surface fracture

Wattis well 2 — **Well**

753 — **Spring**

Fig 7 — **Site and direction of photograph**—Number corresponds to figure number in this report

Figure 4. Approximate location of springs, surface fractures, and debris slides in relation to the mined-out longwall panels below the North Fork of the Right Fork of Miller Creek, Carbon County, Utah.

Water collected from the NFRF of Miller Creek from 1988 to 1991 at a location downstream of the mined area showed an increase in dissolved solids from about 300 mg/L before longwall mining to more than 1,500 mg/L after the mining. No definite relationship between mining-related subsidence and spring discharge or water quality from the Blackhawk Formation, Castlegate Sandstone Formation, Price River Formation, and North Horn Formation could be shown at the time of the previous study (Slaughter and others, 1995).

Purpose and Scope

This report documents hydrologic data collected by the USGS from streams and springs in the NFRF of Miller Creek drainage basin in 2004 and 2005. It describes the methods used to collect and analyze those data and presents the results of the analyses. This report also documents water quality and discharge data that were collected from 1992 to 2001 by the Cyprus–Plateau Mining Corporation and reported to UDOGM. This report utilizes all of these data to summarize the long-term effects of longwall mining on the hydrologic system within the NFRF of Miller Creek drainage basin.

Description of the Study Area

The study area is located on the eastern side of the Wasatch Plateau in Carbon and Emery Counties in central Utah (*fig. 1*). The main focus of this investigation is in the upper part of the drainage basin of the NFRF of Miller Creek where coal was mined using the longwall-mining method during 1988–1991. However, springs near the NFRF of Miller Creek drainage basin also were studied to provide background data on hydrologic conditions in the surrounding area. For the purpose of this report ‘study area’ refers to the entire area shown in *figure 5*. The USGS site identifier, USGS station name, latitude, longitude, and underlying geologic formation for each site referenced in this report are listed in *table 1*.

Vegetation and Fracture Photos

During longwall mining, several fractures appeared at the land surface. Most of the larger fractures were filled in by the Cyprus–Plateau Mining Corporation after longwall mining finished. One such fracture opened up on a point of land just southwest of site 500 (*fig. 6*).

A landslide and rockfall occurred during the fall of 1988 that knocked down trees and scoured part of the drainage slope. Sediment, boulders, and trees were deposited in a section of the NFRF of Miller Creek just downstream from Wattis Well 1 (Slaughter and others, 1995) (*fig. 7*). Vegetation has grown around the large boulders; however, streamflow remains redistributed underneath the boulders. When the photo of *figure 7* was taken (September 13, 2005), water could be heard trickling beneath the rocks, but the volume could not be measured. No flow was observed in this area in 2004.

A landslide that occurred near site M–2.1 scoured the hillslope and knocked down trees. Many aspens, grasses, and wildflowers have grown in since the slide occurred (*fig. 8*). In general, the bottom of the drainage basin of the NFRF of Miller Creek remains heavily vegetated. No surface water was observed at site M-2.1 location in 2004 or 2005.

Geologic Setting

During the late Cretaceous period, sediment derived from highlands in western Utah was deposited in coastal-plain settings along shorelines of the western margin of the Cretaceous Western Interior Seaway. Sediments deposited in this setting include continental, coastal-plain, marginal-marine, and offshore-marine sequences (Dubiel, 2000). These deposits created the geologic formations that crop out in the study area. These formations include, from oldest to youngest, the Star Point Sandstone Formation, Blackhawk Formation, Castlegate Sandstone Formation, and Price River Formation, all of which are in the Cretaceous Mesa Verde Group. The North Horn Formation is transitional from the Cretaceous to the Tertiary.

The Star Point Sandstone Formation crops out in the lower reaches of the NFRF of Miller Creek and consists of layered shoreface sandstones that interbed with the underlying Mancos Shale Formation to the east and with the overlying Blackhawk Formation to the west (Dubiel, 2000) (*fig. 9*). The coal beds of the Wattis and Third seam that were mined using the longwall method in the study area are found just above the Star Point Sandstone Formation at the base of the Blackhawk Formation. Coal beds occur depositionally landward of the Star Point Sandstone Formation marine shoreface sandstones. They most likely were deposited in shallow, coastal lagoons and swamps (Dubiel, 2000). The Castlegate Sandstone Formation forms prominent cliffs in the study area and contains minor siltstones near its base. The Price River Formation and North Horn Formation are siltstones that are interbedded with sandstone. Slaughter and others (1995) noted numerous sets of north-south trending joints in exposed bedrock in the stream channel and on exposed outcrops. For a more detailed discussion on the geology of the study area and a history of coal mining in the area, see Slaughter and others (1995) or Dubiel (2000).

Hydrologic Setting

Water enters the subsurface as recharge in the higher altitudes of the study area. It travels downward through various rock formations until it discharges from springs or directly into the NFRF of Miller Creek. Perched aquifers can be found in the Blackhawk Formation over the coal beds. The majority of ground water most likely makes its way into a regional aquifer beneath the coal beds in the Star Point Sandstone Formation. During spring and early summer, snow melt is the main source of surface water in the NFRF of Miller Creek. During the rest of the year, the stream is at baseflow conditions, meaning

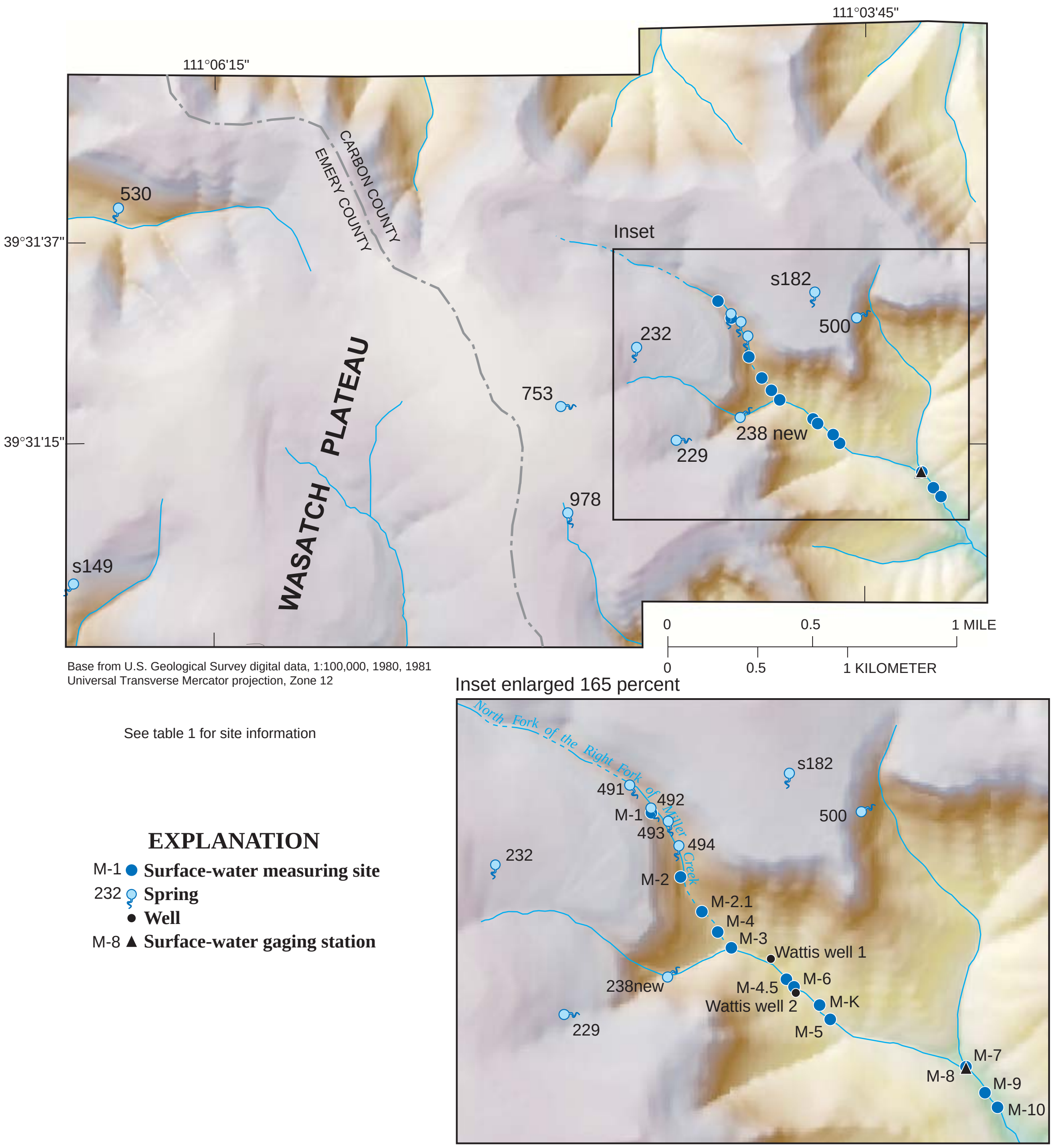
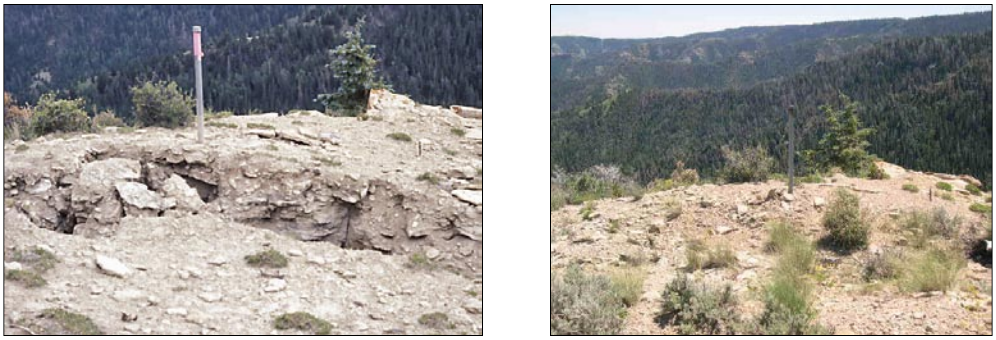


Figure 5. Location of the study area showing hydrologic monitoring sites in the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah.



1989 July 2005

Figure 6. Surface fracture southwest of site 500 created by longwall mining on a plateau above the North Fork of the Right Fork of Miller Creek, Carbon County, Utah.

Figure 7. Photo taken September 13, 2005, of a debris pile that resulted from a landslide near Wattis Well 1 during longwall mining in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 1988.

Figure 8. Photo taken September 13, 2005, showing new growth of vegetation covering a debris pile that resulted from a landslide near site M-2.1 during longwall mining in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 1988.

it receives the majority of its flow from springs and ground water that discharge directly into the creek.

Topography

The NFRF of Miller Creek begins perennial flow at site 491, a spring in the Castlegate Sandstone Formation, at an altitude of 9,450 ft (*fig. 4*). The creek then flows over shale, siltstone, and sandstone in the Wasatch Plateau as it makes its way to Miller Creek and eventually into the Price River (*fig. 9*). The altitude in the study area ranges from 8,300 ft to 10,142 ft.

Climate

The climate is semi-arid and precipitation increases with altitude. A weather station at Hiawatha, Utah, was used to measure precipitation at the study area (Slaughter and others, 1995). The Hiawatha weather station is located 3.5 mi southeast of the study area at an altitude of 7,280 ft. The collection of precipitation data at the Hiawatha weather station was discontinued in 1992; therefore, data from the Electric Lake weather station were used for this study. The Electric Lake weather station is located 10 mi northwest of the study area at an altitude of 8,380 ft (*fig. 1*). The average precipitation during 1971–1992 at the Hiawatha weather station was 14.10 in/yr. At the Electric Lake weather station, the average precipitation during 1971–2000 was 24.47 in/yr (Western Regional Climate Center, 2006). Yearly precipitation for the period immediately prior to longwall mining (1985–1987) measured at the Electric Lake and Hiawatha weather stations was near average, but transitioned into a dry period by 1988. For the period during the longwall mining (1988–1992), both weather stations indicate that the region received below-average precipitation. From 1992–1997, precipitation alternated from above average to below average at the Electric Lake weather station. From 1998–2000, precipitation again was above average. From 2001–2005, precipitation was below average at the Electric Lake weather station. These periods

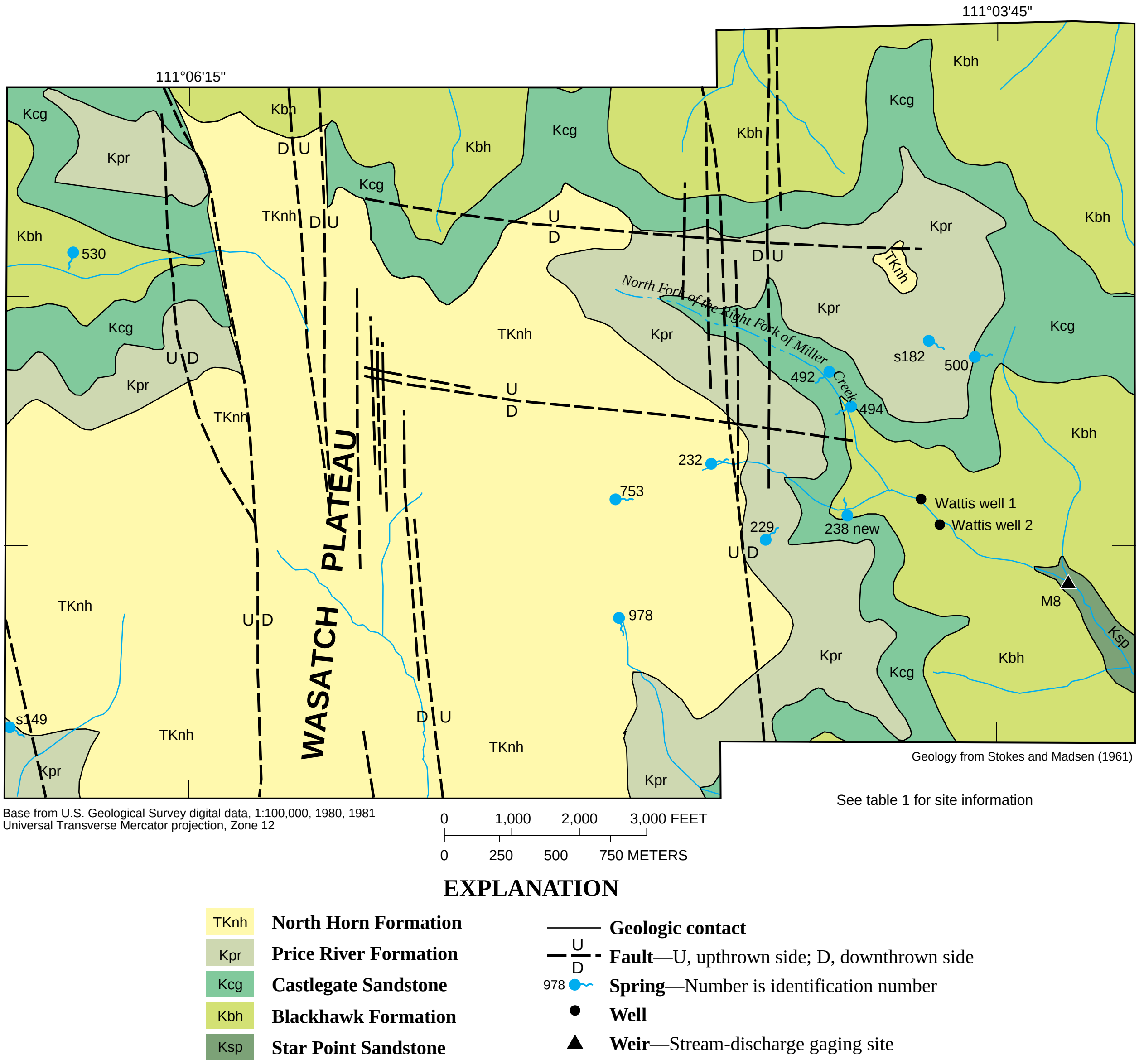


Figure 9. Location of geologic units and selected surface and ground-water monitoring sites in the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah.

of above- and below-average precipitation coincide with the Palmer Drought Severity Index for Utah (National Climatic Data Center, 2006), which indicates drought periods from 1986–1991 and from 1999–2004, with a wetter period in the interim.

Methods of Investigation

Water-quality samples were collected in 2004 and 2005 using standard USGS procedures (U.S. Geological Survey, variously dated). Because of the small discharge at the springs and in the NFRF of Miller Creek, samples either were collected by channeling water into cleaned and rinsed 1-liter plastic bottles and processed later the same day; or samples were collected by pumping and filtering directly from the water source (*fig. 10*). Samples collected for major ion and trace-element analysis were filtered through a 0.45-micrometer (µm) capsule filter. All samples were analyzed at the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Water temperature, specific conductance, pH, and dissolved oxygen measurements were made at each site using a multi-parameter meter. Water-quality and discharge data were collected at sites coincident with those sites reported in Slaughter and others (1995), with some additional sites monitored in the NFRF of Miller Creek in 2005. A replicate sample and a field blank sample were collected during each visit to the study area. Replicate analyses are shown in *table 2*. Results from field blanks are shown in *table 3*.

Sample site locations were determined by digitizing a Cyprus-Plateau Mining Corporation mining map (Cyprus–Plateau Mining Corporation, 1986) and determining the latitude

Figure 10. Water-quality sampling in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah.

and longitude from geographical information software (GIS). The sites were located in the field using a global positioning system (GPS). Heavily vegetated steep slopes in the drainage of the NFRF of Miller Creek often blocked the satellite signal, making precise determination of sample locations difficult. Due to this uncertainty, the area sampled near site 238 in the study by Slaughter and others (1995) is labeled in this report as site 238 new. Sites M–2.1 and M–4.5 are surface-water measurement locations that were added in 2004 and 2005 to better document surface-water flow and were not visited in any prior investigation.

Overburden thickness in this report was determined by subtracting the altitude of mine workings located below selected monitoring points from the surface altitude of those points. The approximate surface altitudes were determined from a topographic map with a 20-ft contour interval (Kucera and Associates, 1975). The altitude of mine workings was determined from Cyprus–Plateau Mining Corporation maps (Cyprus–Plateau Mining Corporation, 1986; 1990; 1993a, b; 1995).

In this report, the term “dissolved” refers to solutes detected in a water sample after it has passed through a 0.45-μm filter. Dissolved solids concentrations in this report refer to measurements derived from analysis of sample residue on evaporation (ROE) at 180°C. All constituents that are not detected in a water sample by the NWQL are reported as less than the minimum reporting level (MRL). The MRL is defined by the NWQL as the smallest concentration of a constituent that may be measured reliably using a given analytical method. Some concentrations are reported below the MRL if the detection criteria for the method were met. Concentrations for detections below the MRL are designated as estimated values.

All water-quality data collected in 2004 and 2005 by the USGS as a part of this study are in the USGS National Water Information System database for Utah available at *http://waterdata.usgs.gov/ut/nwis/qw*.

Water-quality samples and discharge measurements dated prior to 2004 were collected by the Cyprus–Plateau Mining Corporation as part of their monitoring requirements for the State of Utah pursuant to the Surface Mining Control and

Reclamation Act of 1977. Data collected prior to June 1992 were published previously by Slaughter and others (1995). Data from 1992–2001 were obtained from the Utah Division of Oil, Gas, and Mining (2004). The data are available in the Utah Coal Mining Water-Quality Database, available at *http://linux1.ogm.utah.gov/cgi-bin/appx-ogm.cgi*. No information regarding the methods of collection or analysis of these data is available.

Instantaneous discharge measurements were made at stream sites in the NFRF of Miller Creek using a portable 3-inch Modified Parshall Flume when sufficient flow was present. Flow was measured volumetrically using a calibrated water bottle and stopwatch at all other locations.

A V-notch weir was installed in the NFRF of Miller Creek at site M-8 from August 3, 2004, to November 4, 2004, and from June 29, 2005, to November 10, 2005. Gage height was recorded at 15-minute intervals using a calibrated pressure transducer. Discharge was calculated from the gage height data using a standard V-notch weir rating. Daily mean discharge values were calculated for days that had complete gage height record. Daily mean discharge was estimated for days with a partial record of gage height.

Gains or losses in streamflow in various reaches of the NFRF of Miller Creek were determined by measuring discharge at the upstream end of a reach and subtracting that discharge along with the tributary inflow from the discharge measured at the downstream end of the reach.

As reported in Slaughter and others (1995), an obstruction in Wattis Well 1 prevented measurement of water-levels. An attempt was made to monitor water-levels in Wattis Well 2; however, it is believed that the well has been sealed with a well packer (Cecil Slaughter, U.S. Geological Survey, written commun., 2006). Water-levels measured in this well, therefore, will not represent the true water-level in the aquifer.

Quality-Control Results

Differences in major ion concentrations for concurrent samples ranged from 0 to 10 mg/L. Percent difference between concurrent sample concentrations for major ions ranged from 0 to 20 percent. The concurrent samples collected on July 27, 2004, differed in the ROE value by 42 mg/L, or a difference of 18 percent. No analytical problems at the NWQL were documented for ROE during this time period (U.S. Geological Survey, 2006).

Excluding vanadium from the July 2004 concurrent pair, percent differences for trace metals ranged from 0 to 32 percent. Actual differences in measured constituents ranged from 0 to 23µg/L. Vanadium in the July 2004 replicate had a percent difference of 650 percent; however, this was due to a difference of only 1.3 µg/L. This suggests that the vanadium concentration measured at site s149 on July 29, 2004, may be within the range of error for this constituent.

With the exception of chloride and sulfate, no detections were found in any constituents analyzed in the field blanks. Chloride was detected in significant amounts (8.49 mg/L) in the blank collected in September 2005. A negligible concentration of sulfate (0.3 mg/L) was detected in the same blank sample. The amount of chloride measured in the blank sample exceeds the concentrations found in nearly all of the environmental samples. A secondary analysis of the blank sample by the NWQL returned the same result. Examination of independent testing of the blank water by the NWQL also revealed no contamination for the lot number of blank water used for this sample. The contamination found in the blank could be the result of improper cleaning of equipment, or contamination during sample collection and processing. Because the source of the contamination could not be determined, all chloride results collected in September 2005 should be used with caution.

Cation-anion balances for several samples collected in July 2005 had percent differences that were greater than 10 percent. For all of these samples, the bicarbonate concentration was significantly lower than samples collected at other times at the same locations. It is believed that the low bicarbonate values are the result of errors in the alkalinity titration and, therefore, these data have not been used in this report.

The cation-anion balance exceeded 30 percent for the sample collected on July 20, 2005, at site M-8, suggesting a problem with either the collection or analysis of this sample; therefore, the major ion analysis from this sample has not been reported.

Acknowledgements

The authors thank Steven Falk and Jeff McKenzie of the Bureau of Land Management for their assistance with field work, for providing data on mine overburden, and for reviewing this report. In addition, the authors thank UDOGM for providing valuable hydrologic data from the study area.

Thickness of Overburden

Slaughter and others (1995) gave a range of overburden thickness from 300 to 1,300 ft beneath the NFRF of Miller Creek drainage basin. A more detailed analysis of overburden thickness was done for this study using maps that were not previously available. Overburden thickness beneath the monitoring points in the NFRF of Miller Creek drainage basin varied from 30 to 910 ft (*table 4)*. The overburden thickness directly above longwall-panels that were located beneath the streambed ranged from approximately 210–760 ft. The shallowest mining was development mining and occurred in the area beneath site M-5. Mining at the head of the perennial portion of the NFRF of Miller Creek near spring site 491 was about 900 ft beneath the surface. The overburden thickness for mined areas in the western portions of the study area was generally greater than 1,000 ft (Cyprus–Plateau Mining Corporation, 1986; 1990; 1993a, b; 1995).

Hydrologic Conditions and Water Quality

During the summer and early fall of 2004 and 2005, hydrologic field investigations were done by the USGS at the NFRF of Miller Creek study area. During this time, 26 springs and surface water sites were visited (*fig. 5)*. Water-quality samples were collected at 20 of those sites. Field water-quality parameters and discharge were measured at each of the 26 sites. A streamflow-gaging station was installed to monitor discharge in the NFRF of Miller Creek at site M-8. Discharge measurements were made to determine gains or losses in streamflow twice during 2004 and twice during 2005 in the NFRF of Miller Creek.

Springs

Thirteen springs in the study area were monitored in 2004 and 2005. Discharge and water-quality field parameters were measured and recorded during each visit. A water-quality sample also was collected at each site during most visits. Most of the spring sites are outside of the area where shallow longwall mining occurred and were measured to provide background discharge and water-quality data. Site 238-new is directly above a longwall-mined (*fig. 4*) area with 680 ft of overburden (*table 4*). Spring sites 492, 493, and 494 overlay or are near development mining areas (*fig. 4*) where overburden thickness is 910, 905, and 860 ft thick respectively (*table 4*).

Discharge

Discharge measured by the Cyprus–Plateau Mining Corporation during 1992–2001 at 13 springs in the study area is listed in *tables 5* and *6*. All of the springs show a seasonal response in discharge. The springs show significant increases in discharge in June, when the ground-water system receives recharge from melting snow. Discharge at springs tends to taper off during the summer months. To reduce this seasonal bias, only base-flow discharge measurements made from July through October are plotted in *figure 11*. Most springs had greater discharge during the wetter years of the mid-to-late 1990s and lesser discharge during the drought years from 1999 to 2004. Median pre-longwall mining discharge at each of the springs also is plotted in *figure 11*. In most cases, the median value is based on limited July–October measurements made in 1986–1988. The pre-longwall-mining period, when these measurements were made, coincides with a transition to drier-than-normal conditions in the state of Utah. The year 2004 represents climatic conditions at the end of a long (6-year) drought. Therefore, spring discharge in 2004 and 2005 should not necessarily be expected to match conditions observed from 1985 to 1987. However, spring discharge should show an increase that corresponds to increased precipitation during the mid-to-late 1990s. Despite the prolonged drought, spring discharge at 8 of the 13 sites (f*ig. 11*) is at or near flow observed prior to longwall mining. At five sites, 492, 493, 494, 500, and 530, discharge is less than observed prior to longwall mining.

Spring site 530 is about 2 mi away from the longwall mining that took place beneath the NFRF of Miller Creek, and is separated from the NFRF of Miller Creek drainage basin by several normal faults (*fig. 9*). This spring showed an increase to above pre-longwall mining discharge during the wetter mid-to-late 1990s, but dropped below the pre-longwall mining values during the drought period that started in 1999. Older mine-workings (*fig. 2*), several faults (*fig. 9*), and a drainage divide (*fig. 5*) separate site 530 from the NFRF of Miller Creek, and it is unlikely that the changes in discharge seen at Spring 530 are related to mining activity beneath the NFRF of Miller Creek drainage basin.

Site 238 new is located approximately 680 ft above the mine (*table 4*) and is the only spring that was directly undermined by a longwall panel. Discharge at site 238-new was similar to that observed at site 238 in Slaughter and others (1995). Site 229 is near the boundary of the mined area. Discharge at site 229 is slightly greater than that observed prior to longwall mining, but is significantly greater than was measured from 1988 through 1995 (Slaughter and others, 1995).

In 2004 and 2005, discharge at site 492 was very near pre-longwall mining levels. During the wetter period of the mid 1990s, discharge at site 492 was greater than that observed prior to longwall mining. No data are available for site 493 from 1992 to 2003; however, data from 2004 and 2005 show a trend of increasing discharge that is approaching pre-longwall mining values.

Sites 494 and 500 did not show a return to pre-longwall mining levels during the wet period of the mid-to-late 1990s. Except for one measurement in June 1997, site 500 was dry from 1993 to 1997 (*table 5*). In 2004 and 2005, a range in discharge of 0.3 to 0.4 gal/min was measured at site 500 (*table 6*). The pre-longwall mining median value was 1.8 gal/min. Site 500 is approximately 400 ft horizontally from the nearest longwall panel and approximately 1,000 ft from a ground-anchored prism where 6.5 ft of subsidence was surveyed (Slaughter and others, 1995). Estimated discharge at site 494 in 2004 and 2005 ranged from 0.1 to 0.3 gal/min. This compares to a pre-longwall mining median value was 2.2 gal/min. The overburden thickness beneath site 494 was approximately 860 ft (*table 4*). Slaughter and others (1995) did not draw any definite conclusions regarding the effects of mining on discharge at these springs; however, a longer period of data collection suggests that the flowpaths to these springs appear to have been altered.

Water Quality

Field parameters measured at 13 springs in the study area are listed in *tables 5* and *6*. Results from analyses of water

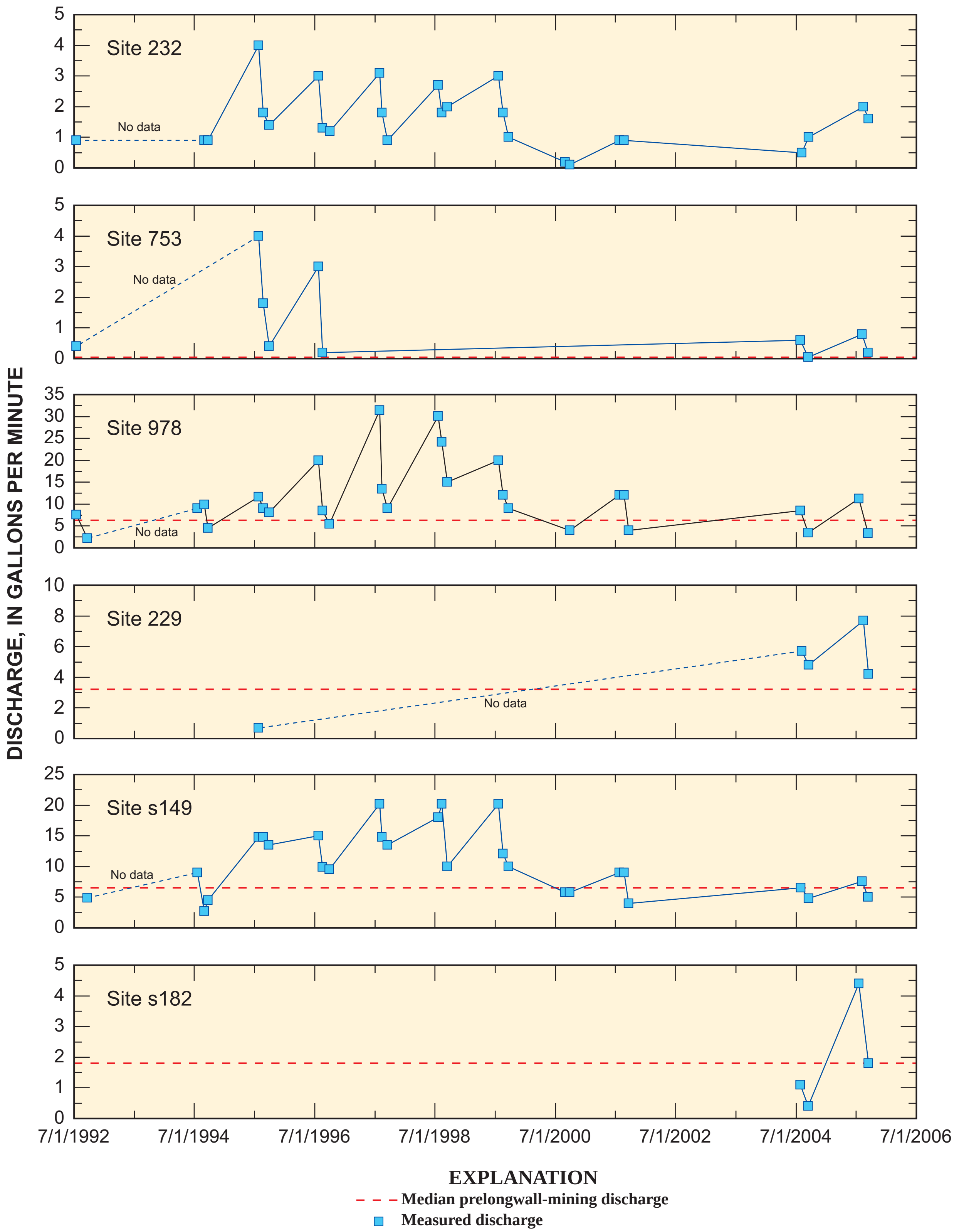


Figure 11. Discharge measured in July–October at selected springs in the North Fork of the Right Fork of Miller Creek study area, Carbon and Emery Counties, Utah, 1992–2005.

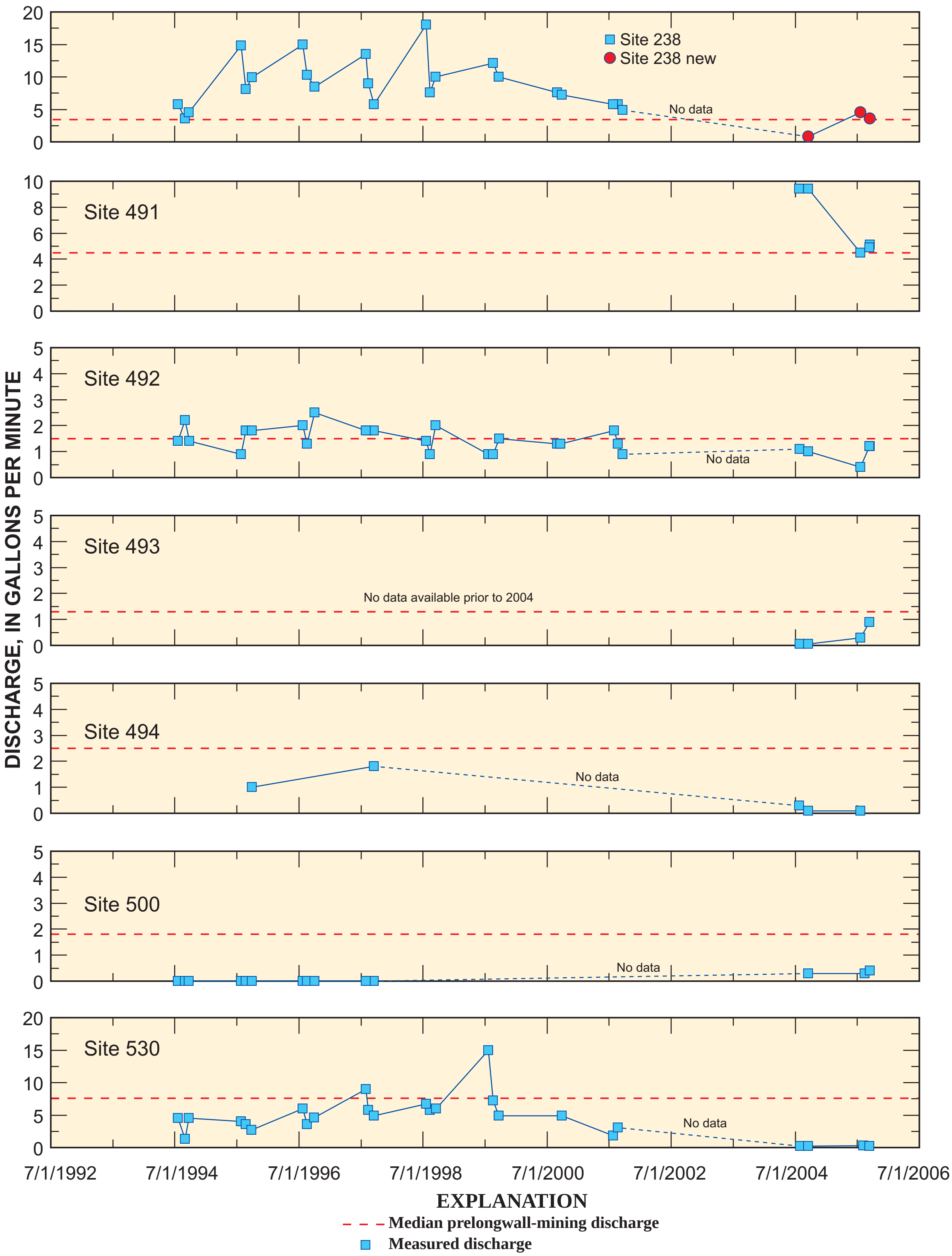


Figure 11. Discharge measured in July–October at selected springs in the North Fork of the Right Fork of Miller Creek study area, Carbon and Emery Counties, Utah, 1992–2005—Continued.

samples collected from these sites are shown in *tables 7* and *8* (major ions) and *table 9* (trace elements).

During 2004 and 2005, the range of pH at spring sites was 6.3 to 8.2. Prior to longwall mining, the range of pH at springs was 6.4 to 8.7 (Slaughter and others, 1995). No dissolved oxygen data are available prior to 2004. Dissolved oxygen concentrations during 2004 and 2005 ranged from 1.6 to 9.6 mg/L. The lowest dissolved oxygen concentrations were measured where discharge was low and the measurement had to be made from small, muddy, organic-rich pools.

To better represent water-quality conditions during baseflow, only analyses made from June through October are used in this report. Excluding site 238-new, the dissolved-solids concentrations in 2004 and 2005 for springs ranged from 163 to 368 mg/L, while the specific conductance was 279 to 617 µS/cm. Prior to longwall mining, the range of dissolved-solids concentrations measured at spring sites was 164–304 mg/L. The range of specific conductance was 205–564 µS/cm (Slaughter and others, 1995). In comparison, the range of dissolved-solids concentrations at spring site 238 new in 2004 and 2005 was 539–709 mg/L (*fig. 12*). The range of specific conductance at site 238 new was 900–995 µS/cm. Prior to longwall mining, the range of dissolved-solids concentrations at site 238 was 208–246 mg/L, while the range of specific conductance was 232–490 µS/cm (Slaughter and others, 1995).

In 2004 and 2005, the range of dissolved-solids concentration at sites s149 and s182 was slightly different from the range measured in the 1990s. However, for these sites, the range measured in 2004 and 2005 is in the range of dissolved-solids concentrations measured throughout the study area. The dissolved-solids concentration measured in 2004 and 2005 at site s149 is lower than that observed in the 1990s. Site s149 is more than 2 mi from the longwall mining that took place beneath the NFRF of Miller Creek (*fig. 5*) and is separated from that area by numerous faults and older mine workings. Site s182 has shown a gradual increase in dissolved-solids concentration since the 1990s; however, in 2004 and 2005 the value was near the median pre-longwall mining value. Site s182 is located near the lateral extent of longwall mining along the same ridge as the location of sites 500 and 494. Discharge appears to have been affected by subsidence at sites 494 and 500, however no significant water-quality changes were observed at these sites, most likely because they are located above any mine workings and coal beds. Since site s182 also is near the top of the drainage basin of the NFRF of Miller Creek and above the coal beds, it also is unlikely to see significant increases in dissolved-solids concentration in the future.

According to data collected by the Cyprus–Plateau Mining Corporation, no change in the dissolved-solids concentration at site 238 was observed during or after longwall mining (*fig. 12*). However, data collected at site 238-new in 2004 and 2005 by the USGS shows an elevated dissolved-solids concentration relative to other springs sampled in the study area. Because of the uncertainty of whether site 238 (previous study) and site 238-new (this study) represent water collected from the same exact location, it cannot be determined if an increase in the dissolved-solids concentration occurred at this site during 2001–2004. It should be noted, however, that specific conductance (which increases with dissolved-solids concentration) measured at nearby site M-3 prior to longwall mining ranged from 267 to 400 µS/cm (Slaughter and others, 1995). Specific conductance measured during 2004 and 2005 at site M-3 was in the range of 994 to 1,140 µS/cm (*table 10*). Site M-3 is a tributary site of the NFRF of Miller Creek and is located a few hundred feet downstream of site 238-new (*fig. 5*). Slaughter and others (1995) noted that the increase in specific conductance at site M-3 occurred from 1988 to 1991, during the period of longwall mining.

The water discharging from site 238 new in 2004 and 2005 predominantly was a magnesium-calcium-sulfate type. The average sulfate concentration at site 238 new in 2004 and 2005 was 252 mg/L. During the same time period, the average sulfate concentration of springs in the study area that discharged from the Castlegate Sandstone Formation was 9.6 mg/L, while water in springs that discharged from the Blackhawk Formation had an average sulfate concentration of 43.6 mg/L. Spring site 238 new discharges from an area that is near the contact of the Castlegate Sandstone Formation and the Blackhawk Formation. Water in the Blackhawk Formation most likely has variable quality, depending on through which part of the formation it flows. The upper portion of the Blackhawk Formation is composed of relatively "clean" sandstone, while the lower portion contains coal deposits and possible marine shales. Water passing through the shales and coal beds would be expected to have a greater dissolved-solids concentration than water that passed only through the "clean" sandstone in the upper (Blackhawk Formation) portion. Waddell and others (1981) report dissolved-solids concentrations in water sampled from springs and wells discharging from the Blackhawk Formation in the range of approximately 60–800 mg/L. The predominant ions in these samples were calcium, magnesium, bicarbonate, and sulfate.

Small amounts of barium, boron, cobalt, lithium, nickel, selenium, vanadium, and zinc were found in most water samples collected from springs. Greater quantities of strontium were found in the spring samples, with the highest levels found in the Price River Formation. In 2004 and 2005 the range of strontium concentrations found in springs discharging from the Price River Formation was from 124 to 302 µg/L (*table 9*). Median strontium concentration measured at site 238 new in 2004 and 2005 was higher than that measured in other springs that discharge from the Castlegate or Blackhawk Formations, but was similar to that measured in the Price River Formation.

Surface Water

A temporary streamflow-gaging station was installed at site M-8 on the NFRF of Miller Creek. Seepage investigations were made along the NFRF of Miller Creek to identify gains

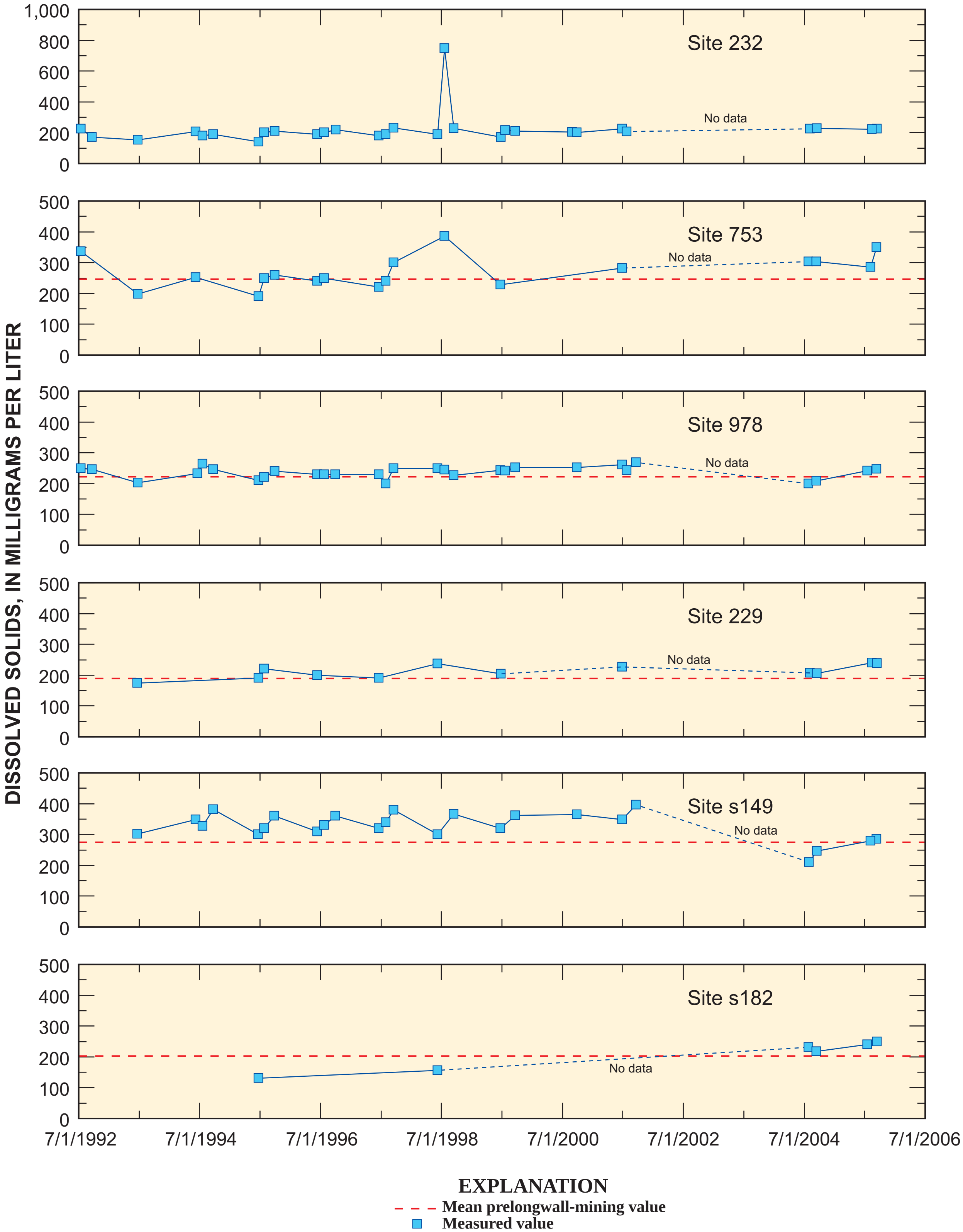


Figure 12. Dissolved-solids concentration measured in June–October at selected springs in the North Fork of the Right Fork of Miller Creek study area, Carbon and Emery Counties, Utah, 1992–2005.

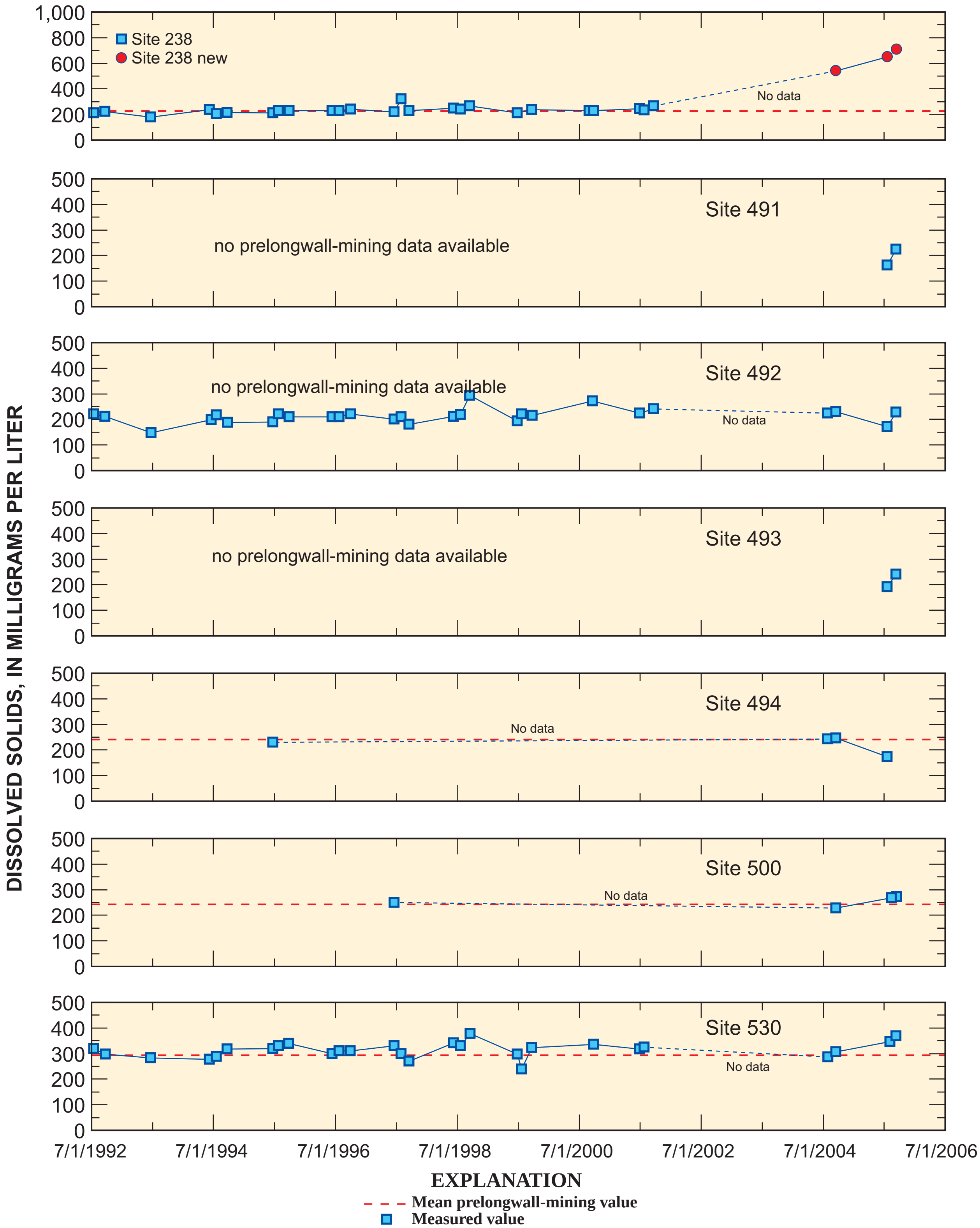


Figure 12. Dissolved-solids concentration measured in June–October at selected springs in the North Fork of the Right Fork of Miller Creek study area, Carbon and Emery Counties, Utah, 1992–2005—Continued.

and losses to the stream twice in 2004 and twice in 2005. During the seepage investigations in 2004, water-quality samples were collected at sites M-3, M-5, and M-8. In 2005, water-quality samples were collected at sites M-2, M-3, M-5, M-6, M-7, M-8, and M-10.

Discharge in the North Fork of the Right Fork of Miller Creek

The gage at site M-8 was operated from late June 2004 through early November 2004. The station then was removed for the winter and again installed in late June 2005. The station was removed again in early November 2005. The daily mean discharge of the NFRF of Miller Creek was determined for these periods (*fig. 13*). Following snowmelt runoff in the spring, the NFRF of Miller Creek receives most of its flow from ground-water discharge. Additional streamflow during the summer months is derived from precipitation (*fig. 13*).

No continuous discharge data were collected for site M-8 prior to the start of longwall mining. Instantaneous discharge measured in October 1987 and July 1988 was greater than 20 gal/min. However, due to rapid fluctuations in discharge caused by evapotranspiration and precipitation events, it is difficult to determine if these measurements represent baseflow conditions. Baseflow discharge from 1989 through 1991 were approximately 3–5 gal/min (Slaughter and others, 1995). This time period coincided with a period of less-than-average precipitation. Precipitation for 2004 and 2005, measured at Electric Lake weather station, also was below average. Baseflow discharge during much of 2004 was less than 5 gal/min at site M-8. During 2005, which received more precipitation than 2004, baseflow increased to near 7–8 gal/min.

Surface Water Gains and Losses During Summer 2004 and 2005

Discharge was measured at 13 sites in the NFRF of Miller Creek during July and September 2004 and July and September 2005 (*fig. 14, table 10)*. Measurements also were made at three springs that flowed into the main channel. Discharge and water-quality field parameters measured at site M-8 by the Cyprus–Plateau Mining Corporation are shown in *table 11*. Prior to 2004, site M-9 appears to have been sampled as a spring that discharged into the NFRF of Miller Creek. No spring was found at this location during 2004 and 2005; therefore, this site was measured in the main flow of the NFRF of Miller Creek. Sites M-3 and M-7 were measured as a tributary to the main channel of the NFRF of Miller Creek.

In 2004, the NFRF of Miller Creek went dry between sites M-2 and M-2.1, and between sites M-4.5 and M-K (*fig. 15*). In 2005, the stream dried up between sites M-2.1 and M-4. During both years, losses in discharge began just downstream of site M-2. Overburden thickness in this area was approximately 600 ft thick (*table 4*). During both years, the creek remained dry, or nearly dry, until water from the tributary at site M-3 entered the main channel of the NFRF of Miller Creek. No dry reaches were observed in the tributary that joins the main channel of the NFRF of Miller Creek at site M-3. Dry reaches were observed in this area in 1989 and 1990 (Slaughter and others, 1995). In 2005, a trickle of water could be heard beneath rocks in the area around site M-4; however, the volume could not be measured. In 2004 another dry reach was observed between sites M-4.5 and M-K. Overburden for this reach ranged from 210 ft thick at site M-4.5 to 90 ft thick at site M-K (*table 4*). In 1991, Slaughter and others (1995) observed dry reaches that extended to just above site M-8. It is estimated that approximately 1,600 ft (of the 6,000 ft measured) of the streambed of the NFRF of Miller Creek was dry during 2004. Only 300 ft of the streambed was dry, or nearly dry, during the wetter year of 2005.

Measurements of discharge in the NFRF of Miller Creek were used to determine gains and losses in streamflow (*table 12*). A set of measurements was made on July 28, 2004, September 14, 2004, July 20, 2005, and September 13, 2005. Cumulative gains and losses in streamflow from the headwaters of the NFRF of Miller Creek at spring 491 downstream to site M-10 are shown in *figure 13*. Measurements from 2004 and 2005 show a net loss of water from the stream. In other words, stream loss along the study reach was greater than inflows from tributaries or from the subsurface. For all previous seepage measurements (1986–1991), a net gain always was observed (*fig. 16*). Greater net losses were observed in 2004 than in 2005 due to increased precipitation in 2005. Overall, the location of seepage gains and losses measured in 2004 and 2005 are similar to those documented by Slaughter and others (1995) during and shortly after longwall mining (*fig. 16*). The largest losses generally occurred between sites M-2 and M-4.5. Overburden thickness beneath this reach was between 700 ft at site M-2 and 210 ft at site M-4.5 (*table 4*). Surface flow immediately downstream of the tributary confluence near site M-3 came from the tributary, as the main channel above the confluence was dry below site M-4. In July and September 2004, the inflow from site M-3 also dried up by site M-4.5. In 2005, the reach from M-3 to site M-4.5 saw relatively little gain or loss in flow. Overburden thickness beneath this reach was between 380 ft at site M-3 and 210 ft at site M-4.5 (*table 4*). During 2004 and 2005, the stream gained water from site M-K to site M-8. Prior to longwall mining, this reach showed a gain in 1986 and 1987, but showed a slight loss in 1988. In 2004, the reach from site M-8 to M-10 remained steady or had a slight gain in discharge. During 2005, the same reach was steady or had a slight loss in discharge.

Seepage investigations made prior to longwall mining and originally presented in Slaughter and others (1995) show a gain-loss pattern in the NFRF of Miller Creek that changes temporally (*fig. 16*). These changes were most likely driven by changes in annual precipitation in the drainage basin. In 1986, following a wet cycle in the state of Utah, no streamflow losses were observed. In 1987 and 1988, the reach between M-2 and M-6 showed a loss of 4.0 and 5.0 ft^3/s respectively.

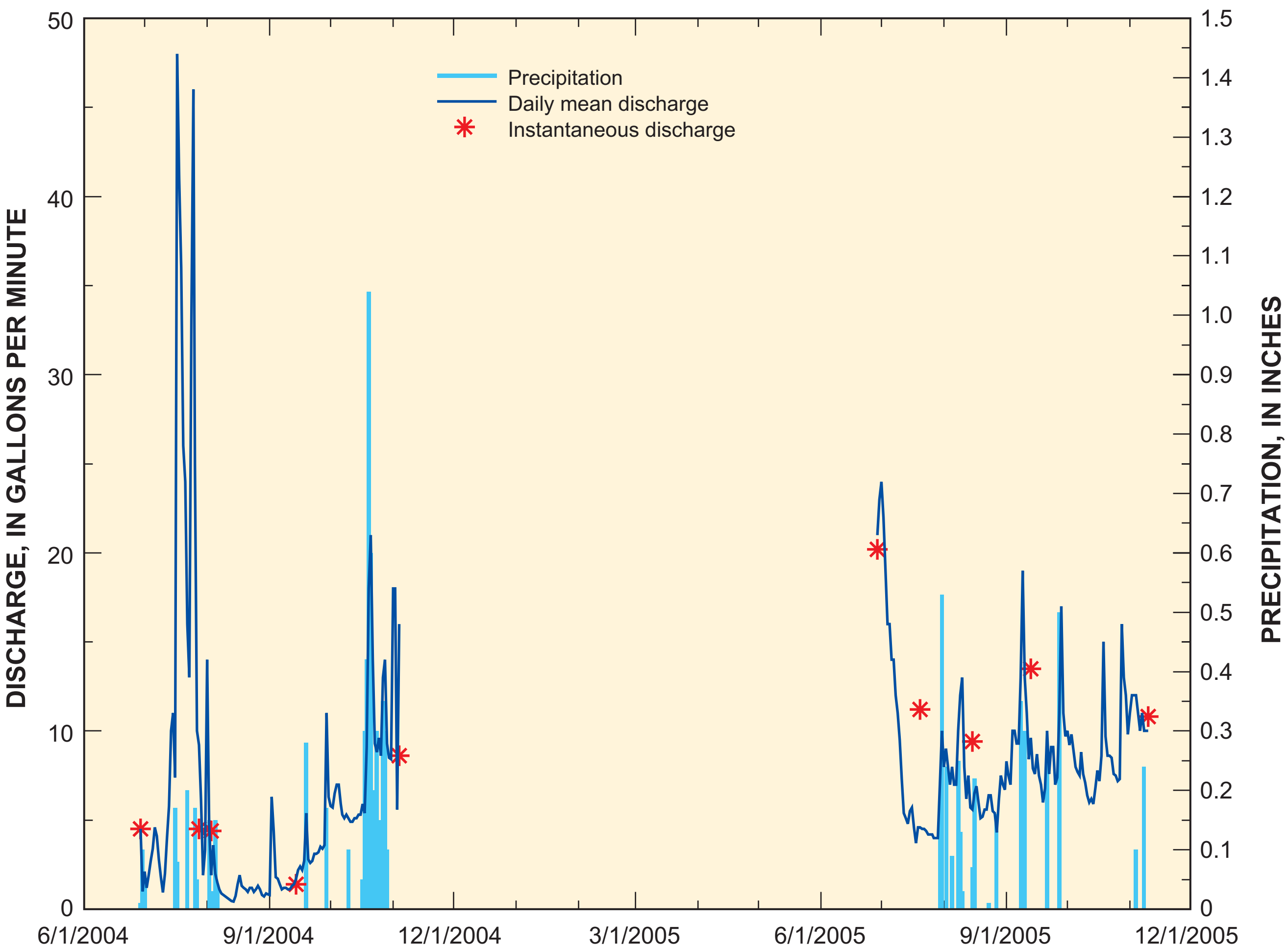


Figure 13. Daily mean and instantaneous discharge measured at site M-8 in the North Fork of the Right Fork of Miller Creek with precipitation measured at Electric Lake weather station, Carbon and Emery Counties, Utah, 2004–2005.

In 2004 this reach lost an average of 18.4 ft^3/s, while in 2005, this reach lost an average of 5.7 ft^3/s. Losses for this reach observed in 1987 and 1988 could have been caused by loss to the subsurface through pre-existing joints in the bedrock beneath the creek. These joints may have opened up further during the longwall mining induced subsidence, exacerbating the losses observed in this reach. After longwall mining occurred, Slaughter and others (1995) attributed much of the streamflow loss in this area to a surface fracture observed near site M-6. This fracture was not observed in 2004 or 2005 and may have been sealed by Cyprus–Plateau Mining personnel. The greatest losses in flow in 2004 and 2005 were observed between sites M-2 and M-4.5.

Average discharge measured at site M-3 appears to have increased since longwall mining ended. The 2004–2005 average discharge at site M-3 was 7.2 gal/min. The average discharge at this site from 1988 to 1991 was 1.6 gal/min (Slaughter and others, 1995). The average pre-longwall mining value was 11.8 gal/min. Slaughter and others (1995) documented areas in the tributary upstream of site M-3 where water was diverted to the subsurface at two sandstone-siltstone contacts. No dry reaches were observed in this area in 2004 or 2005.

Water Quality

Specific-conductance measurements made at several sites along the NFRF of Miller Creek are shown in *figure 17*. Specific conductance during spring runoff is much lower than that measured during baseflow conditions due to dilution of the water from melting snow, therefore, only measurements made in June–October are shown in *figure 17*. Specific conductance has remained near pre-longwall mining levels at sites M-1 downstream to sites M-2.1 and M-4. All surface water in the NFRF of Miller Creek downstream of, and including, the tributary at site M-3 appears to have increased in specific conductance during the longwall-mining period and has not dropped since that time. The specific conductance of water generally increases with the dissolved-solids concentration in the water (Hem, 1985). At site M-8, where multiple water-quality samples have been collected, the increase in specific

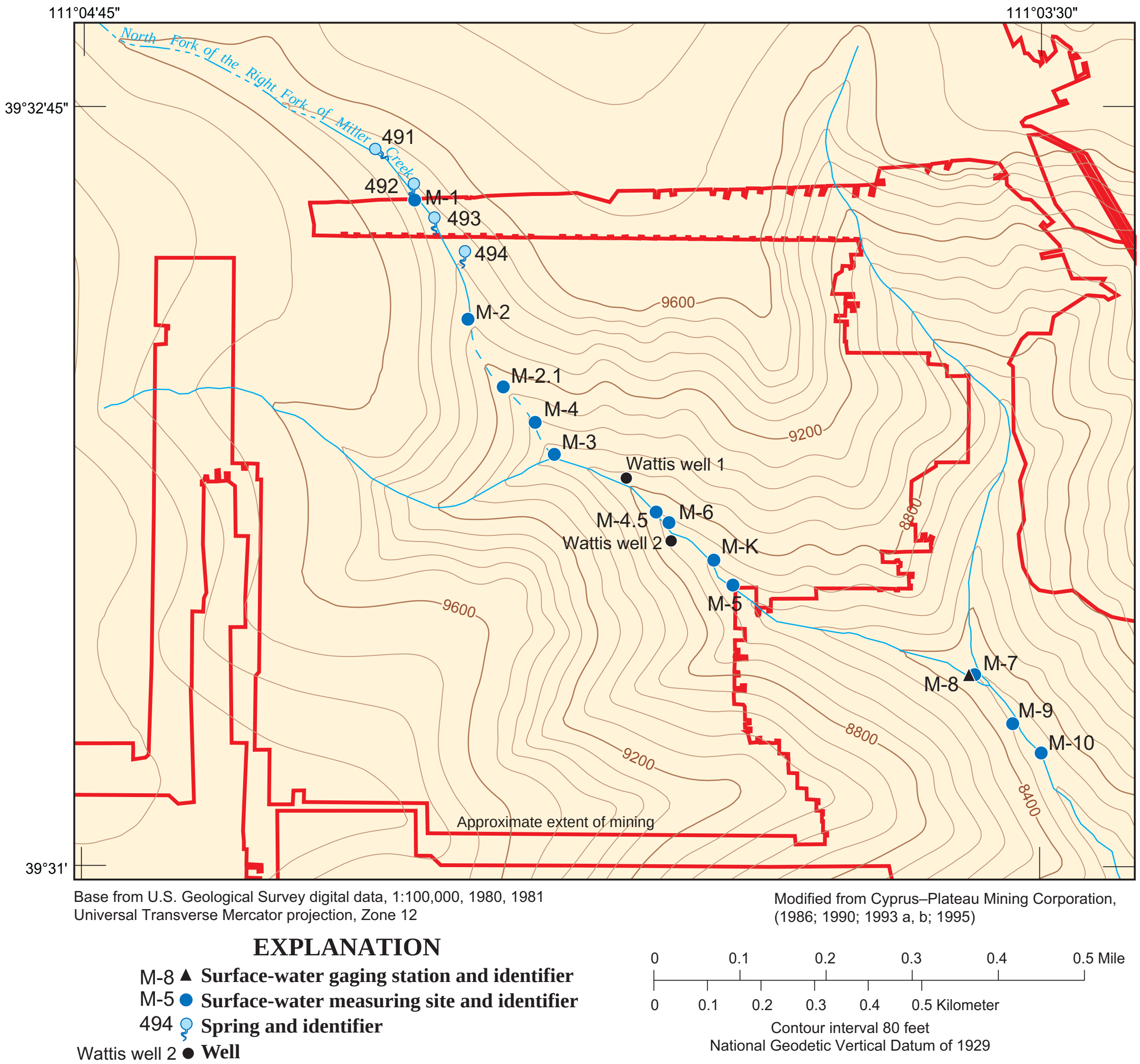


Figure 14. Surface-water measuring sites in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah.

conductance and dissolved-solids concentration is the result of an increase in calcium, magnesium, and sulfate (*fig. 18*).

Results from water-quality analyses of major ions at surface-water sites in the NFRF of Miller Creek are shown in *tables 13* and *14*. Water at site M-2 has a calcium-magnesium concentration (*fig. 19*) and sulfate-bicarbonate concentration (*fig. 20*) that is similar to most springs sampled. Downstream of site M-2, water in the NFRF of Miller Creek and in the tributary at site M-3 increases in magnesium, calcium, and sulfate. Bicarbonate concentration is relatively constant for all sites in the NFRF of Miller Creek. Sites M-5, M-6, M-7, M-8, and M-10 have magnesium-calcium-sulfate concentrations that are significantly higher than spring samples. These sites also have magnesium-calcium-sulfate concentrations that are higher than samples collected during longwall mining and documented by Slaughter and others (1995).

Slaughter and others (1995) documented an increase in dissolved-solids concentration at site M-8 from 310 mg/L prior to mining beneath the NFRF of Miller Creek to a maximum of 1,600 mg/L which was measured during longwall mining. The range of dissolved-solids concentrations measured at site M-8 in 2004 and 2005 was from 1,880 to 2,220 mg/L. This indicates a slight increase in dissolved-solids concentration since mining was completed. For comparison, the maximum contaminant level (MCL) for dissolved-solids in drinking water in the state of Utah is 2,000 mg/L (Utah Department of Environmental Quality, 2006).

Sulfate is the constituent found in the greatest quantity at site M-8. Slaughter and others (1995) documented an increase in sulfate concentration at this site from 45 mg/L prior to longwall mining to a maximum of 871 mg/L that occurred during longwall mining. In 2004 and 2005, the range of sulfate concentration at site M-8 was from 1,090 to 1,320

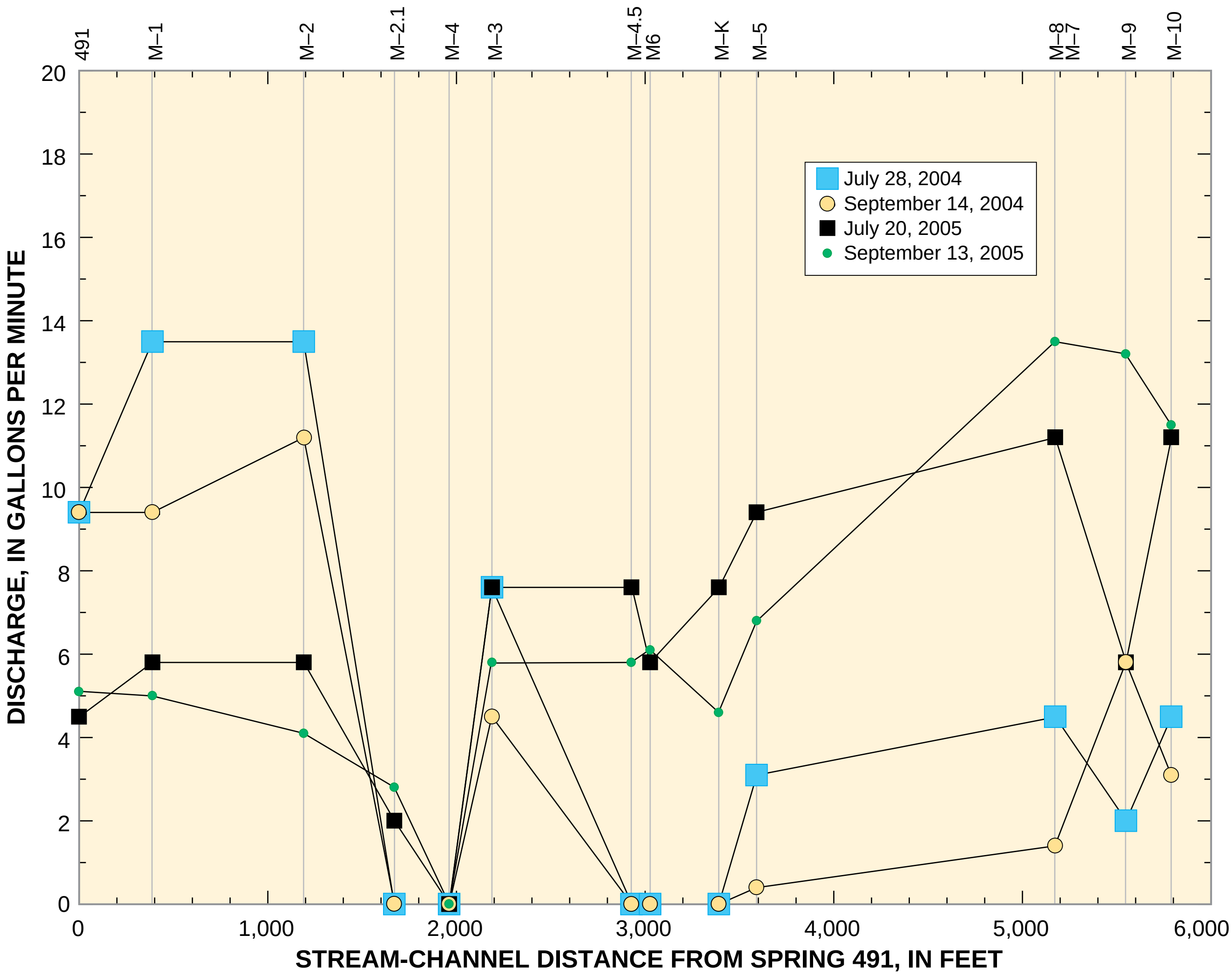


Figure 15. Discharge downstream from the headwaters at site 491 in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 2004–2005.

mg/L. The MCL for sulfate is 1,000 mg/L (Utah Department of Environmental Quality, 2006). Concentrations of calcium and magnesium measured at site M-8 also are slightly higher than those measured during longwall mining and documented by Slaughter and others (1995) (*fig. 18*).

Trace-element concentrations in water sampled from the NFRF of Miller Creek are similar to those measured in water samples from springs (*table 15*). Small concentrations of barium, boron, cobalt, lithium, nickel, selenium, vanadium, and zinc were in most water samples collected from the NFRF of Miller Creek. Strontium was the only trace element with concentrations greater than those in samples collected from area springs. The highest strontium concentrations were found in samples collected downstream of site M-4 and are associated with increases in calcium and magnesium. Limited strontium data during longwall mining beneath the NFRF of Miller Creek indicated concentrations of 400 and 2,200 µg/L in Wattis Well 2 and at in-mine locations, respectively (Slaughter and others, 1995). The only available analysis of strontium levels in stream water indicated concentrations of 330 µg/L at site M-8 that occurred during longwall mining (Slaughter and others, 1995). In 2004 and 2005, the range of strontium concentrations at site M-8 was from 801 to 908 µg/L. No pre-mining data for strontium concentrations are available for comparison. Waddell and others (1986) noted high (30–3,600 µg/L) concentrations of strontium in water discharging from the Blackhawk Formation that paralleled concentration of dissolved solids.

The coal deposits in the Blackhawk Formation likely are the source of the sulfate, magnesium, calcium, and strontium found at sites 238 new, M-3, M-5, M-6, M-7, M-8 and M-10. All of these constituents were found in high concentrations in water that was sampled from water discharging inside the mine by Slaughter and others (1995). Coal from the Wasatch Plateau generally is considered “low-sulfur,” however it is estimated to contain up to 0.6 percent sulfur. The coal also is esti-

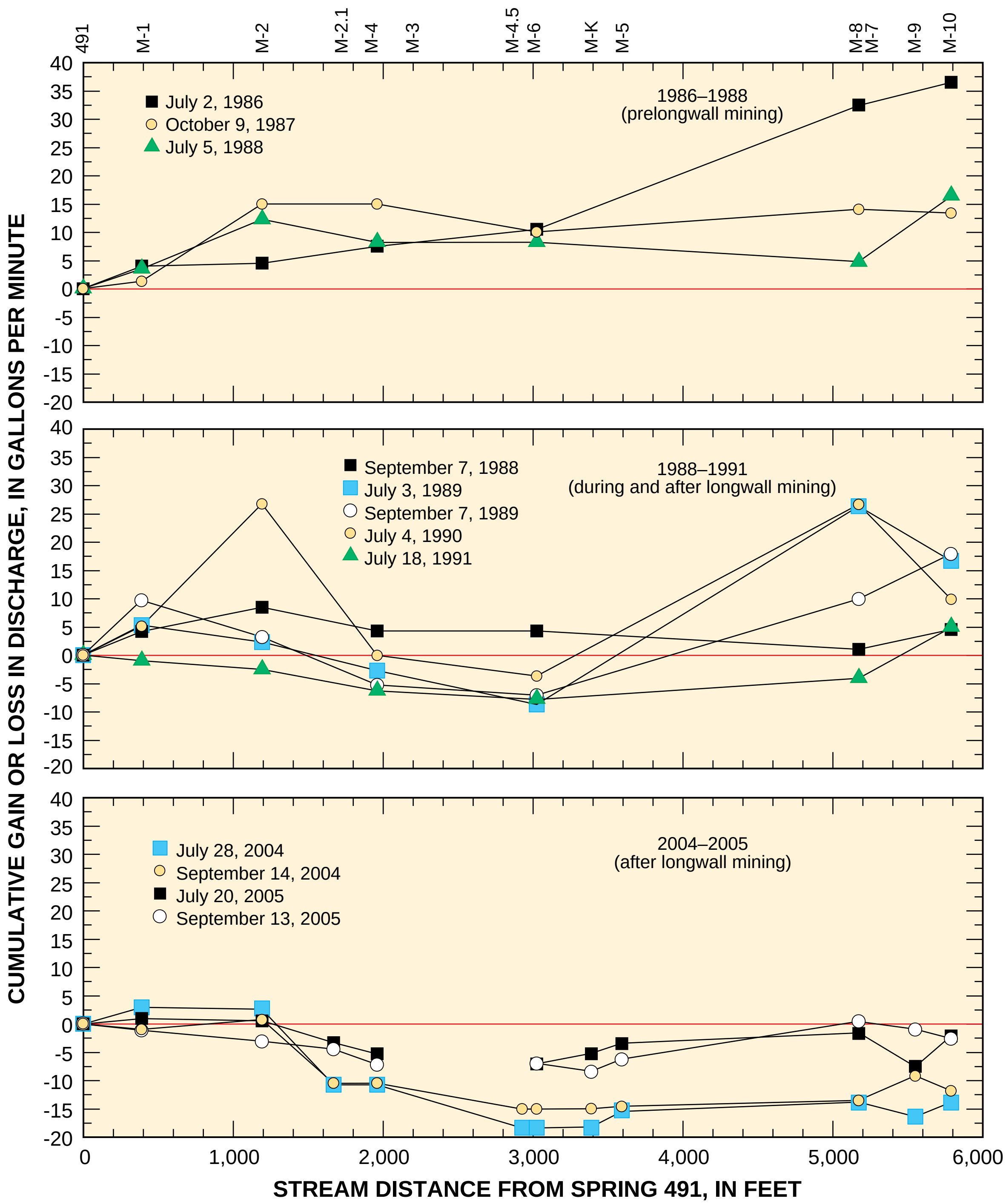


Figure 16. Cumulative gains and losses in flow in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 2004–2005.

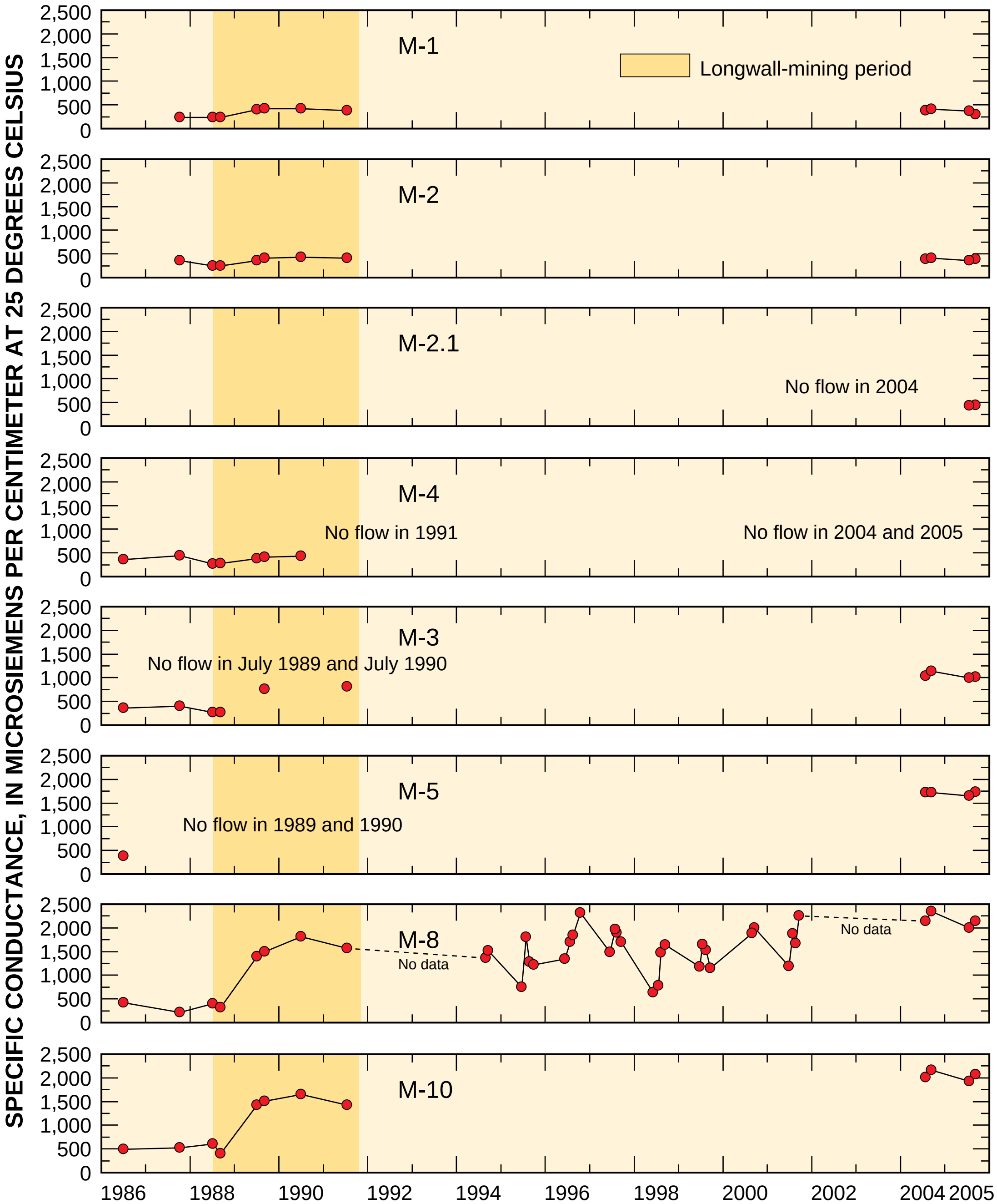


Figure 17. Specific conductance measured in June–October at selected sites in the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 1986–2005.

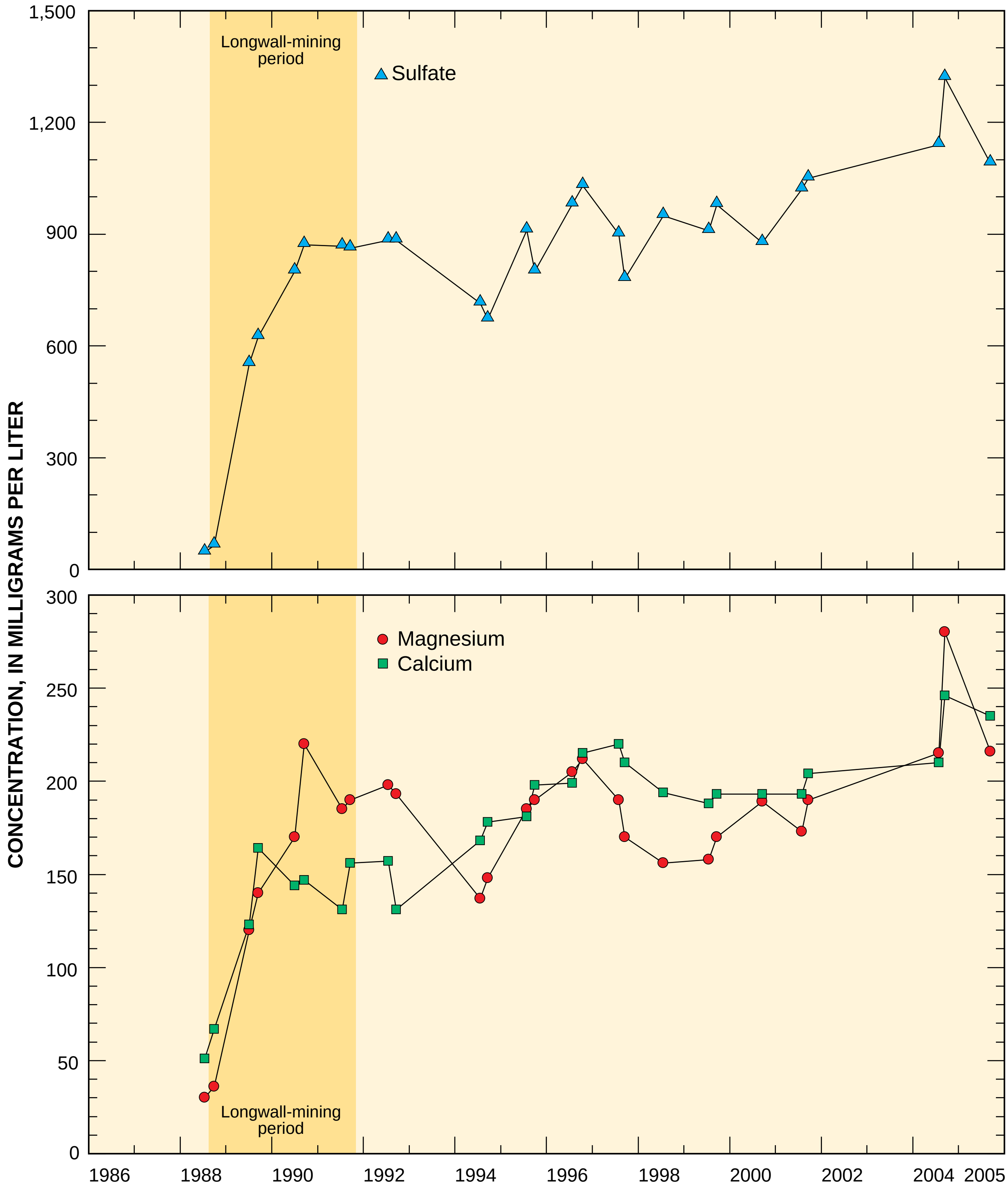


Figure 18. Concentration of sulfate and magnesium and calcium at site M-8 in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 1988–2005.

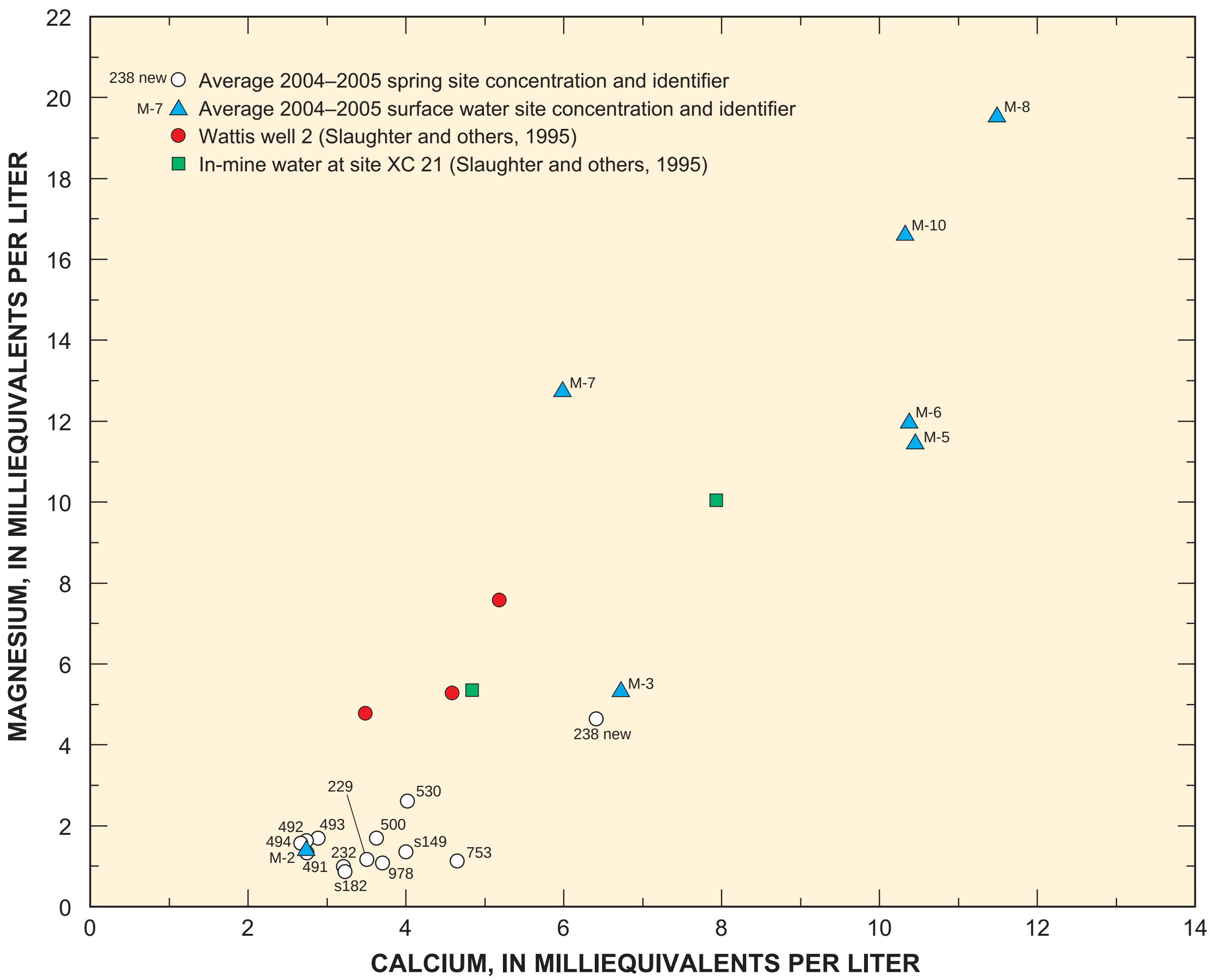


Figure 19. Concentration of calcium and magnesium in water from the North Fork of the Right Fork of Miller Creek drainage basin, Carbon and Emery Counties, Utah.

mated to contain about 0.08 percent magnesium (Kirschbaum, 2000). The lack of trace metals, neutral pH, and relatively high dissolved oxygen concentration measured in the NFRF of Miller Creek suggests that if water is passing through exposed coal beds, it does not appear to be oxidizing metallic sulfides that often are associated with coal deposits. This is consistent with chemical analyses of most Colorado Plateau coals that indicate that most of the associated sulfur is from an organic rather than a mineralogic source (Affolter, 2000).

Summary and Conclusions

In 2004 and 2005, the U.S. Geological Survey, in cooperation with the Bureau of Land Management, reassessed the hydrologic system in and around the drainage basin of the North Fork of the Right Fork (NFRF) of Miller Creek, in Carbon and Emery Counties, Utah. The reassessment occurred 13 years after cessation of underground coal mining that was performed beneath private land at shallow depths (30 to 880 ft) and beneath a perennial stream. This study is a follow-up to a previous USGS study of the effects of underground coal mining and the resulting land subsidence on the hydrologic system in the area from 1988 to 1992. During the summers of 2004 and 2005, the USGS measured discharge and collected water-quality samples from springs and surface water at various locations in the NFRF of Miller Creek drainage basin. A temporary streamflow-gaging station was operated in the North Fork of the Right Fork of Miller Creek. This study also utilized data collected by Cyprus–Plateau Mining Corporation from 1992 through 2001.

Of thirteen monitored sites, five (sites 492, 493, 494, 500, and 530) have discharge levels that have not returned to those observed prior to August 1988, which is when longwall coal mining began beneath the NFRF of Miller Creek drainage basin. Discharge at sites 494 and 500 did not increase with increased precipitation during the mid-1990s, as was seen in

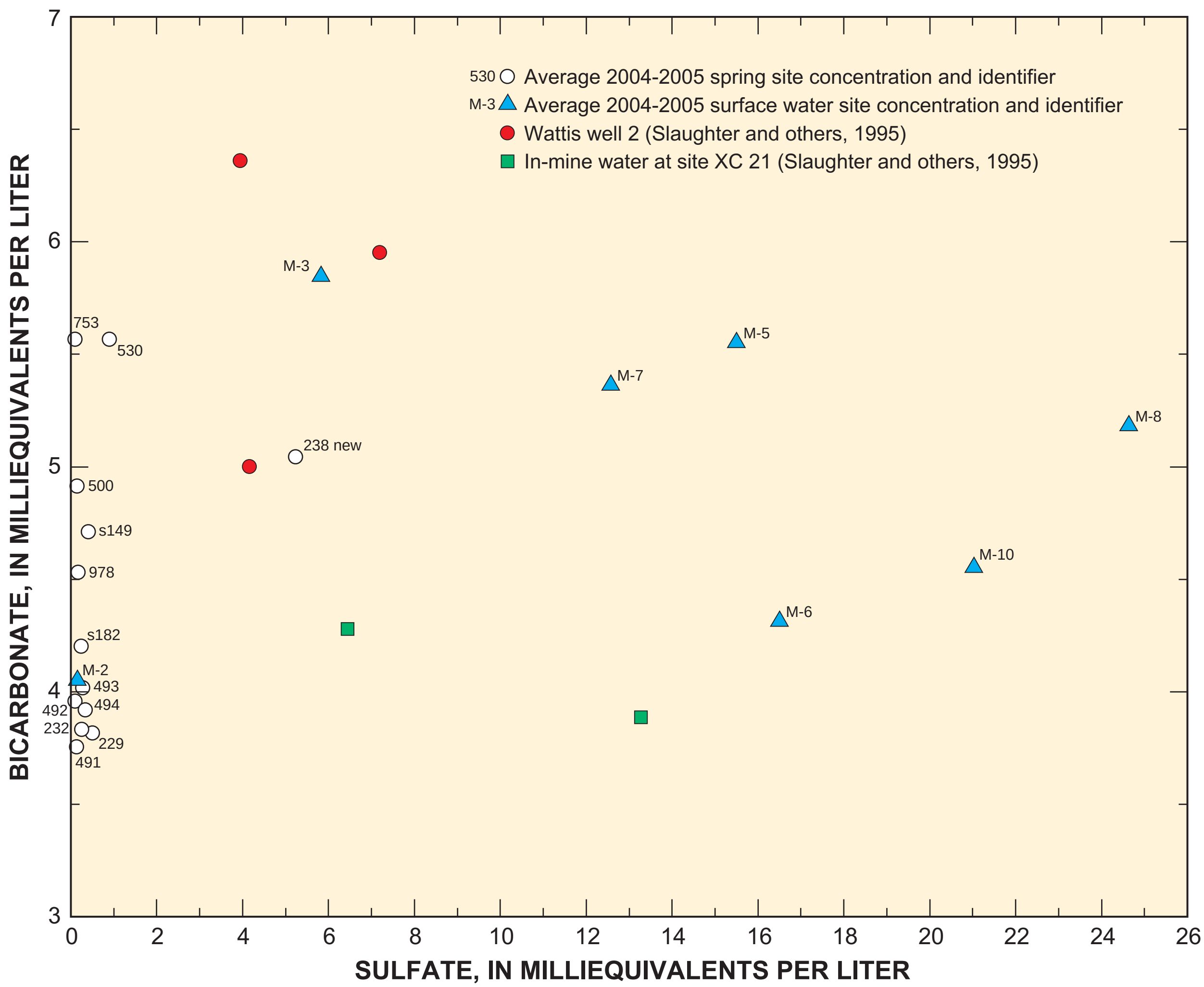


Figure 20. Concentration of sulfate and bicarbonate in water from the North Fork of the Right Fork of Miller Creek drainage basin, Carbon and Emery Counties, Utah.

other springs in the area. This suggests that flowpaths to these springs may have been altered by land subsidence caused by underground coal mining. Discharge at sites 492 and 530 did increase during the 1990s and is likely currently less than that observed prior to longwall mining due to a drought that occurred from 1999–2004. Site 530 is also likely separated hydrologically from the NFRF of Miller Creek drainage basin. Insufficient data exist for site 493 from which to draw any conclusions on whether it has been affected by longwall mining activity. Discharge at site 229 is slightly greater than that observed prior to longwall mining, but is significantly greater than was measured from 1988 through 1995 (Slaughter and others, 1995). This suggests that site 229 has not been permanently impacted by mining related subsidence.

Water quality at spring site 238-new, which is located over a longwall panel, is elevated in magnesium, calcium, and sulfate, in relation to other springs in the study area. Dissolved-solids concentration at site 238 new ranged from 539–709 mg/L. Dissolved-solids concentration for all other springs in the study area ranged from 163 to 360 mg/L and was near the median value measured prior to longwall mining beneath the NFRF of Miller Creek drainage basin. Discharge at site 238 new is similar to discharge measured prior to longwall mining at site 238.

Baseflow measured at site M-8 in the NFRF of Miller Creek during the summer of 2004 was near 5 gal/min. Baseflow in 2005 increased to 7–8 gal/min, due to increased precipitation. This is slightly greater than the range of baseflow measured near the end of the longwall mining period which was approximately 3–5 gal/min.

Seepage investigations carried out in the summer of 2004 and 2005 along the NFRF of Miller Creek showed a net loss of surface flow along the studied reach. Overall, the study reach was observed to gain in discharge prior to longwall mining, although specific areas within the study reach did have streamflow losses prior to longwall mining. The greatest loss in discharge occurred from site M-2 to M-4.5. Overburden thickness in this area is between 700 ft thick at site M-2 and 210 ft thick at site M-4.5. Overburden thickness at the place where the surface flow first dried up was approximately 600 ft thick. In 2004, approximately 1,600 ft of the streambed of the NFRF of Miller Creek was dry. Only 300 ft of the streambed was dry during the wetter year of 2005. Prior to longwall mining, no dry reaches were observed, though seepage losses were documented. The overburden thicknesses beneath the area where streamflow losses occurred in the NFRF of Miller Creek could be compared to other cases where longwall mining has occurred or is proposed beneath a perennial stream. However, the local geology of the area, including rock type and amount of pre-existing fractures or joints, should be considered when using the NFRF of Miller Creek as a guide.

Water quality at sites M-5, M-6, M-7, M-8 and M-10, downstream of the longwall-mined area, showed higher concentrations of magnesium, calcium, sulfate, and strontium in relation to water in the upper reach of the NFRF Miller Creek and to springs sampled in the area. Dissolved-solids concentration measured at site M-8 in 2004 and 2005 ranged from 1,880 to 2,220 mg/L, while sulfate concentrations ranged from 1,090 to 1,320 mg/L. The dissolved solids and sulfate maximum contaminant levels for drinking water in Utah are 2,000 mg/L and 1,000 mg/L, respectively. Concentrations of these ions are slightly greater than that measured during and just following mining beneath the NFRF of Miller Creek drainage basin, but are significantly higher than those measured prior to mining. With the exception of strontium, dissolved metals concentrations in the NFRF of Miller Creek were similar to those measured in area springs. pH in the creek and at all spring sites was near neutral.

The relatively higher concentrations of magnesium, calcium, sulfate, and strontium at sites 238-new, M-3, M-5, M-6, M-7, M-8 and M-10 suggests that water in this area of the NFRF of Miller Creek has most likely has been in contact with the coal beds or mine workings in the Blackhawk Formation. It is unclear if water that leaves the stream in the upper portion of the creek re-enters the stream after passing through the mine workings or coal beds.

Qualitative observations of the creek bottom suggest that mining-related activities have had little effect on vegetative growth. Some scaring of the hillslopes from debris slides still is evident; however, other areas where debris slides occurred show renewed growth of aspens.

A comparison of this and the previous USGS study indicates some of the major effects to the hydrologic system of the NFRF of Miller Creek drainage basin remain, while others appear to have lessened. Major persistent effects include increases in dissolved-solids and sulfate concentrations in water samples collected in the NFRF of Miller Creek, significant loss of streamflow in a portion of the creek, and an apparently long-term decrease in discharge at two springs. Effects that appear to have lessened since the last report include increased streamflow in a tributary of the NFRF of Miller Creek, increased baseflow at the streamflow-gaging site, and a significant increase in discharge at a spring previously believed to have been impacted by longwall mining.

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Table 1. Latitude, longitude, and geologic formation of springs, surface-water sites, and wells in and around the North Fork of the Right Fork of Miller Creek drainage basin, Carbon and Emery Counties, Utah.

[See figure 5 for site locations. USGS site identifier and USGS station name from USGS NWIS database. Latitude and longitude coordinates are referenced to North American Datum of 1983. Springs discharge from respective geologic formations, surface water flows over respective geologic formations, and wells are finished in respective geologic formation. NWIS, National Water Information System; Kpr, Price River Formation; TKnh, North Horn Formation; Kbh, Blackhawk Formation; Kcg, Castlegate Sandstone Formation; Ksp, Starpoint Sandstone Formation]

Site no.	USGS site identifier	USGS station name	Latitude	Longitude	Geologic formation
Spring sites in the North Fork of the Right Fork of Miller Creek drainage basin					
229	393141111043001	(D-15-8)18bcd-S1	39.52139	111.076	Kpr
232	393148111044001	(D-15-7)13aaa-S1	39.52611	111.078	TKnh
238 new[1]	393143111041401	(D-15-8)18bdc-S1	39.52250	111.071	Kbh
491	393142111042201	(D-15-8)7cdc-S2	39.52833	111.073	Kcg
492	393151111041301	(D-15-8)7cdc-S1	39.52778	111.072	Kcg
493	393136111041501	(D-15-8)18bab-S2	39.52722	111.071	Kcg
494	393154111041401	(D-15-8)18bab-S1	39.52667	111.07083	Kcg
500	393157111034701	(D-15-8)18aab-S1	39.52750	111.06389	Kcg
753	393145111045801	(D-15-13)13abd-S1	39.52306	111.08306	TKnh
s182	393156111035901	(D-15-8)18abb-S1	39.52889	111.06653	Kpr
Spring sites outside of the North Fork of the Right Fork of Miller Creek drainage basin					
530	393155111063701	(D-15-7)11cba-S1	39.53306	111.11167	Kbh
s149	393050111065401	(D-15-7)15dda-S1	39.51433	111.11497	Kpr
978	393133111045701	(D-15-7)13dba-S1	39.51877	111.08250	TKnh
Surface water sites in the North Fork of the Right Fork of Miller Creek drainage basin					
M-1	—	—	39.52750	111.07194	Kcg
M-2	393132111041501	M-2 North Fork of the Right Fork Miller Creek	39.52556	111.07083	Kbh
M-2.1	—	—	39.52444	111.07000	Kbh
M-3	393124111040801	M3 North Fork of the Right Fork Miller Creek	39.52333	111.06889	Kbh
M-4	—	—	39.52386	111.06931	Kbh
M-4.5	—	—	39.52239	111.06667	Kbh
M-5	393116111035401	M5NEW North Fork of the Right Fork Miller Creek	39.52119	111.06500	Kbh
MK	—	—	39.52222	111.06639	Kbh
M-6	393120111035901	M-6 North Fork of the Right Fork Miller Creek	39.52222	111.06639	Kbh
M-7	393111111033501	M-7 North Fork of the Right Fork Miller Creek	39.51972	111.05972	Ksp
M-8	393101111025801	Sample Site at Weir on North Fork of the Right Fork	39.51967	111.05968	Ksp
M-9	—	—	39.51892	111.05892	Ksp
M-10	393107111032901	M-10 North Fork of the Right Fork Miller Creek	39.51858	111.05803	Ksp
Monitoring wells in the North Fork of the Right Fork of Miller Creek drainage basin					
Wattis Well 1	393123111035901	(D-15-8)18acb-1	39.52294	111.06753	Kbh
Wattis Well 2	393119111035601	(D-15-8)18acd-1	39.5221194	111.06636	Kbh

[1]Due to difficulty locating this site, ‘new’ is used to differentiate between the original site 238 that was referenced in Slaughter and others, 1995 and this site.

Table 2. Summary of constituents in replicate pairs collected in the North Fork of the Right Fork of Miller Creek study area, Carbon County, Utah.

[See figure 5 for site locations; mg/L, milligrams per liter; ˚C, degrees Celsius; µg/L, micrograms per liter; <, less than; e, estimated; —, no data]

Constituent	Replicate pair collected at site s182 on July 27, 2004		Replicate pair collected at site 978 on September 13, 2004		Replicate pair collected at site 229 on August 15, 2005		Replicate pair collected at site M-10 on September 13, 2005	
Calcium, dissolved (mg/L)	68	68.4	73.8	75.6	72.3	71.5	220	222
Magnesium, dissolved (mg/L)	13.8	13.8	13.3	13.5	14.5	14.2	216	214
Sodium, dissolved (mg/L)	3.03	2.86	1.85	1.96	1.78	1.8	8.21	8.32
Potassium, dissolved (mg/L)	.98	.9	.6	.72	1.37	1.38	6.37	6.3
Chloride, dissolved (mg/L)	4	3.77	1.37	1.36	1.28	1.28	9.14	8.94
Fluoride, dissolved (mg/L)	<.2	<.2	<.2	<.2	.1	.1	.2	.2
Silica, dissolved (mg/L)	8.14	8.05	4.97	5.09	4.92	4.96	8.2	8.21
Sulfate, dissolved (mg/L)	15.1	15	9.3	9.1	24.7	24.7	1,050	1,040
Residue on evaporation, dried at 180˚C (mg/L)	231	189	208	199	240	243	1,810	1,800
Aluminum, dissolved (µg/L)	<2	<2	<2	<2	<2	<2	e1	e1
Barium, dissolved (µg/L)	44	43	57	57	81	81	33	33
Boron, dissolved (µg/L)	12	13	e8	11	8	9	73	74
Cadmium, dissolved (µg/L)	<.04	<.04	<.04	<.04	<.04	<.04	<.04	<.04
Chromium, dissolved (µg/L)	<.8	<.8	<.8	<.8	<.8	<.8	.08	.07
Cobalt, dissolved (µg/L)	.3	.305	.179	.186	.124	.12	.13	.12
Iron, dissolved (µg/L)	<6	<6	12	11	<6	<6	5e	4e
Lead, dissolved (µg/L)	<.08	<.08	<.08	<.08	<.08	<.08	<.08	<.08
Lithium, dissolved (µg/L)	5.4	5.5	2.3	2.8	4.3	4.1	42.2	42.6
Manganese, dissolved (µg/L)	e.1	<.2	6.2	6.9	<.2	<.2	11.8	12
Molybdenum, dissolved (µg/L)	<.4	<.4	.6	.6	e.2	e.2	e.3	e.3
Nickel, dissolved (µg/L)	2.44	2.51	.14	.15	2.37	2.26	—	—
Selenium, dissolved,µg/L)	1.5	1.4	<.4	<.4	2.4	2.5	.37	.34
Silver, dissolved (µg/L)	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Strontium, dissolved (µg/L)	258	235	65.6	67.5	286	281	813	820
Vanadium, dissolved (µg/L)	.2	1.5	.2	.2	.2	.2	.15	.13
Zinc, dissolved (µg/L)	.7	.7	2.8	1.9	e.6	1.6	.35e	<.6

Table 3. Summary of constituents analyzed in field blanks collected in the North Fork of the Right Fork of Miller Creek study area, Carbon County, Utah.

[See figure 5 for site locations; mg/L, milligrams per liter; ˚C, degrees Celsius; µg/L, micrograms per liter; <, less than; e, estimated; —, no data]

Constituent	Sample collected August 4, 2004	Sample collected September 5, 2004	Sample collected August 16, 2005	Sample collected September 4, 2005
Calcium, dissolved (mg/L)	0.01	0.01e	e0.01	<0.02
Magnesium, dissolved (mg/L)	<.008	<.008	<.008	<.008
Sodium, dissolved (mg/L)	<.1	<.1	<.2	<.02
Potassium, dissolved (mg/L)	<.16	<.16	<.16	<.16
Chloride, dissolved (mg/L)	<.2	<.2	<.2	8.49
Fluoride, dissolved (mg/L)	<.17	<.17	<.1	<.1
Silica, dissolved (mg/L)	<.04	<.04	<.04	<.04
Sulfate, dissolved (mg/L)	<.18	<.18	<.18	.3
Residue on evaporation, dried at 180˚C, in mg/L	<10	<10	<10	<10
Aluminum, dissolved (µg/L)	<2	<2	<2	<2
Barium, dissolved (µg/L)	<.2	<.2	<.2	<.2
Boron, dissolved (µg/L)	<8	<8	<8	<8
Cadmium, dissolved (µg/L)	<.04	<.04	<.04	<.04
Chromium, dissolved (µg/L)	<.8	<.8	<.8	<.04
Cobalt, dissolved (µg/L)	<.014	<.014	<.014	<.04
Iron, dissolved (µg/L)	<6.4	<6.4	<6	<6
Lead, dissolved (µg/L)	<.08	<.08	<.08	<.08
Lithium, dissolved (µg/L)	<.6	<.6	<.6	<.6
Manganese, dissolved (µg/L)	<.2	<.2	<.2	<.2
Molybdenum, dissolved (µg/L)	<.4	<.4	<.4	<.4
Nickel, dissolved (µg/L)	<.06	<.06	<.06	—
Selenium, dissolved (µg/L)	<.4	<.4	<.4	<.08
Silver, dissolved (µg/L)	<.2	<.2	<.2	<.2
Strontium, dissolved (µg/L)	<.4	<.4	<.4	<.4
Vanadium, dissolved (µg/L)	<.14	<.14	<.14	<.1
Zinc, dissolved (µg/L)	<.6	<.6	e.4	<.6

Table 4. Overburden thickness at selected springs and monitoring points along the North Fork of the Right Fork of Miller Creek, Carbon County, Utah.

[See figure 5 for site location. All measurements are in feet. Altitude is referenced to NGVD 29. Overburden thickness determined from difference between the mine roof and site altitude. Total mining height is assumed to be 90 percent of the total coal height in each mined area below each site]

Site no.	Altitude of site [1]	Altitude of mine roof [2]	Overburden thickness	Underlying coal seam	Mining type	Total mining height
Spring sites						
491	9,400	8,495	905	Third Seam	near development	7.2
492	9,400	8,490	910	Third Seam	near development	7.2
493	9,390	8,485	905	Third Seam	over development	7.2
494	9,340	8,480	860	Third Seam	over development near longwall	7.2
238 new[3]	9,180	8,500	680	Wattis Seam	over longwall	7.9
Surface water sites						
M-1	9,370	8,490	880	Third Seam	over development	7.0
M-2	9,230	8,470	760	Third Seam	over longwall	7.2
M-2	9,230	8,530	700	Wattis Seam	over development	7.9
M-2.1	9,120	8,455	665	Third Seam	over development near longwall	6.3
M-2.1	9,120	8,515	605	Wattis Seam	near longwall	7.9
M-4	8,980	8,450	530	Third Seam	over longwall	5.8
M-4	8,980	8,520	460	Wattis Seam	over development near longwall	7.9
M-3	8,900	8,450	450	Third Seam	over development near longwall	5.4
M-3	8,900	8,520	380	Wattis Seam	over longwall	7.9
M-4.5	8,730	8,445	285	Third Seam	near development	5.3
M-4.5	8,730	8,520	210	Wattis Seam	over longwall	7.9
M-6	8,660	8,515	145	Wattis Seam	over development near longwall	7.9
MK	8,600	8,510	90	Wattis Seam	over development near longwall	7.9
M-5	8,540	8,510	30	Wattis Seam	over development near longwall	7.9
M-7	8,300	—	—	—	none	—
M-8	8,320	—	—	—	none	—
M-9	8,280	—	—	—	none	—
M-10	8,290	—	—	—	none	—

[1]Kucera and Associates (1975).

[2]Cyprus-Plateau Mining Corporation (variously dated).

[3]Due to difficulty locating this site, 'new' is used to differentiate between the original site 238 that was referenced in Slaughter and others, 1995 and this site.

Table 5. Field parameters and discharge measured by the Cyprus–Plateau Mining Corporation at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 1992–2001.

[See figure 5 for site location; gal/min, gallons per minute; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; —, no data]

Site no.	Date	Time	Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Dissolved oxygen (mg/L)
North Horn Formation							
232	6/17/1992	1430	—	360	5.1	7.1	—
232	7/15/1992	1330	.9	327	7.8	7.0	—
232	9/21/1992	1045	—	333	10.2	6.0	—
232	6/24/1993	1430	7.2	323	4.6	6.1	—
232	6/9/1994	0830	2.7	385	3.0	7.0	—
232	7/19/1994	1530	<4.5	340	12.9	7.8	—
232	8/31/1994	1635	.9	277	13.3	7.9	—
232	9/21/1994	1145	.9	358	12.9	7.6	—
232	6/22/1995	1300	22.4	262	5.2	7.4	—
232	7/27/1995	1500	4.0	398	6.0	7.3	—
232	8/23/1995	1610	1.8	332	6.0	6.4	—
232	9/28/1995	0815	1.4	229	6.1	7.2	—
232	6/12/1996	1350	8.5	400	8.0	7.4	—
232	7/23/1996	1505	3.0	365	9.0	7.8	—
232	8/19/1996	1415	1.3	304	6.0	7.5	—
232	10/1/1996	0915	1.2	423	5.0	7.9	—
232	6/18/1997	1515	12.1	330	7.0	8.2	—
232	7/30/1997	—	3.1	399	5.0	7.1	—
232	8/13/1997	1740	1.8	405	6.0	7.5	—
232	9/16/1997	—	.9	384	5.5	7.8	—
232	6/8/1998	1710	12.0	265	4.0	7.2	—
232	7/19/1998	1845	2.7	480	5.0	7.4	—
232	8/11/1998	1533	1.8	285	13.0	7.4	—
232	9/15/1998	1555	2.0	329	12.0	7.8	—
232	6/25/1999	—	10.0	300	5.0	6.9	—
232	7/20/1999	1400	3.0	336	5.0	7.6	—
232	8/18/1999	0905	1.8	218	6.0	7.5	—
232	9/21/1999	1610	1.0	219	7.0	7.9	—
232	8/29/2000	1200	.2	240	7.0	8.1	—
232	9/26/2000	1415	.1	363	10.0	7.8	—
232	6/28/2001	0940	2.7	297	8.0	7.0	—
232	7/25/2001	1105	.9	313	5.0	7.0	—
232	8/23/2001	1550	.9	292	11.0	7.8	—
753	7/15/1992	1200	.4	458	7.6	8.0	—
753	6/24/1993	1400	10.8	347	4.7	6.4	—
753	6/9/1994	0900	1.8	477	2.2	7.3	—
753	6/22/1995	1400	3.0	382	5.5	7.4	—
753	7/27/1995	1515	4.0	489	8.0	7.7	—
753	8/23/1995	1615	1.8	403	8.0	7.1	—
753	9/28/1995	0800	.4	285	7.9	7.7	—
753	6/12/1996	1430	8.0	506	6.0	8.3	—
753	7/23/1996	1545	3.0	423	9.0	8.0	—
753	8/19/1996	1425	.2	395	10.0	7.9	—
978	7/15/1992	1145	7.6	444	5.9	7.0	—
978	9/21/1992	1015	2.2	443	6.8	6.2	—
978	6/24/1993	1330	41.7	377	5.5	6.2	—
978	6/20/1994	0900	15.3	484	3.7	7.4	—

Table 5. Field parameters and discharge measured by the Cyprus–Plateau Mining Corporation at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 1992–2001—Continued.

Site no.	Date	Time	Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Dissolved oxygen (mg/L)
			North Horn Formation				
978	7/19/1994	1500	9.0	412	13.9	7.8	—
978	8/31/1994	0910	9.9	258	11.2	8.3	—
978	9/21/1994	1140	4.5	496	12.7	7.9	—
978	6/22/1995	1345	20.2	442	5.0	7.2	—
978	7/26/1995	1830	11.7	472	5.0	7.3	—
978	8/23/1995	1540	9.0	380	5.0	6.6	—
978	9/28/1995	0845	8.1	268	6.0	7.3	—
978	6/12/1996	1440	45.0	544	5.0	8.0	—
978	7/23/1996	1550	20.0	398	8.0	8.0	—
978	8/19/1996	1355	8.5	360	7.0	7.7	—
978	9/30/1996	1615	5.5	473	6.0	7.5	—
978	6/17/1997	1837	29.2	420	5.5	8.1	—
978	7/30/1997	—	31.4	425	5.0	7.6	—
978	8/13/1997	1805	13.5	404	5.5	7.3	—
978	9/16/1997	—	9.0	472	8.0	7.9	—
978	6/8/1998	1655	90.0	362	4.0	7.4	—
978	7/19/1998	1815	30.1	691	16.0	7.5	—
978	8/11/1998	1610	24.2	379	9.0	7.3	—
978	9/15/1998	1440	15.0	380	11.0	7.4	—
978	6/24/1999	—	40.0	435	3.0	7.2	—
978	7/20/1999	1345	20.0	408	5.0	7.4	—
978	8/17/1999	1645	12.1	344	6.0	7.4	—
978	9/21/1999	1630	9.0	247	6.0	7.9	—
978	8/29/2000	1155	—	273	6.0	7.5	—
978	9/26/2000	1335	4.0	455	7.0	7.6	—
978	6/28/2001	0915	13.5	378	8.0	7.2	—
978	7/25/2001	1120	12.1	365	5.0	7.1	—
978	8/23/2001	1530	12.1	383	10.0	7.5	—
978	9/19/2001	0950	4.0	193	7.0	7.6	—
			Price River Formation				
229	6/22/1993	1545	31.4	312	3.9	6.2	—
229	6/22/1995	1315	82.6	395	6.0	7.2	—
229	7/27/1995	1445	.7	478	7.0	7.4	—
229	6/12/1996	1420	50.0	458	4.0	7.8	—
229	6/18/1997	1545	44.9	457	4.5	8.2	—
229	6/8/1998	1745	120.0	326	4.0	7.2	—
229	6/25/1999	—	30.0	369	5.0	6.6	—
229	6/28/2001	1000	.0	359	8.0	7.0	—
s149	9/21/1992	1530	4.9	649	6.5	6.1	—
s149	6/21/1993	1730	56.1	533	5.4	6.0	—
s149	6/9/1994	1000	30.1	629	4.2	7.4	—
s149	7/19/1994	1030	9.0	604	12.8	7.8	—
s149	8/31/1994	1017	2.7	522	10.7	7.8	—
s149	9/21/1994	1000	4.5	643	8.6	7.8	—
s149	6/21/1995	1545	256	572	6.0	7.3	—
s149	7/26/1995	1815	14.8	554	7.0	7.3	—
s149	8/23/1995	1055	14.8	548	8.0	7.1	—
s149	9/27/1995	1700	13.5	561	7.0	7.3	—
s149	6/12/1996	1100	120	688	5.0	8.2	—
s149	7/24/1996	1020	15.0	628	7.0	8.1	—

Table 5. Field parameters and discharge measured by the Cyprus–Plateau Mining Corporation at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 1992–2001—Continued.

Site no.	Date	Time	Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Dissolved oxygen (mg/L)
Price River Formation—Continued							
s149	8/19/1996	1135	9.9	517	8.0	8.5	—
s149	9/30/1996	1110	9.5	668	6.5	7.8	—
s149	6/17/1997	1720	65.0	590	6.0	7.9	—
s149	7/30/1997	—	20.2	654	6.5	7.6	—
s149	8/13/1997	1155	14.8	602	7.0	8.2	—
s149	9/16/1997	—	13.5	682	8.0	8.3	—
s149	6/8/1998	1440	210	388	5.0	7.8	—
s149	7/19/1998	1730	18.0	699	7.0	7.4	—
s149	8/11/1998	1110	20.2	539	10.0	8.0	—
s149	9/15/1998	1300	10.0	553	10.0	8.1	—
s149	6/24/1999	—	60.0	521	5.0	7.2	—
s149	7/20/1999	1150	20.2	566	7.0	7.3	—
s149	8/17/1999	1610	12.1	440	7.0	7.4	—
s149	9/21/1999	1115	10.0	349	7.0	7.6	—
s149	8/29/2000	0945	5.8	428	5.0	7.5	—
s149	9/26/2000	1120	5.8	516	6.0	7.5	—
s149	6/27/2001	1125	20.2	436	7.0	8.2	—
s149	7/25/2001	1410	9.0	354	6.0	7.8	—
s149	8/23/2001	1455	9.0	426	12.0	7.7	—
s149	9/19/2001	1450	4.0	383	7.0	7.5	—
s182	6/22/1995	1230	24.2	247	5.0	6.4	—
s182	6/09/1998	1430	15.0	227	5.0	7.1	—
Castlegate Sandstone Formation							
[1]238	6/17/1992	1400	—	407	5.0	7.4	—
[1]238	7/15/1992	1345	—	383	5.0	7.4	—
[1]238	9/21/1992	1030	—	400	5.1	6.2	—
[1]238	6/22/1993	1530	22.4	339	5.4	6.2	—
[1]238	6/9/1994	0800	14.4	438	3.1	7.0	—
[1]238	7/20/1994	1230	5.8	373	11.8	7.9	—
[1]238	8/31/1994	0845	3.6	325	11.5	8.1	—
[1]238	9/21/1994	1600	4.5	353	9.2	7.6	—
[1]238	6/22/1995	1315	49.4	410	6.2	7.6	—
[1]238	7/27/1995	1430	14.8	465	5.0	7.6	—
[1]238	8/23/1995	1550	8.1	357	6.0	6.4	—
[1]238	9/28/1995	0830	9.9	252	5.2	7.6	—
[1]238	6/12/1996	1410	32.0	495	5.0	7.9	—
[1]238	7/23/1996	1520	15.0	386	5.0	7.8	—
[1]238	8/19/1996	1400	10.3	341	5.0	7.8	—
[1]238	10/1/1996	0935	8.5	530	5.0	7.8	—
[1]238	6/18/1997	1535	58.3	438	5.5	8.2	—
[1]238	7/30/1997	—	13.5	459	5.0	7.6	—
[1]238	8/13/1997	1745	9.0	403	6.0	7.6	—
[1]238	9/16/1997	—	5.8	478	5.0	8.0	—
[1]238	6/8/1998	1730	85.0	373	5.0	7.9	—
[1]238	7/19/1998	1855	18.0	516	7.0	7.8	—
[1]238	8/11/1998	1540	7.6	339	11.0	7.5	—
[1]238	9/15/1998	1510	10.0	369	9.0	7.6	—
[1]238	6/25/1999	—	20.0	434	5.0	7.0	—
[1]238	8/18/1999	0915	12.1	250	6.0	7.4	—
[1]238	9/21/1999	1615	10.0	231	6.0	7.9	—
[1]238	8/29/2000	1210	7.6	329	4.0	7.8	—

Table 5. Field parameters and discharge measured by the Cyprus–Plateau Mining Corporation at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 1992–2001—Continued.

Site no.	Date	Time	Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Dissolved oxygen (mg/L)
Castlegate Sandstone Formation—Continued							
[1]238	9/26/2000	1400	7.2	415	7.0	7.7	—
[1]238	6/28/2001	0955	17.1	348	8.0	7.3	—
[1]238	7/25/2001	1040	5.8	648	5.0	7.1	—
[1]238	8/23/2001	1555	5.8	355	9.0	7.7	—
[1]238	9/19/2001	1005	4.9	279	5.0	7.7	—
492	6/25/1993	1100	3.1	—	5.9	6.3	—
492	6/20/1994	0800	2.2	420	4.3	8.0	—
492	7/20/1994	1200	1.4	368	13.0	8.1	—
492	8/31/1994	1100	2.2	330	10.2	7.7	—
492	9/26/1994	1100	1.4	303	11.1	8.0	—
492	6/22/1995	1100	1.0	377	3.8	6.9	—
492	7/27/1995	1545	.9	327	7.0	8.0	—
492	8/23/1995	1640	1.8	546	6.0	6.9	—
492	9/28/1995	0935	1.8	—	6.7	7.2	—
492	6/12/1996	1315	1.0	454	5.0	7.5	—
492	7/23/1996	1435	2.0	345	6.0	7.8	—
492	8/19/1996	1750	1.3	412	6.0	7.6	—
492	10/1/1996	0845	2.5	445	8.0	8.2	—
492	6/18/1997	1425	1.8	380	5.0	7.9	—
492	7/30/1997	—	1.8	430	7.0	8.3	—
492	8/13/1997	1850	1.8	420	7.0	8.1	—
492	9/17/1997	—	1.8	394	6.0	8.0	—
492	6/9/1998	1500	2.0	271	5.0	7.8	—
492	7/20/1998	0950	1.4	444	9.0	7.9	—
492	8/12/1998	1000	.9	484	9.0	7.6	—
492	9/15/1998	1645	2.0	321	11.0	8.0	—
492	6/25/1999		1.3	324	6.0	7.2	—
492	7/20/1999	1500	.9	400	9.0	8.3	—
492	8/18/1999	0955	.9	372	6.0	7.9	—
492	9/22/1999	0950	1.5	238	6.0	8.2	—
492	8/29/2000	1320	1.3	415	8.0	8.0	—
492	9/19/2000	0900	1.3	408	5.0	7.8	—
492	6/28/2001	1025	1.8	318	8.0	8.0	—
492	7/30/2001	1445	1.8	280	5.0	7.6	—
492	8/23/2001	1625	1.3	318	9.0	8.1	—
492	9/19/2001	0930	.9	480	14.0	7.6	—
494	6/25/1993	1130	1.3	360	5.4	6.4	—
494	6/22/1995	1115	2.0	408	9.0	7.5	—
494	9/28/1995	1010	1.0	420	7.0	8.0	—
494	6/17/1997	1445	1.8	504	16.0	8.5	—
494	9/17/1997	1135	1.8	458	8.0	8.3	—
500	6/25/1993	1245	.0	—	—	—	—
500	7/20/1994	1230	.0	—	—	—	—
500	8/31/1994	1800	.0	—	—	—	—
500	9/21/1994	0812	.0	—	—	—	—
500	6/22/1995	1232	.0	—	—	—	—
500	7/27/1995	1540	.0	—	—	—	—
500	8/23/1995	1700	.0	—	—	—	—
500	9/28/1995	0955	.0	—	—	—	—

Table 5. Field parameters and discharge measured by the Cyprus–Plateau Mining Corporation at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 1992–2001—Continued.

Site no.	Date	Time	Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (˚C)	pH (standard units)	Dissolved oxygen (mg/L)
			Castlegate Sandstone Formation—Continued				
500	6/11/1996	1305	.0	—	—	—	—
500	7/23/1996	1421	.0	—	—	—	—
500	8/19/1996	1145	.0	—	—	—	—
500	10/1/1996	0815	.0	—	—	—	—
500	6/18/1997	1325	.9	533	14.0	8.2	—
500	7/30/1997	1938	.0	—	—	—	—
500	8/13/1997	1720	.0	—	—	—	—
500	9/16/1997	1815	.0	—	—	—	—
			Blackhawk Formation				
530	6/21/1993	1430	3.6	539	8.5	6.6	—
530	6/8/1994	1615	1.4	607	9.9	8.3	—
530	7/19/1994	0845	4.5	588	11.4	8.1	—
530	8/31/1994	0925	1.3	471	10.0	7.8	—
530	9/21/1994	0850	4.5	565	9.5	8.1	—
530	6/22/1995	0800	2.5	541	5.0	7.9	—
530	7/27/1995	0915	4.0	582	7.0	7.9	—
530	8/23/1995	1015	3.6	515	11.0	8.0	—
530	9/27/1995	1015	2.7	614	7.0	8.1	—
530	6/12/1996	0845	6.0	745	6.0	7.8	—
530	7/24/1996	0900	6.0	623	8.0	8.5	—
530	8/19/1996	1025	3.6	478	8.0	8.8	—
530	9/30/1996	0955	4.6	588	6.0	7.9	—
530	6/18/1997	0900	14.8	675	6.5	8.2	—
530	7/30/1997	—	9.0	528	9.0	7.7	—
530	8/13/1997	1240	5.8	560	10.0	8.1	—
530	9/17/1997	—	4.9	668	8.0	8.2	—
530	6/9/1998	1600	9.0	450	6.0	8.1	—
530	7/20/1998	0915	6.7	620	9.0	8.1	—
530	8/11/1998	1205	5.8	475	11.0	8.0	—
530	9/16/1998	1045	6.0	415	10.0	8.0	—
530	6/25/1999	—	8.0	464	11.0	8.1	—
530	7/20/1999	1440	15.0	399	7.0	7.6	—
530	8/18/1999	1015	7.2	526	7.0	8.0	—
530	9/21/1999	1350	4.9	354	12.0	8.1	—
530	8/29/2000	1135	—	—	—	—	—
530	9/26/2000	1555	4.9	489	7.0	8.1	—
530	6/28/2001	1145	5.8	479	10.0	8.3	—
530	7/25/2001	1305	1.8	493	7.0	7.9	—
530	8/23/2001	1045	3.1	490	11.0	8.1	—
530	9/19/2001	1045	—	—	—	—	—

[1]Original site 238 referenced in Slaughter and others (1995).

Table 6. Field parameters and discharge measured by the U.S. Geological Survey at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 2004–2005.

[See figure 5 for site locations; gal/min, gallons per minute; µS/cm, microsiemens per centimeter; ˚C, degrees Celsius; mg/L, milligrams per liter; —, no data; e, estimated]

Site no.	Date	Time	Discharge, gal/min	Specific conductance (µS/cm)	Water temperature (˚C)	pH (standard units)	Dissolved oxygen (mg/L)
			North Horn Formation				
232	8/04/2004	1440	—	400	8.0	6.7	3.1
232	9/15/2004	1600	1.0	409	5.2	7.0	9.0
232	8/15/2005	1050	2.0	397	4.9	7.2	—
232	9/14/2005	1105	1.6	404	4.9	6.9	8.2
753	7/27/2004	1635	.6	506	12.0	7.3	5.3
753	9/13/2004	1545	<.1	528	8.1	7.2	6.6
753	8/04/2005	1030	.8	489	10.2	7.0	—
753	9/12/2005	1700	.2	617	5.8	7.5	4.7
978	7/27/2004	1730	8.5	446	5.6	6.9	8.4
978	9/13/2004	1635	3.5	445	6.5	7.0	8.2
978	7/18/2005	1640	11.2	442	3.0	7.0	—
978	9/12/2005	1655	3.4	279	6.0	7.3	8.2
			Price River Formation				
229	8/4/2004	1315	5.7	422	5.0	6.9	9.2
229	9/15/2004	1700	4.8	420	5.5	7.5	9.6
229	8/15/2005	1145	7.7	430	4.8	7.0	—
229	9/14/2005	1205	4.2	435	5.1	7.1	8.4
s149	7/29/2004	1515	6.5	481	9.0	7.6	8.8
s149	9/16/2004	1330	4.8	500	9.2	7.9	9.1
s149	8/04/2005	1420	7.6	500	7.4	8.2	—
s149	9/12/2005	1340	5.0	489	6.9	7.1	8.9
s182	7/27/2004	1530	1.1	447	8.0	6.5	8.2
s182	9/13/2004	1500	.4	420	10.6	6.3	7.7
s182	7/18/2005	1530	4.4	397	6.4	7.4	6.8
s182	9/14/2005	1335	1.8	446	7.9	7.5	7.7
			Castlegate Sandstone				
[1]238 new	9/14/2004	1510	.8	900	8.7	7.9	8.4
[1]238 new	7/20/2005	1320	4.5	901	10.6	8.1	—
[1]238 new	9/13/2005	1300	3.6	995	5.4	8.1	8.9
491	7/28/2004	1120	9.4	386	11.8	7.6	7.6
491	9/14/2004	1050	9.4	416	9.8	7.7	8.0
491	7/20/2005	0945	4.5	359	8.3	6.7	—
491	9/12/2005	1345	4.9	390	7.0	7.8	6.8
491	9/13/2005	1040	5.1	395	6.6	7.8	8.2
492	7/28/2004	1200	1.1	387	9.1	7.8	7.9
492	9/14/2004	1140	1.0	400	8.1	7.9	8.6
492	7/20/2005	1015	.4	409	8.6	7.1	—
492	9/12/2005	1415	1.2	400	8.2	8.0	6.9
492	9/13/2005	1052	1.2	357	5.8	8.1	8.4

Table 6. Field parameters and discharge measured by the U.S. Geological Survey at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, 2004–2005—Continued.

Site no.	Date	Time	Discharge, gal/min	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Dissolved oxygen (mg/L)
			Castlegate Sandstone—Continued				
493	7/28/2004	1235	<.1	442	13.7	7.4	3.3
493	9/14/2004	1255	<.1	448	12.8	7.2	1.6
493	7/20/2005	1105	e.3	433	9.4	7.4	—
493	9/12/2005	1500	.9	429	11.6	7.3	4.4
493	9/13/2005	1500	e.9	—	—	—	—
494	7/25/2004	1300	e.3	440	17.0	7.5	6.4
494	9/14/2004	1230	e.1	434	13.3	7.0	3.2
494	7/20/2005	1130	e.1	423	8.6	7.3	—
494	9/13/2005	1505	e.1	—	—	—	—
500	9/16/2004	1520	.3	493	8.6	7.9	8.8
500	8/15/2005	1400	.3	493	9.0	7.5	—
500	9/14/2005	1440	.4	488	7.9	7.7	7.5
			Blackhawk Formation				
530	7/29/2004	1310	.2	595	11.1	7.0	5.6
530	9/16/2004	1115	.2	600	9.3	7.1	7.1
530	8/4/2005	1155	.3	606	10.4	7.6	—
530	9/12/2005	1530	.2	357	10.5	7.2	5.2

[1]Due to difficulty locating this site, 'new' is used to differentiate between the original site 238 that was referenced in Slaughter and others, 1995 and this site.

Table 7. Concentration of dissolved major ions at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined from water samples collected and analyzed by the Cyprus–Plateau Mining Corporation, 1992–2001.

[See figure 5 for site location. All measurements given in milligrams per liter; <, less than; —, no data]

Site no.	Date	Time	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Sulfate	Chloride	Solids
					North Horn Formation					
232	7/15/1992	1330	58.0	8.0	2.0	1.0	164	16.0	2.0	226
232	9/21/1992	1045	53.0	8.0	2.0	1.0	146	19.0	2.0	170
232	6/24/1993	1430	57.0	9.0	2.0	1.0	156	19.0	2.0	152
232	6/9/1994	0830	56.0	8.0	2.0	<1	174	<2.0	2.0	208
232	7/19/1994	1530	52.0	8.0	2.0	1.0	175	6.0	2.0	180
232	9/21/1994	1145	60.0	9.0	—	1.0	182	6.0	2.0	190
232	6/22/1995	1300	46.8	6.8	1.8	1.2	128	30.0	2.0	140
232	7/27/1995	1500	59.6	9.1	2.2	1.2	170	10.0	2.0	200
232	9/28/1995	0815	61.1	9.2	2.2	1.2	179	4.0	1.0	210
232	6/12/1996	1350	57.6	8.6	1.9	.9	160	<10.0	2.0	190
232	7/23/1996	1505	68.3	10.5	2.4	1.3	189	10.0	2.0	200
232	10/1/1996	0915	64.7	9.8	2.4	1.3	186	<10.0	2.0	220
232	6/18/1997	1515	58.2	8.5	2.0	1.2	156	10.0	1.0	180
232	7/30/1997	—	62.0	9.6	2.3	1.4	—	<5	<0.5	190
232	9/16/1997	—	60.0	11.0	2.4	1.6	—	<5	<0.5	230
232	6/8/1998	1710	47.0	7.0	2.0	1.0	135	9.0	2.0	190
232	7/19/1998	1845	57.0	9.0	1.0	1.0	177	11.0	2.0	748
232	9/15/1998	1555	58.0	9.0	2.0	<1	183	10.0	2.0	229
232	6/25/1999	—	52.0	8.0	2.0	<1	158	9.0	2.0	171
232	7/20/1999	1400	60.0	9.0	2.0	<1	179	10.0	2.0	216
232	9/21/1999	1610	59.0	9.0	4.0	1.0	185	9.0	2.0	210
232	8/29/2000	1200	59.0	9.0	3.0	2.0	184	9.0	3.0	204
232	9/26/2000	1415	59.0	9.0	2.0	1.0	182	10.0	2.0	202
232	6/28/2001	0940	56.0	9.0	2.0	1.0	184	10.0	1.7	226
232	7/25/2001	1105	59.0	9.0	3.0	1.0	181	10.0	1.8	208
753	7/15/1992	1200	90.0	9.0	1.0	<1	236	31.0	<1	336
753	6/24/1993	1400	72.0	10.0	2.0	<1	210	<2	2.0	198
753	6/9/1994	0900	72.0	10.0	1.0	<1	232	5.0	2.0	252
753	6/22/1995	1400	64.3	8.7	1.8	1.3	173	30.0	2.0	190
753	7/27/1995	1515	81.6	11.4	1.8	.8	232	<10	1.0	250
753	9/28/1995	0800	85.2	12.5	1.7	1.1	245	4.0	1.0	260
753	6/12/1996	1430	76.8	10.7	1.6	1.0	218	<10	2.0	240
753	7/23/1996	1545	89.6	12.8	1.8	1.0	258	<10	<1	250
753	6/17/1997	1850	75.0	10.0	1.5	.9	227	10.0	<1	220
753	7/30/1997	—	82.0	11.0	1.7	1.2	—	<5	<.5	240
753	9/16/1997	—	74.0	15.0	2.0	1.7	—	<5	<.5	300
753	7/19/1998	1825	77.0	11.0	<1	<1	249	4.0	<1	386
753	6/24/1999	—	74.0	11.0	2.0	<1	224	—	1.0	228
753	6/28/2001	0925	77.0	11.0	2.0	1.0	254	5.0	1.7	282
978	7/15/1992	1145	63.0	11.0	2.0	<1	228	<5	<.5	240
978	9/21/1992	1015	58.0	11.0	2.0	1.0	182	<5	<.5	300
978	6/24/1993	1330	73.0	12.0	2.0	<1	216	4.0	<1	386
978	6/20/1994	0900	74.0	13.0	2.0	<1	234	—	1.0	228
978	7/19/1994	1500	70.0	12.0	3.0	1.0	164	5.0	1.7	282
978	9/21/1994	1140	78.0	14.0	2.0	<1	225	<5	<.5	240

Table 7. Concentration of dissolved major ions at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined from water samples collected and analyzed by the Cyprus–Plateau Mining Corporation, 1992–2001—Continued.

Site no.	Date	Time	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Sulfate	Chloride	Solids
North Horn Formation—Continued										
978	6/22/1995	1345	71.6	11.4	2.3	.5	214	<5	<.5	300
978	7/26/1995	1830	74.1	12.6	2.1	.7	225	4.0	<1	386
978	9/28/1995	0845	73.1	13.0	1.9	.7	220	—	1.0	228
978	6/12/1996	1440	78.1	12.5	2.3	.5	223	5.0	1.7	282
978	7/23/1996	1550	78.6	13.7	2.3	.7	231	<5	<.5	240
978	9/30/1996	1615	82.8	14.5	2.0	.8	230	<5	<.5	300
978	6/17/1997	1837	72.4	11.5	2.2	.5	230	4.0	<1	386
978	7/30/1997	—	63.0	12.0	2.0	1.9	—	—	1.0	228
978	9/16/1997	—	68.0	14.0	2.0	1.1	—	5.0	1.7	282
978	6/8/1998	1655	70.0	11.0	2.0	<1	227	<5	<.5	240
978	7/19/1998	1815	68.0	11.0	<1	<1	230	<5	<.5	300
978	9/15/1998	1440	72.0	13.0	2.0	<1	231	4.0	<1	386
978	6/24/1999	—	75.0	13.0	2.0	<1	239	—	1.0	228
978	7/20/1999	1345	72.0	12.0	2.0	<1	231	5.0	1.7	282
978	9/21/1999	1630	72.0	12.0	3.0	<1	236	<5	<.5	240
978	9/26/2000	1335	71.0	13.0	1.0	<1	232	<5	<.5	300
978	6/28/2001	0915	68.0	12.0	2.0	<1	226	4.0	<1	386
978	7/25/2001	1120	71.0	12.0	2.0	<1	228	—	1.0	228
978	9/19/2001	0950	70.0	13.0	2.0	<1	234	5.0	1.7	282
Price River Formation										
229	6/22/1993	1545	56.0	8.0	1.0	<1	182	6.0	<1	174
229	6/22/1995	1315	67.9	9.9	1.3	.8	184		1.0	190
229	7/27/1995	1445	66.1	10.1	1.4	.7	185	10.0	2.0	220
229	6/12/1996	1420	67.3	10.1	1.4	.6	183	10.0	1.0	200
229	6/18/1997	1545	66.4	9.8	1.5	.8	190	<10	<1	190
229	6/8/1998	1745	64.0	10.0	2.0	< 1.	190	9.0	2.0	237
229	6/25/1999	—	63.0	10.0	2.0	< 1.	205	11.0	1.0	204
229	6/28/2001	1000	62.0	10.0	2.0	< 1.	187	12.0	1.0	226
s149	6/21/1993	1730	88.0	22.0	3.0	1.0	260	70.0	2.0	302
s149	6/9/1994	1000	81.0	22.0	3.0	1.0	262	45.0	2.0	348
s149	7/19/1994	1030	88.0	26.0	4.0	2.0	320	—	2.0	328
s149	9/21/1994	1000	100	30.0	4.0	2.0	265	77.0	2.0	382
s149	6/21/1995	1545	81.9	20.3	3.2	1.5	235	40.0	<1	300
s149	7/26/1995	1815	88.2	24.6	3.5	1.4	255	50.0	2.0	320
s149	9/27/1995	1700	92.2	27.4	3.5	1.6	274	65.0	3.0	360
s149	6/12/1996	1100	87.1	24.2	3.5	1.3	261	50.0	2.0	310
s149	7/24/1996	1020	94.8	27.6	3.5	1.5	271	60.0	2.0	330
s149	9/30/1996	1110	90.2	26.2	3.4	1.5	266	70.0	2.0	360
s149	6/17/1997	1720	85.9	23.5	3.3	1.3	274	40.0	2.0	320
s149	7/30/1997	—	88.0	25.0	3.6	1.9	—	59.0	<.5	340
s149	9/16/1997	—	85.0	29.0	3.8	2.1	—	71.0	2.1	380
s149	6/8/1998	1440	77.0	20.0	3.0	1.0	263	28.0	3.0	301
s149	9/15/1998	1300	83.0	25.0	3.0	2.0	270	58.0	2.0	366
s149	6/24/1999	—	82.0	23.0	3.0	1.0	261	39.0	1.0	320
s149	9/21/1999	1115	84.0	26.0	3.0	2.0	273	59.0	2.0	362
s149	9/26/2000	1120	81.0	26.0	3.0	2.0	264	68.0	2.0	365
s149	6/27/2001	1125	80.0	23.0	3.0	1.0	261	54.0	2.0	348
s149	9/19/2001	1450	86.0	25.0	4.0	2.0	268	62.0	2.1	396

Table 7. Concentration of dissolved major ions at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined from water samples collected and analyzed by the Cyprus–Plateau Mining Corporation, 1992–2001—Continued.

Site no.	Date	Time	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Sulfate	Chloride	Solids
Price River Formation—Continued										
s182	6/22/1995	1230	40.1	7.5	3.2	.9	122	10.0	3.0	130
s182	6/9/1998	1430	38.0	7.0	3.0	<1	125	9.0	3.0	156
Castlegate Sandstone Formation										
238	7/15/1992	1345	65.0	12.0	1.0	1.0	218	<2	<1	212
238	9/21/1992	1030	64.0	13.0	2.0	1.0	170	39.0	1.0	222
238	6/22/1993	1530	54.0	10.0	2.0	<1	196	<2	<1	178
238	6/9/1994	0800	66.0	12.0	1.0	1.0	180	17.0	2.0	238
238	7/20/1994	1230	60.0	12.0	2.0	1.0	192	21.0	1.0	206
238	9/21/1994	1600	70.0	14.0	2.0	1.0	214	19.0	1.0	216
238	6/22/1995	1315	66.3	11.6	1.5	.9	199	10.0	1.0	210
238	7/27/1995	1430	66.7	13.2	1.7	1.2	185	20.0	1.0	230
238	9/28/1995	830	67.1	13.7	1.8	1.2	190	22.0	1.0	230
238	6/12/1996	1410	70.7	12.6	1.7	.9	198	20.0	1.0	230
238	7/23/1996	1520	71.0	14.4	1.8	1.3	196	30.0	1.0	230
238	10/1/1996	0935	69.6	14.2	1.8	1.4	191	30.0	1.0	240
238	6/18/1997	1535	70.6	12.8	1.7	1.1	198	10.0	<1	220
238	7/30/1997	—	52.0	11.0	1.5	1.2	—	22.0	<.5	320
238	9/16/1997	—	68.0	16.0	2.1	1.8	—	20.0	1.5	230
238	6/8/1998	1730	66.0	13.0	2.0	<1	209	9.0	2.0	247
238	7/19/1998	1855	63.0	12.0	<1	1.0	197	25.0	2.0	241
238	9/15/1998	1510	66.0	14.0	2.0	1.0	198	27.0	2.0	267
238	6/25/1999	—	67.0	13.0	2.0	<1	206	17.0	1.0	210
238	9/21/1999	1615	64.0	13.0	3.0	1.0	197	27.0	<1	239
238	8/29/2000	1210	65.0	13.0	3.0	1.0	198	27.0	1.0	230
238	9/26/2000	1400	64.0	13.0	1.0	1.0	193	31.0	1.0	231
238	6/28/2001	0955	63.0	13.0	2.0	1.0	192	24.0	1.0	246
238	7/25/2001	1040	64.0	13.0	2.0	<1	191	27.0	.9	235
238	9/19/2001	1005	65.0	14.0	2.0	1.0	199	27.6	1.0	268
492	7/16/1992	0930	62.0	14.0	2.0	<1	188	23.0	2.0	220
492	9/21/1992	1345	52.0	19.0	3.0	1.0	214	<2	2.0	212
492	6/25/1993	1100	40.0	11.0	2.0	<1	130	2.0	3.0	148
492	6/20/1994	0800	56.0	20.0	4.0	<1	214	6.0	2.0	198
492	7/20/1994	1200	48.0	18.0	2.0	<1	198	<2	2.0	218
492	9/26/1994	1100	45.0	17.0		<1	175	<4	2.0	188
492	6/22/1995	1100	52.0	20.0	2.8	.6	204	<10	3.0	190
492	7/27/1995	1545	52.9	20.2	2.8	.7	195	10.0	2.0	220
492	9/28/1995	935	55.5	21.0	2.8	.6	193	11.0	3.0	210
492	6/12/1996	1315	54.0	20.5	2.8	.5	195	10.0	2.0	210
492	7/23/1996	1435	55.1	20.4	2.8	.7	202	<10	2.0	210
492	10/1/1996	0845	53.8	20.0	2.9	.7	194	<10	2.0	220
492	6/18/1997	1425	58.2	21.5	2.8	.8	249	<10	2.0	200
492	7/30/1997	—	53.0	19.0	2.8	.7	—	<5	<.5	210
492	9/17/1997	—	49.0	18.0	3.2	1.1	—	<5	2.2	180
492	6/9/1998	1500	47.0	17.0	3.0	<1	185	<5	3.0	211
492	7/20/1998	0950	49.0	16.0	2.0	<1	196	6.0	2.0	219
492	9/15/1998	1645	50.0	19.0	3.0	<1	198	6.0	3.0	294
492	6/25/1999	—	52.0	19.0	3.0	<1	200	5.0	2.0	193
492	7/20/1999	1500	52.0	19.0	2.0	<1	195	5.0	2.0	220

Table 7. Concentration of dissolved major ions at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined from water samples collected and analyzed by the Cyprus–Plateau Mining Corporation, 1992–2001—Continued.

Site no.	Date	Time	Calcium	Magnesium	Sodium	Potassium	Alkalinity	Sulfate	Chloride	Solids
Castlegate Sandstone Formation—Continued										
492	9/22/1999	0950	51.0	18.0	4.0	<1	202	6.0	2.0	215
492	9/19/2000	0900	51.0	19.0	3.0	<1	199	6.0	3.0	272
492	6/28/2001	1025	50.0	18.0	3.0	<1	199	5.0	1.8	225
492	9/19/2001	0930	51.0	19.0	3.0	<1	204	5.0	2.3	241
494	6/22/1995	1115	61.8	22.8	3.3	<.3	189	80.0	2.0	230
500	6/18/1997	1325	59.0	20.8	2.7	.7	228	10.0	2.0	250
Blackhawk Formation										
530	7/15/1992	1430	87.0	23.0	4.0	<1	274	45.0	—	320
530	9/22/1992	1050	70.0	33.0	6.0	3.0	236	80.0	4.0	298
530	6/21/1993	1430	68.0	28.0	5.0	<1	280	31.0	4.0	282
530	6/8/1994	1615	67.0	28.0	5.0	<1	280	25.0	4.0	278
530	7/19/1994	0845	68.0	30.0	5.0	1.0	285	31.0	4.0	288
530	9/21/1994	0850	76.0	32.0	5.0	1.0	270	25.0	4.0	318
530	6/22/1995	0800	75.4	32.3	5.5	1.0	291	20.0	5.0	320
530	7/27/1995	0915	73.2	32.1	5.4	.7	285	30.0	5.0	330
530	9/27/1995	1015	76.0	32.1	5.3	1.1	273	35.0	5.0	340
530	6/12/1996	0845	77.6	33.7	5.8	.8	287	30.0	5.0	300
530	7/24/1996	0900	76.5	33.2	5.5	.8	284	30.0	5.0	310
530	9/30/1996	0955	74.2	30.9	5.0	.8	285	30.0	5.0	310
530	6/18/1997	0900	78.1	32.4	5.9	.7	318	20.0	6.0	330
530	7/30/1997	—	74.0	31.0	5.4	1.2	—	23.0	2.9	300
530	9/17/1997	—	75.0	36.0	6.9	1.3	—	22.0	7.1	270
530	6/9/1998	1600	68.0	29.0	6.0	<1	277	26.0	6.0	341
530	7/20/1998	0915	66.0	29.0	4.0	<1	282	27.0	6.0	330
530	9/16/1998	1045	72.0	30.0	5.0	<1	294	27.0	7.0	378
530	6/25/1999	—	69.0	30.0	5.0	<1	291	26.0	5.0	297
530	7/20/1999	1440	65.0	13.0	1.0	1.0	190	24.0	<1	239
530	9/21/1999	1350	72.0	30.0	<1	<1	278	26.0	5.0	323
530	9/26/2000	1555	68.0	30.0	6.0	<1	278	35.0	5.0	335
530	6/28/2001	1145	70.0	30.0	5.0	<1	279	34.0	5.3	318
530	7/25/2001	1305	70.0	30.0	5.0	<1	281	34.0	5.2	325

Table 8. Concentration of dissolved major ions at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined from water samples collected and analyzed by the U.S. Geological Survey, 2004–2005.

[See figure 5 for site location; mg/L, milligrams per liter; <, less than; —, no data]

Site no.	Date	Time	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity, measured in field (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Solids, residue at 180°C (mg/L)
North Horn Formation													
232	8/4/2004	1140	68.3	11.1	1.8	1.9	208	253	11.6	2.2	<0.2	5.8	225
232	9/15/2004	1600	51.6	8.0	1.3	.8	191	232	12.9	1.6	<.2	3.7	228
232	8/15/2005	1050	69.8	11.3	1.8	1.0	184	224	12.5	1.8	<.2	4.9	222
232	9/14/2005	1105	69.4	11.2	1.6	1.0	186	226	13.4	2.2	<.2	4.9	224
753	7/27/2004	1635	93.9	13.6	1.5	2.1	268	326	6.3	3.6	<.2	8.1	304
753	9/13/2004	1545	87.8	13.9	1.6	1.2	273	332	6.9	2.6	<.2	6.1	303
753	8/4/2005	1030	88.6	11.7	1.6	1.5	256	310	5.1	1.7	<.2	7.0	285
753	9/12/2005	1700	103	15.0	2.1	13.1	321	390	3.2	5.6	<.2	9.3	350
978	7/27/2004	1730	72.0	12.8	1.7	.7	226	276	9.6	1.8	<.2	4.7	200
978	9/13/2004	1630	73.8	13.3	1.9	.6	232	282	9.3	1.4	<.2	5.0	208
978	7/18/2005	1640	73.6	12.3	1.6	.7	—	193	7.7	1.9	<.2	4.8	241
978	9/12/2005	1655	78.2	13.5	1.7	.7	222	271	8.2	1.8	<.2	5.0	248
Price River Formation													
229	8/4/2004	1315	67.5	13.7	1.7	1.3	198	240	24.4	1.7	<.2	5.0	207
229	9/15/2004	1700	69.7	13.4	1.8	1.3	189	229	24.2	1.4	<.2	5.1	206
229	8/15/2005	1145	72.3	14.5	1.8	1.4	189	230	24.7	1.3	<.2	4.9	240
229	9/14/2005	1205	72.1	14.6	1.6	1.3	191	232	26.2	1.7	<.2	5.0	238
s149	7/29/2004	1515	71.1	14.8	2.5	.8	233	282	20.2	2.3	<.2	5.9	210
s149	9/16/2004	1330	79.9	16.8	3.1	.9	241	291	18.6	1.8	<.2	7.1	246
s149	8/4/2005	1420	84.9	16.4	2.8	1.0	242	293	20.5	1.7	<.2	6.6	280
s149	9/12/2005	1340	85.1	17.1	2.9	1.1	234	283	20.6	2.0	<.2	6.8	286
s182	7/27/2004	1530	68.0	13.8	3.0	1.0	223	271	15.1	4.0	<.2	8.1	231
s182	9/13/2004	1500	47.4	7.4	1.7	.3	197	240	8.8	2.2	<.2	6.0	217
s182	7/18/2005	1530	68.2	12.6	3.1	.9	150	182	12.3	3.6	<.2	8.3	240
s182	9/14/2005	1335	74.2	13.8	2.9	.8	212	258	11.5	3.3	<.2	8.6	250
Castlegate Sandstone Formation													
[1]238 new	9/14/2004	1510	119	55.4	2.9	1.8	271	326	230	2.8	<.2	4.8	539
[1]238 new	7/20/2005	1320	125	50.9	2.7	1.8	220	266	243	3.0	<.2	4.9	648
[1]238 new	9/13/2005	1300	142	62.3	2.8	1.8	276	331	282	3.3	<.2	5.2	709
491	7/20/2005	0945	50.0	14.6	2.7	.7	124	151	6.1	2.1	<.2	5.1	163
491	9/12/2005	1345	60.3	17.3	2.7	1.2	190	229	7.4	2.8	<.2	5.9	224
492	7/28/2004	1200	54.6	19.6	2.6	.8	204	247	5.7	2.8	<.2	6.0	224
492	9/14/2004	1140	54.3	19.0	2.9	.7	196	237	4.8	2.4	<.2	6.4	230
492	7/20/2005	1015	53.3	19.1	2.7	.8	161	196	4.0	1.9	<.2	5.4	171
492	9/12/2005	1415	58.1	21.0	2.6	.6	200	240	5.4	2.6	<.2	6.7	229
493	7/20/2005	1105	55.8	19.3	4.0	1.2	152	185	12.8	3.2	<.2	6.8	191
493	9/12/2005	1500	60.2	21.5	3.3	.3	204	245	15.0	2.9	<.2	7.1	240

Table 8. Concentration of dissolved major ions at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined from water samples collected and analyzed by the U.S. Geological Survey, 2004–2005—Continued.

Site no.	Date	Time	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Alkalinity, measured in field (mg/L as $CaCO_3$)	Bicarbonate (mg/L as HCO_3)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Silica (mg/L)	Solids, residue at 180°C (mg/L)
Castlegate Sandstone Formation—Continued													
494	7/28/2004	1310	48.3	17.4	2.8	1.2	194	236	19.3	3.6	<.2	5.9	243
494	9/14/2004	1230	56.8	19.6	3.4	.5	200	242	17.7	2.6	<.2	6.8	246
494	7/20/2005	1130	55.9	19.8	4.1	.9	147	178	12.8	2.9	<.2	7.0	173
500	9/16/2004	1520	67.8	19.3	2.6	.4	249	302	7.1	3.1	<.2	6.4	229
500	8/15/2005	1400	74.9	20.9	2.7	.5	493	306	7.7	3.1	<.2	6.4	269
500	9/14/2005	1440	75.7	21.3	2.5	.5	240	291	7.9	5.1	<.2	6.5	272
Blackhawk Formation													
530	7/29/2004	1310	82.0	31.5	4.9	.6	284	344	40.0	4.6	<.2	8.5	286
530	9/16/2004	1115	77.6	31.0	4.9	.5	275	335	46.0	4.2	<.2	8.7	307
530	8/4/2005	1155	78.6	30.1	4.6	.5	279	340	42.1	4.2	<.2	8.1	347
530	9/12/2005	1530	84.3	33.6	4.7	.5	280	339	46.3	4.6	<.2	8.6	368

[1]Due to difficulty locating this site, ‘new’ is used to differentiate between the original site 238 that was referenced in Slaughter and others, 1995 and this site.

Table 9. Concentration of dissolved trace elements at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined and analyzed by the U.S. Geological Survey, 2004–2005.

[See figure 5 for site location. All values are in micrograms per liter; <, less than; e, estimated; —, no data; M, presence of constituent verified but not quantified]

Site no.	Date	Time	Aluminum	Barium	Boron	Cadmium	Chromium	Cobalt	Iron
North Horn Formation									
232	8/4/2004	1140	2	130	16	<0.04	<0.8	0.317	9
232	9/15/2004	1600	<2	88	8	e.02	<.8	.162	<6
232	8/15/2005	1050	<2	104	10	<.04	<.8	.138	<6
232	9/14/2005	1105	e1	120	13	<.04	.05	e.03	e4
753	7/27/2004	1635	4	86	11	<.04	<.8	.662	78
753	9/13/2004	1545	M	102	10	<.04	<.8	.446	56
753	8/4/2005	1030	2	72	9	<.04	<.8	.283	70
753	9/12/2005	1700	3	112	15	<.04	.05	.91	426
978	7/27/2004	1730	e1	53	8	<.04	<.8	.349	<6
978	9/13/2004	1630	<2	57	8	<.04	<.8	.179	12
978	7/18/2005	1640	<2	49	10	<.04	<.8	.195	<6
978	9/12/2005	1655	<2	57	9	<.04	.14	e.03	e5
Price River Formation									
229	8/4/2004	1315	2	88	10	<.04	<.8	.304	<6
229	9/15/2004	1700	M	86	8	<.04	<.8	.232	<6
229	8/15/2005	1145	<2	81	8	<.04	<.8	.124	<6
229	9/14/2005	1205	<2	92	13	<.04	.05	e.02	7
s149	7/29/2004	1515	<2	85	14	<.04	<.8	.331	<6
s149	9/16/2004	1330	e1	102	15	<.04	<.8	.173	<6
s149	8/4/2005	1420	<2	93	15	<.04	e.4	.132	<6
s149	9/12/2005	1340	e1	98	17	<.04	.04	—	e5
s182	7/27/2004	1530	<2	44	12	<.04	<.8	.3	<6
s182	9/13/2004	1500	<2	30	e7	<.04	<.8	.094	<6
s182	7/18/2005	1530	M	41	14	<.04	<.8	.177	<6
s182	9/14/2005	1335	<2	47	14	<.04	.05	.267	e3
Castlegate Sandstone Formation									
[1]238 new	9/14/2004	1510	e1	29	13	<.04	<.8	.364	<6
[1]238 new	7/20/2005	1320	2	45	27	e.04	<.8	.33	<6
[1]238 new	9/13/2005	1300	e1	50	17	e.02	e.04	.07	7
491	7/20/2005	0945	8	26	12	<.04	<.8	.158	10
491	9/12/2005	1345	3	28	14	<.04	.16	—	14
492	7/28/2004	1200	e1	22	11	e.03	<.8	.255	<6
492	9/14/2004	1140	<2	21	11	e.04	<.8	.187	<6
492	7/20/2005	1015	2	21	27	.07	<.8	.148	<6
492	9/12/2005	1415	M	23	13	.04	.09	e.03	e4
493	7/20/2005	1105	2	30	27	.05	<.8	.397	e4
493	9/12/2005	1500	2	20	15	.04	.08	.05	8
494	7/28/2004	1310	e1	24	13	e.02	<.8	.322	<6
494	9/14/2004	1230	M	20	12	.04	<.8	.226	<6
494	7/20/2005	1130	e1	26	19	.04	<.8	.446	<6

Table 9. Concentration of dissolved trace elements at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined and analyzed by the U.S. Geological Survey, 2004–2005—Continued.

Site no.	Lead	Lithium	Manga-nese	Molyb-denum	Nickel	Selenium	Silver	Strontium	Vanadium	Zinc
North Horn Formation										
232	<0.08	2.8	37.5	e0.2	2.44	e0.4	<.2	171	0.3	1.6
232	<.08	2.3	.3	<.4	.9	1.1	<.2	107	.2	5
232	<.08	3.5	.5	<.4	2.43	2	<.2	161	.2	e.4
232	<.08	3.1	<.2	e.2	—	1.6	<.2	165	e.07	e.6
753	e.05	2.5	130	e.2	3.71	<.4	<.2	72.8	.8	e.6
753	<.08	3.1	94.6	e.2	.11	<.4	<.2	64.9	.4	.8
753	e.05	2.1	49.1	<.4	2.54	<.4	<.2	61.3	.8	.9
753	e.06	2.8	713	e.4	—	e.07	<.2	84.8	.36	.7
978	<.08	2.6	5.6	.5	2.76	e.2	<.2	67.1	.2	2.5
978	<.08	2.3	6.2	.6	.14	<.4	<.2	65.6	.2	2.8
978	<.08	2.5	.6	.5	1.91	<.4	<.2	62	.2	e.4
978	<.08	2.1	<.2	.5	—	.18	<.2	69.5	<.1	<.6
Price River Formation										
229	<.08	3.5	6.3	e.2	2.42	2.2	<.2	284	.3	2.3
229	<.08	3.7	6.1	.4	.75	2.2	<.2	269	.5	.9
229	<.08	4.3	<.2	e.2	2.37	2.4	<.2	286	.2	e.6
229	<.08	3.7	<.2	e.2	—	2.1	<.2	302	<.1	<.6
s149	<.08	4.4	.4	e.3	2.69	1.1	<.2	189	1.6	e.3
s149	<.08	4.6	.2	e.4	<.06	1.5	<.2	215	.2	.7
s149	<.08	5.1	<.2	e.3	2.35	1.3	<.2	233	.6	1
s149	<.08	5.4	.6	e.4	—	1.2	<.2	260	.16	<.6
s182	<.08	5.4	e.1	<.4	2.44	1.5	<.2	258	.2	.7
s182	<.08	3.1	e.1	<.4	e.04	.9	<.2	124	e.1	4.1
s182	<.08	5.9	<.2	<.4	1.72	1.1	<.2	229	.3	1.4
s182	<.08	5.5	<.2	<.4	4.71	1	<.2	248	e.07	1
Castlegate Sandstone Formation										
[1]238 new	<.08	7.6	.9	.4	3.8	.7	<.2	194	.8	1.9
[1]238 new	<.08	10.4	.6	e.3	4.31	.9	<.2	214	.4	3.1
[1]238 new	<.08	8.6	3.4	e.2	—	.62	<.2	230	.17	2.1
491	.24	2	8.3	e.4	2.19	e.4	<.2	71.8	.9	1.7
491	<.08	2.4	7.8	e.4	—	.2	<.2	74.4	.11	e.3
492	<.08	4.4	.7	e.2	2.3	.9	<.2	80.6	.2	e.4
492	<.08	4.5	.4	e.2	.93	1.2	<.2	76.1	.5	1.1
492	.13	4.3	e.2	e.2	1.83	1.3	<.2	73.4	.3	1
492	<.08	4.3	<.2	e.2	—	1.1	<.2	82.4	e.08	1.1
493	.53	8	7.5	.7	3.06	2.9	<.2	102	3.5	1.8
493	e.04	5.5	.8	e.3	—	1.6	<.2	98.3	.22	.9
494	<.08	5.6	1.2	e.4	2.27	1.5	<.2	81.9	.7	1.1
494	<.08	6.4	.4	e.3	1.16	1.9	<.2	91.6	.6	1.8
494	.1	7.9	3.2	.5	2.12	2.3	<.2	99.7	.7	1.1

Table 9. Concentration of dissolved trace elements at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined and analyzed by the U.S. Geological Survey, 2004–2005—Continued.

Site no.	Date	Time	Aluminum	Barium	Boron	Cadmium	Chromium	Cobalt	Iron
Castlegate Sandstone Formation—Continued									
500	9/16/2004	1520	<2	38	12	.04	<.8	.147	<6
500	8/15/2005	1400	4	34	11	.04	<.8	.142	e5
500	9/14/2005	1440	M	40	13	.07	.2	.05	e6
Blackhawk Formation									
530	7/29/2004	1310	<2	39	19	<.04	<.8	.421	<6
530	9/16/2004	1115	<2	39	20	<.04	<.8	.17	<6
530	8/4/2005	1155	<2	36	17	.03	<.8	.12	<6
530	9/12/2005	1530	<2	42	20	<.04	.08	.11	e5

[1]Due to difficulty locating this site, ‘new’ is used to differentiate between the original site 238 that was referenced in Slaughter and others, 1995 and this site.

Table 9. Concentration of dissolved trace elements at selected springs in and around the North Fork of the Right Fork of Miller Creek, Carbon and Emery Counties, Utah, determined and analyzed by the U.S. Geological Survey, 2004–2005—Continued.

Site no.	Lead	Lithium	Manga-nese	Molyb-denum	Nickel	Selenium	Silver	Strontium	Vanadium	Zinc
Castlegate Sandstone Formation—Continued										
500	<.08	2.8	e.1	<.4	.21	e.3	<.2	76.4	.2	1.9
500	<.08	3	.5	<.4	2.54	.7	<.2	86.5	.3	.7
500	<.08	2.8	e.2	<.4	—	.42	<.2	87.2	e.07	.65
Blackhawk Formation										
530	<.08	9.8	.6	e.2	3.3	1.4	<.2	135	.7	.7
530	<.08	10.5	.6	e.2	.39	1	<.2	125	.2	2.9
530	e.05	9.1	e.1	<.4	2.54	1.4	<.2	130	.7	4
530	<.08	9.4	2.8	<.4	—	1.2	<.2	136	.15	1

Table 10. Water-quality field parameters and discharge measured by the U.S. Geological Survey at selected sites along the North Fork of the Right Fork of Miller Creek drainage basin, Carbon County, Utah, 2004–2005.

[See figure 5 for site location; gal/min, gallons per minute; µS/cm, microsiemens per centimeter; °C, degrees Celsius; mg/L, milligrams per liter; —, no data]

Site no.	Date	Time	Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Dissolved oxygen (mg/L)
M-1	7/28/2004	1150	13.5	384	12.4	7.6	6.7
M-1	9/14/2004	1150	9.4	407	10.2	7.9	7.2
M-1	7/20/2005	1040	5.8	370	9.7	7.1	—
M-1	9/13/2005	1105	5.1	296	4.9	8.2	9
M-2	7/28/2004	1345	13.5	386	11.1	7.9	7.9
M-2	9/14/2004	1315	11.2	411	9.0	7.8	7.8
M-2	7/20/2005	1200	5.8	356	11.1	7.6	—
M-2	9/13/2005	1135	4.1	393	4.3	8.2	8.9
M-2.1	7/28/2004	1400	no flow	—	—	—	—
M-2.1	9/14/2004	1345	no flow	—	—	—	—
M-2.1	7/20/2005	1225	2.0	432	13.3	8.2	
M-2.1	9/13/2005	1200	2.8	444	5.7	8.4	9.2
M-4	7/28/2004	1420	no flow	—	—	—	—
M-4	9/14/2004	1355	no flow	—	—	—	—
M-4	7/20/2005	1230	no flow	—	—	—	—
[1]M-3	7/28/2004	1450	7.6	1,030	6.5	7.4	8.9
[1]M-3	9/1/2004	1330	7.6	—	—	—	—
[1]M-3	9/14/2004	1400	4.5	1,140	5.1	7.4	8.4
[1]M-3	11/4/2004	1305	4.8	—	—	—	—
[1]M-3	6/29/2005	1530	13.5	—	—	—	—
[1]M-3	7/20/2005	1255	7.6	994	5.7	7.7	—
[1]M-3	8/15/2005	1045	5.8	—	—	—	—
[1]M-3	9/13/2005	1235	5.8	1,010	4.9	7.8	8.9
M-4.5	7/28/2004	1530	no flow	—	—	—	—
M-4.5	9/14/2004	1600	no flow	—	—	—	—
M-6	7/28/2004	1600	no flow	—	—	—	—
M-6	9/14/2004	1430	no flow	—	—	—	—
M-6	7/20/2005	1415	5.8	1,630	9.7	8.1	—
M-6	9/13/2005	1410	6.1	1,800	6.4	8.0	8.6
M-K	7/28/2004	1607	no flow	—	—	—	—
M-K	9/14/2004	1445	no flow	—	—	—	—
M-K	7/20/2005	1430	7.6	1,630	12.3	8.2	—
M-5	7/28/2004	1630	3.1	1,720	13.2	7.7	6.7
M-5	9/14/2004	1620	.4	1,720	7.2	7.7	7.0
M-5	7/20/2005	1445	9.4	1,650	12.4	8.0	—
M-5	9/13/2005	1435	6.8	1,730	7.2	8.1	9
[1]M-7	7/28/2004	1710	no flow	—	—	—	—
[1]M-7	9/14/2004	1715	no flow	—	—	—	—
[1]M-7	7/20/2005	1535	.4	1,500	21.3	8.2	—
[1]M-7	9/13/2005	1525	1.1	1,490	9.7	8.5	7.96
M-8	6/29/2004	1235	4.5	—	—	—	—

Table 10. Water-quality field parameters and discharge measured by the U.S. Geological Survey at selected sites along the North Fork of the Right Fork of Miller Creek drainage basin, Carbon County, Utah, 2004–2005—Continued.

Site no.	Date	Time	Discharge (gal/min)	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Dissolved oxygen (mg/L)
M-8	7/28/2004	1735	4.5	2,140	14.1	7.9	6.8
M-8	8/3/2004	1415	4.4	—	—	—	—
M-8	9/14/2004	1715	1.4	2,350	7.3	7.9	8.3
M-8	11/4/2004	1420	8.6	—	—	—	—
M-8	6/29/2005	1135	20.2	—	—	—	—
M-8	7/20/2005	1530	11.2	2,000	17.6	8.3	—
M-8	8/15/2005	1230	9.4	—	—	—	—
M-8	9/13/2005	1515	13.5	2,140	7.9	8.4	8.3
M-8	11/10/2005	1230	10.8	—	—	—	—
[2]M-9	7/28/2004	1725	4.5	2,040	13.8	7.9	7.0
[2]M-9	9/14/2004	1740	5.8	2,190	8.2	8.0	8.5
[2]M-9	7/20/2005	1550	5.8	1,950	18.0	8.3	
[2]M-9	9/13/2005	1600	13.2	2,070	8.4	8.4	8.1
M-10	7/28/2004	1810	4.5	2,010	13.6	7.9	6.9
M-10	9/14/2004	1750	3.1	2,160	8.1	7.9	8.4
M-10	7/20/2005	1600	11.2	1,930	18.3	8.3	—
M-10	9/13/2005	1600	11.5	2,070	8.6	8.4	8.0

[1]Sites M-3 and M-7 are tributaries to the North Fork of the Right Fork of Miller Creek.

[2]Site M-9 measured in the North Fork of the Right Fork of Miller Creek.

Table 11. Water-quality field parameters and discharge at site M-8 measured by the Cyprus–Plateau Mining Corporation, North Fork of the Right Fork of Miller Creek drainage basin, Carbon County, Utah, 1992–2001.

[See fig. 5 for site location; µS/cm, microsiemens per centimeter; °C, degrees Celsius; gal/min, gallons per minute; —, no data]

Site no.	Date	Time	Specific conductance (µS/cm)	Water temperature (°C)	pH (standard units)	Discharge, gal/min
M-8	7/16/1992	0800	1,750	8.5	—	4.0
M-8	9/21/1992	1245	1,730	12.8	6.9	0.4
M-8	6/21/1993	1000	1,740	9.0	7.0	5.8
M-8	6/8/1994	1400	1640	13.6	8.4	20.2
M-8	7/20/1994	0830	1,500	13.3	8.2	17.9
M-8	8/31/1994	1320	1,360	15.0	8.3	18.0
M-8	9/21/1994	1330	1,520	15.0	8.4	80.8
M-8	6/22/1995	0945	751	4.8	8.3	548
M-8	7/27/1995	1345	1,800	18.0	8.3	98.7
M-8	8/23/1995	1800	1,282	10.0	8.3	35.9
M-8	9/28/1995	1040	1,220	7.6	8.4	13.5
M-8	6/12/1996	1500	1,340	10.0	8.8	44.9
M-8	7/23/1996	1345	1,700	22.0	8.4	3.0
M-8	8/19/1996	1540	1,840	15.0	8.5	2.7
M-8	10/18/1996	1235	2,320	—	8.5	1.3
M-8	6/18/1997	1630	1,490	12.5	8.2	71.8
M-8	7/31/1997	—	1,970	10.5	7.9	10.8
M-8	8/13/1997	1645	1,900	12.0	8.2	15.7
M-8	9/17/1997	—	1,700	9.0	8.4	15.7
M-8	6/9/1998	1140	640	8.0	8.4	265
M-8	7/20/1998	1035	778	18.0	8.4	13.0
M-8	8/11/1998	1440	1,480	19.0	8.2	9.0
M-8	9/15/1998	1545	1,640	13.0	8.2	25.1
M-8	6/25/1999	—	1,180	11.0	8.4	30.0
M-8	7/20/1999	1615	1,650	12.0	8.5	15.0
M-8	8/17/1999	0915	1,530	9.0	8.4	12.1
M-8	9/21/1999	1700	1,150	8.0	8.3	20.0
M-8	8/29/2000	1255	1,890	12.0	8.2	13.5
M-8	9/19/2000	1055	2,000	9.0	8.1	12.1
M-8	6/27/2001	1440	1,190	11.0	8.3	29.6
M-8	7/30/2001	1105	1,880	16.0	8.3	13.5
M-8	8/23/2001	1715	1,670	14.0	8.5	13.5
M-8	9/19/2001	1035	2,250	10.0	7.6	4.5

Table 12. Cumulative gain or loss in discharge downstream of the headwaters starting with site 491 in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 2004–2005.

[See figure 5 for site location. All values are in gallons per minute; e, estimated; —, no data]

Main channel site no.	491		M-1			M-2	M-2.1
Tributary site no.		**492**		**493**	**494**		
July 28, 2004							
Discharge	9.4	1.1	13.5	0.0	e0.3	13.5	0.0
Seepage gain or loss between stream sites			3.0			-.3	-13.5
Cumulative gain or loss from site 491	0		2.9			2.7	-10.8
September 14, 2004							
Discharge	9.4	1.0	9.4	.0	e.1	11.2	0.0
Seepage gain or loss between stream sites			-1.0			1.7	-11.2
Cumulative gain or loss from site 491	0		-1.0			.7	-10.5
July 20, 2005							
Discharge	4.5	.4	5.8	e.3	e.1	5.8	2.0
Seepage gain or loss between stream sites			.9			-.4	-3.8
Cumulative gain or loss from site 491	0		.9			.5	-3.3
September 13, 2005							
Discharge	5.1	1.2	5.1	e.9	e.1	4.1	2.8
Seepage gain or loss between stream sites			-1.2			-1.9	-1.3
Cumulative gain or loss from site 491	0		-1.2			-3.2	-4.5

Table 12. Cumulative gain or loss in discharge downstream of the headwaters starting with site 491 in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 2004–2005—Continued.

M-4		M-4.5	M-6	MK	M-5	M-8		M-9	M-10
	M-3						M-7		
July 28, 2004									
0.0	7.6	0.0	0.0	0.0	3.1	4.5	0.0	2.0	4.5
0.0		-7.6	.0	.0	3.1	1.4		-2.5	2.5
-10.8		-18.4	-18.4	-18.4	-15.3	-13.9		-16.4	-13.9
September 14, 2004									
0.0	4.5	0.0	.0	.0	.4	1.4	.0	5.8	3.1
0.0		-4.5	.0	.0	.4	1.0		4.4	-2.7
-10.5		-15.0	-15.0	-15.0	-14.6	-13.6		-9.2	-11.9
July 20, 2005									
0.0	7.6	—	5.8	7.6	9.4	11.2	.4	5.8	11.2
-2.0			-1.8	1.8	1.8	1.8		-5.8	5.4
-5.3			-7.1	-5.3	-3.5	-1.7		-7.5	-2.1
September 13, 2005									
0.0	5.8	—	6.1	4.6	6.8	13.5	1.1	13.2	11.5
-2.8			.3	-1.5	2.2	6.7		-1.4	-1.7
-7.3			-7.0	-8.5	-6.3	.4		-1.0	-2.7

Table 13. Concentration of dissolved major ions at site M-8 determined from water samples collected and analyzed by the Cyprus–Plateau Mining Company in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 1992–2001.

[See figure 5 for site locations. All values in milligrams per liter; <, less than; —, no data]

Site no.	Date	Time	Calcium	Magne-sium	Sodium	Potassium	Alkalinity, measured in field	Sulfate as $CaCO_3$	Chloride	Solids, residue at 180°C
M-8	7/16/1992	0800	157	198	9.00	5.00	298	883	14.0	1,540
M-8	9/21/1992	1245	131	193	10.0	7.00	250	883	12.0	1,460
M-8	6/21/1993	1000	170	175	9.00	6.00	342	823	10.0	1,470
M-8	6/8/1994	1400	161	140	8.00	10.0	315	694	8.00	1,290
M-8	7/20/1994	0830	168	137	9.00	10.0	324	714	8.00	1,360
M-8	9/21/1994	1330	178	148	10.0	12.0	345	671	10.0	1,250
M-8	6/22/1995	0945	89.6	39.5	2.30	1.90	219	160	2.00	450
M-8	7/27/1995	1345	181	185	9.20	7.60	320	910	10.0	1,550
M-8	9/28/1995	1040	198	190	9.30	8.20	360	800	11.0	1,610
M-8	6/12/1996	1500	141	91.5	4.10	3.60	264	430	3.00	880
M-8	7/23/1996	1345	199	205	10.0	10.0	288	980	11.0	1,700
M-8	10/18/1996	1235	215	212	9.50	7.10	360	1,030	12.0	1,670
M-8	6/18/1997	1630	166	108	4.60	4.20	265	530	4.00	1,030
M-8	7/31/1997	—	220	190	8.10	6.30	—	900	6.10	1,700
M-8	9/17/1997	—	210	170	8.00	6.70	—	780	17.0	1,600
M-8	6/9/1998	1140	101	51.0	3.00	2.00	243	252	3.00	<10
M-8	7/20/1998	1035	194	156	5.00	6.00	273	949	7.00	385
M-8	6/25/1999	—	169	119	5.00	4.00	262	681	4.00	1,200
M-8	7/20/1999	1615	188	158	6.00	5.00	260	909	6.00	1,580
M-8	9/21/1999	1700	193	170	8.00	6.00	279	979	<10	1,690
M-8	9/19/2000	1055	193	189	7.00	6.00	256	877	7.00	1,870
M-8	6/27/2001	1440	184	159	7.00	5.00	280	906	5.50	1,590
M-8	7/30/2001	1105	193	173	7.00	10.0	259	1,020	8.70	1,700
M-8	9/19/2001	1035	204	190	7.00	6.00	277	1,050	6.20	1,790

Table 14. Concentration of dissolved major ions at selected sites determined from water samples collected and analyzed by the U.S. Geological Survey in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 2004–2005.

[See figure 5 for site locations. All values in milligrams per liter; ˚C, degrees Celsius; <, less than; —, no data]

Site no.	Date	Time	Calcium	Magne-sium	Sodium	Potas-sium	Alkalinity, measured in field	Bicar-bonate	Sulfate as $CaCO_3$	Chloride	Fluoride	Silica	Solids, residue at 180˚C
M-2	7/20/2005	1200	50.9	15.1	2.72	1.04	132	161	7.7	2.69	0.2	5.09	210
M-2	9/13/2005	1135	59.0	18.2	2.78	1.05	207	247	7.4	2.70	.1	5.98	221
M-3	7/28/2004	1500	138	65.8	3.28	2.59	332	404	277	3.75	.2	4.47	641
M-3	9/14/2004	1420	141	67.2	3.22	2.99	329	399	295	3.11	.2	4.53	775
M-3	7/20/2005	1255	124	57.3	3.08	2.35	216	262	275	3.44	.2	4.00	709
M-3	9/13/2005	1235	136	67.0	3.35	2.52	298	361	273	3.57	.2	4.69	709
M-6	7/20/2005	1415	202	132	4.12	4.54	180	219	738	3.65	.2	4.92	1,370
M-6	9/13/2005	1410	214	158	4.31	4.55	254	307	847	4.36	.2	5.17	1,540
M-5	7/28/2004	1630	209	139	4.34	4.99	294	357	756	4.62	.2	5.07	1,410
M-5	9/14/2004	1620	212	148	4.88	5.25	283	343	812	4.28	<.2	5.55	1,470
M-5	7/20/2005	1445	200	122	4.19	4.32	276	334	577	3.11	.2	4.76	1,090
M-5	9/13/2005	1435	217	146	4.17	4.19	265	320	834	4.39	.2	4.87	1,520
M-7	7/20/2005	1535	115	155	13.3	6.17	243	294	654	14.9	.3	10.2	1,280
M-7	9/13/2005	1525	125	154	11.8	5.00	304	360	554	14.7	.3	9.94	1,150
M-8	7/28/2004	1735	210	215	8.28	7.60	246	298	1,140	9.21	.2	8.33	1,920
M-8	9/14/2004	1715	246	280	10.9	9.12	252	303	1,320	10.1	.2	9.29	2,220
M-8	7/20/2005	1530	—	—	—	—	—	338	—	—	—	—	—
M-8	9/13/2005	1515	235	216	7.28	6.10	292	347	1,090	7.15	.2	7.24	1,880
M-10	7/20/2005	1600	194	187	8.02	6.90	183	220	970	8.04	.2	8.25	1,730
M-10	9/13/2005	1600	220	216	8.21	6.37	280	335	1,050	9.14	.2	8.20	1,810

Table 15. Concentration of dissolved trace elements determined from samples collected and analyzed by the U.S. Geological Survey in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 2004–2005.

[See figure 5 for site locations. All values are in micrograms per liter; <, less than; e, estimated; —, no data; M, presence of constituent verified but not quantified]

Site no.	Date	Time	Aluminum	Barium	Boron	Cadmium	Chromium	Cobalt	Iron
M-2	7/20/2005	1200	7	32	15	<0.04	<0.8	0.198	14
M-2	9/13/2005	1135	4	27	12	<.04	.11	.050	32
M-3	7/28/2004	1500	M	23	23	.04	<.8	.634	<6
M-3	9/14/2004	1420	<2	24	26	.06	<.8	.677	<6
M-3	7/20/2005	1255	18	26	28	.06	<.8	.348	<6
M-3	9/13/2005	1235	2	25	23	.04	.05	.090	e4
M-5	7/28/2004	1630	e1	35	32	<.04	<.8	.980	<6
M-5	9/14/2004	1620	M	33	31	<.04	<.8	.826	e4
M-5	7/20/2005	1445	2	37	42	<.04	<.8	.603	e3
M-5	9/13/2005	1435	e1	40	32	e.02	.08	.060	<6
M-6	7/20/2005	1415	e1	32	31	<.04	<.8	.295	<6
M-6	9/13/2005	1410	e1	29	33	e.02	.08	.040	<6
M-7	7/20/2005	1535	e1	37	86	<.04	<.8	.409	e4
M-7	9/13/2005	1525	e2	34	79	<.04	.08	.130	e5
M-8	7/28/2004	1735	<2	32	79	<.04	<.8	1.24	e6
M-8	9/14/2004	1715	e1	27	74	<.04	<.8	.688	<19
M-8	7/20/2005	1530	3	41	104	<.04	<.8	.519	<6
M-8	9/13/2005	1515	e1	34	61	<.04	.06	.080	<18
M-10	7/20/2005	1600	e1	39	89	<.04	<.8	.406	e4
M-10	9/13/2005	1600	e1	33	73	<.04	.08	.130	e5

Table 15. Concentration of dissolved trace elements determined from samples collected and analyzed by the U.S. Geological Survey in the North Fork of the Right Fork of Miller Creek, Carbon County, Utah, 2004–2005—Continued.

Site no.	Lead	Lithium	Manga-nese	Molyb-denum	Nickel	Selenium	Silver	Strontium	Vanadium	Zinc
M-2	0.51	2.80	8.3	e.4	2.38	e.4	<0.2	77.1	1.30	10.7
M-2	<.08	2.80	7.0	e.4	—	.26	<.2	80.4	.13	<.6
M-3	<.08	13.4	.5	e.4	10.2	1.30	<.2	272	.30	4.40
M-3	<.08	14.5	2.9	e.4	9.09	.80	<.2	274	.50	6.50
M-3	.35	14.1	9.2	.4	6.95	1.20	<.2	238	.30	19.6
M-3	<.08	11.9	1.4	e.4	—	1.00	<.2	252	e.06	3.40
M-5	<.08	22.2	8.2	e.3	9.96	.80	<.2	595	.40	2.60
M-5	<.08	24.5	40	e.3	4.44	.70	<.2	608	.90	4.80
M-5	<.08	27.5	12.3	e.3	6.43	1.20	<.2	557	.60	2.60
M-5	<.08	23.4	5.3	e.3	—	.75	<.2	627	e.06	.94
M-6	e.04	20.2	.6	e.3	8.21	1.40	<.2	559	1.40	2.90
M-6	<.08	24.1	.4	e.2	—	.70	<.2	625	.11	1.10
M-7	e.07	36.8	6.6	.6	5.52	1.30	<.2	467	2.20	2.00
M-7	<.08	39.3	8.6	e.4	—	.25	<.2	459	.28	<.6
M-8	<.08	39.5	21	e.4	9.67	.60	<.2	838	2.30	3.00
M-8	<.08	52.1	1.5	e.2	3.19	.90	<.2	908	.80	5.40
M-8	<.08	50.1	7.5	e.4	5.83	1.30	<.2	801	.50	3.20
M-8	<.08	41.0	5.5	e.3	—	.46	<.2	859	.14	<.6
M-10	<.08	39.6	11	e.4	7.80	1.40	<.2	782	1.30	2.70
M-10	<.08	42.2	12	e.3	—	.37	<.2	813	.15	e.35

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