HYDROLOGY AND SUBSIDENCE POTENTIAL OF PROPOSED COAL-LEASE TRACTS IN DELTA COUNTY, COLORADO

By Tom Brooks

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JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

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

For sale by:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, CO 80225
Telephone: (303) 234-5888

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METRIC CONVERSIONS

The following factors may be used to convert inch-pound units to the International System (SI) of units. SI is an organized system of units adopted by the 11th General Conference of Weights and Measures in 1960.

Multiply inch-pound units	*By*	*To obtain SI units*
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06308	liter per second
foot squared per day (ft^2/d)	0.09290	meter squared per day
micromhos per centimeter at 25°C	1.000	microsiemens per centimeter at 25°C

To convert degree Fahrenheit (°F) to degree Celsius (°C) use the following formula: °C=(°F-32)x5/9. To convert degree Celsius (°C) to degree Fahrenheit (°F) use the following formula: °F=(°Cx9/5)+32.

GLOSSARY

Aquifer is a geologic formation, part of a formation, or group of formations which yield water in sufficiently large quantities to be important economically; a material that stores and yields water.

Confined aquifer is an aquifer in which ground water is confined under pressure greater than atmospheric by overlying, relatively impermeable strata. The water level in a well penetrating a confined aquifer will be above the upper boundary of the aquifer.

Discharge area is an area in which ground water is discharged to the land surface, to surface-water bodies, or to the atmosphere.

Ground water is water in the saturated zone.

Hydraulic conductivity is the property or capacity of a porous rock, sediment, or soil to transmit a fluid. It is expressed as the quantity of water that will flow through a unit cross-sectional area of a porous material per unit of time under a hydraulic gradient of 1.00 at a specific temperature.

Hydraulic connection exists when ground water flows from one aquifer to another, when surface water recharges ground water, or when ground water discharges as a spring or into a stream.

Infiltration is the movement of water from the land surface into the underlying soil or rock through pores or small openings.

Micrograms per liter (μg/L, UG/L) is a unit expressing the concentration of a chemical constituent in solution as weight (micrograms) of solute per unit volume (liter) of water.

Milligrams per liter (mg/L, MG/L) is a unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water; 1 mg/L equals 1,000 μg/L.

National Geodetic Vertical Datum of 1929 (NGVD of 1929) is a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

Percent sodium (percent Na) is the percentage of total cations comprised by sodium (concentrations in milliequivalents per liter).

Porosity is the property of a rock or soil containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume. It may be expressed as a decimal fraction or as a percentage.

Recharge area is an area in which water is absorbed that eventually reaches the zone of saturation in one or more aquifers.

Saturated zone is that part of the water-bearing material in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Specific conductance is a measure of the ability of water to conduct an electrical current; it is expressed in micromhos per centimeter at 25° Celsius.

Storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head.

Subsidence is an effect of underground mining which causes geologic bed separation and rubblization of material above the mined-out area. These effects may be transmitted to the surface in the form of cracks, bulges, or depressions.

Transmissivity is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is hydraulic conductivity multiplied by the aquifer thickness.

Unconfined aquifer is an aquifer where the water table is the upper surface of the saturation zone.

Water hardness is the concentration of calcium and magnesium expressed as equivalent calcium carbonate.

Water table is the surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body far enough to hold standing water.

Water type is the classification of water based upon predominant cations and anions in a sample. Expressed in milliequivalents per liter.

HYDROLOGY AND SUBSIDENCE POTENTIAL OF PROPOSED COAL-LEASE TRACTS IN DELTA COUNTY, COLORADO

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ABSTRACT

Potential subsidence from underground coal mining and associated hydrologic impacts were investigated at two potential coal-lease tracts in Delta County, Colo. Alteration of existing flow systems could affect water users in the surrounding area.

The Mesaverde Formation in the study area transmits little ground water because of the negligible transmissivity of the 1,300 feet of fine-grained sandstone, coal, and shale comprising the formation. The transmissivities of coal beds within the lower part of the Mesaverde Formation ranged from 1.5 to 16.7 feet squared per day; the transmissivity of the upper part of the Mesaverde Formation, based on a single test, was 0.33 foot squared per day. Transmissivities of the alluvium ranged from 108 to 230 feet squared per day. The transmissivity of unconsolidated Quaternary deposits, determined from an aquifer test, was about 1,900 feet squared per day.

An inventory was made of 20 wells (18 in the Paonia study area and 2 in the Cedaredge study area) and 16 springs in the Paonia study area. Wells completed in the Mesaverde Formation yielded a sodium bicarbonate type water. Water levels in wells ranged from 149 to 2,209 feet below the land surface in the Paonia study area and were 25 and 217 feet below the land surface in the Cedaredge study area.

Spring discharges in the Paonia study area ranged from 0.02 to 8.41 gallons per minute. The waters were of the calcium sodium bicarbonate type.

Tests conducted in October 1982 indicated that Terror Creek in the Paonia study area lost 0.59 cubic foot per second along about 1.5 miles of thin alluvium overlying the lower Mesaverde Formation. Measurements in the same week indicated that Oak Creek in the Cedaredge study area gained 0.92 cubic foot per second along about 1.5 miles of thick alluvium overlying the Mesaverde Formation. The stream waters were a calcium bicarbonate type.

Mining beneath Stevens Gulch and East Roatcap Creek could produce surface expressions of subsidence. Subsidence could partly drain alluvial valley aquifers or streamflow in these drainages.

INTRODUCTION

Underground coal mining has been proposed for two areas in the North Fork Gunnison River drainage in Delta County, Colo. (fig. 1). Underground mining of these areas may cause subsidence which can interrupt flows of springs and streams, as indicated by Dunrud (1976) at the Oliver Mine about 8 miles northeast of Paonia. Subsidence can interrupt surface- and ground-water flow systems by creating tension fractures and compression bulges, causing new flow conduits or diversion and damming of existing flow paths. The water resources of these areas are essential for irrigation, domestic, and industrial use, and any disturbance of the natural hydrologic system may have significant impacts. No previous detailed hydrologic studies have been done in the areas; therefore, the U.S. Bureau of Land Management funded a study by the U.S. Geological Survey to determine potential impacts from mining on the hydrology of the two proposed coal-lease tracts.

Purpose and Objectives

The purpose of this report is to summarize the hydrologic investigation. The study objective was to provide data and a limited interpretation of surface- and ground-water flow systems. Specific objectives were to:

1. Provide surface- and ground-water data to support future interpretation of changes within the surface- or ground-water systems.
2. Provide a limited interpretation of the local hydrogeology based on the available data. This includes:
    a. Inference of ground-water flow direction.
    b. Determination of ground-water recharge and discharge areas.
    c. Description of the potential effects of subsidence on the the surface- and ground-water flow systems.

Approach

The study objectives were met by reviewing existing information and collecting and analyzing some additional data. A literature search was conducted, and information was gathered from private companies and government agencies. Wells and springs were inventoried and water-quality samples were collected and analyzed to determine the quantity and quality of surface and ground waters. Streamflow gain-and-loss measurements were made to determine surface- and ground-water relations. Finally, an interpretation was made of the hydrogeologic system and potential subsidence effects on the local hydrologic system.

Previous Investigations

Previously published reports of interest include a paper by Dunrud (1976), which describes subsidence associated with coal mining in Utah and Colorado, and an environmental statement on west-central Colorado by the U.S. Bureau of Land Management (1979). Unpublished reports include

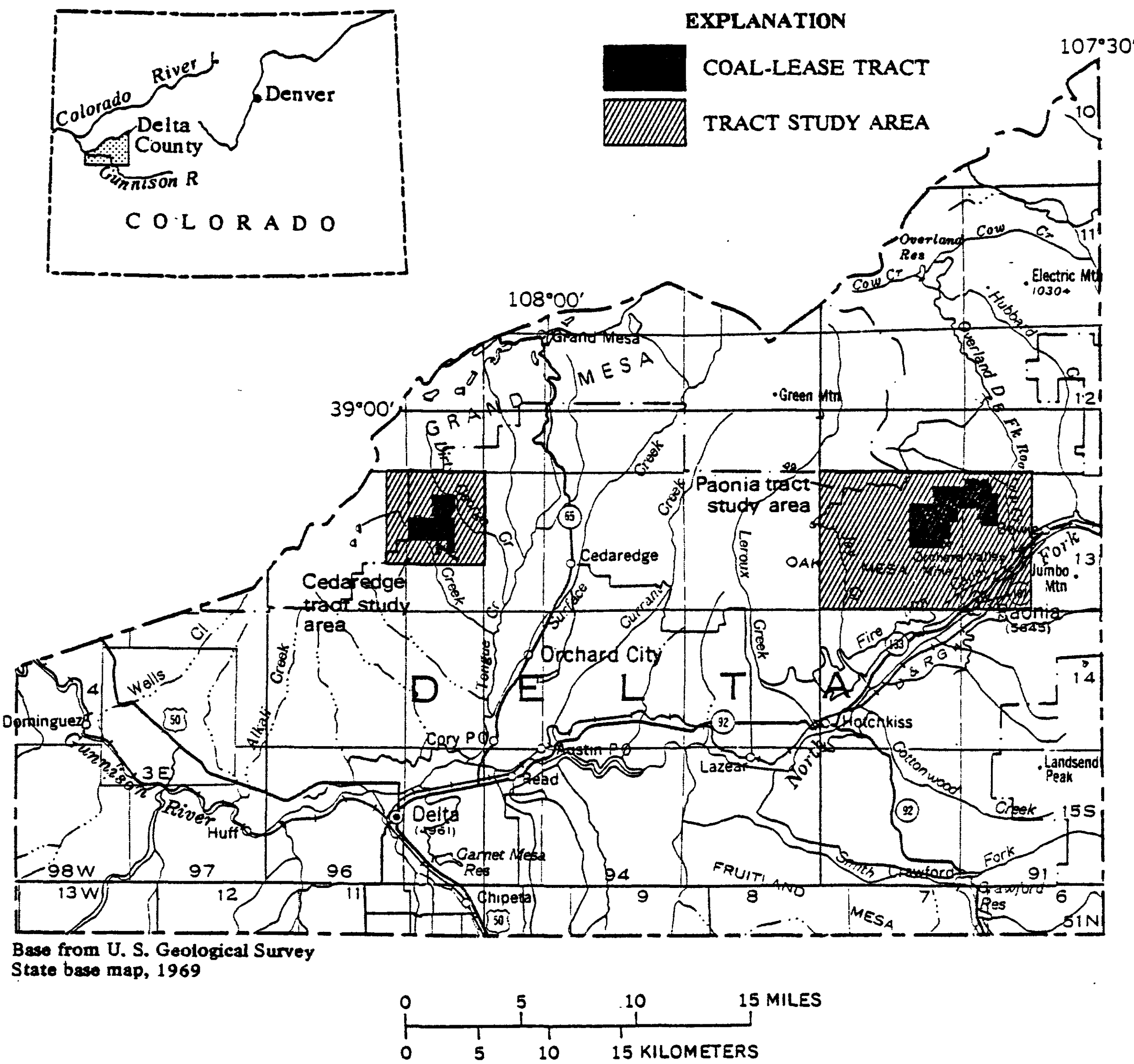


Figure 1.--Location of the study areas.

ground-water investigations of Stevens Gulch for Colorado Westmoreland, Inc., by Wright Water Engineers, Inc. (1977); a hydrologic summary of the North Fork area by the Colorado Mined Land Reclamation Division (1981); and an analysis of aquifer tests on coal seams west of Cedaredge for the Grand Mesa Coal Co., by Kaman Tempo (1982). Geologic maps for the study area include the Montrose 1°x2° quadrangle by Tweto and others (1976), the Bowie and Gray Reservoir quadrangles by Junge (1978), and the Cedaredge area by Hail (1972).

Acknowledgments

Well and spring owners allowed the author access to their private lands to collect onsite data. Some information also was provided by Colorado Westmoreland, Inc., and the Grand Mesa Coal Co.

DESCRIPTION OF STUDY AREAS

Location

The two areas discussed in this report have a combined area of about 66 mi^2 (16 mi^2 near Cedaredge and 50 mi^2 north of Paonia) and are both on the southern slope of the Grand Mesa, Delta County, in western Colorado (fig. 1). The Cedaredge tract study area is about 6 mi west of Cedaredge in an area of rugged, sloping terrain. The Paonia tract study area, located east of the Cedaredge tract, is about 3 mi north of the town of Paonia and is characterized by very steep topography. Cedaredge is on Colorado Highway 65, 10 mi north of its intersection with Colorado Highway 92. Paonia is less than 1 mi south of the intersection of Colorado Highways 133 and 187 in eastern Delta County. Both are located in the North Fork Gunnison River valley.

Climate

The North Fork Gunnison River valley generally is semiarid. On adjacent valley slopes, precipitation normally increases and temperature decreases with altitude. The altitude at Cedaredge is 6,180 ft above sea level and the mean annual temperature is 48.6°F (McKee, 1972). The altitude at Paonia is 5,700 ft and the mean annual temperature is 49.6°F (McKee, 1972). Mean annual precipitation is 11.7 in. at Cedaredge and 15.3 in. at Paonia. Mean annual snowfall is 40.1 in. at Cedaredge and 51.8 in. at Paonia (McKee, 1972). Winds and weather fronts generally move across the areas from west to east.

Geology

Relevant stratigraphy includes the Upper Cretaceous Mesaverde Formation and the Tertiary Wasatch Formation, both of which include sandstone, shale, claystone, and mudstone. Unconsolidated sand, silt, cobbles, and boulders overlie bedrock. Bedrock in the study areas dips 3° to 5° to the north beneath the Grand Mesa.

The Rollins Sandstone Member, a persistent quartzose sandstone, is about 150 to 200 ft thick in the lease areas, and is the basal member of the Mesaverde Formation. This member lies greater than 200 ft beneath the most likely coal bed to be mined (D-seam). Coal beds, bounded by shale and sandstone are found in the unnamed coal-bearing member as much as 600 ft above the top of the Rollins Sandstone Member. The unnamed barren member of the Mesaverde Formation, above the coal member, is about 500 ft thick, and consists of fine-grained sandstone and shale. The Ohio Creek Member of the Mesaverde Formation, a sequence of sandstone and mudstone (Johnson and May, 1980), overlies the barren member. The Wasatch Formation, which overlies the Ohio Creek Member, consists of claystone, mudstone, and shale and is the primary source of sediment deposited in streambeds in the study areas.

Faults were found in the Mesaverde Formation in the Orchard Valley Mine, 3 mi north of Paonia. Cores of the formation obtained by Colorado Westmoreland, Inc., have additional fractures. The extent of fracturing and faulting is not known, although Dunrud (1976) suggests that many stream valleys follow linear zones that are more jointed than surrounding bedrock. Jointing may be associated more commonly with valleys than with ridges. No information exists on faulting or fracturing in the Cedaredge study area.

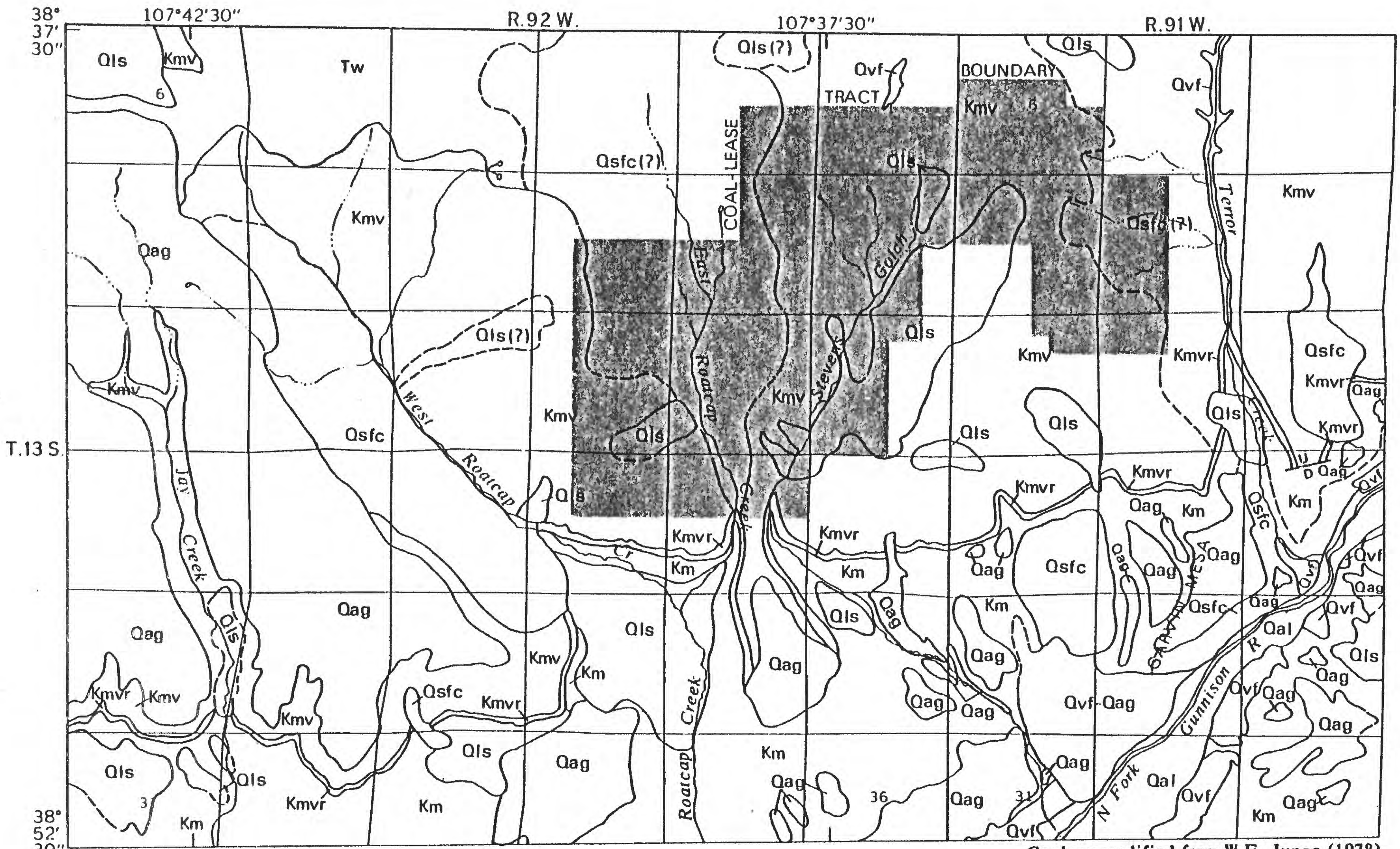
Unconsolidated deposits of Quaternary age overlie the coal-bearing and barren members of the Mesaverde Formation in the Paonia and Cedaredge lease areas, and are located in valleys as well as on ridges. These deposits include landslide debris, boulders, gravel, alluvium, and colluvium, which are derived primarily from claystones of the Wasatch Formation and the overlying Grand Mesa basalts. The extent of these deposits in the Paonia study area is shown in figure 2. Unconsolidated material covers a larger part of the Cedaredge study area than the Paonia area, but geologic mapping has not been adequate to determine the extent to which this is true.

A greater area of bedrock in the Cedaredge study area is overlain by thick, unconsolidated Quaternary deposits than in the Paonia area. This is due to the differences in topography of the two areas. The Cedaredge study area in western Delta County is rugged, but not nearly as steep as the Paonia study area in the eastern part of the county. The steeper slopes and greater stream gradients in eastern Delta County create a greater potential for sediment transport in streams, resulting in the erosion of surficial deposits from local valley walls and cliff fronts facing the North Fork Gunnison River, and exposure of the underlying bedrock. The lease tract area near Paonia is farther away from the source of basalt, which can decrease the rate of erosion of the surficial deposits.

HYDROLOGIC SYSTEM

Surface Water

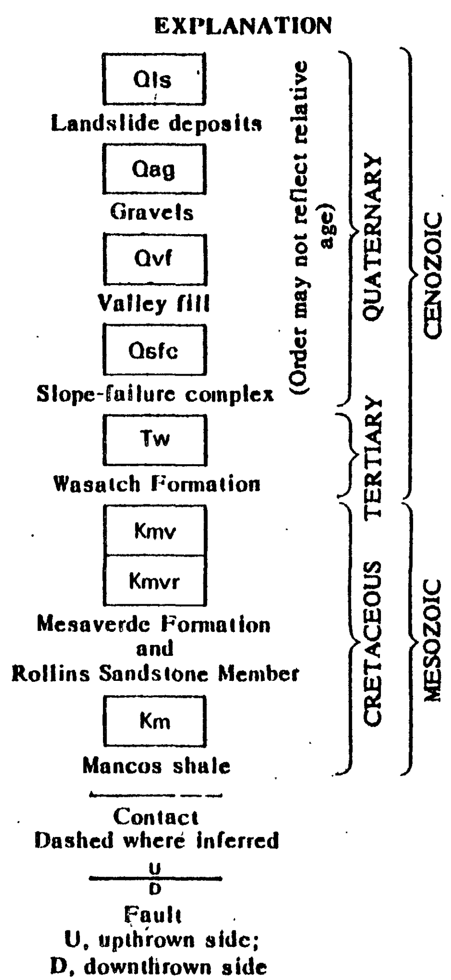
Terror Creek is the only perennial stream in the Paonia study area, though not in the proposed lease tract. The creek drains an eastern part of the Grand Mesa, contributing flow to the North Fork Gunnison River. Stevens Gulch and East Roatcap Creek within the Paonia lease tract are both dry by



Base from U.S. Geological Survey
1:24 000, Gray Reservoir and
Bowie, 1978

Geology modified from W.E. Junge (1978)

Figure 2.--Hydrogeology of the Paonia tract study area.



Rocks exposed and their water-bearing properties

Erathem	System	Geologic unit	Average thickness (feet)	Lithology	Water-bearing properties
CENOZOIC	QUATERNARY	Landslide, gravel, valley fill, and slope-failure deposits.	[1]200	Unconsolidated clay, silt, sand, gravel, pebbles, cobbles, and boulders.	Source of all seeps and springs in study areas. An alluvial well near Paonia yields 25 gallons per minute.
	TERTIARY	Wasatch Formation.	1000	Variegated shale and claystone, some conglomerate. Lenticular limestones and sandstones locally present.	No information available; not considered an aquifer in the study areas.
MESOZOIC	CRETACEOUS	Mesaverde Formation (includes Rollins Sandstone Member at base).	1300	Basal cross-bedded quartzose sandstone. Interbedded sandstone, shale, carbonaceous shale, and coal. Massive sandstone overlying conglomerate in upper part.	Perched ground water within sandstone lenses and fractured sandstone. No producing wells in the study areas. Transmissivities of rocks in the North Fork Gunnison River valley range from 0.33 foot squared per day (unfractured rocks) to 400 feet squared per day (fractured rocks).
		Mancos Shale.	3000+	Gray marine shale and siltstone. Basal sandstone member. Limestone stringers locally.	Little information available. Typically contains saline water. Seldom developed.

[1] Maximum thickness

Figure 2.--Hydrogeology of the Paonia tract study area--Continued.

late summer because discharge from the alluvium is limited. The drainage area of Terror Creek is about 30.5 mi^2, whereas that of Stevens Gulch is about 5.5 mi^2, and that of East Roatcap Creek is about 4 mi^2.

Water is diverted from Terror Creek near an outcrop of the Rollins Sandstone (SE¼NE¼NE¼ sec. 17, T. 13 S., R. 91 W.) to domestic users at Garvin Mesa. In late summer, water is diverted from Cow Creek (downstream from Overland Reservoir, north of the study area) through Overland Ditch to East Roatcap Creek.

Oak and Camp Creeks are the two principal streams in the Cedaredge study area. Oak Creek is perennial, and most of its 21-mi^2 drainage area is recharged by water from the alluvium. Water is diverted from Oak Creek via Hoosier Ditch (sec. 18, T. 13 S., R. 95 W.) until about July or August. Oak Creek water is diverted toward the south and used to irrigate farms near Delta. Camp Creek normally flows until late summer or early fall, but flows for a longer time during years when precipitation is greater than normal. Camp Creek maintained a small flow during late September 1982. Water is diverted from Camp Creek through Eagle Ditch and Dirty George Creek.

Ground Water

The Mesaverde Formation and Quaternary deposits are the primary hydrogeologic units within the study areas; each has distinct hydrologic properties. The overlying siltstone, mudstone, and shale of the Wasatch Formation probably transmit little water. The Wasatch Formation is not considered an aquifer in the study areas. The Mesaverde Formation is recharged in outcrops along the North Fork Gunnison River valley. The formation probably transmits very little water because its transmissivity is small. Ground water may be transmitted downdip and northward within the Mesaverde Formation and may discharge somewhere north of the Grand Mesa, or it may discharge somewhere down the North Fork Gunnison River valley. Any discharge would be small and likely subject to evapotranspiration.

In the Paonia area, streamflow losses are significant along a 1.5-mi reach of Terror Creek along which the lower part of the Mesaverde Formation crops out and is recharged. While drilling test holes in 1982, Colorado Westmoreland, Inc., found that the potentiometric head declined as drilling progressed deeper into the Mesaverde Formation. This is characteristic of a recharge area. No springs issue from the Mesaverde Formation in the Paonia study area, indicating this is a recharge area, not a discharge area.

The saturated thickness of the Mesaverde Formation differs in the Paonia and Cedaredge study areas because the topography and geology of the two areas are different. There is less opportunity in the Paonia study area for precipitation and runoff to infiltrate into the exposed areas of the Mesaverde Formation because the terrain is very steep and ravines are numerous. Limited infiltration results in limited ground-water recharge and ravines also allow rapid drainage of infiltration water. The slopes in the Cedaredge study area are less steep, and the area has sufficient unconsolidated cover to allow more time for water to infiltrate into the Mesaverde Formation.

No wells completed in the Mesaverde Formation produce sufficient water for any use within the Paonia study area, although domestic wells completed in the Mesaverde Formation have been used for several years in the Cedaredge area. Colorado Westmoreland, Inc., drilled a well in the Mesaverde Formation in the Paonia study area that had insufficient yield. However, a well in the alluvium in Stevens Gulch and other unconsolidated deposits yielded 25 gal/min (J. V. Roberts, Colorado Westmoreland, Inc., oral commun., 1982). Unconsolidated Quaternary deposits locally recharge and discharge in the North Fork Gunnison River valley, ultimately contributing water to the river. These deposits comprise the more productive aquifers in the Delta-Paonia area. This is especially true in the Paonia area where most water supplies are developed from valley alluvium along the North Fork Gunnison River. Valley-slope deposits consist of landslide deposits and other unconsolidated Quaternary deposits which receive recharge on the higher slopes and discharge water from the lower slopes. All springs inventoried in the Paonia study area originate from unconsolidated deposits, which in many places are underlain by the less permeable Mesaverde Formation.

All perennial springs in the coal-lease tract area overlie a minimum of 1,500 ft of overburden. Spring SC13092l3ACA1, the nearest spring to the southern coal outcrop, is about 1,500 ft above the coal. Springs supplying domestic water to Oak Mesa are just outside the Paonia proposed lease tract in sec. 16, T. 13 S., R. 92 W. The saturated unconsolidated deposits from which these springs issue are west of East Roatcap Creek drainage area.

The Mesaverde Formation transmits little water. Water within the Mesaverde Formation normally is limited to relatively small and isolated lenticular sandstones. The primary hydraulic conductivity of the Mesaverde Formation is small. A lithologic examination of the formation reveals that the 150- to 200-ft thick Rollins Sandstone Member at the base of the formation could conduct water, although its near-vertical exposures permit little recharge. The 600-ft thick coal member above the Rollins Sandstone Member conducts more water through secondary hydraulic conductivity features such as fractures than it does otherwise; however, core drilling indicates that fracture zones probably are not areally extensive.

The barren member of the Mesaverde Formation (above the coal member) consists of as much as 500 ft of fine-grained lenticular sandstone and shale containing some coal (Johnson, 1948). The sandstones are discontinuous and transmit little water. The barren member probably is the least permeable unit in the Mesaverde Formation.

Small transmissivity values and small storage coefficients are characteristic of the Mesaverde Formation in the Delta-Paonia area. The following range of values is given in reports by the Colorado Mined Land Reclamation Division (1981), Kaman Tempo (1982), and Wright Water Engineers, Inc. (1977). Transmissivities reported for coal beds ranged from 1.5 to 16.7 ft^2/d, and storage coefficients were 0.00004 to 0.097. These values indicate that these beds have little potential for supplying water for domestic use. The transmissivity of the barren member of the Mesaverde Formation is reported to be 0.33 ft^2/d. These small transmissivity values are consistent with the results of aquifer tests in the Mesaverde Formation in the Book Cliffs area in northern Mesa County, Colo. (T. A. Hailu, J. F. Sato & Associates, oral commun., 1982). Results of aquifer tests indicate that the Mesaverde Formation ransmits little water where undisturbed, although significant quantities of water can be transmitted where the Mesaverde Formation is fractured.

Transmissivity values and storage coefficients reported for unconsolidated Quaternary deposits are greater than those reported for the Mesaverde Formation. Alluvium in Stevens Gulch in the Paonia study area had reported transmissivities ranging from 187 to 230 ft^2/d and a storage coefficient of about 0.0002 (Wright Water Engineers, Inc., 1977). Alluvium near the Bear Mine, about 6 mi northeast of the Paonia study area, had a transmissivity of 108 ft^2/d and a storage coefficient of 0.2 (Colorado Mined Land Reclamation Division, 1981). Unconsolidated Quaternary deposits less than 6 mi east of the Cedaredge study area had a transmissivity of about 1,900 ft^2/d (Kaman Tempo, 1982). Unconsolidated Quaternary deposits can transmit a significant quantity of water. The more extensive the unconsolidated deposit, the more potential there is for ground-water recharge, discharge, and storage for long periods.

Hydrologic Data

Well and Spring Inventory

Well and spring data collected in the Paonia and Cedaredge study areas are summarized in tables 1 and 2. Location of the data-collection sites is shown in figures 3 and 4. The numbering system for the data-collection sites is given in the final section "System of Numbering Wells, Springs, and Streamflow Gain-and-Loss Measurement Sites."

Wells were examined during the summer of 1982, and water-level measurements were made when possible. Most water levels in the Paonia study area were very deep (534 to 2,029 ft below land surface) and were measured using spontaneous-potential and electrical-resistivity geophysical equipment. Depths to water in two wells in the Cedaredge study area were 25 and 217 ft below land surface. The well in which depth to water was 25 ft is affected by a ground-water and surface-water connection with Camp Creek.

Water Quality

Four wells were sampled and the water analyzed for chemical quality in the Paonia study area, and one well was sampled and the water analyzed for chemical quality in the Cedaredge study area. Water-sample analyses for wells, springs, and streamflow are listed in table 3; gain-and-loss measurements are listed in table 4. Water in wells penetrating the Mesaverde Formation in both study areas was a sodium bicarbonate type, and the specific conductance ranged from 750 to 4,230 μmhos (micromhos per centimeter at 25°C). The specific conductance of water from 19 wells completed in the Mesaverde Formation measured outside the study areas (but within the North Fork Gunnison River valley) ranged from 325 to 5,390 μmhos and had a mean of 1,351 μmhos. The water in these wells also was a sodium bicarbonate type.

Table 1.—*Data for wells completed in the Mesaverde Formation within the proposed coal-lease tracts*

Well No.	Altitude (feet)	Well depth (feet)	Depth to water (feet below land surface)	Date water level measured	Date sampled	Well status (10/07/82)	Remarks
SC01309106DAC1	7,950	1,500	1,355	06/04/82	———	Sealed	Saturated zone at 200 feet.
SC01309107BBA1	8,300	1,975	1,750	08/20/82	———	Perforated PVC casing	
SC01309107CDC1	8,715	2,150	2,029	07/20/82	———	Sealed	Water level rose after drilling completed.
SC01309107DCA1	8,231	1,694	1,390	06/04/82	———	Sealed	
SC01309108CBB1	7,754	928	909	11/07/81	———	Sealed	Driller lost circulation in 'D' seam. Hole failed at 925 feet. Moisture at 845+ feet.
SC01309117CBC1	7,422	690	534	07/21/82	———	Perforated PVC casing	
SC01309118BDA1	8,597	1,963	(1)	———	———	Perforated PVC casing	Driller lost circulation throughout drilling.
SC01309210CDA1	8,578	2,035	1,199	07/21/82	———	Sealed	Wet sand at 120 feet.
SC01309211CBA1	8,253	1,420	———	———	———	Sealed	Depth to water was 40 feet before sealed. Hydraulic connection with surface water affects water level in well.
SC01309211DBB1	8,565	2,073	1,140	07/21/82	———	Sealed	Depth to water was 1,230 feet on 12/11/81.
SC01309214AAB1	7,932	1,055	1,238	07/29/82	07/29/82	Perforated PVC casing	Driller noted depth to water was 600 feet.
SC01309214CBD1	7,480	509	149	09/13/77	08/16/81	Perforated PVC casing	U.S. Geological Survey observation well.
SC01309214DBD1	8,161	1,100	1,067	07/21/82	———	Sealed	Much water at 520 feet. Hole failed at 1,100 feet. Depth to water was 487 feet on 11/12/81.
SC01309215ABD1	8,310	1,655	1,044	07/21/82	07/21/82	Perforated PVC casing	Depth to water was 700 feet at 1,280-feet drilling depth; depth to water was 1,311 feet after drilling completed.
SC01309215BAC1	8,193	1,545	1,372	07/15/82	———	Sealed	Driller noted depth to water was 900 feet. Logger noted water entering hole after drilling completed.
SC01309215BDD1	8,196	1,475	999	07/25/82	———	Perforated PVC casing	Driller noted depth to water was 720 feet.
SC01309215DAC1	7,762	663	646	07/21/82	07/21/82	Sealed	Water level rose to a depth of 610 feet at 922-foot drilling depth.
SC01309215DCC1	8,045	1,169	818	07/21/82	———	Sealed	Hole dry 0 to 879 feet. Saturated 963 to 1,018 feet.
SC01309508AAC1	[2]6,020	585	25	06/26/79	———	PVC casing	Water level reflects hydraulic connection between surface water and aquifer. U.S. Geological Survey observation well.
SC01309517BCB1	[2]6,760	378	217	06/26/79	08/13/81	PVC casing	Discharged 0.75 gallon per minute for 35 hours with 20 feet of drawdown. U.S. Geological Survey observation well.

[1]Well dry.
[2]Altitude from U.S. Geological Survey 7½-minute topographic quadrangle.

Table 2.—*Data for springs issuing from unconsolidated Quaternary deposits within the Paonia tract study area*

Spring No.	Altitude, approximate (feet)	Use	Owner	Discharge (gallons per minute)	Date inventoried	Remarks
SC01309105BCC1	7,570	Stock---	Colorado Westmoreland, Inc.	2.00	08/18/82	Unimproved spring flows into stock pond.
SC01309105CDC1	7,280	Stock---	U.S. Bureau of Land Management.	1.50	08/18/82	Well-exposed alluvium-bedrock contact.
SC01309105DCB1	7,270	Stock---	U.S. Bureau of Land Management.	3.25	08/16/82	Unimproved spring, very contaminated by livestock.
SC01309105DCC1	7,190	Stock---	U.S. Bureau of Land Management.	8.41	08/11/82	
SC01309107ADC1	7,840	Stock---	Colorado Westmoreland, Inc.	.22	08/10/82	Flows through black PVC pipe.
SC01309108DBC1	7,180	Stock---	U.S. Bureau of Land Management.	----	08/11/82	Not sampled; discharge too small to be measured.
SC01309202ABA1	8,180	Unused--	J. A. Morrell--------	1.00	08/17/82	Flows 200 feet to creek. Three openings.
SC01309202ABB1	8,230	Unused--	J. A. Morrell--------	.75	08/17/82	Discharges to creek bed.
SC01309203CAB1	9,200	Stock---	ABMSS Investment-----	.58	08/11/82	Six points of discharge, possibly filtration from irrigation ditch uphill.
SC01309203DAA1	9,000	Stock---	J. A. Morrell--------	6.00	08/11/82	Water piped 1,000 feet to outlet.
SC01309210ACC1	8,780	Domestic	N. W. Grosse-Rhode--	5.20	08/16/82	Water piped 1,000 feet to outlet.
SC01309210BAA1	9,020	Domestic	N. W. Grosse-Rhode--	4.80	08/17/82	Water piped 2,000 feet through PVC pipe from spring to outlet.
SC01309210DBB1	8,725	Stock---	N. W. Grosse-Rhode--	.02	08/18/82	
SC01309211CDB1	8,160	Unused--	Colorado Westmoreland, Inc.	3.75	08/19/82	In a dry creek bed.
SC01309213ACA1	7,930	Stock---	Colorado Westmoreland, Inc.	2.73	08/12/82	Morrell Spring No. 1.
SC01309215ABC1	8,005	Stock---	U.S. Bureau of Land Management.	.16	08/12/82	Water collected in metal cistern. Flows 200 feet through PVC pipe to trough.

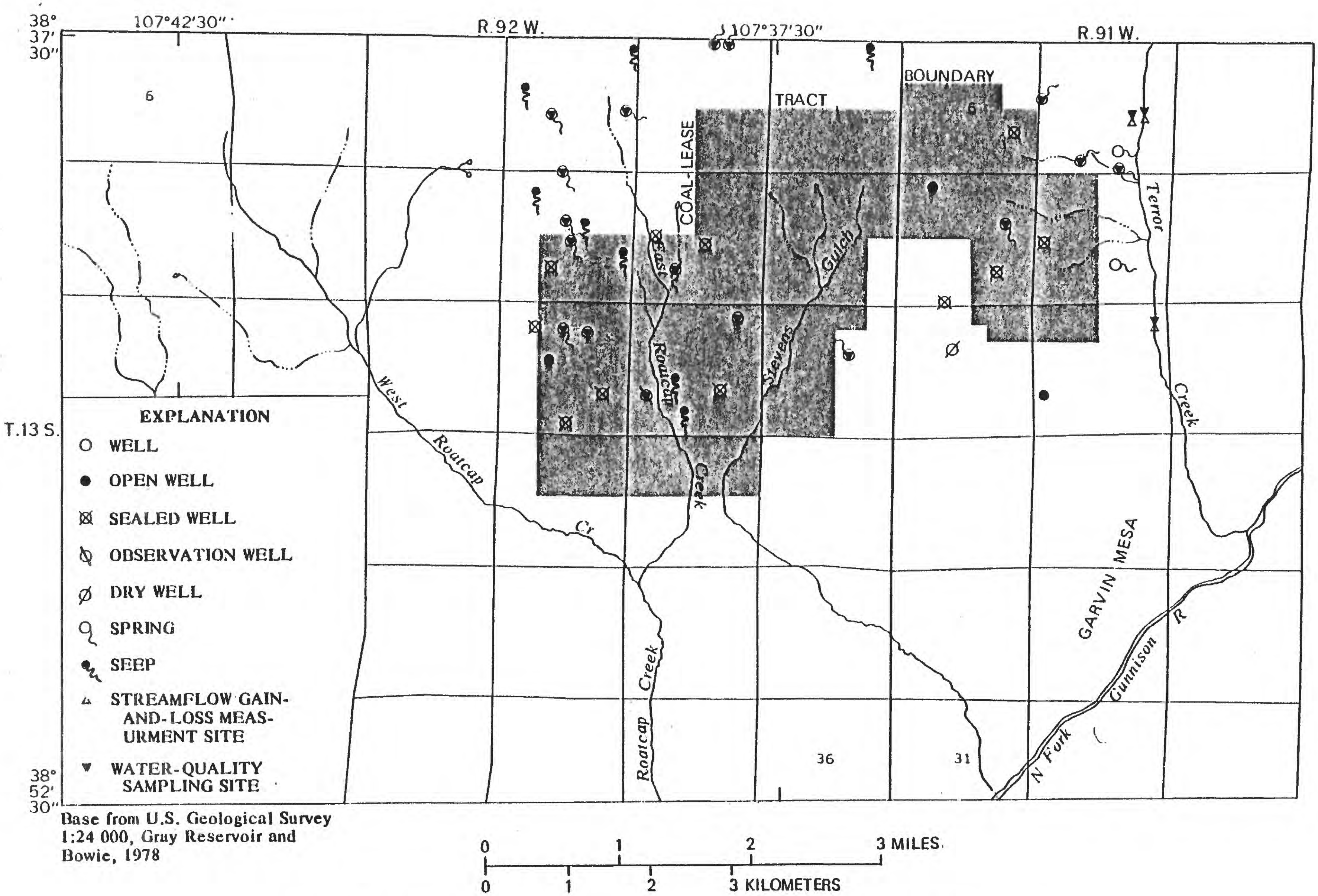


Figure 3.-- Location of data-collection sites within the Paonia tract study area.

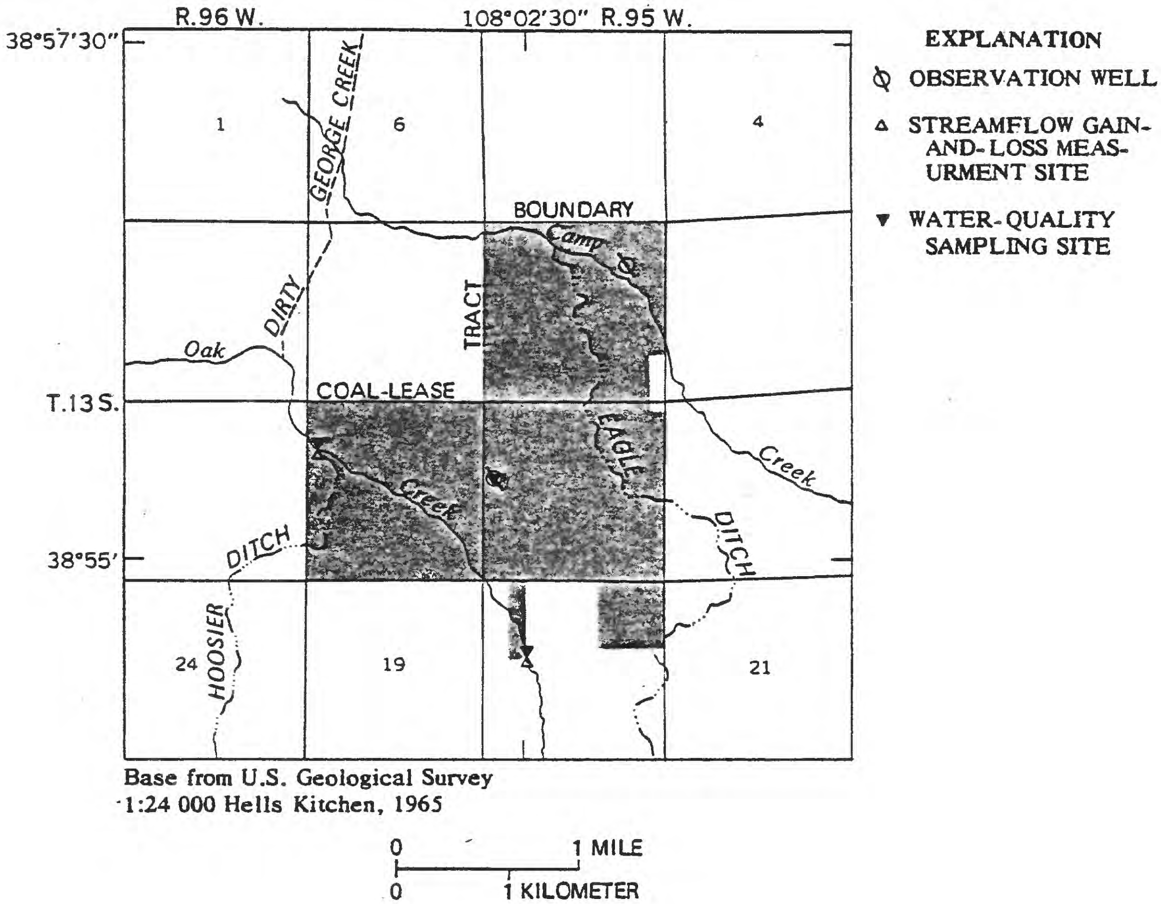


Figure 4.--Data-collection sites within the Cedaredge tract study area.

Water-quality analyses of samples collected at measurement sites are given in table 3. Terror Creek had basic water (8.0 to 8.3 pH) and specific conductance ranged from 175 to 180 µmhos. The water was a calcium bicarbonate type.

Ground-water Levels and Springflow

The water in well SC01309214CBD1 probably is affected by a ground-water and surface-water connection. Depth to water in this well was less than would be expected in wells penetrating the Mesaverde Formation in the Paonia study area, and its water-quality analysis is atypical of analyses of water in the Mesaverde Formation. Boron is a significant trace constituent in water in the Mesaverde Formation. Concentrations range from 1,000 to 2,000 µg/L (micrograms per liter) except for well SC01309214CBD1.

Sixteen springs, all issuing from unconsolidated Quaternary deposits, were inventoried in the Paonia study area during the late summer of 1982. Other springs may have existed, but had ceased flowing by late summer. Discharge was measured for 15 springs, and water-quality samples were obtained for 14 springs. Discharge ranged from 0.02 to 8.41 gal/min, specific conductance ranged from 242 to 678 µmhos, and pH ranged from 5.5 to 8.1. The spring waters were a calcium sodium bicarbonate type.

Streamflow Gain-and-Loss Measurements

Gain-and-loss measurements were made to determine if streams were gaining or losing water from or to the underlying geologic strata through the streambed. Measurements were made on Terror Creek in the Paonia study area and on Oak Creek in the Cedaredge study area. No surface inflows or outflows were found between measurement sites. Measurement sites are shown in figures 3 and 4. Measurement data are given in table 4.

The reach on Terror Creek was chosen because it crosses the lower part of the Mesaverde Formation and has overlying alluvium. Three measurements were made--one on the East Fork, one on the West Fork, and one on the main stem. Both upstream sites were less than 100 ft upstream from the confluence forming Terror Creek, and the downstream measurement site was at the Rollins Sandstone Member exposure upstream from the Terror Ditch diversion. A 0.59-ft^3/s loss was measured along this approximately 1.5-mi reach, indicating that the lower part of the Mesaverde Formation receives recharge in the Paonia study area.

Streamflow gain-and-loss measurements on Oak Creek in the Cedaredge study area indicate a hydraulic connection between water in the alluvium and the stream. Oak Creek gained 0.92 ft^3/s along about a 1.5-mi reach of alluvial streambed, indicating the alluvium contributes baseflow. Values for pH were 8.5 and 8.7, and specific conductance was 410 µmhos at both sites. The water was a calcium bicarbonate type.

Table 3.--*Chemical analyses of ground and surface waters in the study areas*

[LOCAL IDENTIFIER = location of well, spring, or streamflow gain-and-loss measurement site (see section on numbering of wells, springs, and streamflow gain-and-loss sites in text); SITE, GW, well; SP, spring; SW, stream; UMHOS, micromhos per centimeter at 25°Celsius; Deg C, degrees Celsius; MG/L, milligram per liter; UG/L, microgram per liter; 110QRNR, Quaternary deposits; 211MVRD, Upper Cretaceous Mesaverde Formation]

LOCAL IDENT-I-FIER	SITE	GEO-LOGIC UNIT	DATE OF SAMPLE	SPE-CIFIC CON-DUCT-ANCE (UMHOS) (00095)	PH (UNITS) (00400)	TEMPER-ATURE (DEG C) (00010)	HARD-NESS (MG/L AS CACO3) (00900)	CALCIUM DIS-SOLVED (MG/L AS CA) (00915)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG) (00925)	SODIUM, DIS-SOLVED (MG/L AS NA) (00930)
SC01309105BCC1	SP	110QRNR	82-08-18	398	7.1	8.5	180	47	15	45
SC01309105CDC1	SP	110QRNR	82-08-18	666	8.1	10.5	240	60	22	50
SC01309105DAB1	SW	-------	82-10-05	180	8.2	7.0	65	17	5.4	6.6
SC01309105DAB2	SW	-------	82-10-05	175	8.3	9.0	63	16	5.6	5.7
SC01309105DCC1	SP	110QRNR	82-08-11	644	8.1	16.0	280	70	25	55
SC01309107ADC1	SP	110QRNR	82-08-10	502	5.8	8.0	200	49	19	42
SC01309117AAD1	SW	-------	82-10-05	180	8.0	8.0	67	17	6.9	6.5
SC01309202ABA1	SP	110QRNR	82-08-17	367	6.8	5.0	120	40	4.8	34
SC01309202ABB1	SP	110QRNR	82-08-17	437	8.0	8.0	160	51	8.7	25
SC01309203CAB1	SP	110QRNR	82-08-11	242	6.2	11.5	120	28	11	7.0
SC01309203DAA1	SP	110QRNR	82-08-11	266	5.5	13.0	91	25	6.8	24
SC01309210ACC1	SP	110QRNR	82-08-16	269	6.1	10.0	120	28	13	7.2
SC01309210BAA1	SP	110QRNR	82-08-17	313	6.4	12.0	140	33	15	9.2
SC01309210DBB1	SP	110QRNR	82-08-18	349	6.4	15.5	180	41	19	9.6
SC01309211CDB1	SP	110QRNR	82-08-19	501	7.3	11.0	200	44	21	38
SC01309213ACA1	SP	110QRNR	82-08-12	678	7.3	9.5	280	69	25	56
SC01309214AAB1	GW	211MVRD	82-07-29	2500	8.4	26.9	43	12	3.1	650
SC01309214CBD1	GW	211MVRD	81-08-16	750	7.3	11.0	150	38	14	140
SC01309215ABC1	SP	110QRNR	82-08-12	631	7.2	15.0	300	84	21	24
SC01309215ABD1	GW	211MVRD	82-08-04	2820	7.1	19.5	8	2.1	.7	750
SC01309215DAC1	GW	211MVRD	82-08-03	4230	7.5	21.5	37	9.0	3.2	1300
SC01309517BCB1	GW	211MVRD	81-08-13	1330	7.2	14.0	21	4.3	2.5	350
SC01309520BCD1	SW	-------	82-10-06	410	8.7	8.0	200	53	17	9.1
SC01309613AAD1	SW	-------	82-10-06	410	8.5	6.5	210	55	17	8.3

Table 3.--*Chemical analyses of ground and surface waters in the study areas*--Continued

LOCAL IDENT-I-FIER	DATE OF SAMPLE	PERCENT SODIUM (00932)	SODIUM AD-SORP-TION RATIO (00931)	POTAS-SIUM, DIS-SOLVED (MG/L AS K) (00935)	ALKA-LINITY LAB (MG/L AS CACO3) (90410)	SULFATE DIS-SOLVED (MG/L AS SO4) (00945)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL) (00940)	FLUO-RIDE, DIS-SOLVED (MG/L AS F) (00950)	SILICA, DIS-SOLVED (MG/L AS SIO2) (00955)	GEN, NO2+NO3 DIS-SOLVED (MG/L AS N) (00631)
SC01309105BCC1	82-08-18	35	1.6	1.2	231	25	3.7	.2	14	.21
SC01309105CDC1	82-08-18	31	1.5	2.2	324	23	4.4	.2	15	.24
SC01309105DAB1	82-10-05	18	.4	1.6	76	8.0	1.2	.1	23	<.10
SC01309105DAB2	82-10-05	16	.3	1.5	72	10	.9	.1	19	<.10
SC01309105DCC1	82-08-11	30	1.6	2.6	333	22	5.9	.2	15	<.10
SC01309107ADC1	82-08-10	31	1.4	2.2	276	14	4.0	.3	33	.50
SC01309117AAD1	82-10-05	17	.4	1.5	77	10	1.5	.1	20	<.10
SC01309202ABA1	82-08-17	38	1.4	2.5	185	12	1.0	.2	10	.11
SC01309202ABB1	82-08-17	25	.9	2.3	210	20	1.4	.2	12	<.10
SC01309203CAB1	82-08-11	11	.3	2.2	131	<5.0	.6	.1	34	.19
SC01309203DAA1	82-08-11	36	1.2	.9	128	5.0	3.8	.2	30	.79
SC01309210ACC1	82-08-16	11	.3	2.1	129	<5.0	1.3	.2	42	.44
SC01309210BAA1	82-08-17	12	.4	2.8	157	<5.0	1.4	.2	47	.27
SC01309210DBB1	82-08-18	10	.3	1.7	194	6.0	2.4	.2	33	<.10
SC01309211CDB1	82-08-19	30	1.3	1.0	261	9.0	3.0	.2	34	2.1
SC01309213ACA1	82-08-12	31	1.6	1.7	288	62	6.0	.2	18	.24
SC01309214AAB1	82-07-29	95	43	23	1360	43	130	1.4	8.7	.39
SC01309214CBD1	81-08-16	66	5.3	2.8	380	50	4.4	.3	14	.19
SC01309215ABC1	82-08-12	15	.6	1.2	303	36	6.3	.3	17	<.10
SC01309215ABD1	82-08-04	99	114	6.5	1570	<5.0	56	3.5	10	<.10
SC01309215DAC1	82-08-03	98	102	13	2750	11	180	1.9	16	<.10
SC01309517BCB1	81-08-13	97	37	2.1	740	2.0	6.5	3.0	12	.21
SC01309520BCD1	82-10-06	9	.3	2.0	215	17	1.7	.2	20	<.10
SC01309613AAD1	82-10-06	8	.3	1.8	217	20	1.0	.2	19	<.10

Table 3.--*Chemical analyses of ground and surface waters in the study areas*--Continued

LOCAL IDENT-I-FIER	DATE OF SAMPLE	PHOS-PHORUS, ORTHO, DIS-SOLVED (MG/L AS P) (00671)	ALUM-INUM, DIS-SOLVED (UG/L AS AL) (01106)	ARSENIC DIS-SOLVED (UG/L AS AS) (01000)	BARIUM, DIS-SOLVED (UG/L AS BA) (01005)	BORON, DIS-SOLVED (UG/L AS B) (01020)	CADMIUM DIS-SOLVED (UG/L AS CD) (01025)	CHRO-MIUM, DIS-SOLVED (UG/L AS CR) (01030)	COPPER, DIS-SOLVED (UG/L AS CU) (01040)	IRON, DIS-SOLVED (UG/L AS FE) (01046)
SC01309105BCC1	82-08-18	.020	<10	<1	86	130	<1	<10	<1	<3
SC01309105CDC1	82-08-18	.090	<10	<1	110	130	<1	<10	<1	<3
SC01309105DAB1	82-10-05	--	--	1	--	<10	<1	<10	--	130
SC01309105DAB2	82-10-05	--	--	<1	--	<10	<1	<10	--	140
SC01309105DCC1	82-08-11	--	10	<1	140	40	<1	<10	<1	4
SC01309107ADC1	82-08-10	<.010	<10	<1	67	10	<1	<10	<1	<3
SC01309117AAD1	82-10-05	--	--	<1	--	<10	<1	<10	--	110
SC01309202ABA1	82-08-17	.010	10	<1	97	130	<1	<10	<1	5
SC01309202ABB1	82-08-17	<.010	10	1	120	130	<1	<10	<1	11
SC01309203CAB1	82-08-11	.030	20	1	9	<10	<1	<10	3	4
SC01309203DAA1	82-08-11	--	20	<1	100	<10	<1	<10	11	12
SC01309210ACC1	82-08-16	.270	<10	1	15	110	<1	<10	1	6
SC01309210BAA1	82-08-17	.120	10	2	8	110	<1	10	4	4
SC01309210DBB1	82-08-18	.030	10	1	8	120	1	<10	1	11
SC01309211CDB1	82-08-19	.020	10	<1	71	110	<1	<10	<1	10
SC01309213ACA1	82-08-12	--	20	<1	76	30	<1	<10	<1	5
SC01309214AAB1	82-07-29	.080	120	5	500	1000	<1	<10	23	420
SC01309214CBD1	81-08-16	.030	10	2	80	80	1	10	4	26
SC01309215ABC1	82-08-12	--	10	<1	56	30	<1	<10	1	6
SC01309215ABD1	82-08-04	.010	<10	1	<100	2000	<1	<10	<1	100
SC01309215DAC1	82-08-03	.020	40	5	2100	2000	<10	10	1	310
SC01309517BCB1	81-08-13	.230	30	0	60	1400	3	10	7	55
SC01309520BCD1	82-10-06	--	--	1	--	<10	<1	<10	--	13
SC01309613AAD1	82-10-06	--	--	1	--	10	<1	<10	--	23

Table 3.--*Chemical analyses of ground and surface waters in the study areas*--Continued

LOCAL IDENT-I-FIER	DATE OF SAMPLE	LEAD, DIS-SOLVED (UG/L AS PB) (01049)	MANGA-NESE, DIS-SOLVED (UG/L AS MN) (01056)	MERCURY DIS-SOLVED (UG/L AS HG) (71890)	MOLYB-DENUM, DIS-SOLVED (UG/L AS MO) (01060)	NICKEL, DIS-SOLVED (UG/L AS NI) (01065)	SELE-NIUM, DIS-SOLVED (UG/L AS SE) (01145)	SILVER, DIS-SOLVED (UG/L AS AG) (01075)	ZINC, DIS-SOLVED (UG/L AS ZN) (01090)
SC01309105BCC1	82-08-18	<1	2	.3	<1	<1	2	<1	4
SC01309105CDC1	82-08-18	<1	8	.1	<1	<1	2	<1	<3
SC01309105DAB1	82-10-05	<100	--	<.1	<1	--	<1	--	23
SC01309105DAB2	82-10-05	<100	--	<.1	1	--	<1	--	<3
SC01309105DCC1	82-08-11	1	17	<.1	<1	<1	1	<1	19
SC01309107ADC1	82-08-10	<1	2	<.1	<1	<1	1	<1	11
SC01309117AAD1	82-10-05	<100	--	<.1	<1	--	<1	--	6
SC01309202ABA1	82-08-17	7	15	1.0	<1	1	1	<1	4
SC01309202ABB1	82-08-17	<1	82	.5	<1	1	<1	<1	4
SC01309203CAB1	82-08-11	<1	<1	.7	<1	<1	<1	<1	7
SC01309203DAA1	82-08-11	<1	3	<.1	<1	<1	<1	<1	63
SC01309210ACC1	82-08-16	<1	2	.1	<1	<1	<1	<1	89
SC01309210BAA1	82-08-17	<1	<1	<.1	<1	<1	<1	<1	52
SC01309210DBB1	82-08-18	<1	14	<.1	<1	3	<1	<1	8
SC01309211CDB1	82-08-19	<1	35	<.1	<1	15	1	<1	10
SC01309213ACA1	82-08-12	<1	1	<.1	<1	<1	2	<1	48
SC01309214AAB1	82-07-29	<1	40	.1	57	10	7	<1	50
SC01309214CBD1	81-08-16	1	66	.0	26	1	0	0	39
SC01309215ABC1	82-08-12	<1	9	<.1	<1	<1	1	<1	70
SC01309215ABD1	82-08-04	<1	40	<.1	<1	<1	<1	<1	10
SC01309215DAC1	82-08-03	5	120	.1	14	5	<1	<1	83
SC01309517BCB1	81-08-13	0	8	.0	12	0	1	0	15
SC01309520BCD1	82-10-06	<100	--	<.1	<1	--	<1	--	5
SC01309613AAD1	82-10-06	<100	--	<.1	<1	--	<1	--	38

Table 4.--*Gain-and-loss measurements and quality of water in Terror and Oak Creeks*

Location No.	Description of site	Discharge (cubic feet per second)	Date measured	Temperature (degrees Celsius)	pH (units)	Specific conductance (micromhos per centimeter at 25° Celsius)
SC01309105DAB1	West Fork Terror Creek, ≈100 feet upstream from junction with Terror Creek	1.63	10/05/82	7.0	8.2	180
SC01309105DAB2	East Fork Terror Creek, ≈60 feet upstream from junction with Terror Creek	2.69	10/05/82	9.0	8.3	175
SC01309117AAD1	Terror Creek, 5 feet upstream from irrigation diversion, and within Rollins Sandstone Member	3.73	10/05/82	8.0	8.0	180
SC01309520BCD1	Oak Creek, near Fairview Mine	1.58	10/06/82	8.0	8.7	410
SC01309613AAD1	Upper Oak Creek	.66	10/06/82	6.5	8.5	410

SUBSIDENCE POTENTIAL

General

Subsidence potential due to underground coal mining can be affected by mine dimensions, mine depth, coal-extraction rate, and mining methods. The more areally extensive and the greater the mine height, the greater the potential for subsidence and impacts on overlying rock units. Deeper mining generally decreases surface expressions of subsidence. The most affected area is a zone directly over the mined-out area which commonly consists of caved rubble. This rubble zone is seldom greater than 5 to 11 times the mined thickness. Bed separation extends upwards for distances of about 5 to 30 times the mined thickness. These values were obtained from S. S. Peng (University of West Virginia, Department of Mining Engineering, oral commun., 1982), and are probable but not absolute. The worst-case condition is a surface subsidence equal to the mined thickness, although this is unlikely. Surface subsidence commonly is greatest directly above the mined area and decreases with increasing horizontal distance from the mined area. The area affected by subsidence is dependent upon the angle of draw. The angle of draw is the angle, measured from the vertical, that a straight line makes in cross section from the perimeter of the mine to the perimeter of the area affected by subsidence at the surface. Angle of draw depends on the lithology of the overburden, and is estimated to be 15° to 20° for the Mesaverde Formation in the study areas (C. R. Dunrud, U.S. Geological Survey, oral commun., 1982).

In areas where longwall mining or room-and-pillar mining with pillar removal is practiced, the rate of extraction commonly determines how long subsidence will continue. In general, the faster the rate of coal extraction, the sooner subsidence is completed. In the Somerset area, about 9 mi east of Paonia, when pillars are extracted, subsidence commonly is completed 1 or 2 years after mining has ceased (Dunrud, 1976). Mining methods determine subsidence effects. Room-and-pillar mining can create a patchwork of subsidence depressions where extraction is not uniform, whereas longwall methods produce more general subsidence throughout a larger area. Tension fractures occur above barrier pillars and mine boundaries, and compression bulges may occur over unsupported areas. Fractures may widen and deepen due to erosion.

Stratigraphy, lithology, structure, and topography also may control subsidence effects. Strong, brittle geologic materials, such as well-cemented sandstone, fracture more readily than weaker, more ductile materials, such as claystone, siltstone, or alluvium. Surface fractures commonly decrease in number and size with increasing mining depth. Existing fracture zones, joint patterns, or faults may reactivate in response to mining, and could create subsidence fractures at the surface. This reaction may affect normal surface- and ground-water flow systems. Therefore, lithology and geologic structure need to be precisely determined in order to predict potential impacts of subsidence on hydrology.

Study Areas

This report considers potential subsidence primarily for the Paonia study area because more geologic and subsidence information is available for this area than for the Cedaredge study area. In general, potential subsidence effects on hydrology include alteration of stream-channel geometry, stream-erosion rates, loss of surface water from impoundments, hydraulic characteristics of geologic media (which affect recharge and discharge), and spring discharge and location.

Steep stream gradients in the Paonia study area should prevent changes in stream-channel geometry because of incised drainages. The hydraulic conductivity of the Mesaverde Formation could be locally affected, although how much is uncertain. Altering of hydraulic conductivity would decrease with distance from the areas of coal extraction.

Overburden thickness increases north of the Paonia study area, because the bedrock dips 3° to 5° northward, and land-surface altitudes increase to the north as well. Therefore, the severity of surface subsidence would be greatest near the coal outcrops and in the southwestern part of the lease tract (fig. 2).

The impacts of bed-separation and rubble zones are decreased with increasing overburden thickness. The following are estimates of the maximum values of the thickness of bed-separation and rubble zones suggested by S. S. Peng (University of West Virginia, Department of Mining Engineering, oral commun., 1982). If the bed-separation zone were as great as 30 times the mined section, assuming a 10- to 15-ft coal-bed thickness, between 300 and 450 ft of bed separation could occur. If the rubble zone were 11 times the coal-bed thickness, 110 to 165 ft of rubble could result. Using these estimates of the total thickness of the bed-separation and rubble zones, an overburden thickness of greater than 600 ft is necessary to attenuate surface subsidence effects. These values, although not absolute, may serve as a guideline for mine planning.

Greater overburden thicknesses decrease the potential for subsidence fractures to extend from the mine to the surface. A thick overburden may prevent or decrease losses of water from streams, surface impoundments, springs, and seeps into fractures. Surface or ground water might recharge the overburden and drain into the underground mine workings, where cracks occur and interconnect with the mine.

Sandstones of the Mesaverde Formation generally are hard, brittle, and locally jointed, and might fracture as a result of subsidence. Mudstones and claystones in the formation may expand when in contact with water and seal fractures in bedrock overburden (De Graff and Romesburg, 1982). The Colorado Mined Land Reclamation Division (1981) report on the Blue Ribbon Mine, 2 mi east of the Paonia study area, noted that cracks in competent rocks, such as sandstone, tend to remain open, while cracks in the incompetent rocks, such as mudstone and claystone, and soils are likely to fill.

Mining is likely to occur beneath Stevens Gulch and East Roatcap Creek, resulting in possible inflow to the mine. Dewatering by the mine may be limited to the period of spring runoff when the ephemeral streams flow, or may be needed for a longer period because irrigation water is diverted into East Roatcap Creek through the summer months. Some stream alluvium could be dewatered, although alluvium thickens northward, overlying greater overburden.

Colorado Westmoreland, Inc., pumps water from alluvium in Stevens Gulch all year. Alluvial deposits contain fine siltstone and clay sediments derived from the Wasatch Formation. The silt and clay could seal subsidence cracks. The southern limit of the alluvium is near the northeast corner of sec. 23, T. 13 S., R. 92 W., and is shown in figure 2. The thickness of the Mesaverde Formation overburden near this section, based on data from well SC01309214CBD1, is 500 ft or greater.

Mining beneath East Roatcap Creek may cause subsidence cracks to reach the streambed and partly drain the streamflow that is derived from spring runoff or diverted from Overland Ditch. Another drainage outside the tract area could be used to transport the diverted water if significant streamflow were lost through the East Roatcap Creek streambed.

The Mesaverde Formation and overlying unconsolidated Quaternary deposits are more saturated in the Cedaredge study area than in the Paonia study area. An estimated inflow of 7 to 12 gal/min (December 1982) enters the Red Canyon Mine, about 3 mi northwest of Cedaredge. Few faults were reported, but the overburden consists of saturated Mesaverde Formation overlain by saturated unconsolidated Quaternary deposits (L. M. Reschke, Grand Mesa Coal Co., oral commun., 1982). An abandoned mine adjacent to the Red Canyon Mine requires an estimated pumping rate of 16 gal/min to keep pace with the inflow.

Faults are not well defined in either study area. A fault could conduct water into an underground mine with or without subsidence or provide an origin for subsidence fractures during mining. Detailed spatial descriptions of subsidence are dependent on where future coal extraction would occur.

CONCLUSIONS

Unconsolidated Quaternary deposits in the North Fork Gunnison River valley are locally recharged at higher altitudes and discharged at lower altitudes. The Mesaverde Formation also is recharged in the North Fork Gunnison River valley. Ground water may move downdip following the formation and may discharge north of the Grand Mesa or downstream in the North Fork Gunnison River drainage. The Mesaverde Formation generally transmits and stores little ground water except where it is fractured.

Most springs in the Paonia study area are in the northern part of the area. Overburden thickens to the north because geologic beds dip north as the topographic altitude increases. Spring SC01309213ACA1, the nearest spring to the southern coal outcrop, is about 1,500 ft above the coal and should not be affected by underground coal mining. Springs supplying domestic water to Oak Mesa are just outside the Paonia proposed lease tract in sec. 16, T. 13 S., R. 92 W. Mining within the proposed lease tract should not affect spring discharge because the saturated unconsolidated deposits from which these springs issue are west of East Roatcap Creek drainage divide.

The primary concerns in the Paonia study area are the impacts from mining beneath Stevens Gulch and East Roatcap Creek. Stream channels are likely joint-controlled and overlie less overburden than adjacent ridges. Faults or subsidence fractures could channel inflow into the mine from overlying alluvial aquifers. The potential for mine inflow would increase southward, being greatest near the coal outcrop. Alluvial silt and clay could seal small subsidence fractures, but a large fault could partly dewater the alluvial aquifers.

Mining and potential subsequent subsidence will alter the original permeability of the strata near the mine. However, fracturing, rubbling, and bed separation will increase only the local permeability of the Mesaverde Formation. The Rollins Sandstone Member would not be disturbed because it lies greater than 200 ft below the most likely coal bed to be mined (D-seam). Fracturing would result in insignificant additional recharge to the Mesaverde Formation because permeability of the strata would be increased only near the mine and the increase in recharge area would be only a small part of the total. Local dewatering of the Mesaverde Formation would have no effect on current local water use because the Mesaverde Formation is not presently a viable water source.

Insufficient information prevents a detailed analysis of the impacts of subsidence on the hydrology of the Cedaredge study area. Oak and Camp Creeks and water from saturated alluvial aquifers may flow into mines through subsidence fractures or existing fractures or faults. Stream-channel geometry has been altered by subsidence near the Red Canyon Mine where there is less than 100 ft of overburden. Greater mine inflows would be expected in the Cedaredge study area than in the Paonia study area because alluvial aquifers are thicker, more extensive, and saturated to a greater thickness.

Additional or more detailed conclusions require better geologic descriptions of the study areas and properly designed aquifer testing of relevant geologic units. There is typically more unconsolidated cover in the study areas than current (1982) geologic mapping indicates. All values for aquifer characteristics are reported, but aquifer-testing conditions were not monitored by the U.S. Geological Survey.

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SYSTEM OF NUMBERING WELLS, SPRINGS, AND STREAMFLOW GAIN-AND-LOSS MEASUREMENT SITES

The well-numbering system in this report is based on the U.S. Bureau of Land Management system of land subdivision. The number shows the location of the well or test hole by quadrant, township, range, section, and position within the section. A graphical illustration of this method of well location is shown in figure 5. The capital letter at the beginning of the location number indicates the quadrant in which the well is located. Four quadrants are formed by the intersection of the base line and the principal meridian--A indicates the northeast quadrant, B the northwest quadrant, C the southwest quadrant, and D the southeast quadrant. The first numeral indicates the township, the second indicates the range, and the third indicates the section in which the well is located. Lowercase letters following the section number locate the well within the section. The first letter denotes the quarter section, the second letter denotes the quarter-quarter section, and the third letter denotes the quarter-quarter-quarter section. The letters are assigned within the section in a counterclockwise direction, beginning with (a) in the northeast quarter of the section. Letters are assigned within each quarter section and within each quarter-quarter section in the same manner. Where two or more locations are within the smallest subdivision, consecutive numbers beginning with 1 are added to the letters in the order in which the wells or test holes were inventoried. For example, SC01309517BCB1 indicates a well in the northwest quarter of the southwest quarter of the northwest quarter of sec. 17, T. 13 S., R. 95 W., and shows that this is the first well inventoried in the quarter-quarter-quarter section. The capital letter C indicates the township is south of the base line and that the range is west of the principal meridian.

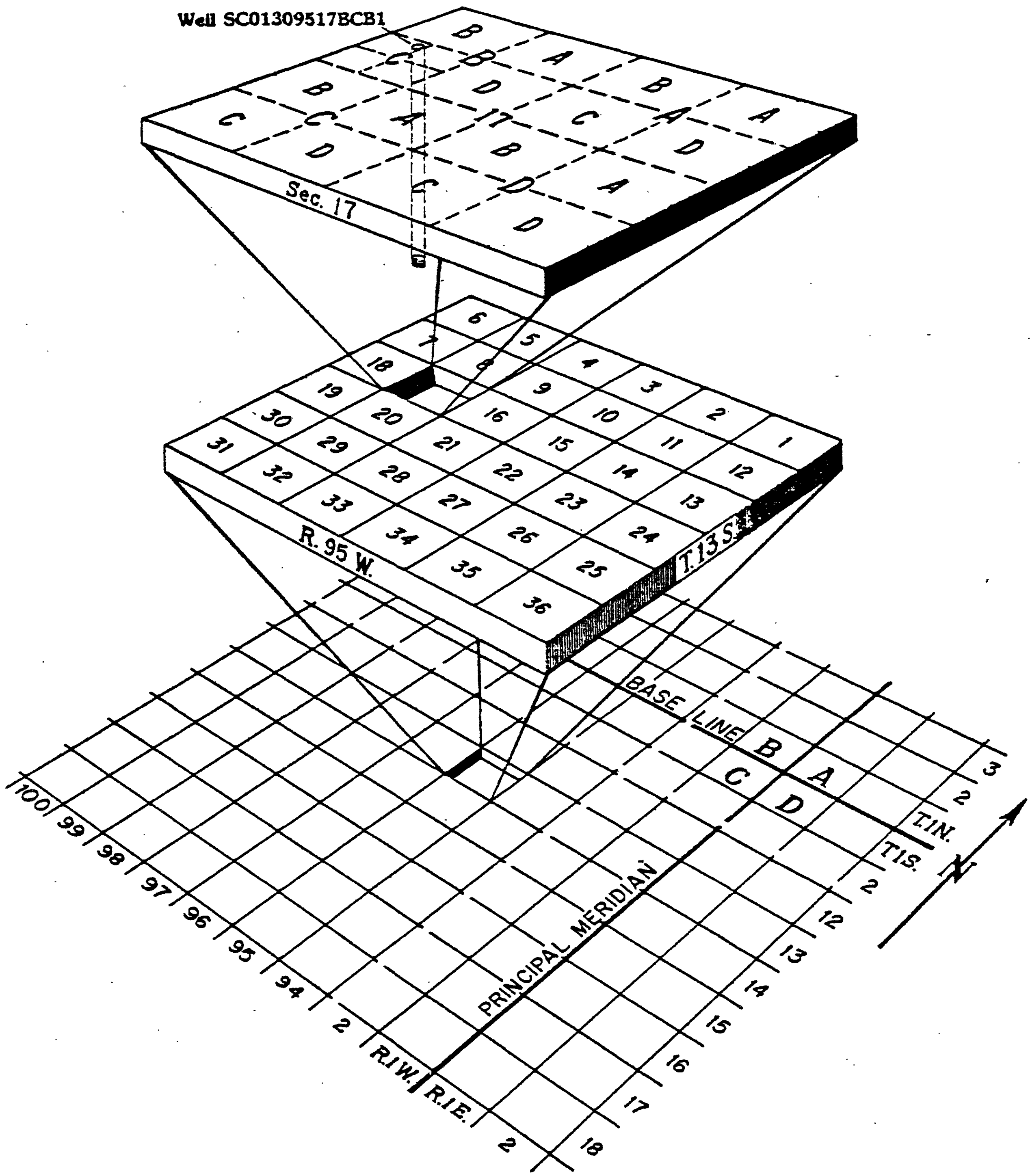

Figure 5.—System of numbering wells, springs, and gain-loss sites.