

HYDROLOGY OF COAL-LEASE AREAS

NEAR DURANGO, COLORADO

By Tom Brooks

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4125

Prepared in cooperation with the
U.S. BUREAU OF LAND MANAGEMENT and the
U.S. FOREST SERVICE

Lakewood, Colorado
1985



DEPARTMENT OF THE INTERIOR

DONALD P. HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

Colorado District Chief
U.S. Geological Survey
Water Resources Division
Box 25046, Mail Stop 415
Denver Federal Center
Denver, CO 80225

Copies of this report can be
purchased from:

Open-File Services Section
Books and Open-File Reports
Building 41, Box 25425
Denver Federal Center
Denver, CO 80225
Telephone: (303) 236-7476

CONTENTS

	Page
Abstract-----	1
Introduction-----	2
Purpose and scope-----	2
Description of study area-----	4
Data collection-----	4
Acknowledgements-----	10
Geology-----	10
Stratigraphy and lithology-----	10
Structure-----	14
Hydrogeology and ground-water quality-----	15
Bedrock units-----	15
Unconsolidated deposits-----	18
Stollsteimer Creek study area-----	18
Location-----	18
Surface-water characteristics-----	18
Ground-water characteristics-----	20
Bedrock units-----	20
Alluvium deposits-----	21
Mine development and effects-----	24
Hay Gulch study area-----	26
Location-----	26
Surface-water characteristics-----	26
Ground-water characteristics-----	28
Bedrock units-----	28
Alluvium deposits-----	30
Mine development and effects-----	30
Needs for future studies-----	32
Summary and conclusions-----	33
Hydrology-----	33
Mining effects-----	34
Needs for future studies-----	34
References-----	35
Supplementary Data-----	36

FIGURES

	Page
Figures 1-5. Maps showing:	
1. Location of the Durango study area-----	3
2. Data-collection sites outside the Stollsteimer Creek and Hay Gulch study areas-----	5
3. Location of well and spring sites in the Stollsteimer Creek study area-----	6
4. Location of streamflow-measurement sites in the Stollsteimer Creek study area-----	7
5. Location of data-collection sites in the Hay Gulch study area-----	8
6. Diagram of numbering wells, springs, and streamflow- measurement sites using township, range, and section-----	9
7-8. Maps showing:	
7. Hydrogeology of the Durango study area-----	11
8. Location of coal-lease tracts of the Chimney Rock Mine-----	19
9. Map and hydrogeologic section of Stollsteimer Creek valley-----	22
10-11. Maps showing:	
10. Coal-lease tracts of the National King Coal Mine-----	27
11. Abandoned and future mine areas, National King Coal Mine-----	31

TABLES

	Page
Table 1. Chemical analyses of water samples from wells, springs, and streams-----	37
2. Well information-----	41
3. Spring information-----	43
4. Stream and ditch discharge and water-quality data-----	44

CONVERSION FACTORS

The following factors can be used to convert inch-pound units to the International System (SI) of units.

<i>Multiply inch-pound units</i>	<i>By</i>	<i>To obtain SI units</i>
cubic foot per second (ft ³ /s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
gallon per minute (gal/min)	0.06309	liter per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square foot per day (ft ² /d)	0.09290	square meter per day
square mile (mi ²)	2.590	square kilometer

Temperature can be converted to degree Celsius (°C) or degree Fahrenheit (°F) by the following equations:

$$^{\circ}\text{C} = 9/5(^{\circ}\text{F}-32)$$

$$^{\circ}\text{F} = 5/9 (^{\circ}\text{C}+32)$$

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

milligrams per liter (mg/L).

HYDROLOGY OF COAL-LEASE AREAS
NEAR DURANGO, COLORADO

By Tom Brooks

ABSTRACT

The U.S. Bureau of Land Management leases Federal lands and minerals for coal mining near Durango, Colorado. This report addresses the hydrologic suitability of those lands for coal leasing; the report describes the general hydrology of the Durango area and, more specifically, the hydrology of the Stollsteimer Creek study area 32 miles east of Durango and the Hay Gulch study area 12 miles southwest of Durango.

The most productive aquifers in the Durango study area are Quaternary alluvium and the Tertiary Animas Formation. Water wells completed in alluvium typically yield 5 to 20 gallons per minute; wells completed in the Animas Formation yield as much as 50 gallons per minute. Water quality in these aquifers is variable, but it generally is suitable for domestic use.

The coal-bearing Cretaceous Fruitland and Menefee Formations were mined by surface methods at the Chimney Rock Mine in the Stollsteimer Creek study area and by underground methods at the National King Coal Mine in the Hay Gulch study area. Effects of surface mining in the Stollsteimer Creek area are: (1) Dewatering of an alluvial aquifer; and (2) local degradation of alluvium water quality by spoil-pile effluent. Effects of underground mining in the Hay Gulch area are: (1) Introduction of water with greater dissolved-solids concentrations into the upper Hay Gulch alluvium from mine runoff; (2) subsidence fracturing which could dewater streams and the alluvial aquifer.

INTRODUCTION

Surface and underground coal mines have been operating in parts of Montezuma, La Plata, and Archuleta Counties, Colorado for more than a century (fig. 1). The U.S. Bureau of Land Management has designated parts of these counties as a Known Recoverable Coal Resource Area (KRCRA), and may offer additional coal-mining tracts for leasing.

Surface and ground water may be disturbed by open-pit mining and underground mining. As more coal tracts are leased, the possibility for disruption of existing surface- and ground-water supplies increases. Such disruption is a particular concern in rural areas, where ground water is important for domestic and stock use. Mining may alter recharge and discharge areas, water chemistry, and flow characteristics. During 1983-84, the U.S. Geological Survey, in cooperation with the BLM and U.S. Forest Service, studied the hydrology of the area and assessed the hydrologic effects of present and future coal mining in the area.

Purpose and Scope

The purpose of this report is to describe the general hydrology of the KRCRA and the hydrology and hydrologic effects of mining in two specific study areas within the KRCRA shown in figure 1: the Stollsteimer Creek area and the Hay Gulch area. The Stollsteimer Creek study area includes a surface mine located in a stream valley, where mining may affect surface water, ground water, and water quality. The Hay Gulch study area includes an underground mine that may cause surface-water losses through subsidence fractures, and may alter ground-water chemistry.

The major study objective was to define the ground- and surface-water characteristics of the specific and general study areas. Specific objectives were to:

1. Prepare a bibliography of previous studies.
2. Define local and regional ground-water flow systems as data permit.
3. Determine surface- and ground-water chemistry in areas proximal to coal mining.
4. Describe the ability of geologic units in the specific study areas to transmit ground water.
5. Determine the potential impacts of coal mining on the hydrologic systems in the specific study areas.
6. List needs for future hydrologic investigations.

The study objectives were met by several methods. Well information and data were obtained from the U.S. Geological Survey, Colorado State Engineer's Office, and mining companies. Wells and springs were inventoried and stream discharges were measured. The effects of flooding in Stollsteimer Creek were determined using methods described by McCain and Jarrett (1976). The land surface overlying underground mines was examined for evidence of subsidence.

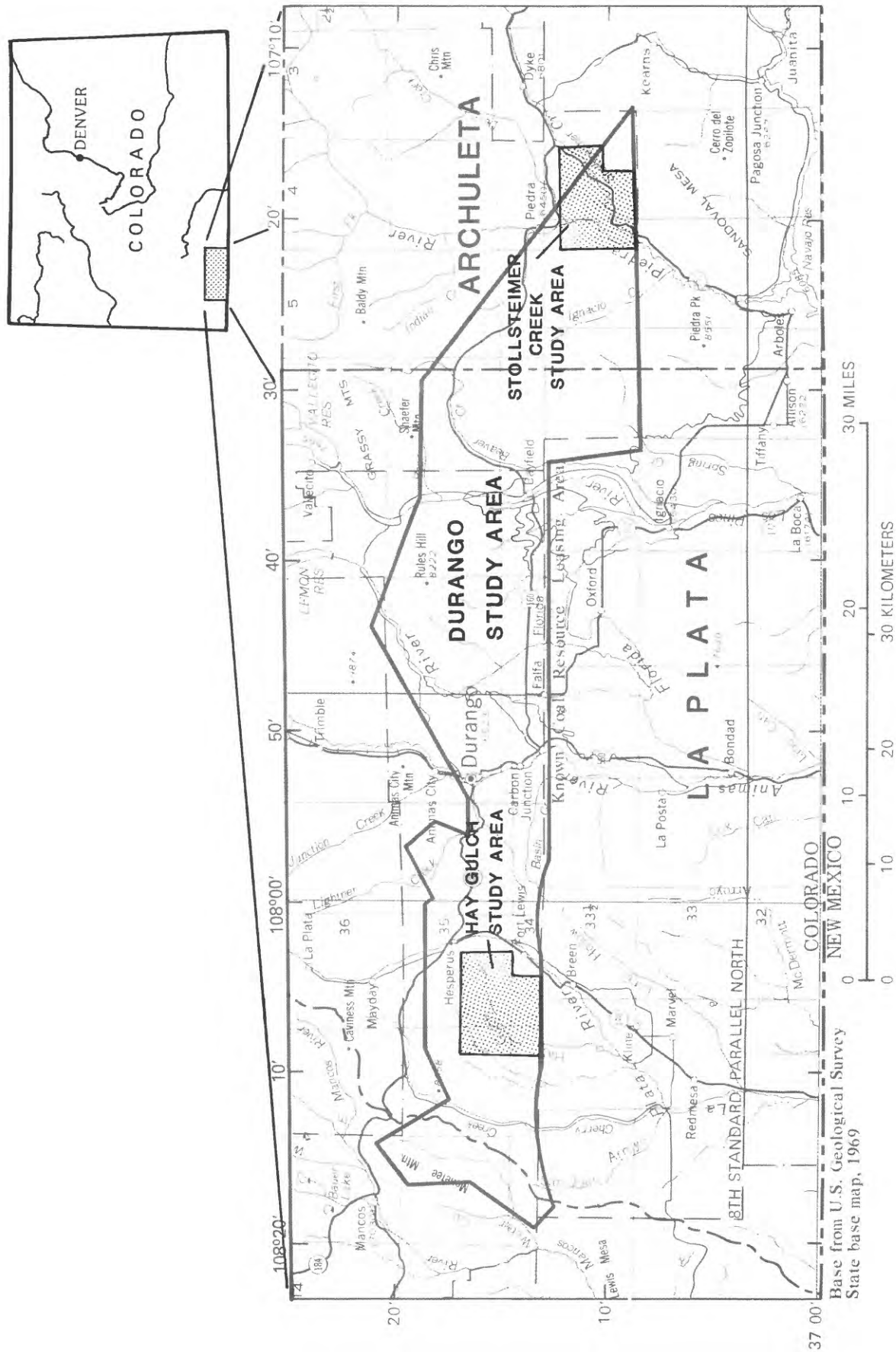


Figure 1.--Location of the Durango study area.

Description of the Study Area

The KRCRA is approximately 420 mi²; it is referred to in this report as the Durango study area (fig. 1). The location of the two smaller study areas in the Durango study area, the Stollsteimer Creek study area (including the Chimney Rock Mine) in Archuleta County and the Hay Gulch study area (including the National King Coal Mine) in La Plata County, also are shown in figure 1. Hydrologic data were collected extensively in these specific areas. Additional data were collected in the larger Durango study area to support an interpretation of hydrologic conditions in the smaller study areas.

The Durango study area comprises parts of eastern Montezuma County, central La Plata County, and western Archuleta County (fig. 1). The Hay Gulch study area is approximately 12 mi southwest of Durango in La Plata County, and the Stollsteimer Creek study area is about 32 mi southeast of Durango in Archuleta County.

The vegetation and topography of the Durango study area is varied. Scrub oak, pinyon pine, and juniper are common in the south and far west. Moderately steep canyons contain ephemeral, seasonal, and perennial streams that generally flow south-southwest. Pinyon pine, scrub oak, juniper, ponderosa pine, and aspen are common in the steeper northern and eastern parts.

Altitudes range from about 6,600 ft near the National King Coal Mine to 8,800 ft northeast of Durango. The area is semiarid, and precipitation ranges from 16 in. in the south to 25 in. in the north (McCain and Jarrett, 1976). Mean monthly temperatures at Durango range from 28.3°F in January to 69.7°F in August. The mean annual temperature is 48.7°F (National Climatic Data Center, 1983).

Data Collection

Hydrologic data in this report include field data collected by the U.S. Geological Survey between March 1983 and November 1983 and data obtained from private companies and from previous studies. Most data were collected in the Stollsteimer Creek and Hay Gulch study areas because these areas currently are mined, and additional mining is expected nearby. Location of data sites are shown in figures 2-5. An explanation of the well-numbering system used in this report is given in figure 6.

Water chemistry, well, spring, and streamflow data are listed in tables 1-4 in the Supplementary Data section at the back of this report. Site numbers on the map correlate with site numbers in the tables. Water-quality data for 41 wells, 2 springs, and 7 stream sites are given in table 1. Hydrologic data are given for 52 wells in table 2, including depth-to-water measurements for 49 wells. Hydrologic data for 4 springs are given in table 3. Site descriptions, discharge, temperature, pH, and specific-conductance data are given for 24 stream and irrigation-ditch measurement sites in table 4. Data collected at surface-water sites include 89 discharge measurements and 6 water-quality analyses. Streamflow measurements were made on Deep Creek (in Deep Canyon) in August 1983, Stollsteimer Creek in September 1983, and on Cabezón Creek (in Cabezón Canyon) in November 1983.

EXPLANATION

- 26 O WELL AND SITE NUMBER. (See tables 1, 2, 3, and 4)
- 55 SPRING AND SITE NUMBER. (See tables 1 and 3)
- Q WELL WITH WATER-QUALITY SAMPLE
- 77 SPRING WITH WATER-QUALITY SAMPLE
- 77 Δ STREAM SITE AND NUMBER. (See tables 1 and 4)

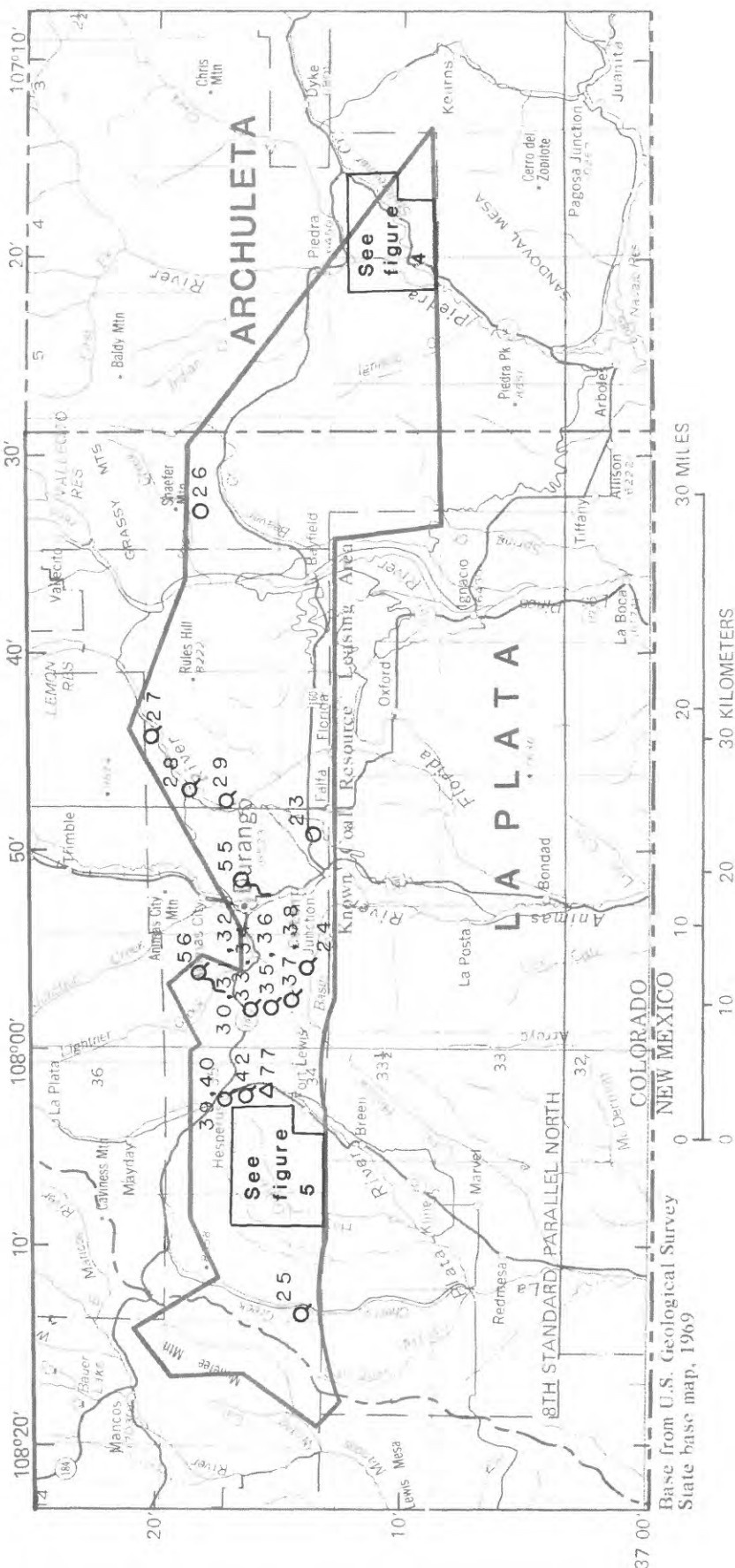


Figure 2.--Data-collection sites outside the Stollsteimer Creek and Hay Gulch study areas.

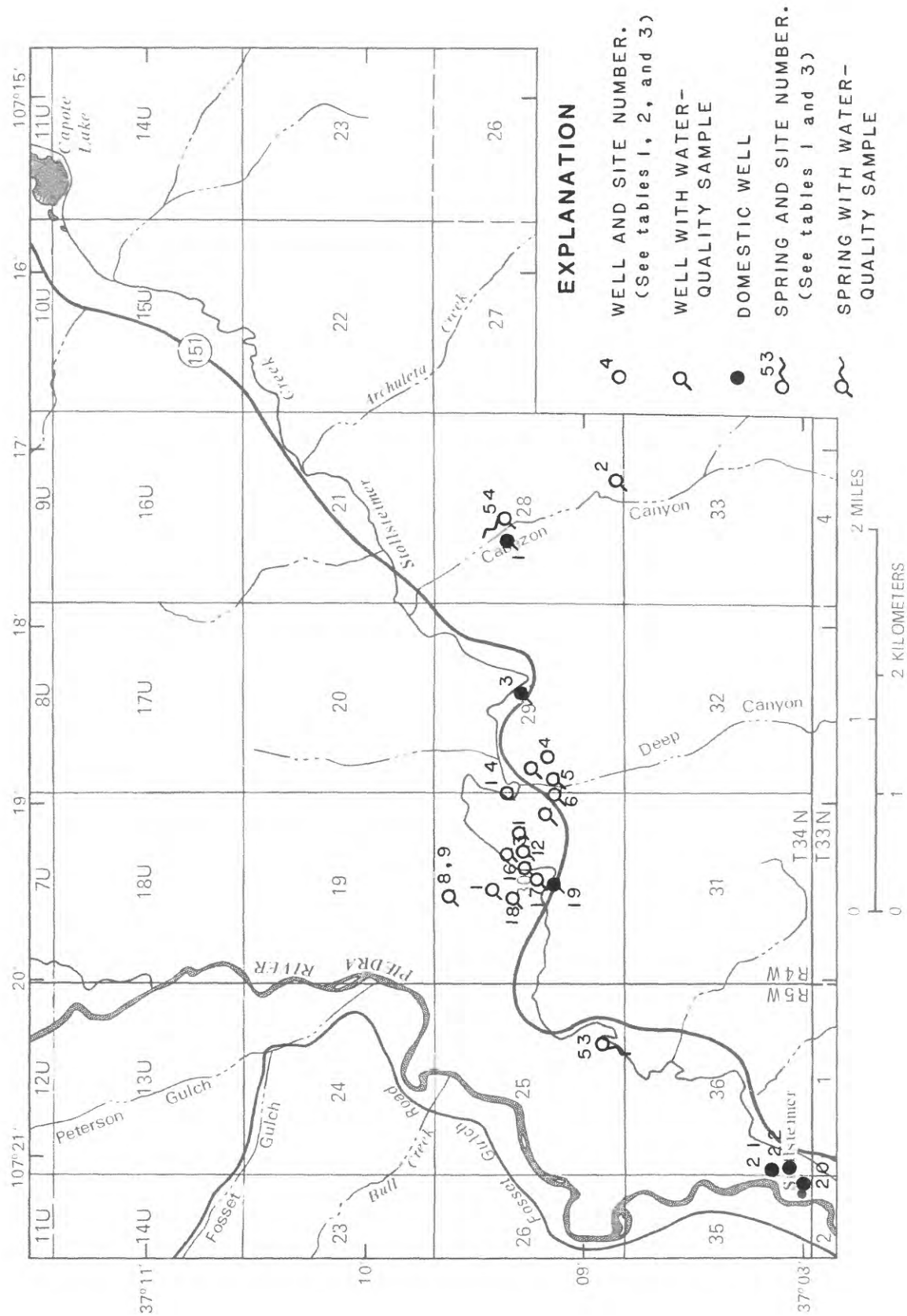


Figure 3.--Location of well and spring sites in the Stollsteimer Creek study area.

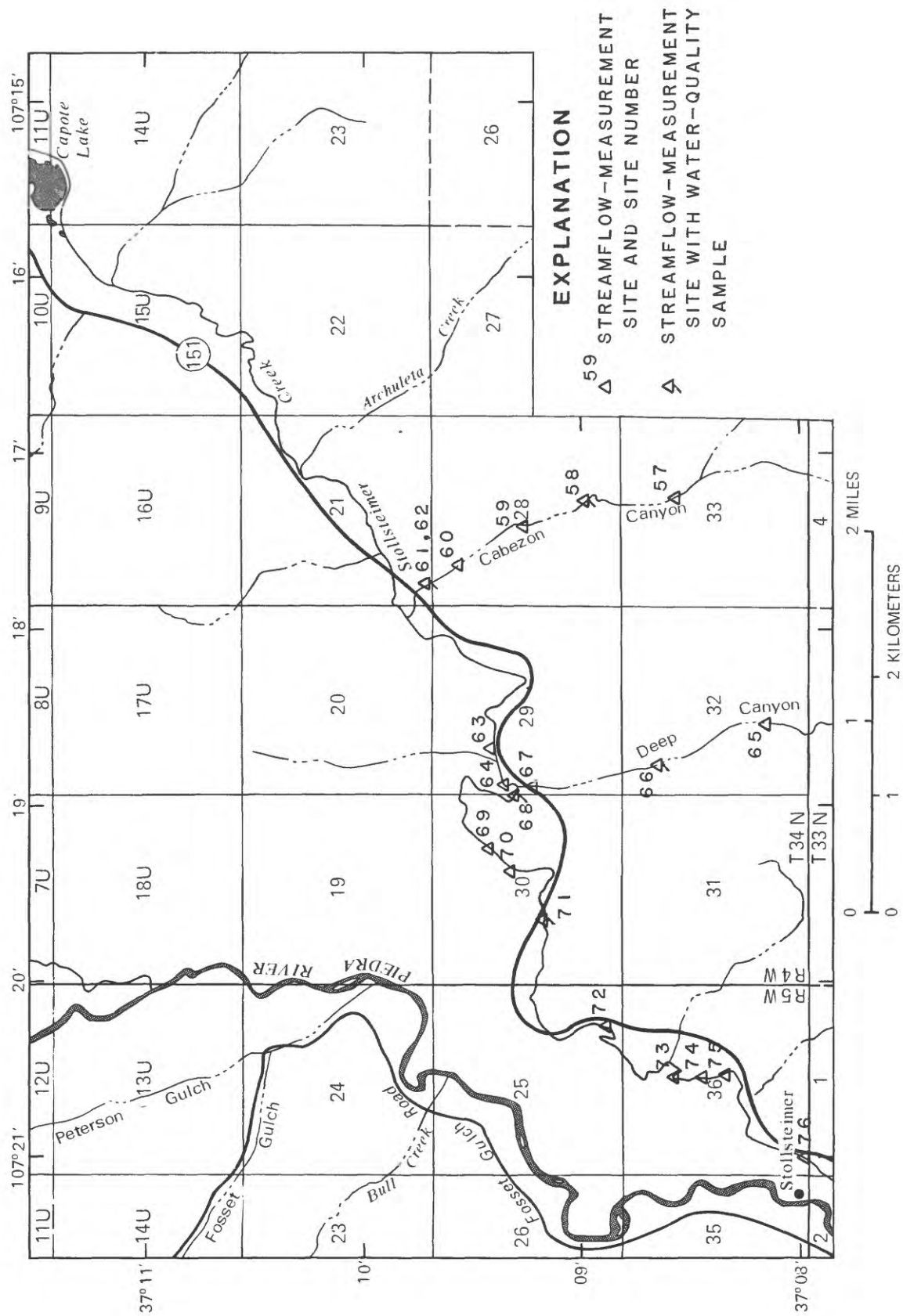


Figure 4.--Location of streamflow-measurement sites in the Stollsteimer Creek study area.

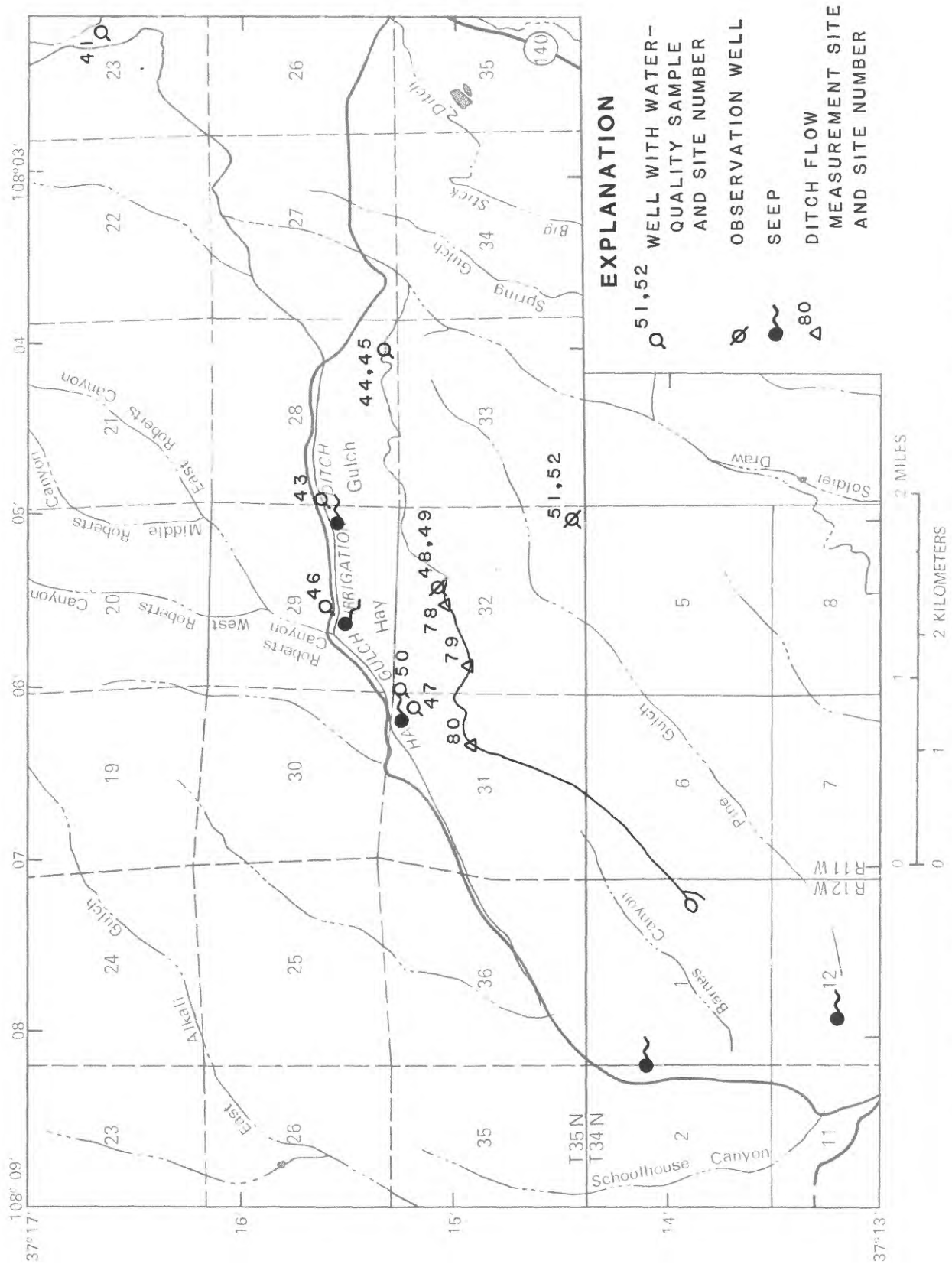


Figure 5.--Location of data-collection sites in the Hay Gulch study area.

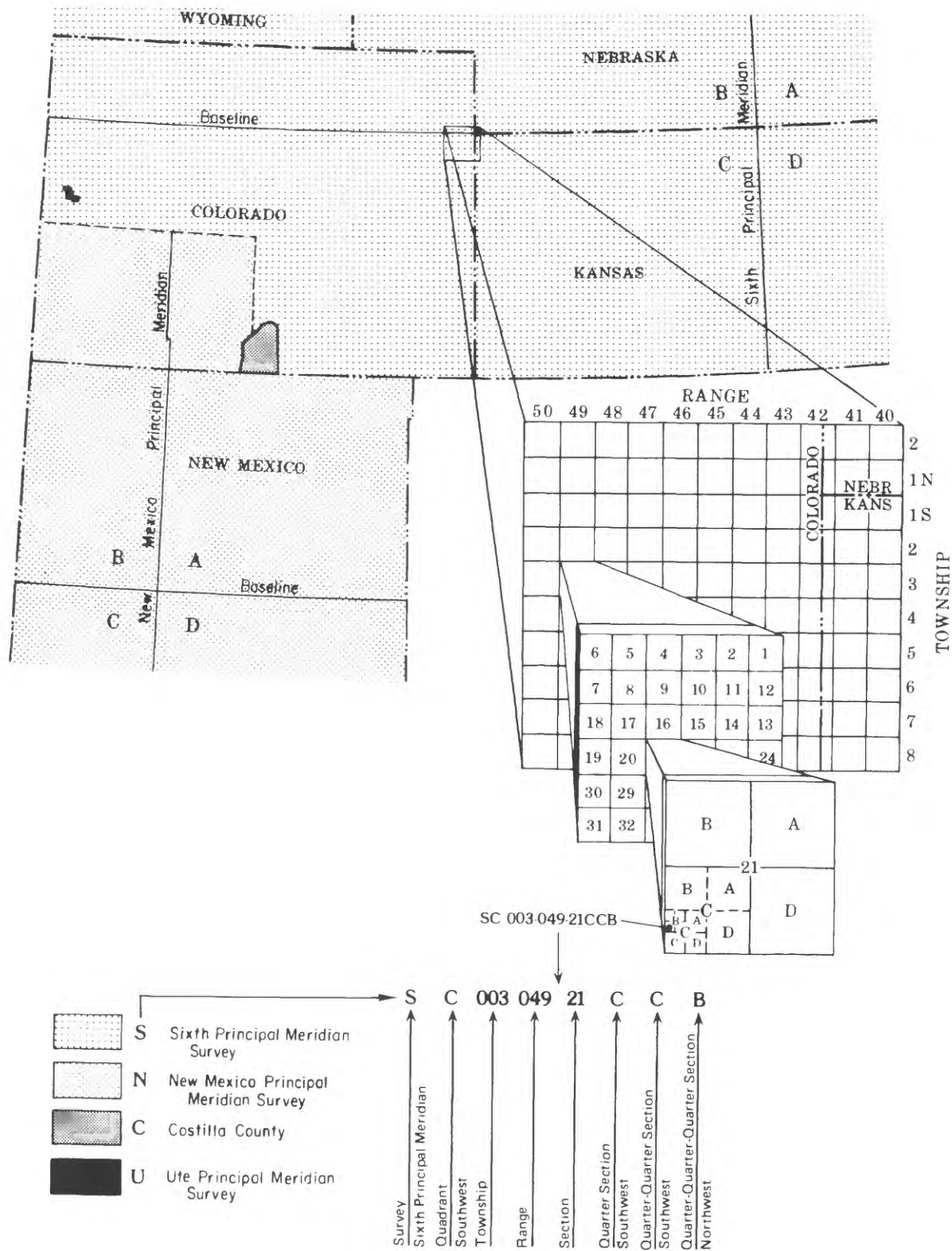


Figure 6.--System of numbering wells, springs, and streamflow-measurement sites using township, range, and section.

Acknowledgments

Property owners allowed access to their lands for data collection. Information supplied by Perma Mining Corporation and National King Coal, Inc. supplemented descriptions of the geology and hydrology near their mines.

GEOLOGY

Stratigraphy and Lithology

The stratigraphic units in the Durango study area consist of bedrock and unconsolidated rocks (fig. 7). The geologic units described in this report include (from oldest to most recent) the Mancos Shale, Point Lookout Sandstone, Menefee Formation, Cliff House Sandstone, Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale of Late Cretaceous age; Animas and San Jose Formations of Tertiary age; and terrace deposits and alluvium of Quaternary age. Lithologies of bedrock rock include shale, fine- to medium-grained sandstone, coal, siltstone, and claystone. Valley-fill alluvium consists of gravel, sand, silt, and clay. Terrace deposits consisting of well-rounded boulders and gravel overlie bedrock. The geologic and lithologic descriptions of geologic units are from Zapp (1949) unless otherwise noted.

The Mancos Shale is a marine shale and approximately 1,900 ft thick near the Animas River. Outcrops are present northeast and northwest of Durango.

The Point Lookout Sandstone typically is a marine, cliff-forming, medium-grained massive sandstone. It is about 400 ft thick in the Durango area and thins eastward. The lower section is transitional and conformable with the underlying Mancos Shale. The lower section of the Point Lookout Sandstone consists of thin sandstone beds with interbedded shale that becomes proportionally thicker in the unit as the formation thins eastward. The upper massive sandstone section is about 100 ft thick at the western boundary of the Durango study area, 70 ft thick near the Animas River, and about 35 ft thick in the Florida River Valley. Outcrop areas are discontinuous in the Durango study area. Some outcrops are about 5 mi west of Durango; some outcrops are northeast of Durango. The Point Lookout Sandstone is the lowest formation of the Mesaverde Group. It is mapped as part of the Mesaverde Group northeast of Durango, near the northern rim of the Durango study area.

The Menefee Formation conformably overlies the Point Lookout Sandstone. Its lithology consists of nonmarine sandstone, shale, and coal. Near the western boundary of the Durango study area, the formation is approximately 350 ft thick. The formation thins northeastward to approximately 120 ft thick about 10 mi northeast of Durango. Coal is mined from this formation in the Hay Gulch area, but the formation thins abruptly from Hay Gulch east to the La Plata River, a distance less than 5 mi. The Menefee Formation is the middle formation of the Mesaverde Group. It is mapped as part of the Mesaverde Group northeast of Durango, near the northern boundary of the Durango study area.

EXPLANATION

Erathem	System and series	Geologic unit (map symbol)	Maximum thickness (feet)	Lithology	Hydrologic characteristics
CENOZOIC	QUATERNARY	Alluvium (Qal)	80	Semi- to unconsolidated gravel, sand, pebbles, silt, cobbles, and boulders.	Well yields average 14 gal/min. Transmissivity of Stollsteimer Creek alluvium is 13,000 ft ² /d. ⁴
		Terrace deposits (Qt)	80	Consolidated, poorly sorted clay, silt, sand, gravel and boulders.	Well yields of 5 to 10 gal/min. ¹
		Intrusive bodies (Ti)	unknown	Fine to coarse-grained igneous rock.	No information available; no outcrops in the Durango study area.
	TERTIARY	San Jose Formation (Tsj)	2,500	Arkose sandstone, shale, and conglomerate.	Well yields of 1 to 10 gal/min. ²
		Animas Formation (Tka)	1,400	Variegated shale with interbedded breccia, conglomerate, and sandstone.	Well yields as much as 50 gal/min. ² Transmissivities as much as 100 ft ² /d in New Mexico. ³
MESOZOIC	UPPER CRETACEOUS	Kirtland Shale (Kk)	1,200	Gray, slope-forming interbedded and carbonaceous shale, siltstone, and sandstone.	Well yields of 5 to 10 gal/min. ^{1,2}
		Fruitland Formation (Kf)	300	Locally fossiliferous shale, black shale, coal, and sandstone. Gray, brown, and black in color.	Transmissivity of coal is 25 ft ² /d and shale is 0.3 ft ² /d. Storage coefficient of coal is 1.0 X 10 ⁻⁴ .
		Pictured Cliffs Sandstone (Kpc)	300	Light colored, fine to medium grained, cliff-forming sandstone.	Well yields as much as 5 gal/min. ¹ Transmissivity is 0.001 to 3 ft ² /d in New Mexico. ³
		Lewis Shale (Kl)	1,825	Dark gray to black, marine, slope-forming shale and sandy shale.	Well yields normally less than 1 gal/min; One well yielded 10 gal/min.

Figure 7.--Hydrogeology of the Durango study area--Continued.

MESOZOIC	UPPER CRETACEOUS	MESAVERRDE GROUP (Kmv)			Well yields as much as 17 gal/min. ² Transmissivity is 2 ft ² /d. ³
		Cliff House Sandstone (Kch)	350	Yellow-brown to red, very fine to fine-grained marine sandstone.	
PALEOZOIC	JURASSIC	Menefee Formation (Kmf)	350	Interbedded sandstone, gray to black shale and coal; thins eastward.	Well yields as much as 15 gal/min. ² Transmissivity is 50 ft ² /d or less. ³
		Point Lookout Sandstone (Kpl)	400	Lower half is interbedded sandstone and shale and upper half is medium-grained cliff-forming sandstone.	Well yields as much as 6 gal/min. Transmissivity is 240 ft ² /d in New Mexico. ³
		Mancos Shale (Km)	1,900	Gray to dark gray marine shale and sandy shale.	Well yields as much as 10 gal/min in landslide slump blocks. ²
		Dakota Sandstone (Kd)	200	Light gray to brown sandstone with localized siltstone and carbonaceous shales.	No information available; no outcrops in the Durango study area.
	TRIASSIC	Morrison Formation (Jm)	1,200(?)	Variegated shale and claystone with sandstone lenses.	Do.
		Dolores Formation (Trd)	600	Non-marine red shale, sandstone, and siltstone.	Do.
	PERMIAN	Cutler Formation (Pc)	2,000	Red, non-marine shale, siltstone, and mudstone.	Do.
	PERMIAN/ PENNSYLVANIAN	Rico, Hermosa, and Molas Formations; undifferentiated (Prm)	2,975	Marine and non-marine sequence of shale, siltstone, sandstone, conglomerate, and breccia.	Do.

¹Brogden and others, 1979

²Brogden and Giles, 1976

³Stone and others, 1983

⁴D. R. Piteau and Associates Ltd., 1982

Figure 7.--Hydrogeology of the Durango study area--Continued.

The Cliff House Sandstone is unconformable or intertongues with the underlying Menefee Formation. It is a very fine- to fine-grained coastal marine sandstone, 325 ft thick in the Durango area. The unit thins and grain sizes are progressively smaller eastward. Outcrops are present west and northeast of Durango. The Cliff House Sandstone is the upper formation of the Mesaverde Group. It is mapped as part of the Mesaverde Group along the northern boundary of the Durango study area east of Durango.

The base of the Lewis Shale intertongues with and conformably overlies the Cliff House Sandstone. It is of marine origin and contains interbedded shale. It is approximately 1,800 ft thick near the Animas River and thickens eastward. The upper 300 ft is sandy and is transitional with the overlying Pictured Cliffs Sandstone. Outcrops are present southwest of Durango and along the northern rim of the Durango study area east of Durango.

The Pictured Cliffs Sandstone is transitional from sandstone to shale, downward through approximately 300 ft. It conformably overlies the Lewis Shale. The formation is of marine origin and typically consists of a cliff-forming, fine- to medium-grained sandstone. Outcrops are present south of Durango and along the northern boundary of the Durango study area east of Durango. There is a small outcrop in the extreme eastern part of the study area.

The Fruitland Formation and the Kirtland Shale commonly are mapped together and have similar characteristics. The Fruitland Formation is mapped separately in the extreme eastern part of the Durango study area because mining has made available additional geological information. The Fruitland Formation conformably overlies the Pictured Cliffs Sandstone. The Fruitland Formation and the Kirtland Shale consist of shale, sandstone, and coal. Approximate thicknesses are 1,200 ft for the Kirtland Shale and 300 ft for the Fruitland Formation. Outcrops are present south of Durango and in the eastern part of the study area.

The Animas Formation unconformably overlies the undifferentiated Fruitland Formation and the Kirtland Shale. It ranges from unweathered conglomerate to shale with a maximum thickness of 1,400 ft. Outcrop areas are extensive in the Durango study area east of Durango.

The San Jose Formation unconformably overlies the Animas Formation. It consists of interbedded sandstone, shale, and conglomerate; outcrops are present in the southeastern part of the Durango study area.

Quaternary deposits range from a few feet to 100 ft in thickness and consist of alluvium, colluvium, and terrace deposits. Alluvium in the Durango study area consists of gravel, sand, silt, and various combinations of these materials. Colluvium consists of unsorted gravel, sand, and silt and overlies bedrock. Terrace deposits consist of well-rounded boulders overlying bedrock.

Structure

The primary structural feature of the Durango study area is the San Juan Basin, which includes parts of New Mexico, Colorado, and Arizona. The Durango

study area is on the northern rim of the basin (see fig. 1). Stratigraphic units dip toward the basin's center in northwestern New Mexico. In the western part of the Durango study area, the stratigraphic beds dip southeast; in the eastern part of the Durango study area, stratigraphic beds dip southwest. The southward structural dip generally is steepest along the upper rim of the San Juan Basin east of Durango and north of Bayfield where the dip is as much as 55°. The general dip typically is less than 10°.

Secondary structural features in the Durango study area include anticlines, synclines, monoclines, and local faults and fractures. In the central part of the study area are northeastward-trending normal faults with displacements from 60 ft to 300 ft. Faults have not been mapped in the specific study areas, although small faults have been encountered during coal mining in the National King Coal Mine in the Hay Gulch study area and in the Chimney Rock Coal Mine in the Stollsteimer Creek study area. Fracturing is common in coal beds in the Fruitland and Menefee Formations.

HYDROGEOLOGY AND GROUND-WATER QUALITY

Bedrock Units

The hydrogeologic properties of the bedrock units are dependent primarily on permeability and porosity. Permeability is dependent on interconnected pores, solution channels, and fractures. Other factors that determine hydrologic characteristics are saturated thickness and the continuity of permeable zones. Hydrogeologic characteristics of geologic units in the Durango area and upper San Juan Basin are summarized in the explanation of figure 7.

Transmissivity is a measure of the ability of an aquifer to transmit water. The most transmissive bedrock aquifers in the Durango study area are the Animas Formation and the lower Menefee Formation. Coal seams in the Menefee and Fruitland Formations typically are more permeable than shale or sandstone because of fractures which formed in coal during diagenesis (coal formation). These aquifers yield 10 gal/min or more, dependent on local hydrologic conditions and well construction. Zapp (1949) reported that the rock units in the Durango study area thin from west to east, probably because of compaction of finer-grained sediment present in the east. Therefore, aquifers also thin eastward and have lower permeability and transmissivity values in the east compared to the west. Other hydrogeologic units in the Durango study area can provide sufficient water for domestic use, although information is insufficient to establish whether or not they contain significant aquifers.

Analyses of water samples indicate that the bedrock aquifers contain water with similar chemical characteristics, except for the Menefee Formation, which contains water with larger dissolved-solids concentrations than other bedrock aquifers. The average concentration of dissolved solids in water in bedrock aquifers is 788 mg/L; values ranged from 135 mg/L to 3,350 mg/L (see table 1 in the Supplemental Data section at the back of this report). The principal cations are calcium and magnesium; the principal anions are bicarbonate (alkalinity in table 1) and sulfate.

The Mancos Shale generally is not considered to be an aquifer through most of its thickness. However, this formation yields water to wells near landslides or in slump blocks, where yields as large as 10 gal/min are reported (Brogden and Giles, 1976).

The Point Lookout Sandstone potentially is a high-yielding aquifer in the Durango study area, although little hydrologic information is available because the aquifer has been only sparsely developed. This aquifer yields adequate water supplies for domestic use. Well yields of 6 gal/min have been reported, although greater values can be expected with properly designed and constructed wells. The Point Lookout Sandstone thins eastward, so potential well yields probably decrease toward the east.

Samples were collected from three wells completed in the Point Lookout Sandstone in the Durango study area. No dominant ions were discerned. Dissolved-solids concentrations were 555 mg/L, 800 mg/L, and 923 mg/L.

The lower part of the Menefee Formation is more permeable than the upper part and is hydrogeologically connected with the underlying Point Lookout Sandstone. The coal seams are the most permeable zones in the formation because of fractures. Well yields range from 3 gal/min to 15 gal/min; approximately 8 gal/min is common. The maximum transmissivity for this formation is expected to be as much as 50 ft²/d in New Mexico in the San Juan Basin (Stone and others, 1983). The Menefee Formation thins eastward, and a corresponding reduction in transmissivity is likely.

Water samples were collected from 14 wells completed in the Menefee Formation. The dominant ions were sodium and bicarbonate. The ions are distinct compared with ion variations in other samples from other aquifers. Dissolved-solids concentrations ranged from 209 mg/L to 3,350 mg/L, with an average of 1,090 mg/L.

Wells completed in the Cliff House Sandstone produce as much as 17 gal/min in the Durango study area; yields of about 10 gal/min are common. Permeability probably is greater in the western part of the study area compared to the east because the formation is thicker and contains coarser material. Transmissivity was reported to be 2 ft²/d in New Mexico in the San Juan Basin (Stone and others, 1983).

Water samples were collected from five wells completed in the Cliff House Sandstone in the Durango study area. The water quality was variable, with no dominant cation and bicarbonate as the dominant anion. Dissolved-solids concentrations ranged from 135 mg/L to 1,140 mg/L, with an average of 550 mg/L.

The Lewis Shale is rarely developed for a water supply. One well completed in shale and sandstone beds of the formation had a reported yield of 10 gal/min. Well yields as large as 3 gal/min are reported south of the Durango study area on the Southern Ute Indian Reservation (Brogden and others, 1979). Much of the Lewis Shale is not an aquifer, based on formation lithology.

No hydrologic information is available for the Pictured Cliffs Sandstone in the Durango study area. Well yields as large as 5 gal/min are reported

south of the Durango study area on the Southern Ute Indian Reservation (Brogden and others, 1979). Transmissivity values from 0.001 ft²/d to 3 ft²/d were reported in New Mexico within the San Juan Basin (Stone and others, 1983). This formation is not considered to be an aquifer in the Durango study area, based on formation lithology.

The Fruitland Formation and the Kirtland Shale have common lithologic characteristics. Most available hydrologic data are for the Fruitland Formation. Two aquifer tests were performed using a pumping well and an observation well, both completed in the Fruitland Formation near the Chimney Rock Mine in the Stollsteimer Creek study area. These wells have perforations through three coal seams, and shale separates the coal seams. The first test was performed by D.R. Piteau and Associates Limited (1982). This test was a 24-hour drawdown-and-recovery test at a constant discharge. The transmissivity value was 28 ft²/d; the storage coefficient value was 1.3×10^{-4} . A second test was performed by the U.S. Geological Survey in 1983 using the same wells. The test time was increased to 33 hours, with an average pumping rate of 3.6 gal/min. The transmissivity value was 25 ft²/d, and the storage coefficient was estimated to be 1×10^{-4} .

Slug tests were performed using two wells near the Chimney Rock Mine. The estimated transmissivity value for a sandstone and shale underlying the lowest coal seam in the Fruitland Formation was 0.3 ft²/d. The estimated transmissivity value for the lower Fruitland Formation and valley colluvium was 125 ft²/d; most of the transmissivity value is due to the greater permeability of the colluvium.

Water samples were collected from six wells completed in the Fruitland Formation in the Stollsteimer Creek study area. One sample was collected from a well completed in the Kirtland Shale. For samples from both formations, the dominant ions were calcium and bicarbonate. Dissolved-solids concentrations ranged from 312 mg/L to 1,040 mg/L, with an average of 524 mg/L.

The Animas Formation has the best potential of the bedrock units for ground-water development. Wells completed in this formation reportedly yield as much as 50 gal/min in the Durango study area (Brogden and Giles, 1976), and as much as 75 gal/min on the Southern Ute Indian Reservation (Brogden and others, 1979), south of the Durango study area. Transmissivity is expected to be 100 ft²/d in New Mexico in the San Juan Basin (Stone and others, 1983).

Water quality of the Animas Formation is described by Brogden and Giles (1976). The dissolved-solids concentrations ranged from 309 mg/L to 455 mg/L for samples from seven wells completed in the Animas Formation.

Little information exists on the San Jose Formation and its ability to transmit ground water in the Durango study area. However, transmissivity of the San Jose Formation may be greater than other bedrock formations, based on formation lithology and aquifer testing south of the Durango study area in New Mexico (Stone and others, 1983).

Unconsolidated Deposits

Alluvium deposits contain the best aquifers in the Durango study area, as well as in the San Juan Basin. These aquifers typically yield the most water to wells and contain water of better quality than bedrock aquifers. Well yields were reported to be as much as 500 gal/min for La Plata River gravels (John Hanau, Amax Coal Company, written commun., 1983). Wells completed in alluvium and colluvium commonly yield from 5 gal/min to 20 gal/min.

An aquifer test of alluvium along Stollsteimer Creek in the Chimney Rock Mine was performed by D.R. Piteau and Associates Limited (1982). The step-drawdown test determined a transmissivity value of approximately 13,000 ft²/d.

Water quality in unconsolidated deposits is diverse and commonly is similar to water chemistry of local bedrock. Dominant cations generally were calcium and magnesium; dominant anions generally were bicarbonate and sulfate. Dissolved-solids concentrations ranged from 280 mg/L to 1,130 mg/L, with an average of 644 mg/L.

STOLLSTEIMER CREEK STUDY AREA

Location

The Stollsteimer Creek study area is in the southeast part of the Durango study area (fig. 1) and contains the Chimney Rock Mine tracts (fig. 8). The hydrology of this study area is described as it relates to potential mining impacts.

Surface-Water Characteristics

The Stollsteimer Creek drainage area, upstream from the confluence with the Piedra River, is 126 mi². Spring runoff usually occurs in April. The average stream slope from Capote Lake to the confluence with the Piedra River is 0.006, and in the Stollsteimer Creek study area the slope is about 0.007. The saturated alluvium in the Stollsteimer Creek valley produces perennial flow in Stollsteimer Creek. Maximum stream discharge for Stollsteimer Creek measured near the Chimney Rock Mine (site number 63 in fig. 4) in 1983 was 309 ft³/s on April 22; minimum discharge measured at the same location in the same year was 1.84 ft³/s on October 19.

Cabazon Creek in Cabazon Canyon (fig. 4) has a drainage area of 6.9 mi², and a stream length of 5.5 mi. The stream slope is 0.036 in its main channel. The stream is perennial except during freezing periods in midwinter. Discharge measurements in 1983 at site numbers 61 and 62 (fig. 4) ranged from 7.27 ft³/s on April 22 to 0.18 ft³/s on November 7.

Drainages that are tributary to Stollsteimer Creek have thin alluvium deposits and typically do not support perennial flow. Deep Creek in Deep Canyon (fig. 4) has a drainage area of 4.2 mi², with a main channel length of 4.4 mi. The channel slope is 0.046. The largest discharge measurement in 1983 was 6.41 ft³/s on April 22 at site number 67 (fig. 4). The creek was dry

by August 10, 1983. Discharge typically ceases by June or July (as reported by local residents).

Streamflow measurements were used to determine rates of gain or loss on Stollsteimer, Cabezon, and Deep Creeks in 1983. Data for these and other streamflow measurements are in table 4 in the Supplementary Data section at the back of the report.

Stollsteimer Creek gained water between site numbers 64 and 70 (fig. 4) in the mine-lease area in September 1983. Discharge decreased downstream from the mine. In November 1983, Cabezon Creek gained from 0.05 ft³/s to 0.18 ft³/s, between about 1 mile upstream of the confluence with Stollsteimer Creek and near the confluence.

Deep Creek gained from 0.03 ft³/s to 0.04 ft³/s between site numbers 65 and 66 when measured in August 1983.

The dominant ions for Stollsteimer, Cabezon, and Deep Creeks were calcium and bicarbonate. Specific-conductance values were larger for water samples taken from Stollsteimer Creek than from its tributaries, probably because of increased traveltime, increased opportunity for dissolution of solids, and increased contribution of ground water from alluvium and bedrock. Specific-conductance values increased in the three creeks through summer 1983. Values for creeks sampled on July 21, 1983, were 820 μ S/cm (microsiemens per centimeter at 25° Celsius) for Stollsteimer Creek, 500 μ S/cm for Cabezon Creek, and 380 μ S/cm for Deep Creek. The nearest sites (site numbers 61, 63, and 67 in fig. 4) were selected for comparison.

Ground-Water Characteristics

Bedrock Units

The Pictured Cliffs Sandstone is as much as 250 ft thick in the Stollsteimer Creek study area and dips about 10° to the southwest. The shale and sandstone in the lower Fruitland Formation likely impede ground-water movement between the Pictured Cliffs Sandstone and overlying formations. No wells are completed in the Pictured Cliffs Sandstone in the Stollsteimer Creek study area or its proximity.

The Fruitland Formation also dips about 10° to the southwest and is about 100 ft thick at the Chimney Rock Mine. It consists of interbedded sandstone, shale, and coal. Some clay is noted in well drillers' logs.

Three important coal seams in the Fruitland Formation are the A, B, and C seams. The C seam is the lowest of the three seams. About 30 ft of shale and sandstone separate the C seam and the Pictured Cliffs Sandstone.

The transmissivity of a 40-ft thickness of the Fruitland Formation, including A, B, and C coal seams, was 25 ft²/d; and the storage coefficient was 1.0×10^{-4} . Slug-type well tests indicated that the Fruitland Formation is less permeable in the zone between the C seam and the underlying Pictured Cliffs Sandstone. The estimated transmissivity value was 0.3 ft²/d.

The hydraulic gradient in the Fruitland Formation near the mine is toward the Stollsteimer Creek valley. Five wells completed in the Fruitland Formation in the proximity of the Chimney Rock Mine indicate that the aquifer is confined to semiconfined. Four of the wells (site numbers 5, 7, 10, and 18 in fig. 3) are located in the valley floor; the water level in each is above the coal seams. The fifth well (site number 8 in fig. 3) is located north of the mine at a higher altitude. The water level in this well is below the coal seams but higher than the water levels in the other four wells completed in the Fruitland Formation. Therefore, the general direction of ground-water movement is from the well at the north toward the lower four wells. However, little ground water is transmitted because of the small transmissivity of the Fruitland Formation.

Short flow paths predominate in the Fruitland Formation in the Stollsteimer Creek study area. Recharge to the formation occurs from infiltration of precipitation in topographically high areas at surface exposures of the Fruitland Formation or from infiltration through overlying deposits. Discharge occurs to the alluvium in Stollsteimer Creek valley or is lost to evapotranspiration from the Fruitland Formation.

The dominant ions were calcium and bicarbonate in water from the Fruitland Formation in the Stollsteimer Creek study area. Concentrations of dissolved solids ranged from 312 mg/L to 1,040 mg/L with an average of 513 mg/L. Water quality was generally suitable for domestic use, although concentrations of sulfate, iron, and manganese for 13 ground-water and 3 surface-water samples exceeded U.S. Environmental Protection Agency (U.S. EPA) public drinking-water standards (1977a, 1977b).

Alluvium Deposits

Alluvial deposits that fill the Stollsteimer Creek valley have a maximum thickness of 60 ft (D.R. Piteau and Associates Limited, 1982). These deposits include coarse-grained sandstone, gravel, and silt near the contact with underlying bedrock. Figure 9 shows a cross section of the alluvium at the Chimney Rock Mine.

Ground-water discharge through the alluvial aquifer in a downstream direction can be determined using Darcy's Law, which may be expressed as:

$$Q = KIA,$$

where

Q is ground-water discharge;
 K is the hydraulic conductivity;
 I is the hydraulic gradient; and
 A is the cross-sectional area of the aquifer.

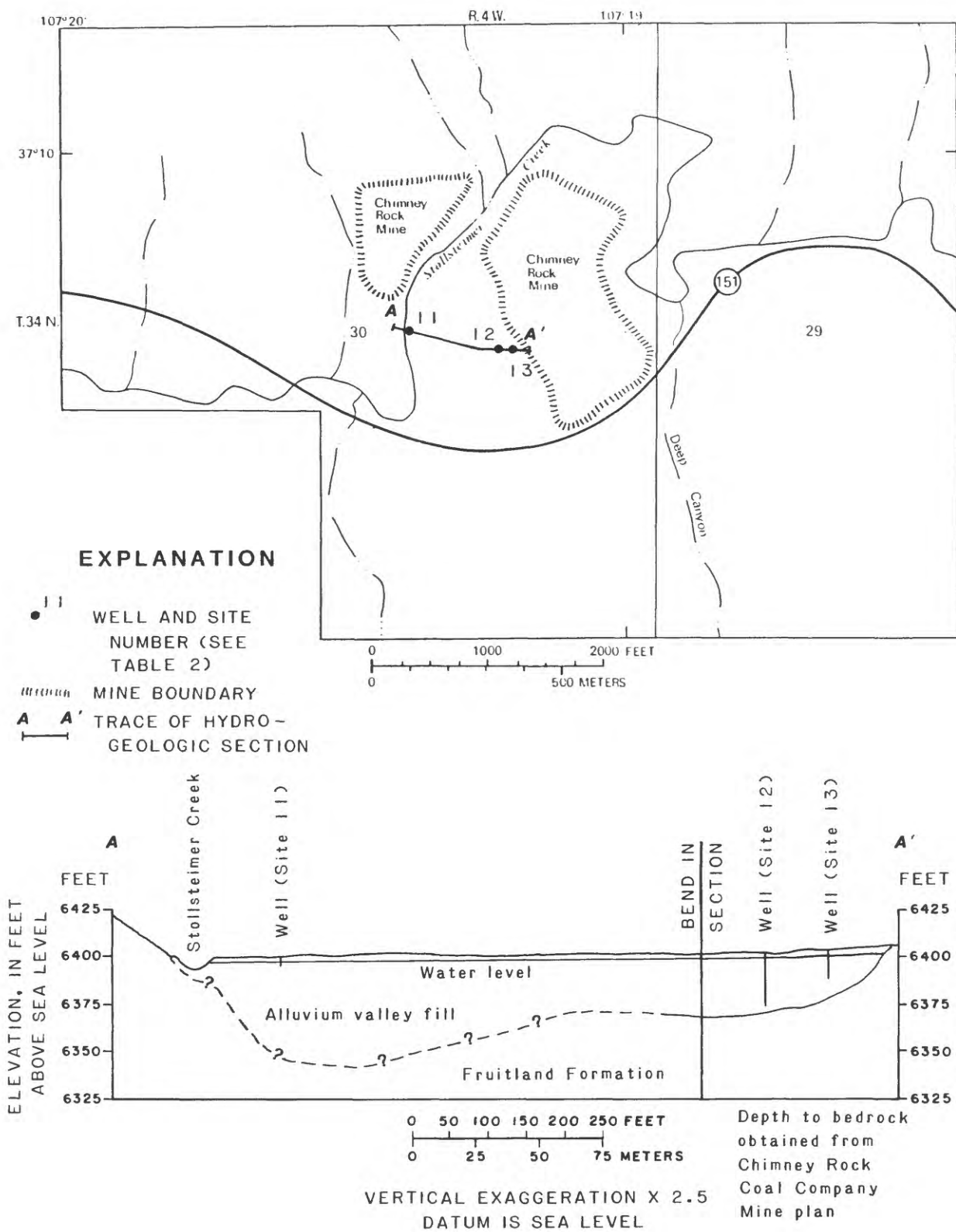


Figure 9.--Map and hydrogeologic section of Stollsteimer Creek valley.

The transmissivity of a 46-ft thick saturated thickness of the alluvial aquifer is reported to be 13,000 ft²/d (D.R. Piteau and Associates Limited, 1982); therefore, the average hydraulic conductivity is about 285 ft/d. The hydraulic gradient is assumed to be equal to the stream gradient of 0.007. The cross-sectional area of saturated alluvium is about 29,000 ft². Therefore, ground-water discharge through the alluvium in a downstream direction is about 0.7 ft³/s, which is about 10 percent of the discharge in Stollsteimer Creek during the summer.

The main source of recharge to the alluvial aquifer in the Stollsteimer Creek study area is from infiltration of precipitation. Lesser amounts of recharge occur by lateral flow from coal beds in the Fruitland Formation. Although some reaches of Stollsteimer Creek may recharge the aquifer, the streamflow measurements made in September 1983 indicate that the alluvium discharges to the creek in the vicinity of the Chimney Rock Mine. Streamflow gains probably result from: (1) A decreased cross-sectional area of the valley alluvium in the vicinity of the mine; (2) discharge to the creek from spoil piles in the mine; and (3) discharge from the Fruitland Formation coal seams that underly the alluvium near the stream-gage site NB03400430ACA (site number 69 in fig. 4). However, the Fruitland Formation contributes relatively little water to streamflow, because the few, thin coal seams transmit little water.

Recharge to Cabezón Creek alluvium is from infiltration of precipitation and from flow through coal beds in the Fruitland Formation where the coal beds are in contact with the alluvium. Discharge from the Fruitland Formation in Cabezón Canyon would raise the specific conductance of the water in the alluvium and increase streamflow in Cabezón Creek. Cabezón Creek gains water downstream from the approximate contact of the Fruitland Formation and alluvium, and these gains coincide with increases in specific-conductance values from 460 µS/cm to 580 µS/cm over about a 1-mi reach. The specific conductance of a water sample taken from a well (site number 2) completed in the Fruitland Formation in Cabezón Canyon was 698 µS/cm.

Deep Canyon has a smaller drainage area than Cabezón Canyon; therefore, there is less opportunity for recharge and discharge. Streamflow in Deep Creek is seasonal and indicates less ground-water discharge.

Dissolved-solids concentration of an alluvial-water sample from Cabezón Creek (site number 1) was 280 mg/L, and an alluvial-water sample (site number 6) from Deep Creek was 330 mg/L. Dissolved-solids concentration for Stollsteimer Creek alluvium water samples ranged from 330 mg/L to 1,130 mg/L. Dissolved-solids concentrations are greater for water samples taken from wells completed in Stollsteimer alluvium than for wells completed in Cabezón Canyon and Deep Canyon alluvium. Samples taken from wells completed in Stollsteimer Creek alluvium exceeded the maximum concentration of dissolved solids recommended for public drinking water (U.S. EPA, 1977a). Concentrations of sulfate, iron, and manganese exceeded these standards for 5 out of 7 water samples taken from wells completed in the alluvium along Stollsteimer Creek.

The dominant ions of water samples taken from wells completed in Stollsteimer Creek alluvium were calcium, sulfate, and bicarbonate. The dominant ions of water samples taken from wells completed in Cabezón Canyon and Deep Canyon alluvium were calcium and bicarbonate. The proportion of bicarbonate anion to sulfate anion is diminished in Stollsteimer Creek alluvium water, compared with Cabezón and Deep Canyon alluvial water.

Water quality in the alluvium is similar to that in the Fruitland Formation. The similarity of water quality, the lack of outcrops of bedrock aquifers upgradient and north of Stollsteimer Creek, and the fact that bedrock of low transmissivity likely discharges any water to adjacent topographic lows suggest that the principal ground-water flow systems are local in the Stollsteimer Creek study area.

Mine Development and Effects

The Chimney Rock Mine (figs. 8 and 9) ceased mining in July 1985 and is located in the Stollsteimer Creek valley. It was the largest coal mine in the Durango study area and the last active surface mine in the area.

Bedrock overlying the coal was removed from mine pits and backfilled into a previously mined pit, creating spoils. Spoil piles are covered with topsoil and revegetated. In the spring of 1983, spoils were backfilled around a perforated casing in the center of an open pit. This well (site number 15) subsequently has been monitored for depth-to-water and for water quality.

The water table in the spoil pile rose through 1983 and is expected to rise slowly until it reaches equilibrium. The permeability and infiltration rate is much greater for the spoil-pile material than for the original undisturbed bedrock. Vertical hydraulic conductivity is also much greater for spoil-pile material than for bedrock, which allows more infiltration downwards through the pile. A larger volume of ground water is contained in the spoil pile than in a comparable volume of bedrock, and more ground water is transported through the spoils. The permeability of the spoil piles will decrease in time because of weathering of the shale into finer-grained clay and because of spoil-pile compaction.

The principal source of recharge to the spoil piles is from alluvial water upgradient from the spoil piles, based on depth-to-water measurements in wells upstream and downstream from the spoil pile. Alluvial water passes through the spoils material and then returns to the alluvium further down the valley. Recharge from alluvial water will increase the saturated thickness in the spoil pile until the water level is in equilibrium.

Discharge from the spoil pile into Stollsteimer Creek alluvium will increase downstream from the spoils as the water level rises in the spoil pile. Samples from wells completed in alluvium upstream from the spoil piles had an average dissolved-solids concentration of 463 mg/L; samples from wells completed in alluvium downstream from the spoil pile had an average dissolved-solids concentration of 789 mg/L. The dissolved-solids concentration of water

in the spoil pile was 559 mg/L. Although the dissolved-solids concentration of water in the spoil pile was greater than the average dissolved-solids concentration of alluvial water upstream, it does not account for the significantly higher values in alluvial waters downstream from the mine. Alluvial water downstream from the spoil piles may be affected by effluent from older spoil piles (more than 10 years) north of the spoil pile from which water was sampled and by the airborne coal dust and mining particulates that have been deposited near the mine.

The dominant ions of the spoil-pile-water sample were sodium and bicarbonate, distinctly different from other ground water sampled in the Stollsteimer Creek study area. Clay and shale zones above and between coal seams are recorded in well-drilling logs and probably are the source of sodium in the spoil pile. The dissolved-solids concentration of ground water in the spoil pile may increase with time because of increasing spoil-pile compaction resulting in the slowing of ground-water movement through the spoil pile.

Chimney Rock Mine had encountered little ground water in recent mining, although dewatering was required in previous pits. Mine workings were above the water table in the Fruitland Formation.

Mining of the Fruitland Formation may cause:

1. Increases of dissolved solids in water in Stollsteimer Creek and alluvium downstream from the mine. These effects would diminish downstream.
2. Temporary dewatering of the Fruitland Formation and adjacent saturated alluvium, if future mining occurs below the water table of the Fruitland Formation.
3. Increased baseflow downstream from the mine because of increased ground-water storage in the spoil piles.
4. Increases in stream sedimentation, dependent on spoil-pile slope stability.

Mining in Deep Canyon or Cabezon Canyon would cause similar effects. Because most ground water in the Stollsteimer Creek study area is within local flow systems, any hydrologic effects from mining in Deep or Cabezon Canyons eventually would affect Stollsteimer Creek and its alluvium.

Increases in dissolved solids would be accompanied by increases in sulfate and sodium concentrations, because greater concentrations of these constituents are found presently in the spoil-pile water. Continued mining is not expected to lower the pH of Stollsteimer Creek downstream from the mine; the effluent from the spoil piles is small in proportion to the total streamflow in Stollsteimer Creek, and the bicarbonate in the stream and alluvium would buffer any potential changes in the pH of the stream.

Flooding would increase dissolved solids and sedimentation temporarily in Stollsteimer Creek. A 100-year flood would flush mining contaminants (coal dust and other particulates) from low-lying areas in the mine. The flood

would have a depth of about 5-ft and a discharge of about 2,000 ft³/s at the Chimney Rock Mine. These values were calculated using the McCain and Jarrett (1976) method for estimating flood characteristics at ungaged sites. The 100-year flood would cause a backwater reservoir upstream from a culvert (corrugated metal pipe-arch with dimensions of 17.2 ft by 11.3 ft) located at the northern bend of Stollsteimer Creek separating the two parts of the mine. The headwater altitude at the upstream end of the culvert would be approximately 6,430 ft (using nomographs developed by the U.S. Department of Transportation, 1965), and the base of a reclaimed spoil pile near the culvert is about 6,430 ft. The 100-year flood would have little effect on spoil piles.

Reclamation plans state that, at the conclusion of mining, the culvert and associated fill material that dams Stollsteimer Creek will be removed. Therefore, the probability of the culvert being in existence during a 100-year flood event before reclamation would be less than 10 percent.

HAY GULCH STUDY AREA

Location

The Hay Gulch study area is in the southwestern part of the Durango study area (fig. 1) and contains the National King Coal Mine tracts (fig. 10). The coal seam being removed at the mine is in the Menefee Formation. The hydrology of this study area is described as it relates to potential mining impacts. The description of upper Hay Gulch in this report refers to the approximate 6-mi reach of Hay Gulch upstream from its confluence with Pine Gulch.

Surface-Water Characteristics

Surface-water features in the Hay Gulch study area include the Hay Gulch irrigation ditch, the southern diversion of the Hay Gulch irrigation ditch, and upper Pine Gulch. Water flows in the ditches throughout the year. The Hay Gulch irrigation ditch diverts water from the La Plata River near Hesperus (fig. 1) for augmenting streamflow in Hay Gulch. The irrigation diversion also provides water to the lower drainage of Pine Gulch, which is normally dry by early summer. Water is diverted from the Hay Gulch irrigation ditch near the eastern rim of Hay Gulch and into the southern diversion of the Hay Gulch irrigation ditch. The southern diversion runs south of Hay Gulch along the divide between Hay Gulch and Pine Gulch and then enters the lower Pine Gulch drainage above the confluence with Hay Gulch.

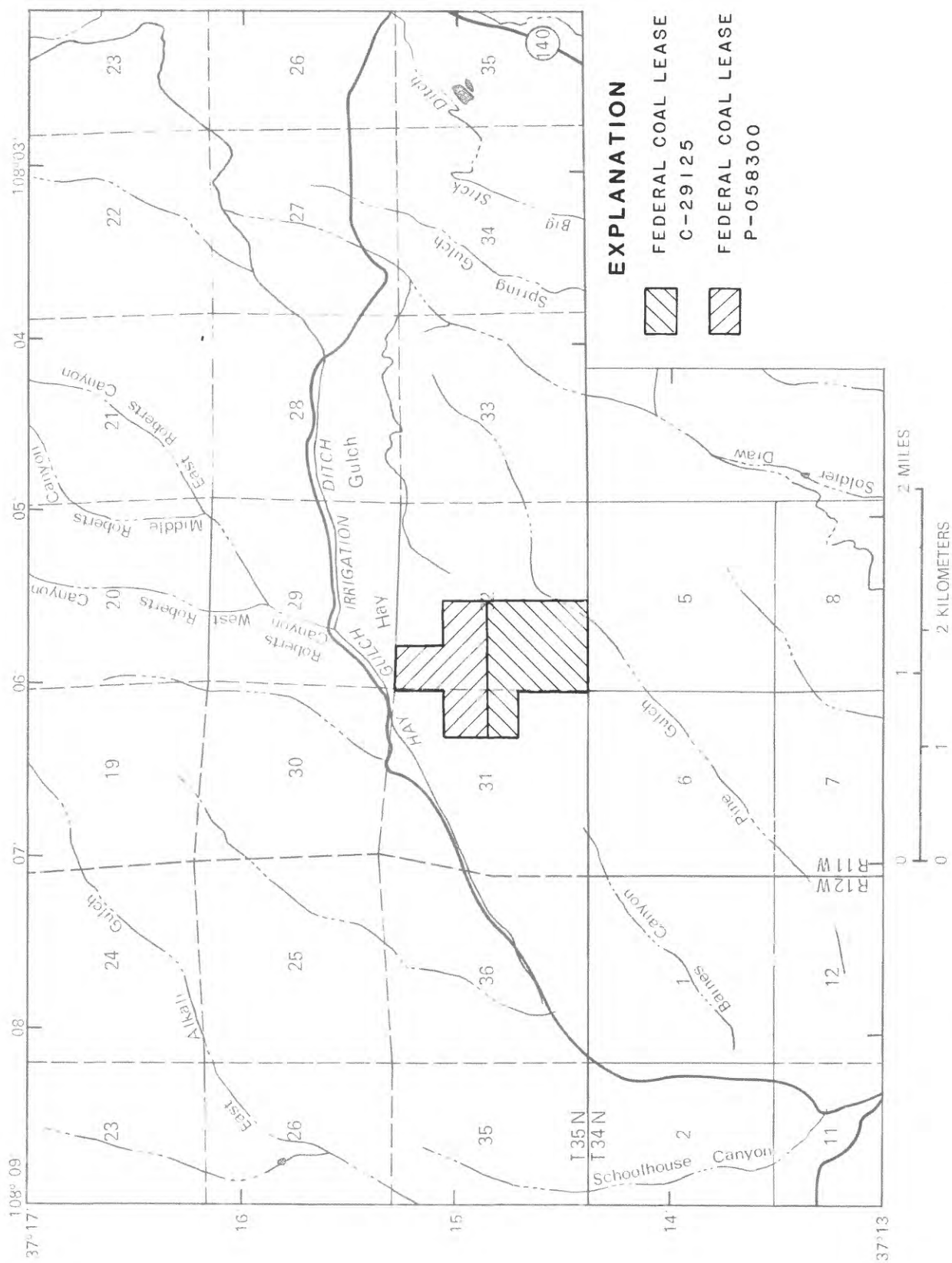


Figure 10.--Coal-lease tracts of the National King Coal Mine.

Flow measurements were made on the southern diversion of the Hay Gulch irrigation ditch in July and September 1983. Three flow-measurement sites were selected to determine if fractures from subsidence after mine pillar removal result in a loss of flow. The reach between site number 78 and site number 79 (fig. 5) overlies a part of an underground mine where mine pillars had been removed. The reach between site numbers 79 and 80 overlies a part of an underground mine where mine pillars are still in place. No flow losses were measured in either reach, indicating that there was no leakage from the ditch. However, sediment deposition in the ditch channel probably impedes any infiltration.

The specific conductance of water in the southern diversion of the Hay Gulch irrigation ditch was approximately 150 $\mu\text{S}/\text{cm}$, which is similar to the specific conductance of water in the La Plata River from where the water is diverted. The similarity of specific-conductance values indicates no contribution from ground water in the reach from the source at the La Plata River in Hesperus to the flow-measurement sites.

Ground-Water Characteristics

Bedrock Units

Geologic formations in the Hay Gulch study area are the Point Lookout Sandstone, the Menefee Formation, the Cliff House Sandstone, and valley alluvium.

No wells are completed in the Point Lookout Sandstone in the Hay Gulch study area. The formation is recharged through overlying rock and deposits. The Point Lookout Sandstone lithology is transitional with the overlying Menefee Formation.

The Menefee Formation is about 325 ft thick in the Hay Gulch specific study area and dips about 2° to the southeast. The lower Menefee Formation is saturated and probably is hydrologically connected to the underlying Point Lookout Sandstone. The upper Menefee Formation generally is not considered an aquifer, although underground mining occasionally intercepts and drains small saturated sandstone lenses. The upper Menefee has about seven coal seams. The uppermost coal seam, which is less than 10 ft below the overlying contact with the Cliff House Sandstone, is being removed at the National King Coal Mine.

Three double-completion wells were installed by A.T. Massey Coal Company in 1980 and completed in the Menefee Formation. These wells are located in the Hay Gulch study area, south of Hay Gulch (site numbers 44-45, 48-49, and 51-52). Each double-completion well consists of one well completed in a coal seam in the Menefee Formation and the other well completed in sandstone, less than 40 ft below the coal seam. The interval between completion levels in the hole is sealed with bentonite. The water levels in these wells were used to analyze hydraulic gradients and water movement. The water level of the deeper well was higher than that in the shallow well in two of the three double completions. This suggests that ground water moves upward from the sandstone zone to the more permeable coal units. Data from the the other double-completion well are less reliable because of poor well construction.

Recharge to the Menefee Formation occurs north of the Hay Gulch study area, from precipitation on outcrops or from ground water that infiltrates downward from overlying aquifers. The Menefee Formation also may be recharged by leakage from the overlying alluvial aquifer in Hay Gulch. There is no evidence of major discharge from the Menefee Formation into Hay Gulch. Natural streamflow ceases in upper Hay Gulch by summer.

Ground-water discharge from the Point Lookout Sandstone or Menefee Formation occurs south of the Hay Gulch study area at lower altitudes and may enter the La Plata River drainage. Specific-conductance measurements were made on the La Plata River in February 1984 to determine if the water quality was affected by ground-water discharge into the river. Specific conductance increased from 175 $\mu\text{S}/\text{cm}$ near Fort Lewis to 1,430 $\mu\text{S}/\text{cm}$ above the confluence with Cherry Creek (fig. 1). The greatest increases were measured between the towns of Breen and Kline and near the confluence with Cherry Creek. Increased specific-conductance values in these reaches may be caused by discharge from the Point Lookout Sandstone and the Menefee Formation, because these are the primary bedrock units in this area. Kline is about 1,000 ft lower in altitude than the potential recharge area in the Hay Gulch study area and about 9 mi south of Hay Gulch.

The dominant ions in the Menefee Formation are distinctly sodium and bicarbonate. Dissolved-solids concentrations for water from the three double-completion wells ranged from 654 mg/L (site number 44) to 1,930 mg/L (site number 45). These values may indicate longer flow paths within the Menefee Formation, a geohydrologic unit of low-to-fair transmissivity. Small aquifer transmissivity impedes ground-water movement and increases travel-time, which allows a longer time in contact with solubles in the bedrock. Large concentrations of fluoride and chloride were present in some samples from the Menefee Formation.

The lower Menefee Formation and the Point Lookout Sandstone have better potential for domestic ground-water development than the upper Menefee Formation in the Hay Gulch study area, based on water quality and permeability.

The Cliff House Sandstone overlies the Menefee Formation and is exposed on the divide between upper Hay Gulch and Pine Gulch. In the Hay Gulch study area, the sandstone is about 265 ft thick where it is unweathered and dips about 2° to the southeast. Water movement from the Cliff House Sandstone into the Menefee Formation probably is not occurring, because the upper Menefee Formation contains little water. Any ground-water movement in the Cliff House Sandstone probably would be horizontal toward the southeast.

Alluvium Deposits

The width and thickness of the alluvium are not known. Upper Hay Gulch alluvium is the most permeable aquifer in the Hay Gulch study area. However, alluvial deposits such as in the La Plata River or Stollsteimer Creek drainages are better sorted and, therefore, more permeable.

The alluvium in upper Hay Gulch generally is saturated. Several seep areas are in the valley floor (fig. 5). The seep areas are located near the valley sides and at the confluence of a tributary. The valley floor has more vegetation than the higher divides between drainages. Most of upper Hay Gulch is used for growing hay and for grazing.

One of the six residences in upper Hay Gulch used water from the alluvial aquifer. The other five residences used water from the Hay Gulch irrigation ditch for homes and irrigation, because the alluvial water quality is unsuitable. The dominant cations of alluvial water were calcium and magnesium; the dominant anion was sulfate.

The alluvium in Pine Gulch is shallow and is sufficiently saturated to support grass growth through the summer; pinon-juniper is more typical vegetation at the higher altitudes surrounding Pine Gulch. The saturated alluvium in Pine Gulch is underlain by the lower part of the Cliff House Sandstone.

Mine Development and Effects

The National King Coal Mine (figs. 10 and 11) will continue to mine southward, using room-and-pillar methods. The southern lease tract underlies part of the upper drainage of Pine Gulch, but an agreement with the U.S. Bureau of Land Management permits mining west from the northwest quarter of the southwest quarter of section 32 (T. 35 N., R. 11 W.) rather than undermining Pine Gulch. As little as 50 ft of overburden separate Pine Gulch alluvium and the upper coal seam currently mined by National King Coal Mine in the Menefee Formation.

No measurable dewatering of the southern diversion of the Hay Gulch irrigation ditch has occurred. The National King Coal Mine withdraws alluvial water for mine operation, but the pumping does not significantly dewater the aquifer. Mining occurs above the potentiometric surface in the Menefee Formation, so that only small, permeable lenses are dewatered during mining.

Underground mining has caused tension cracks in the Cliff House Sandstone. These cracks occurred through about 300 ft to 400 ft of overburden above the underground mine. Some were visible at land surface (fig. 11). Most cracks were less than 40 ft long and 6 in. wide, although one crack near the sandstone rim above the mine was about 450 ft long and up to 1 ft wide. Stresses originate where support pillars adjoin open rooms and when pillars in the mine are collapsed after mining is completed. There is about 350 ft of overburden between the longest surface subsidence crack and the underground mine. The limit angle (the angle, measured from the vertical, between the point of stress in the underground mine and the surface crack) is about 30°, which is typical of limit angles in the Somerset mining district, Colorado

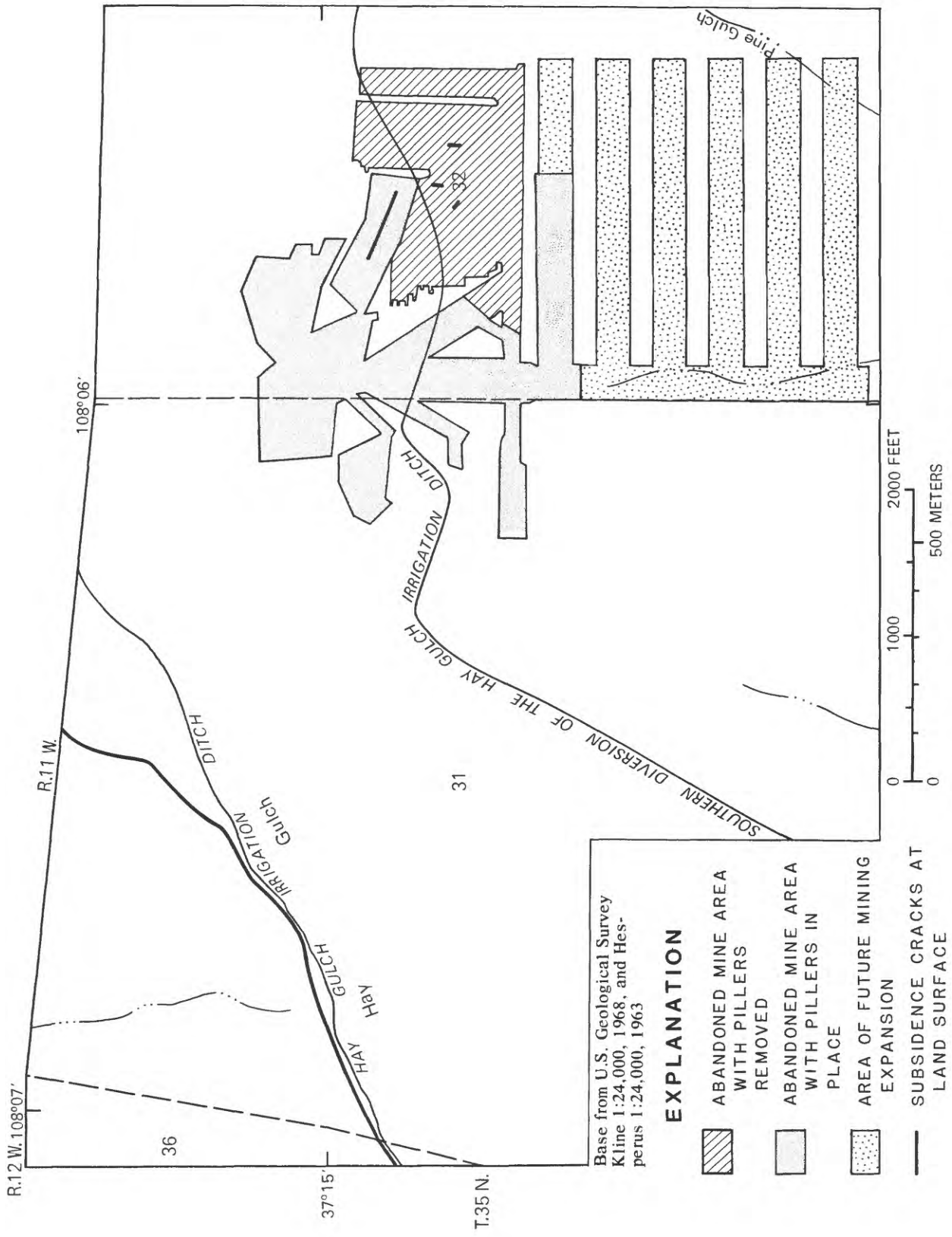


Figure 11.--Underground-mine plans of National King Coal Mine and surface-subsidence cracks.

(Dunrud, 1976). Subsidence effects diminish with increased thickness of overburden. Subsidence will continue during underground mining, and new tension cracks likely will appear at land surface.

Three wells in upper Hay Gulch are completed in the alluvium and are useful in describing the possible effects of mining on water quality in upper Hay Gulch. The first well (site number 43 in fig. 5) is about 1 mi upstream from the National King Coal Mine. The second well (site number 50 in fig. 5) is located in the National King Coal Mine. The third well (site number 47 in fig. 5) is located about 600 ft downstream of the National King Coal Mine.

Specific-conductance values were 1,340 $\mu\text{S}/\text{cm}$ for a water sample from the upstream well (site number 43 in fig. 5), 4,200 $\mu\text{S}/\text{cm}$ for a water sample taken from the mine well (site number 50 in fig. 5), and 2,450 $\mu\text{S}/\text{cm}$ for a water sample taken from the downstream well (site number 47). Concentrations of calcium, magnesium, sodium, nitrate, sulfate, copper, lead, and nickel were greatest in water from the well in the mine, the next greatest in water from the well downstream from the mine, and the smallest in water from the well upstream from the mine. Field pH values for the three water samples were 7.3 upstream, 6.7 in the mine, and 7.1 downstream. Ground-water temperatures were 9.5°C upstream, 12°C in the mine, and 10°C downstream.

Surface runoff from mine areas during the spring snowmelt recharge the alluvial aquifer in upper Hay Gulch. About 15 abandoned mines, most of which are small, are located from about 2 mi upstream to 1 mi downstream of the National King Coal Mine. Mining contaminants have degraded alluvial water quality over the past 100 years. The magnitude of the effect on water quality is not possible to measure, because the natural water quality was not evaluated prior to mining.

Most ground water in the Hay Gulch study area moves downvalley through the Hay Gulch alluvium. Water discharged from the alluvium probably recharges the underlying Menefee Formation and Point Lookout Sandstone and flows south and southeast to the La Plata River, or further south. Mining contaminants that enter the bedrock aquifers through the alluvial aquifer would be transmitted to distant drainages, although the rate would be slow and the volume would be small in proportion to total ground-water flow in the region.

NEEDS FOR FUTURE STUDIES

Additional data collection and analysis are needed in the Durango study area to better describe the hydrogeologic conditions and the potential effects of mining. The interpretation in this report is limited by the number of existing ground-water data-collection sites. Few reports are available that describe the regional hydrology.

The extent of mining impacts on ground water in the Durango study area is dependent on whether flow systems are local, intermediate, or regional. To determine these flow systems, additional streamflow measurements could be made on more streams and rivers to help identify natural discharge from aquifers.

Open-pit mining in Cabezon or Deep Canyons of the Stollsteimer Creek study area probably will result in dewatering during mining, but it is not certain which aquifers could be affected. Wells designed for water-level monitoring and water-quality monitoring prior to mining would help to describe flow systems in the area. Water in spoil piles, alluvium, streams, and bedrock could be sampled and analyzed during this transition period.

Flow systems in the Hay Gulch area need to be defined more specifically. Mine contaminants could be transported through Hay Gulch valley alluvium and into the underlying Menefee Formation and the Point Lookout Sandstone. Ground water in these aquifers might discharge into the La Plata River and increase metal concentrations downstream.

The hydrologic interpretation of the Hay Gulch study area is based on very little data. Additional wells drilled in the alluvium and in the adjacent bedrock would help determine hydraulic gradients in the Hay Gulch area. New wells could be specifically designed for the collection of hydrologic information. Ground-water information from additional wells also would help to define recharge and discharge relationships. Wells could be designed for aquifer testing that would provide values for transmissivity and storage coefficient for various aquifers.

In conclusion, it is important to monitor changes and to describe the hydrologic systems prior to large-scale mining so that future mining impacts may be assessed.

SUMMARY AND CONCLUSIONS

Hydrology

The major aquifers in the Durango study area are alluvial aquifers located in stream valleys and the Animas Formation. Water wells completed in alluvium typically yield 5 to 20 gallons per minute. Water quality in these hydrogeologic units is variable but generally suitable for domestic use. The lower part of the Menefee Formation is developed, but the water generally has high concentrations of dissolved solids. Aquifer permeability generally decreases from west to east in the Durango study area. Other formations are poor aquifers, have unsuitable water quality, or have little known about them.

Water in the Menefee Formation and the Point Lookout Sandstone characteristically have large concentrations of dissolved solids that may indicate long flow systems. Most ground-water in the Durango study area is in local flow systems.

The dominant ions for surface water in the Stollsteimer Creek study area were calcium and bicarbonate. Specific-conductance values were less than 1,000 $\mu\text{S}/\text{cm}$ and increased downstream. The dominant ions of water samples taken from the coal-bearing Fruitland Formation in the Stollsteimer Creek study area were calcium and bicarbonate. Dissolved-solids concentrations of water from the Fruitland Formation ranged from 312 mg/L to 1,040 mg/L. There were large concentrations of sulfate, iron, and manganese in some ground-water and surface-water samples.

The Hay Gulch irrigation ditch and the southern diversion of the Hay Gulch irrigation ditch are the only perennial surface waters in the Hay Gulch study area. The ditches divert water from the La Plata River and had specific conductance values of about 150 $\mu\text{S}/\text{cm}$ in September 1983. The dominant ions in the coal-bearing Menefee Formation in the Hay Gulch study area were sodium and bicarbonate. Dissolved-solids concentrations for water samples from wells completed in the Menefee Formation ranged from 654 mg/L to 1,930 mg/L.

Mining Effects

Mining of coal in the Fruitland Formation in the Stollsteimer Creek study area probably will result in generally acceptable hydrologic impacts if previous mining methods by Chimney Rock Mine were continued. Surface- and ground-water quality are degraded in the Stollsteimer Creek study area, but quality is expected to remain within acceptable levels. Aquifers in the alluvium and the Fruitland Formation have been dewatered in the Stollsteimer Creek study area. More information is needed to accurately assess potential impacts from spoil piles.

Mining of coal in the Menefee Formation in the Hay Gulch study area has resulted in the degradation of water quality in the alluvial aquifer. Contamination from past and present mining has affected water quality in the alluvium in upper Hay Gulch and, possibly, the lower Menefee Formation and Point Lookout Sandstone aquifers. No surface-water losses have occurred through subsidence cracks caused by underground mining. Mining beneath Pine Gulch probably would result in dewatering of overlying aquifers.

Needs for Future Studies

Increasing interest in Federal coal leasings in the Durango study area requires a clearer understanding of hydrology in the Durango study area and its relationship with coal deposits. Effects from coal mining may extend to distant drainages. Additional data collection would provide a more complete framework for assessing the hydrologic effects of mining.

REFERENCES

- Brogden, R.E., Hutchinson, E.C., and Hillier, D.E., 1979, Availability and quality of ground water, Southern Ute Indian Reservation, southwestern Colorado: U.S. Geological Survey Water-Supply Paper 1576-J, 28 p.
- Brogden, R.E., and Giles, T.F., 1976, Availability and chemical characteristics of ground water in central La Plata County, Colorado: U.S. Geological Survey Water-Resources Investigations Report 76-69, scale 1:125,000.
- D.R. Piteau and Associates Ltd., 1982, Preliminary aquifer analysis and estimation of groundwater inflow to two open pits, project number D82-301: Lakewood, Colo., unpublished report, 53 p.
- Dunrud, C.R., 1976, Some engineering geologic factors controlling coal mine subsidence in Utah and Colorado: U.S. Geological Survey Professional Paper 969, 39 p.
- McCain, J.F., and Jarrett, R.D., 1976, Manual for estimating flood characteristics of natural-flow streams in Colorado: Denver, Colorado Water Conservation Board, Technical Manual number 1, 68 p.
- National Climatic Data Center, 1983, Climatological data, Annual summary, Colorado, Durango station: Asheville, N.C.
- Steven, T.A., Lipman, P.W., Hail, W.J., Jr., Barker, Fred, and Luedke, R.G., 1974, Geologic map of the Durango quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-764, scale 1:250,000.
- Stone, W.J., Lyford, F.P., Frenzel, P.F., Mizell, N.H., and Padgett, E.T., 1983, Hydrogeology and water resources of San Juan Basin, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 6, 70 p.
- U.S. Department of Transportation, 1965, Hydraulic charts for the selection of highway culverts: Washington, D.C., Federal Highway Administration Hydraulic Engineering Circular no. 5, 54 p.
- U.S. Environmental Protection Agency, 1977a, National interim primary drinking water regulations: Washington, D.C., EPA-570/9-76-003, 159 p.
- _____, 1977b, National secondary drinking water regulations (proposed): Federal Register, v. 42, no. 62, Mar. 31, Part I, p. 17143-17147.
- Zapp, A.D., 1949, Geology and coal resources of the Durango area, La Plata and Montezuma Counties, Colorado: U.S. Geological Survey Oil and Gas Investigations Map OM-109, scale 1:31,680.

SUPPLEMENTARY DATA

Table 1.--Chemical analyses of water samples from wells, springs, and streams

{µS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligram per liter; µg/L, microgram per liter;
 <, less than; underlined values exceeded primary public drinking water standards; boldface values exceed secondary
 public drinking water standards, established by the U.S. Environmental Protection Agency (1977a, 1977b)}

Site number (see figures 2-5)	Local identifier (see figure 6)	Site type	Sample source	Date of sample	Temper- ature in degrees Celsius	pH (stand- ard units)	Spe- cific con- duct- ance (µS/cm)	Solids, sum of consti- tuents, dis- solved (mg/L)	Hard- ness (mg/L as CaCO ₃)	Potas- sium, dis- solved (mg/L as K)
1	NB03400428BDD1	Well	Alluvium	83-07-19	14.0	6.5	575	280	190	2.4
2	NB03400428DCD1	Well	Fruitland Formation	83-07-27	10.5	6.9	698	446	340	1.9
3	NB03400429ACC1	Well	Alluvium	83-08-16	11.0	7.2	1100	678	490	2.5
5	NB03400429CBB1	Well	Fruitland Formation	83-07-15	13.0	6.9	735	400	270	3.0
6	NB03400429CBB2	Well	Alluvium	83-11-08	8.0	7.4	576	330	220	3.2
7	NB03400429CBB3	Well	Fruitland Formation	83-11-08	10.0	7.2	1410	1040	700	6.0
8	NB03400430ABB1	Well	Fruitland Formation	83-11-08	12.0	7.4	836	434	180	7.4
10	NB03400430ACC1	Well	Fruitland Formation	83-08-22	13.5	6.6	790	512	360	2.2
11	NB03400430ACD1	Well	Alluvium	83-07-20	18.0	5.9	1330	758	650	12
12	NB03400430ADC1	Well	Alluvium	83-07-15	12.0	7.1	898	591	430	2.7
13	NB03400430ADC2	Well	Alluvium	83-07-15	14.5	6.9	1330	953	700	4.6
14	NB03400430ADD1	Well	Alluvium	83-07-19	13.0	6.5	817	565	400	3.6
15	NB03400430DAA1	Well	Spoil pile	83-07-27	11.0	8.0	897	559	90	2.6
16	NB03400430DBA1	Well	Alluvium	83-07-20	18.0	5.9	1420	1130	800	7.1
17	NB03400430DBB1	Well	Alluvium	83-07-19	16.0	6.5	798	513	360	3.5
18	NB03400430DBB2	Well	Fruitland Formation	83-07-22	----	---	----	312	210	2.1
24	NB03401001CCB	Well	Cliff House Sandstone	74-12-12	8.0	8.2	1600	1140	18	2.0
25	NB03401206CDA	Well	Menefee Formation	75-04-10	12.0	6.8	3440	3350	2000	7.1
27	NB03500803CAA1	Well	Cliff House Sandstone	83-07-29	9.5	7.3	417	255	180	1.4
28	NB03500808CCB1	Well	Point Lookout Sandstone	74-12-12	6.0	7.1	1060	800	250	2.8
29	NB03500819BCD	Well	Kirtland Shale	75-04-15	8.5	---	710	444	310	.9
31	NB03501028CDA1	Well	Menefee Formation	83-06-08	9.0	7.0	1860	----	840	----
32	NB03501028CDA2	Well	Menefee Formation	83-06-08	12.0	7.8	1030	----	200	----
33	NB03501028DCC1	Well	Menefee Formation	83-06-08	14.5	8.7	1150	694	2	1.1
34	NB03501028DDB1	Well	Menefee Formation	83-07-26	15.0	8.2	1340	846	14	1.4
35	NB03501034BBC	Well	Menefee Formation	75-04-08	9.0	7.7	1500	1090	4	2.4
36	NB03501034CBB	Well	Cliff House Sandstone	75-04-09	5.0	6.3	1410	1040	450	2.3
37	NB03501034DBC1	Well	Point Lookout Sandstone	83-07-26	11.5	8.9	1380	923	21	1.2
38	NB03501034DCC1	Well	Menefee Formation	83-07-28	15.5	8.4	1650	903	25	1.7
40	NB03501114DDC	Well	Menefee Formation	74-12-09	6.0	6.5	335	209	160	2.0
41	NB03501123ACC	Well	Cliff House Sandstone	75-04-08	6.0	7.6	330	181	88	.6
42	NB03501123DAC1	Well	Cliff House Sandstone	83-07-29	12.5	6.8	239	135	99	.9
43	NB03501128CBB1	Well	Alluvium	83-07-12	9.5	7.3	1340	----	770	----
44	NB03501128DDD1	Well	Menefee Formation	81-07-15	----	---	----	654	17	2.2
45	NB03501128DDD2	Well	Menefee Formation	81-07-15	----	---	----	1930	40	6.2
46	NB03501129DBC1	Well	Menefee Formation	75-04-13	10.0	6.7	950	628	540	4.3
47	NB03501131AAA1	Well	Alluvium	83-07-08	10.0	7.1	2450	----	1600	----
48	NB03501132ABC	Well	Menefee Formation	81-07-15	----	---	----	1010	35	5.7
50	NB03501132BBB1	Well	Alluvium	83-07-06	12.0	6.7	4200	----	3200	----
51	NB03501132DDD1	Well	Menefee Formation	81-07-15	----	---	----	824	14	2.0
52	NB03501132DDD2	Well	Menefee Formation	81-07-15	----	---	----	950	27	4.3
54	NB03400428BDD2	Spring	Alluvium	83-08-16	14.0	7.2	657	362	260	1.4
56	NB03501010CAB1	Spring	Point Lookout Sandstone	83-07-28	9.0	7.2	842	555	410	5.2
58	NB03400428DBC1	Stream	Cabazon Creek	83-11-07	10.0	8.3	540	302	220	1.3
61	NB03400421CCC1	Stream	Cabazon Creek	83-08-16	22.0	8.2	470	263	170	1.2
62	NB03400421CCC2	Stream	Cabazon Creek	83-11-07	10.3	8.2	512	293	200	1.3
66	NB03400432BCA1	Stream	Deep Canyon Creek	83-08-17	17.5	8.3	449	248	160	.7
68	NB03400429BCC1	Stream	Stollsteimer Creek	83-04-22	6.0	8.0	294	200	150	1.7
71	NB03400430CAA1	Stream	Stollsteimer Creek	83-04-22	6.0	8.0	314	226	160	1.8
77	NB03501126DCD1	Stream	La Plata River	83-11-11	5.5	7.7	185	108	90	1.1

Table 1.--Chemical analyses of water samples from wells, springs, and streams--Continued

[μ S/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligram per liter; μ g/L, microgram per liter; <, less than; underlined values exceeded primary public drinking water standards; boldface values exceed secondary public drinking water standards, established by the U.S. Environmental Protection Agency (1977a, 1977b)]

Site number (see figures 2-5)	Calcium, dis- solved (mg/L as Ca)	Magne- sium, dis- solved (mg/L as Mg)	Sodium, dis- solved (mg/L as Na)	Chlo- ride, dis- solved (mg/L as Cl)	Fluo- ride, dis- solved (mg/L as F)	Alka- linity lab (mg/L as CaCO ₃)	Nitro- gen NO ₂ +NO ₃ , dis- solved (mg/L as N)	Sulfate, dis- solved (mg/L as SO ₄)	Alum- inum, dis- solved (μ g/L as Al)
1	60	9.0	27	4.4	.50	194	.26	54	10
2	120	11	14	1.7	.40	245	.38	140	10
3	120	47	35	3.8	.30	250	.39	310	<10
5	85	14	37	3.0	.40	280	.10	79	<10
6	72	9.6	34	3.6	.60	224	<.10	61	100
7	200	49	43	3.5	.30	252	<.10	550	20
8	58	7.8	95	5.8	.50	350	.23	39	50
10	120	14	37	2.4	.30	312	.27	130	<10
11	170	55	47	15	.40	344	.14	230	20
12	110	38	33	5.4	.30	270	.56	230	30
13	190	54	42	8.6	.30	331	.30	440	20
14	99	38	31	8.8	.30	241	.31	230	10
15	28	4.8	180	4.6	.90	386	<.10	99	20
16	230	56	56	22	.30	430	.65	490	20
17	100	27	32	7.1	.40	235	.22	190	20
18	68	9.1	25	1.3	.30	192	.56	78	20
24	5.8	.9	480	32	<u>1.9</u>	----	.01	4.3	---
25	340	280	300	93	.50	----	.27	2000	---
27	59	8.0	28	1.2	.20	228	.29	13	10
28	62	23	200	15	.30	----	.27	220	---
29	110	8.9	44	7.6	.40	----	1.1	91	---
31	200	82	43	5.7	.30	236	.13	680	---
32	44	22	160	10	.90	382	<.10	160	20
33	.6	.1	290	4.3	<u>1.6</u>	608	<.10	23	10
34	3.1	1.4	350	3.2	<u>4.3</u>	757	<.10	18	20
35	.8	.6	470	28	<u>1.7</u>	----	.01	2.9	---
36	96	51	170	15	.80	----	<.10	480	---
37	4.1	2.7	340	20	.60	589	<.10	150	10
38	6.3	2.3	360	7.6	<u>1.7</u>	829	<.10	17	100
40	38	15	10	7.4	.10	----	.02	38	---
41	25	6.2	31	1.5	.40	----	.07	32	---
42	29	6.5	8.1	1.6	.30	102	<.10	16	10
43	160	89	40	12	.30	299	<.10	550	---
44	4.2	.7	273	32	<u>2.1</u>	471	----	57	<10
45	5.0	6.9	773	296	<u>1.6</u>	1233	----	59	<10
46	99	72	17	5.5	.50	----	1.6	230	---
47	310	190	52	100	.30	406	4.2	1000	---
48	8.3	4.2	432	10	<u>2.6</u>	897	----	16	<10
50	490	490	92	59	.30	657	4.4	2600	---
51	4.0	.6	364	24	<u>3.1</u>	696	----	11	<10
52	4.7	3.6	405	44	<u>3.0</u>	770	----	25	<10
54	86	11	24	2.1	.50	240	<.10	81	10
56	70	57	25	3.3	.10	213	.94	250	<10
58	72	9.7	29	2.6	.60	225	<.10	41	<10
61	51	9.3	30	2.5	.60	180	<.10	49	<10
62	62	10	29	2.9	.60	203	<.10	54	<10
66	50	9.2	30	2.8	.40	195	<.10	27	10
68	42	10	9.9	1.7	.10	108	<.10	60	200
71	44	11	12	3.7	.20	103	<.10	82	200
77	28	4.8	2.3	.8	.20	73	.12	19	<10

Table 1.--Chemical analyses of water samples from wells, springs, and streams--Continued

[μS/cm, microsiemens per centimeter at 25° Celsius; mg/L, milligram per liter; μg/L, microgram per liter; <, less than; underlined values exceeded primary public drinking water standards; boldface values exceed secondary public drinking water standards, established by the U.S. Environmental Protection Agency (1977a, 1977b)]

Site number (see figures 2-5)	Arsenic, dis- solved (ug/L as As)	Cadmium, dis- solved (ug/L as Cd)	Copper, dis- solved (ug/L as Cu)	Iron, dis- solved (ug/L as Fe)	Lead, dis- solved (ug/L as Pb)	Manga- nese, dis- solved (ug/L as Mn)	Mercury, dis- solved (ug/L as Hg)	Molyb- denum, dis- solved (ug/L as Mo)	Nickel, dis- solved (ug/L as Ni)
1	1	2	6	63	<1	55	<.1	<1	<1
2	<1	3	1	13	8	26	<.1	<1	<1
3	1	<1	3	16	10	2	<.1	2	1
5	<1	3	3	1100	17	260	<.1	<1	<1
6	<1	<1	22	120	<1	23	<.1	<1	1
7	2	5	19	150	45	380	<.1	<1	2
8	1	8	23	29	<u>120</u>	260	.1	<1	7
10	<1	2	7	20	2	17	<.1	<1	5
11	5	<1	7	2200	<1	4800	<.1	<10	9
12	1	<1	2	29	<1	26	<.1	<1	1
13	1	<1	<1	330	<1	1700	<.1	<1	2
14	<1	2	6	7	1	14	<.1	<1	4
15	<1	2	2	190	4	38	<.1	12	<1
16	1	2	10	88	<1	740	<.1	<1	4
17	3	<1	<1	78	<1	2200	.1	<1	<1
18	<1	<1	7	13	8	13	<.1	<1	4
24	2	--	--	70	---	<10	---	---	--
25	<1	--	--	2500	---	1100	---	---	--
27	3	1	15	6	8	1	<.1	<1	<1
28	<1	--	--	1500	---	100	---	---	--
29	1	--	--	20	---	<10	---	---	--
31	<1	<1	3	90	2	19	<.1	<2	17
32	1	8	1	30	<u>160</u>	12	<.1	<2	25
33	1	<1	<1	9	1	3	.1	<2	15
34	1	2	17	680	18	5	<.1	<1	<1
35	<1	--	--	30	---	<10	---	---	--
36	<1	--	--	20000	---	200	---	---	--
37	<1	<1	<1	14	3	3	<.1	<1	<1
38	1	<1	<1	88	6	11	<.1	<1	<1
40	1	--	--	40	---	70	---	---	--
41	1	--	--	<10	---	<10	---	---	--
42	<1	1	1	220	5	14	<.1	<1	<1
43	1	3	<1	830	6	710	<.1	---	<2
44	<1	<1	<1	<10	<1	1	<.1	<1	<1
45	<1	<1	<1	<10	<1	2	<.1	<1	<1
46	<1	--	--	<10	---	<10	---	---	--
47	<1	<u>15</u>	3	50	<u>190</u>	1700	<.1	---	2
48	<1	<1	<1	<10	<1	<1	<.1	<1	<1
50	<1	10	5	190	<u>210</u>	1300	.1	---	6
51	<1	<1	<1	<10	<1	<1	<.1	---	<1
52	<1	<1	<1	<10	<1	2	<.1	<1	<1
54	<1	9	1	8	<u>130</u>	13	<.1	<1	<1
56	<1	2	<1	5	<u>4</u>	2	<.1	<1	<1
58	1	7	<1	7	35	2	.3	<1	1
61	1	<1	<1	10	<1	2	<.1	<1	<1
62	<1	<1	1	5	<1	<1	<u>2.1</u>	<1	<1
66	1	<1	<1	6	<1	1	<.1	<1	<1
68	2	1	3	220	1	11	<.1	<1	4
71	2	3	5	250	3	14	<.1	<1	5
77	<1	3	4	53	19	19	.1	<1	5

Table 1.--Chemical analyses of water samples from wells, springs, and streams--Continued

[$\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25° Celsius; mg/L, milligram per liter; $\mu\text{g}/\text{L}$, microgram per liter; <, less than; underlined values exceeded primary public drinking water standards; boldface values exceed secondary public drinking water standards, established by the U.S. Environmental Protection Agency (1977a, 1977b)]

Site number (see figures 2-5)	Selenium, dis- solved ($\mu\text{g}/\text{L}$ as Se)	Silica, dis- solved (mg/L as SiO_2)	Sodium ad- sorp- tion ratio	Percent sodium	Zinc, dis- solved ($\mu\text{g}/\text{L}$ as Zn)
1	1	5.9	.9	24	340
2	<1	10	.3	8	11
3	3	9.6	.7	13	11
5	2	9.3	1.0	23	30
6	1	11	1.0	25	23
7	<1	33	.7	12	16
8	2	9.8	3.2	53	7
10	1	14	.9	18	52
11	<1	15	.8	13	53
12	2	9.9	.7	14	37
13	1	13	.7	12	21
14	3	9.2	.7	14	52
15	1	7.7	8.6	81	33
16	1	11	.9	13	69
17	<1	9.8	.8	16	9
18	1	10	.8	21	44
24	<1	8.9	51	98	---
25	<1	17	3.0	25	---
27	<1	7.2	.9	25	220
28	1	13	5.7	63	---
29	1	13	1.1	23	---
31	3	12	.7	--	140
32	<1	10	5.1	--	8
33	<1	8.8	95	99	21
34	<1	10	43	98	51
35	<1	9.7	99	99	---
36	<1	11	3.6	45	---
37	<1	7.9	33	97	6
38	<1	9.4	32	97	66
40	<1	19	.4	12	---
41	--	9.3	1.5	43	---
42	<1	11	.4	15	9
43	<1	13	.6	--	92
44	<1	----	32	98	<1
45	<1	----	53	98	<1
46	1	11	.3	6	---
47	<1	12	.6	--	40
48	<1	----	30	96	<1
50	1	17	.7	--	140
51	<1	----	45	98	<1
52	<1	----	34	97	<1
54	1	12	.7	17	6
56	4	17	.5	12	6
58	1	11	.9	22	4
61	1	11	1.1	28	3
62	1	11	.9	24	4
66	1	11	1.1	29	13
68	2	9.1	.4	13	22
71	1	9.3	.4	14	11
77	<1	8.4	.1	5	26

Table 2.--Well information

Site number (see figs. 2, 3, and 5)	Well identifier (see fig. 6)	Owner	Principal aquifer	Land surface altitude (feet)	Well depth (feet)	Depth to water (feet)	Date water level measured	Date sampled (see table 1)	Remarks
1	NB03400428BDD1	Frere, Louise	Alluvium	6670	6.25	1.37	07/19/1983	07/19/1983	
2	NB03400428DCD1	Ryan International	Fruitland Formation	6840	73.97	39.85	07/12/1983	07/27/1983	Uncased core hole.
3	NB03400429ACC1	Hamilton, W. E.	Alluvium	6490	59.00	30.26	07/07/1983	08/16/1983	
4	NB03400429CBA1	Martinez, Mel	Fruitland Formation	6520	108.40	58.64	06/27/1983	-----	Dissolved gases.
5	NB03400429CBB1	Chimney Rock Coal	Fruitland Formation	6490	47.00	32.73	07/07/1983	07/15/1983	
6	NB03400429CBB2	Chimney Rock Coal	Alluvium/Fruitland Formation	6491	67.00	45.28	11/08/1983	11/08/1983	Slug tested.
7	NB03400429CBB3	Chimney Rock Coal	Fruitland Formation	6497	58.00	22.79	11/08/1983	11/08/1983	Completed below C coal seam; slug tested.
8	NB03400430ABB1	Chimney Rock Coal	Fruitland Formation	6707	206.00	163.00	11/08/1983	11/08/1983	Double completion in A, B, and C coal seams; slug tested.
9	NB03400430ABB2	Chimney Rock Coal	Fruitland Formation	6707	100.00	Dry	-----	-----	Double completion in A, B, and C coal seams.
10	NB03400430ACC1	Chimney Rock Coal	Fruitland Formation	6472	112.78	48.49	07/07/1983	08/22/1983	Completed in A, B, and C coal seams; Observation well while NB03400430DBB2 was pumped.
11	NB03400430ACD1	Chimney Rock Coal	Alluvium	6415	12.05	2.54	07/07/1983	07/20/1983	
12	NB03400430ADC1	Chimney Rock Coal	Alluvium	6412	45.90	11.95	07/07/1983	07/15/1983	Pumping well depth was 61 ft in aquifer test.
13	NB03400430ADC2	Chimney Rock Coal	Alluvium	6412	12.05	10.12	07/07/1983	07/15/1983	Observation well while NB03400430ADC1 was pumped.
14	NB03400430ADD1	Chimney Rock Coal	Alluvium	6452	9.60	9.01	07/07/1983	10/19/1983	Dry by 11/11/83.
15	NB03400430DAA1	Chimney Rock Coal	Spoil Pile (Fruitland Formation rubble)	6527	123.70	106.94	07/07/1983	07/27/1983	
16	NB03400430DBA1	Chimney Rock Coal	Alluvium	6405	7.33	6.52	07/07/1983	07/20/1983	
17	NB03400430DBB1	Chimney Rock Coal	Alluvium	6405	7.08	4.68	07/07/1983	07/19/1983	
18	NB03400430DBB2	Chimney Rock Coal	Fruitland Formation	6467	140.00	53.74	09/02/1983	07/22/1983	Completed in A, B, and C coal seams; pumping well in aquifer test.
19	NB03400430DBC1	Martinez, Mel	Alluvium	6415	55.00	19.14	07/13/1983	-----	
20	NB03400535DDI1	George, Sharon	Alluvium	6315	59.00	22.10	06/28/1983	-----	
21	NB03400536CCB1	Gallegos, John	Alluvium	6315	73.62	15.57	06/23/1983	-----	USGS observation well.
22	NB03400536CCC2	Wilcox, J. C.	Alluvium	6310	-----	14.13	07/13/1983	-----	
23	NB03400901CCC1	Erwin, Paul R.	Animas Formation	6850	95.00	46.60	05/31/1983	-----	
24	NB03401001CCB	Paulek, Grant	Cliff House Sandstone	6880	-----	-----	-----	12/12/1974	
25	NB03401206CDA	Boggs, Rodney	Menefee Formation	6990	152.00	-----	-----	04/10/1975	

Table 2.--Well information--Continued

Site number (see figs. 2, 3, and 5)	Well identifier (see fig. 6)	Owner	Principal aquifer	Land surface altitude (feet)	Well depth (feet)	Depth to water (feet)	Date water level measured	Date sampled (see table 1)	Remarks
26	NB03500617BAB1	Hoover, Bryan B.	Lewis Shale	7600	109.00	21.90	06/16/1983	-----	
27	NB03500803CAA1	Seyfarth, Jay F.	Cliff House Sandstone	7380	147.00	9.10	06/30/1983	07/29/1983	
28	NB03500808CCB1	Engler, Robt.	Point Lookout Sandstone	7275	102.00	17.72	08/02/1983	12/12/1974	
29	NB03500819BCD	Palmer, Terry	Kirtland Shale	7070	100.00	-----	-----	04/15/1975	
30	NB03501028ADC1	Wehner, Leo	Menefee Formation	7440	450.00	377.90	06/07/1983	-----	
31	NB03501028CDA1	LaPlata Vista	Menefee Formation	7290	48.50	7.60	06/09/1983	06/08/1983	
32	NB03501028CDA2	LaPlata Vista	Menefee Formation	7290	465.00	137.60	06/09/1983	06/08/1983	
33	NB03501028DCC1	LaPlata Vista	Menefee Formation	7320	580.00	239.40	06/08/1983	06/08/1983	
34	NB03501028ODB1	Bird, G.	Menefee Formation	7440	490.00	148.00	06/07/1983	07/26/1983	
35	NB03501034BBC	Kneippl, Stephen	Menefee Formation	7445	466.00	270.00	-----	04/08/1975	
36	NB03501034CBB	Capp, Clifford	Cliff House Sandstone	7300	138.00	79.00	04/09/1975	04/09/1975	
37	NB03501034DBC1	Harrell, Lynn	Point Lookout Sandstone	7280	440.00	82.70	06/06/1983	07/26/1983	
38	NB03501034DCC1	Gibson, Dan F.	Menefee Formation	7200	259.00	78.00	07/28/1983	07/28/1983	
39	NB03501114CAD1	Gitile, Walter	Menefee Formation	8315	76.50	45.60	06/02/1983	-----	
40	NB03501114DDC	Carl, Larry	Menefee Formation	8075	86.00	9.00	12/09/1974	12/09/1974	
41	NB03501123ACC	Hesperus Baptist Camp	Cliff House Sandstone	8030	76.00	25.00	04/08/1975	04/08/1975	
42	NB03501123DAC1	Demarest, Donald	Cliff House Sandstone	7980	62.00	13.00	05/01/1983	07/29/1983	
43	NB03501128CBB1	Pfledging, Phillip	Alluvium	7510	7.80	6.26	07/12/1983	07/12/1983	
44	NB03501128DDD1	Massey Coal Co.	Menefee Formation	7860	345.00	291.00	07/21/1983	07/15/1981	Double completion (sandstone).
45	NB03501128DDD2	Massey Coal Co.	Menefee Formation	7860	318.30	299.00	07/21/1983	07/15/1981	Double completion (coal).
46	NB03501129DBC1	Sun Belt Mining	Menefee Formation	7470	57.00	40.00	04/13/1975	04/13/1975	
47	NB03501131AAA1	Huntington, Lawrence	Alluvium	7360	13.50	0.80	07/08/1983	07/08/1983	Well developed from a spring.
48	NB03501132ABC1	Massey Coal Co.	Menefee Formation	7780	338.00	318.00	07/21/1983	07/15/1981	Double completion (sandstone).
49	NB03501132ABC2	Massey Coal Co.	Menefee Formation	7780	300.00	294.00	07/21/1983	-----	Double completion (coal).
50	NB03501132BBB1	National King Coal Co.	Alluvium	7390	80.00	13.26	07/06/1983	07/06/1983	
51	NB03501132DDD1	Massey Coal Co.	Menefee Formation	7680	348.00	283.00	07/21/1983	07/15/1981	Double completion (sandstone).
52	NB03501132DDD2	Massey Coal Co.	Menefee Formation	7680	318.00	302.00	07/21/1983	07/15/1981	Double completion (coal).

Table 3.--Spring information

Site number (see figs. 2, 3, and 5)	Spring identifier (see fig. 6)	Owner	Hydrogeologic unit	Land surface altitude approximate (feet)	Discharge (gallons per minute)	Date discharge measured	pH	Specific conductance per microsiemens per centimeter at 25° Celsius	Date sampled (see table 1)	Remarks
53	NB03400425DCA1	Martinez, Mel	Alluvium	6360	1.3	08/17/83	7.1	940	-----	Flow at Fruitland Formation contact.
54	NB03400428BDD2	Mezner, Marty	Alluvium	6650	0.9 0.2	08/16/83 11/07/83	7.2 7.3	660 690	08/16/83 -----	Combined flow of several small springs.
55	NB03500927DCA1	U. S. Bureau of Land Management	Fruitland Formation	7330	0.97	06/29/83	6.8	1650	-----	Has sulfurous smell; issues from sandstone-shale outcrop.
56	NB03501010CAB1	Colorado Division of Wildlife	Point Lookout Sandstone	7980	3.2 1.7	07/28/83 11/09/83	7.2 6.9	840 900	07/28/83 -----	Developed; flows through plastic pipe.

Table 4.--Stream and ditch discharge and water-quality data

Site number (see figs. 2, 4, and 5)	Local identifier (listed in downstream order; see fig. 6)	Description	Discharge (cubic feet per second)	Date measured	Temperature (degrees Celsius)	pH	Specific conductance (microsiemens per centimeter at 25° Celsius)	Date sampled
57	NB03400433ABB1	Cabezon Creek in alluvium/colluvium valley fill below confluence of three channels.	0.05	11/07/83	8.0	8.5	460	-----
58	NB03400428DBC1	Cabezon Creek near Pictured Cliffs Sandstone (?) outcrop.	1.14	11/07/83	10.0	8.3	540	211/07/83
59	NB03400428BDD3	Cabezon Creek in alluvium/colluvium	1.24	11/07/83	10.0	8.1	580	-----
60	NB03400428BBA	Cabezon Creek in alluvium/colluvium valley fill.	1.22	11/07/83	9.5	8.1	540	-----
61	NB03400421CCC2	Cabezon Creek gaging site in alluvium/colluvium valley fill. Banks are well defined sand/silt/gravel. Bed composed of sand, gravel, and cobbles.	3.42 4.36 7.27 4.69 3.16 2.08 1.83 1.64 1.48 1.26 1.35 1.26 .42 .69	04/08/83 04/14/83 04/22/83 05/05/83 05/12/83 05/18/83 05/25/83 06/02/83 06/09/83 06/16/83 06/23/83 06/30/83 07/07/83 07/14/83 07/21/83	4.5 6.0 ----- 9.0 3.0 12.0 15.0 14.0 15.5 ----- 18.5 18.5 19.0 ----- 18.5	----- ----- ----- ----- ----- 8.1 8.3 ----- ----- ----- ----- ----- ----- ----- -----	450 400 --- 400 420 480 480 500 500 --- 480 480 500 --- 500	----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
62	NB03400421CCC1	Cabezon Creek in alluvium, about 0.3 mi above Highway 151.	1.18	11/07/83	10.5	8.2	510	211/07/83
63	NB03400429BCA	Stollsteimer Creek channel composed of sand, silt, and gravel. Banks are sand, gravel, and boulders.	17.4 75.4 133 309 88.5 63.6 39.0 30.9 22.71 14.8 11.9	03/23/83 04/08/83 04/14/83 04/22/83 05/05/83 05/12/83 05/18/83 05/25/83 06/02/83 06/09/83 06/16/83	3.5 5.0 4.5 7.0 9.0 6.0 14.0 18.0 17.5 19.5 20.0	8.15 ----- ----- ----- ----- ----- 8.3 8.1 8.4 7.9 ----- 8.1	460 460 410 340 460 440 600 600 650 580 ---	----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
64	NB03400429BCB	Stollsteimer Creek alluvial reach above junction with Deep Creek.	6.23 6.94 4.72 31.84 2.07	06/23/83 06/29/83 07/21/83 10/19/83 11/09/83	20.0 20.5 19.5 ----- 10.0	8.1 8.3 8.3 ----- 8.2	820 820 820 --- 500	----- ----- ----- ----- -----
			1.79	09/20/83	15.0	8.1	890	-----

Table 4.--Stream and ditch discharge and water-quality data--Continued

Site number (see figs. 2, 4, and 5)	Local identifier (listed in order; see fig. 6)	Description	Discharge (cubic feet per second)	Date measured	Temperature (degrees Celsius)	pH	Specific conductance (microsiemens per centimeter at 25° Celsius)	Date sampled
77	NB03501126DCD1	La Plata River	36.3	05/25/83	18.0	8.1	620	-----
			26.6	06/02/83	19.0	---	650	-----
			24.1	06/09/83	16.5	7.9	750	-----
			11.3	06/16/83	16.0	---	800	-----
			5.93	06/23/83	19.5	8.1	800	-----
			8.74	06/30/83	18.5	8.2	800	-----
			3.62	07/07/83	19.0	8.4	800	-----
			5.34	07/21/83	21.5	7.8	780	-----
			2.01	10/19/83	----	---	---	-----
			2.67	11/09/83	10.0	8.2	480	-----
77	NB03501126DCD1	La Plata River	----	-----	5.5	7.7	185	211/11/83
78	NB03501132ACB1	Southern Diversion of Hay Gulch Ditch at eastern lease boundary of National King Coal Company; overlies mine area where pillars were removed.	13.03	07/08/83	----	---	---	-----
			12.12	09/15/83	17.0	8.2	150	-----
79	NB03501132BCD1	Southern Diversion of Hay Gulch Ditch at midpoint between gage sites above and below.	12.94	07/08/83	----	---	---	-----
			12.37	09/15/83	18.0	7.8	150	-----
80	NB03501131ACD1	Southern Diversion of Hay Gulch Ditch at western lease boundary of National King Coal Company; overlies mine area with pillars intact.	13.25	07/08/83	----	---	---	-----
			12.64	09/15/83	18.0	7.7	160	-----

¹Gain-and-loss measurement.²Lab analysis included in table 1.³Measured by Chimney Rock Coal personnel.

Table 4.--Stream and ditch discharge and water-quality data--Continued

Site number (see figs. 2, 4, and 5)	Local identifier (listed in order; see fig. 6)	Description	Discharge (cubic feet per second)	Date measured	Temperature (degrees Celsius)	pH	Specific conductance (microsiemens per centimeter at 25° Celsius)	Date sampled
65	NB03400432BBD1	Deep Creek near Fruitland Formation outcrop.	10.03	08/05/83	17.0	8.1	440	-----
66	NB03400432BCA1	Deep Creek in alluvium valley fill.	1.04	08/05/83	17.5	8.3	450	208/17/83
67	NB03400429CBB4	Deep Creek gage site in alluvium valley fill. Banks are steep; composed of sand and silt. Channel composed of silt, sand, and some cobbles.	2.65 2.97 3.52 6.41 5.25 3.70 2.08 1.53 .58 .37 .38 0.21 .13 .31 .11 .09 .03 .00	03/23/83 04/08/83 04/14/83 04/22/83 04/28/83 05/05/83 05/12/83 05/18/83 05/25/83 06/02/83 06/09/83 06/16/83 06/23/83 06/29/83 07/07/83 07/14/83 07/21/83 08/10/83	2.0 --- 6.0 --- 8.0 8.0 1.0 15.0 18.5 16.0 19.0 18.0 20.0 22.0 19.5 25.5 25.5 ---	--- --- --- --- --- --- --- 8.0 --- --- --- 8.1 8.3 --- --- 7.9 --- ---	380 --- 340 --- 210 220 260 400 440 460 420 440 450 420 420 380 380 ---	----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- ----- -----
68	NB03400429BCC1	Flow is restricted by drill pad construction site 1.3 mi upstream. Flow is intermittent; dry at gage site. Stollsteimer Creek near Pictured Cliffs Sandstone (?) outcrop below Deep Canyon Creek.	298 11.89	04/22/83 09/20/83	6.0 15.0	8.0 8.3	294 890	204/22/83 -----
69	NB03400430ACA	Stollsteimer Creek adjacent to mine at Fruitland Formation and alluvium contact.	12.47	09/20/83	15.0	8.7	900	-----
70	NB03400430ACC	Stollsteimer Creek near mine at Fruitland Formation and alluvium contact.	13.46	09/20/83	15.0	8.6	870	-----
71	NB03400430CAA1	Stollsteimer Creek sampled in alluvial reach.	2.98	04/22/83	6.0	8.0	310	204/22/83
72	NB03400525DCD	Stollsteimer Creek about 1.25 mi below mine in an alluvial reach.	12.80	09/20/83	15.0	7.9	790	-----
73	NB03400536ACB	Stollsteimer Creek near Fruitland Formation outcrop.	12.42	09/20/83	17.0	8.1	800	-----
74	NB03400536ACC	Stollsteimer Creek near Fruitland Formation outcrop.	12.58	09/20/83	19.0	8.1	790	-----
75	NB03400536D8B	Stollsteimer Creek at Fruitland Formation outcrop.	11.95	09/20/83	19.0	8.1	800	-----
76	NB03400536CCC1	Stollsteimer Creek at school bridge.	82.8 143 320 170 100 68 43.9	04/08/83 04/14/83 04/22/83 04/28/83 05/05/83 05/12/83 05/18/83	7.0 4.5 --- 8.0 9.0 7.0 15.0	--- --- --- --- --- --- 8.3	500 420 330 370 480 460 580	----- ----- ----- ----- ----- ----- -----