HYDROLOGY OF ALKALI CREEK AND CASTLE VALLEY RIDGE COAL-LEASE TRACTS, CENTRAL UTAH, AND POTENTIAL EFFECTS OF COAL MINING

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[Plates are in pocket]

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
	Length	
foot	0.3048	meter
inch	2.540	centimeter
mile	1.609	kilometer
yard	0.9144	meter
	Area	
acre	0.4047	square hectometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
acre-foot (acre-ft)	0.001233	cubic hectometer
	Rate	
inch per hour (in/h)	2.540	centimeter per hour
inch per year (in/yr)	2.540	centimeter per year
foot per year (ft/yr)	0.3048	meter per year
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
	Yield	
acre-foot per square mile (acre-ft/mi^2)	0.0004761	cubic hectometer per square kilometer
	Hydraulic Conductivity	
foot per day (ft/day)	0.0003528	centimeter per second
	Transmissivity	
square foot per day (ft^2/day)	0.09290	square meter per day
	Gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer
	Pressure	
pounds per square inch (lbs/in^2)	70.31	grams per square centimeter

Concentration of chemical constituents are given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of a chemical constituent as the weight (milligrams) of solute per unit volume (liter of water). One thousand micrograms per liter is equivalent to 1 milligram per liter. The concentration of chemical constituents, in parts per million, is about the same as the concentration in milligrams per liter for concentrations less than 7,000 mg/L.

Concentration of radioisotopes is given in picocuries per liter (pCi/L). A picocurie is a unit quantity of any radioactive nuclide in which 3.7×10^{-2} disintegrations occur per second.

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

Water and air temperature are given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8(°C)+32$$

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

HYDROLOGY OF ALKALI CREEK AND CASTLE VALLEY RIDGE COAL-LEASE TRACTS, CENTRAL UTAH, AND POTENTIAL EFFECTS OF COAL MINING

By R. L. Seiler and R. L. Baskin

ABSTRACT

The Alkali Creek coal-lease tract includes about 2,150 acres in the Book Cliffs coal field in central Utah, and the Castle Valley Ridge coal-lease tract includes about 3,360 acres in the Wasatch Plateau coal field, also in central Utah. Both the Alkali Creek and Castle Valley Ridge coal-lease tracts are near areas where coal is currently (1987) mined by underground methods from the Cretaceous Blackhawk Formation.

The Alkali Creek and Castle Valley Ridge areas have intermittent streams in which flow after snowmelt runoff is locally sustained into midsummer by springflow. The only perennial stream is South Fork Corner Canyon Creek in the Castle Valley Ridge area. Peak flow in both areas generally is from snowmelt runoff; however, peak flow from thunderstorm runoff in the Alkali Creek area can exceed that from snowmelt runoff. Surface-water quality in both areas changes as streamflow decreases.

Estimated annual source-area sediment yield was 0.5 acre-foot per square mile in the Alkali Creek lease tract and it was 0.3 acre-foot per square mile in the Castle Valley Ridge lease tract.

Ground water in the Alkali Creek area occurs in perched aquifers in the Flagstaff Limestone and in other formations above the coal-bearing Blackhawk Formation. The Blackhawk is a regional aquifer in parts of the Book Cliffs coal field; however, local topography probably controls the flow in the Blackhawk in the Alkali Creek coal-lease tract. Annual recharge to the Flagstaff Limestone in the Alkali Creek coal-lease tract is estimated to be about 25 to about 30 acre-feet and total annual ground-water recharge in the coal-lease tract is estimated to be about 48 to about 56 acre-feet. Most of the springs in the area are at formation contacts. Water moves more rapidly through the Flagstaff Limestone than through the Blackhawk Formation.

Ground water in the Castle Valley Ridge area occurs in perched aquifers. The Blackhawk Formation and Star Point Sandstone form a regional aquifer in the southern Wasatch Plateau coal field; however, this aquifer is a localized aquifer in the Castle Valley Ridge area. The principal source of recharge to the aquifers is snowmelt on outcrops. Faults may be major conduits and control the movement of ground water. Ground water discharges at formation contacts, between zones of differing permeability within a formation, near faults, and into mines.

Water sampled from 13 springs in the Alkali Creek area contained dissolved solids at concentrations ranging from 273 to 5,210 milligrams per liter. The least mineralized water discharges from the Flagstaff Limestone

and the most mineralized from the Blackhawk Formation or Quaternary unconsolidated deposits. Ionic composition of water from the Flagstaff is dominated by calcium bicarbonate and water from some springs discharging from the Blackhawk is dominated by sodium bicarbonate. Springwater from other formations is dominated by magnesium, calcium, sulfate, and bicarbonate.

Water sampled from 17 springs in the Castle Valley Ridge area contained dissolved solids at concentrations ranging from 208 to 579 milligrams per liter. Calcium and bicarbonate were the major dissolved constituents in water from most of the springs. The most mineralized water is from a spring in the Star Point Sandstone where the water composition is unlike that of any other springwater in the study area.

Analyses of water from active and inactive mines in the Book Cliffs and Wasatch Plateau coal fields indicate that increased mineralization, decreased pH, and change in water composition occur soon after a section of mine is abandoned. The composition of water from a recently abandoned part of an active mine in the Wasatch Plateau closely resembles that of water discharging from a nearby mine that has been abandoned for more than 30 years.

Mining of the Alkali Creek and Castle Valley Ridge coal-lease tracts likely will result in decreased pH and increased concentration of dissolved solids of the water that enters the mines. Even after mining, the water, especially in the Castle Valley Ridge area, may still meet Utah's drinking-water standards.

Land-surface subsidence after the mines are abandoned will potentially have the greatest effect on the hydrology of the areas because subsidence-caused fractures divert surface- and ground-water flow to the mine workings. This could eventually result after mining the coal of the Alkali Creek and Castle Valley Ridge coal-lease tracts, because subsidence fractures have been observed above coal mines near both tracts. The discharge from some springs could decrease or cease if perching layers are fractured. Springs are the major source of water to both stock and wildlife in both areas.

INTRODUCTION

During March 1985 to January 1987, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management, studied the hydrology in the area of the Alkali Creek and Castle Valley Ridge coal-lease tracts in central Utah (fig. 1). The study was done to provide hydrologic information needed by the U.S. Bureau of Land Management to prepare environmental assessments prior to leasing the coal so that the effects of mining on the water resources of the two areas can be predicted and mitigated.

The Alkali Creek and Castle Valley Ridge coal-lease tracts are in the Book Cliffs and Wasatch Plateau coal fields. Coal is recovered by underground mining of the Cretaceous Blackhawk Formation in these coal fields.

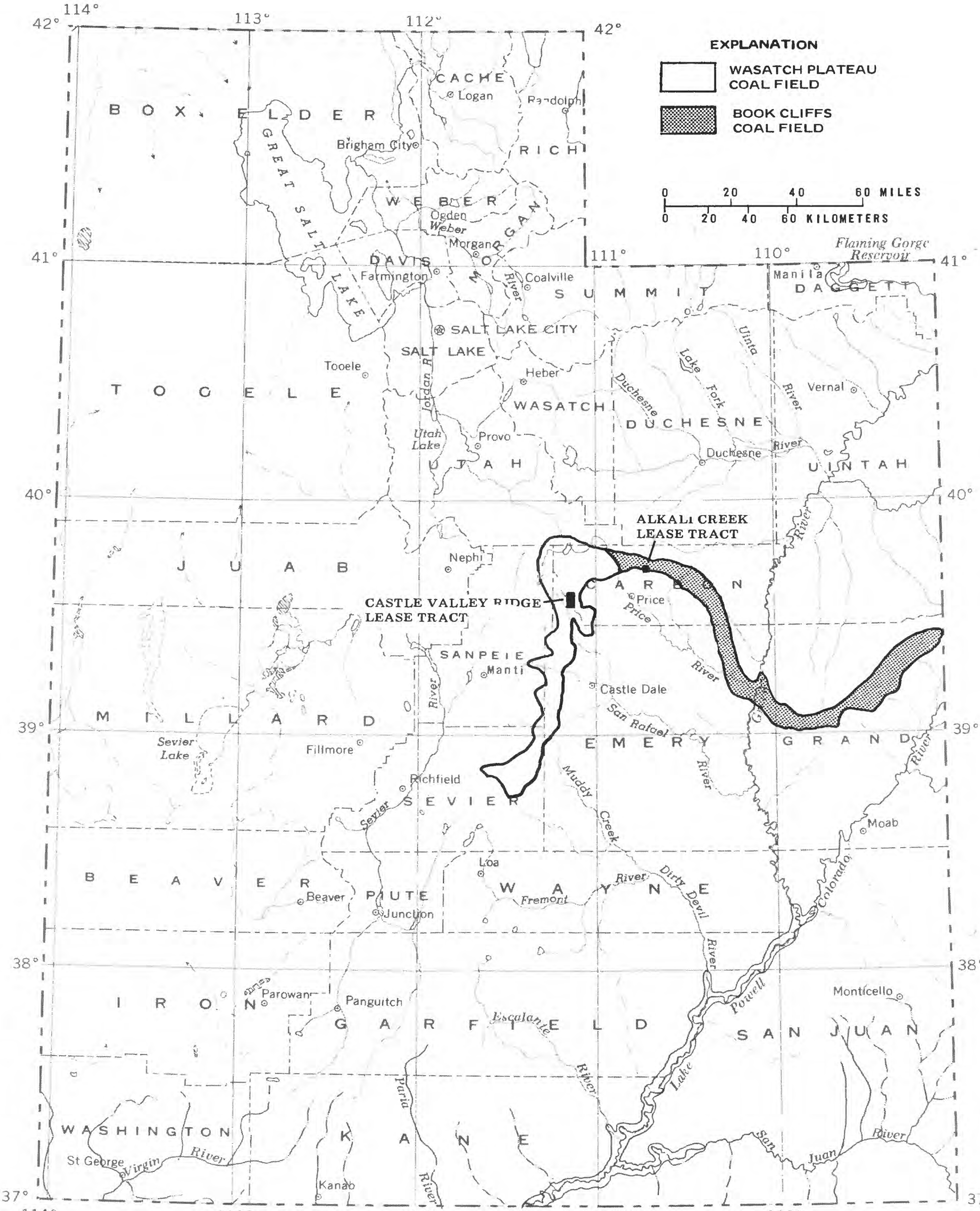

Figure 1.—Location of Alkali Creek and Castle Valley Ridge coal-lease tracts.

Purpose and Scope

The purpose of this report is to describe the hydrology and potential effects of coal mining of the Alkali Creek and Castle Valley Ridge coal-lease tracts in central Utah, based on the results of the study conducted from March 1985 to January 1987. The primary objective of the report is to describe aquifer characteristics, recharge and discharge relations, and chemical quality of streamflow and ground water within and above the coal-bearing strata. A second objective is to estimate peak and mean streamflow and sediment yields from drainages in the coal-lease tracts. A third objective is to estimate qualitatively the potential effects of coal mining on the hydrologic system.

Methods of Investigation

Water-discharge measurements were made of the streams and springs. Streamflow samples to determine suspended-sediment concentrations also were collected. Data needed to characterize the ground-water system were obtained by: (1) Analyzing data from coal-exploration holes on the Alkali Creek and Castle Valley Ridge coal-lease tracts; (2) making an extensive spring inventory; and (3) sampling water from streams, springs, and underground mines for chemical analyses. The geohydrologic data for this study are presented in tables 3-7 (at back of report). Regression equations developed for Utah streams (Thomas and Lindskov, 1983; Christensen and others, 1986) were used to estimate peak and average streamflow from ungaged drainages. Sediment yields from the study areas were estimated using the Pacific Southwest Inter-Agency Committee method as modified by Frickel and others (1975, p. 17).

Because the coal-lease tracts are small, some of the data necessary to characterize the hydrologic system were collected outside the boundaries of the coal-lease tracts. In this report, the Alkali Creek and Castle Valley Ridge study areas are defined as the actual coal-lease tracts plus surrounding areas within 1 to 2 miles of the boundary of the tracts.

Previous Investigations

Hydrologic data specifically for the Alkali Creek and Castle Valley Ridge coal-lease tracts were not available from previous studies; however, both tracts are part of larger areas that have been studied. Regional studies have included those by Waddell and others (1981) who conducted a reconnaissance of the hydrology of the Book Cliffs and Wasatch Plateau coal fields, and Waddell and others (1986) who describe the hydrology of the Price River basin. Lines and others (1984) provided hydrologic information for Area 56 of the Northern Great Plains and Rocky Mountain coal provinces, which includes the Book Cliffs and Wasatch Plateau coal fields. They also provided a bibliography of hydrologic reports available for Area 56. Danielson and others (1981) described the hydrology of the upper drainages of Huntington and Cottonwood Creeks, which include part of the Castle Valley Ridge coal-lease tract.

Several geologic investigations have been made of areas that include the coal-lease tracts. Spieker (1931) mapped the geology of the Wasatch Plateau coal field, and Doelling (1972) summarized geologic investigations of coal, uranium, oil and gas, and other natural resources of the central Utah coal fields. Nethercott (1985) prepared a geologic map of the Deadman Canyon quadrangle which includes the Alkali Creek coal-lease tract. During 1985-86, the U.S. Bureau of Land Management and the U.S. Geological Survey drilled several exploration holes to evaluate the coal resources of the tracts.

Site-Numbering System

The system of numbering wells, springs, and other sites in Utah is based on the cadastral land-survey system of the U.S. Government. The site number, in addition to designating the well or spring, describes its position in the land net. By the land-survey system, the State is divided into four quadrants by the Salt Lake base line and meridian, and these quadrants are designated by the upper-case letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parenthesis. The number after the parenthesis indicates the section, and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres[1]. The letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract, the letter "S" preceding the serial number denotes a spring. If a well or spring cannot be located within a 10-acre tract, one or two location letters are used and the serial number is omitted. Thus, (D-13-11)10bac-S1 designates the first spring visited in the SW$\frac{1}{4}$NE$\frac{1}{4}$NW$\frac{1}{4}$ sec.10, T.13S., R.11E. Other sites where hydrologic data were collected are numbered in the same manner, but three letters are used after the section number and no serial number is used. The numbering system is illustrated in figure 2.

Acknowledgments

The authors express their appreciation to Joe Iriart for access to his land on Alkali Creek for data-collection activities and to Robert Eccli (U.S. Fuels Company) and Christopher Allen (Soldier Creek Coal Company) who acted as guides underground. Lois Arnow of the Garrett Herbarium, University of Utah, provided the plant identifications.

STRATIGRAPHY APPLICABLE TO BOTH AREAS

Even though the two study areas are in different coal fields, the stratigraphy is similar and coal is mined from the same formation in both areas. Strata of the Mancos Shale, Star Point Sandstone, Blackhawk Formation, Castlegate Sandstone, Price River and North Horn Formations, and Flagstaff Limestone are exposed in the study areas. The formations range in age from Cretaceous to early Tertiary and are all of sedimentary origin. Depositional

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[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

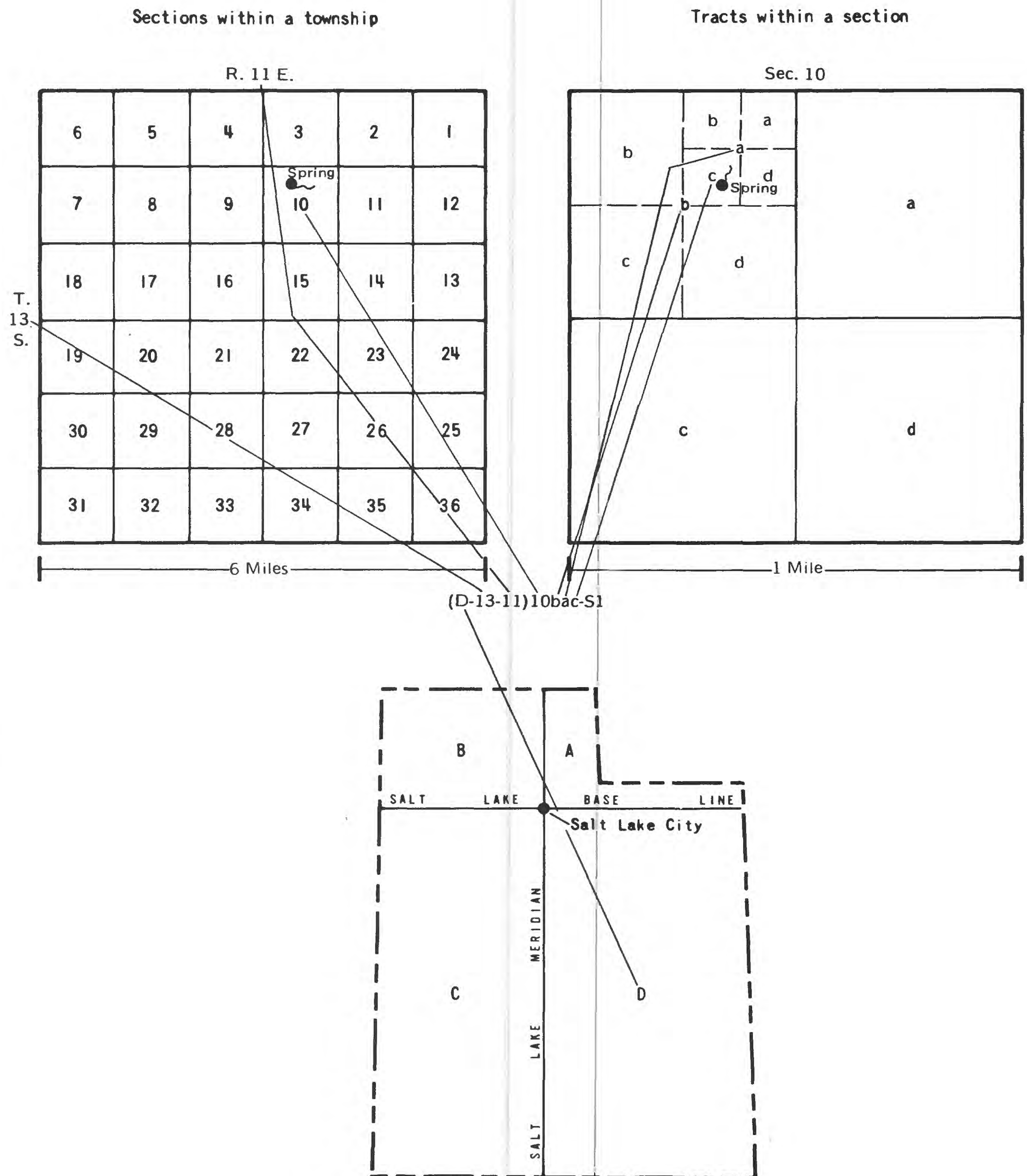

Figure 2.—Site-numbering system used in Utah.

environments have been shallow seas and associated near-shore beaches, deltas, delta plain swamps, river channels, flood plains, and freshwater lakes (Nethercott, 1985). The beds are nearly flat-lying.

The Cretaceous Mancos Shale is the oldest formation exposed in the study areas. Outcrops consist of nonresistant, slightly calcareous and gypsiferous, gray, marine shale. The Mancos intertongues with the Star Point Sandstone and the lower part of the Blackhawk Formation. The Mancos Shale was deposited in a shallow saline sea.

The Cretaceous Star Point Sandstone intertongues with Mancos Shale and the Blackhawk Formation. The Star Point is a light gray to white, massive to thin-bedded marine sandstone. It grades downward from a massive cliff-forming unit at the top to thin interbedded sandstone and shale at the base and is about 350 to 450 feet thick.

The Cretaceous Blackhawk Formation, which contains the coal beds, overlies the Star Point Sandstone and Mancos Shale. Most of the coal is contained in three slope forming members consisting of coal, mudstone, siltstone, and thin-bedded sandstone. The other three members of the Blackhawk Formation consist mainly of cliff-forming sandstone. The Blackhawk Formation is about 900 to 1,100 feet thick.

Coal deposits of the Blackhawk Formation underlie most of the acreage in the study areas, and are commonly exposed along the sides of canyons. The deposits in the Alkali Creek area are fairly well defined by outcrops throughout the area which exhibit distinct contacts with overlying and underlying strata. Deposits in the Castle Valley Ridge area are not as well defined because of complex intertonguing of beds during deposition and post-depositional faulting (Courtney Williamson, U.S. Geological Survey, written commun., 1986).

The Cretaceous Castlegate Sandstone overlies the Blackhawk Formation and consists of a white to gray, massive, resistant sandstone. The Castlegate forms cliffs and is about 200 to 250 feet thick where it crops out.

The Cretaceous Price River Formation overlies the Castlegate Sandstone and is subdivided into two members. The lower slope-forming member consists of mudstone, siltstone, and shale, with interbeds of sandstone. The upper cliff-forming member consists of sandstone with minor beds of shale.

The North Horn Formation overlies the Price River Formation. The North Horn is a gray to gray-green calcareous, silty shale with tan to yellow-gray, fine-grained sandstone with minor beds of limestone and conglomerate. The unit generally forms slopes, but beds of limestone and channel-fill sandstone locally form small ledges. The unit is Late Cretaceous to early Paleocene in age.

Spieker (1931) mapped the Wasatch Formation as overlying the Price River Formation on Castle Valley Ridge. H. H. Doelling (Utah Geological and Mineral Survey, oral commun., April 1986) states that Spieker grouped the North Horn Formation, Flagstaff Limestone, and Colton Formation together as the Wasatch Formation when he mapped the area. Stokes (1964) and Witkind and others

(1978) map the North Horn as the youngest formation in the Castle Valley Ridge coal-lease tract.

The Tertiary Flagstaff Limestone overlies the North Horn Formation and is the youngest formation exposed in the Alkali Creek coal-lease tract. The Flagstaff consists of interbedded light-gray to buff limestone, variegated shale, and fine-grained, reddish-brown, calcareous sandstone. The limestone overlies the sandstone.

The Quaternary unconsolidated deposits are comprised of alluvium, colluvium, slope wash, and pediment gravels in the Alkali Creek area. The thickest and coarsest deposits are generally closest to the cliff faces. The deposits range in size from clay to boulder sized clasts and cover many of the slopes of the base of the Book Cliff escarpment. Deposits in the Castle Valley Ridge area range in thickness from 5 to 100 feet (Spieker, 1931) and consist chiefly of narrow belts of coarse material along stream channels.

ALKALI CREEK STUDY AREA

Physical Setting

The location of the Alkali Creek coal-lease tract is shown in figure 3; the tract is in the Book Cliffs coal field between Coal Creek and Soldier Creek. The tract includes about 2,150 acres and is adjacent to an area actively mined by the Soldier Creek Coal Company. Coal was mined in the Knight Ideal Mine to the west of the lease tract but that mine is now (1987) abandoned.

Topography and Drainage

Parts of the study area are extremely steep and rugged (pl. 1 and fig. 4). Land-surface altitude in the coal-lease tract ranges from about 6,900 feet along the south edge to about 8,340 feet in the northern part of the tract (pl. 1). Vertical sandstone cliffs, some more than 100 feet high, surround most of the study area. The terrain is less rugged in Whitmore Park in the northernmost part of the study area.

Streams have eroded deep, steep-sided canyons into the cliffs. All the drainages along the east side of the coal-lease tract combine with other small drainages east of the tract and discharge into Soldier Creek about 1.3 miles downstream from the Soldier Canyon Mine (pl. 1). Several small drainages in the western part of the tract discharge to Coal Creek. Small drainages in the southern part of the tract discharge to the upstream reaches of Alkali Creek.

Geologic Structure

Nethercott (1985) prepared a geologic map of an area which includes the Alkali Creek lease tract. Some of the geologic formations exposed in the Alkali Creek area are shown in figure 5. No major faults are indicated in the literature and no faults have been encountered in the Soldier Canyon Mine (Thomas Paluso, Soldier Creek Coal Company, oral commun., January 1986). A series of short, inferred, and exposed faults is located about 5 miles east-

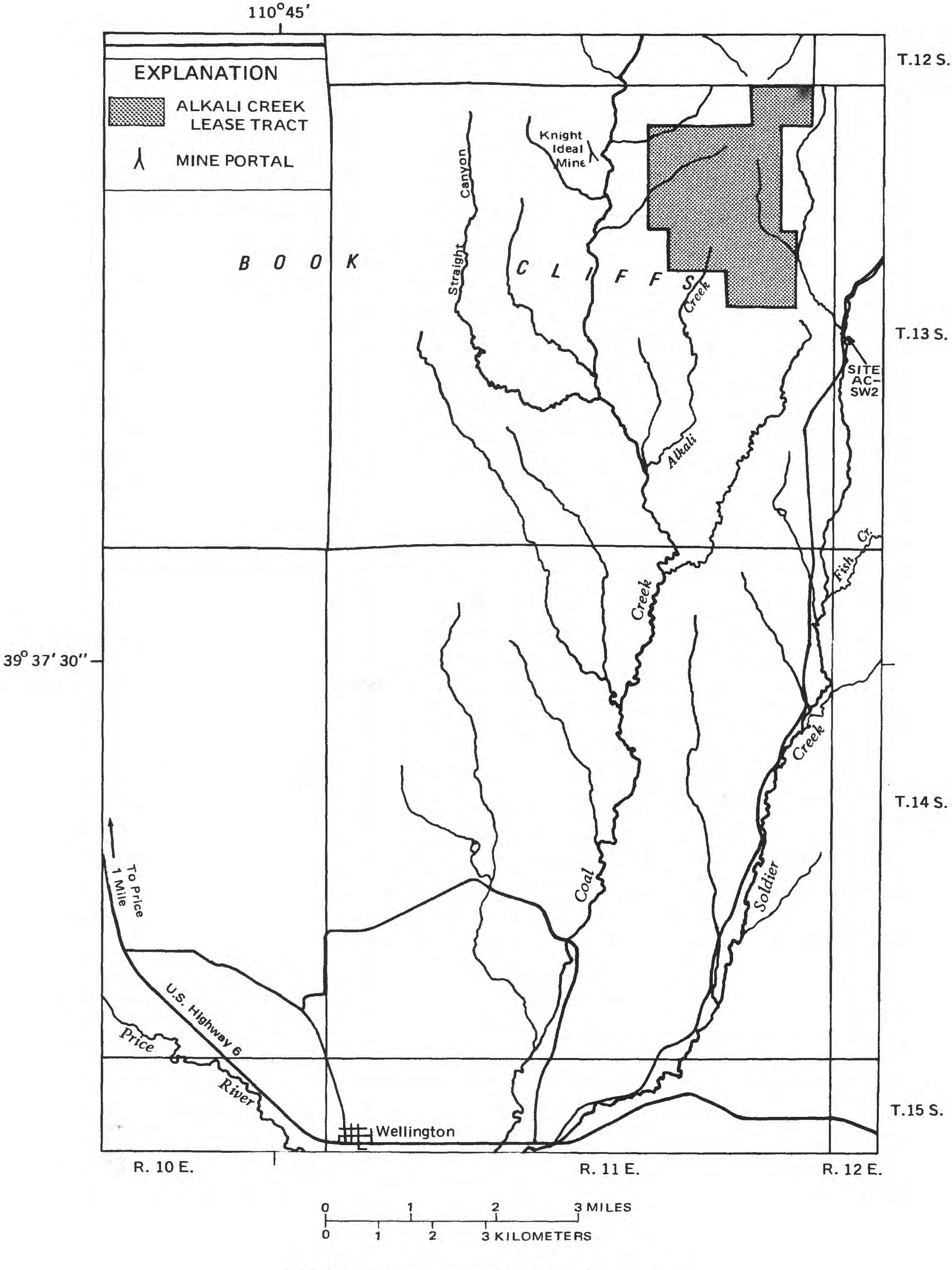

Figure 3.—Location of Alkali Creek lease tract.

Figure 4.—View of part of the Alkali Creek lease tract showing topography and vegetative cover.

northeast of the tract (Witkind and others, 1978). Jointing and fractures have been observed in the mine but there is no apparent pattern. Small faults may be present along burned-coal outcrops where slumping has occurred, but such faults probably are superficial and do not extend past the burned coal. Strata within the area dip 4 to 7 degrees to the north-northeast (Nethercott, 1985).

Climate

The Alkali Creek study area is semiarid; the mean annual precipitation is about 12 to 14 inches with about 6 inches falling from May to September (U.S. Weather Bureau, 1963). Free water-surface evaporation is about 40 in/yr (Farnsworth and others, 1982, map 3).

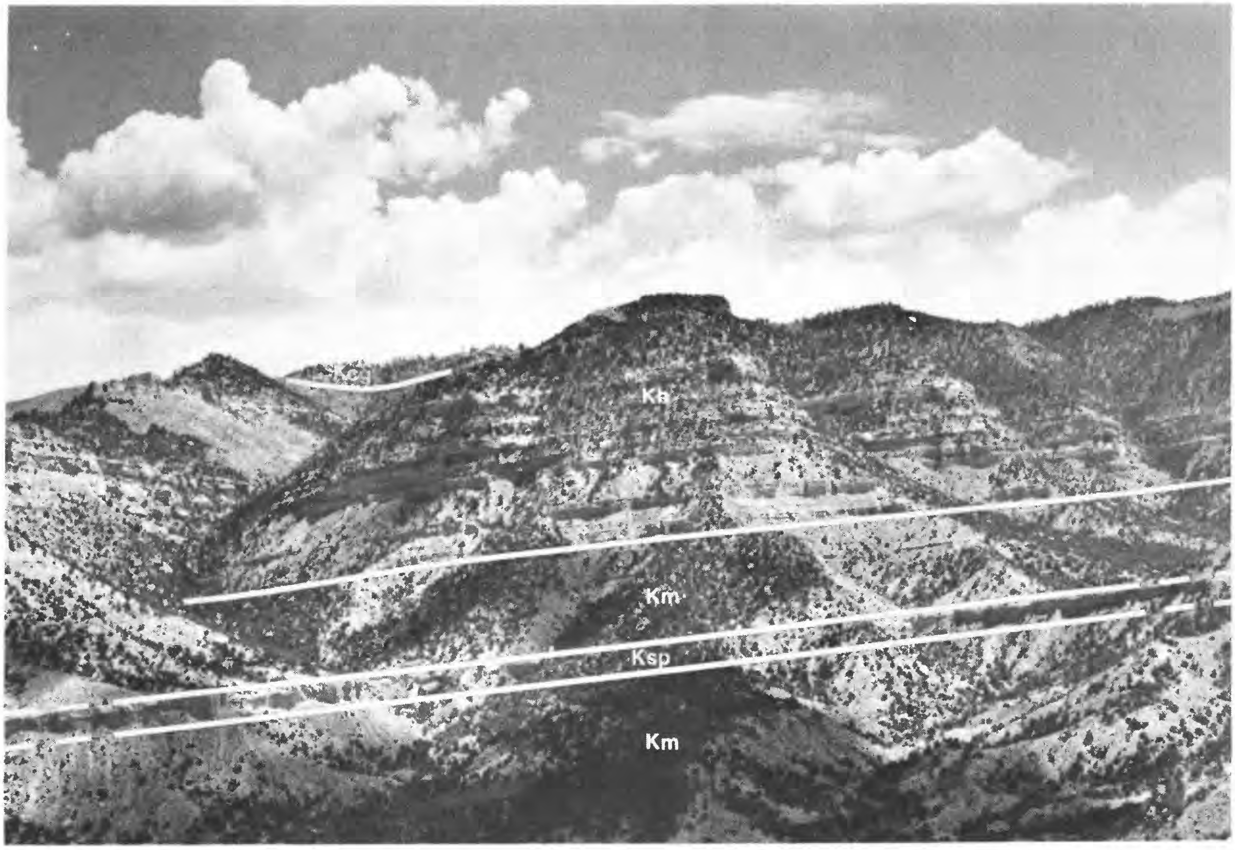

Figure 5.—View (facing northeast) of some geologic formations exposed in the Alkali Creek study area (geologic units: Kcg, Castlegate Sandstone; Kb, Blackhawk Formation; Ksp, Star Point Sandstone (interbed); Km, Mancos Shale).

At the lower altitudes near the study area, the greatest precipitation falls in August and September when intense thunderstorms are common. These storms commonly cause flashfloods. The intensity of a 1-hour storm with a recurrence interval of 2 years is about 0.60 in/h; for a 1-hour storm with a 100-year recurrence interval, it is about 1.50 in/h (Miller and others, 1973, table 11 and figs. 19, 24, 25, 30).

The mean monthly air temperature and precipitation (1958-85) at the Sunnyside weather station, about 17 miles southeast of the Alkali Creek coal-lease tract, are presented in figure 6. From December through February, the mean monthly temperature is below freezing.

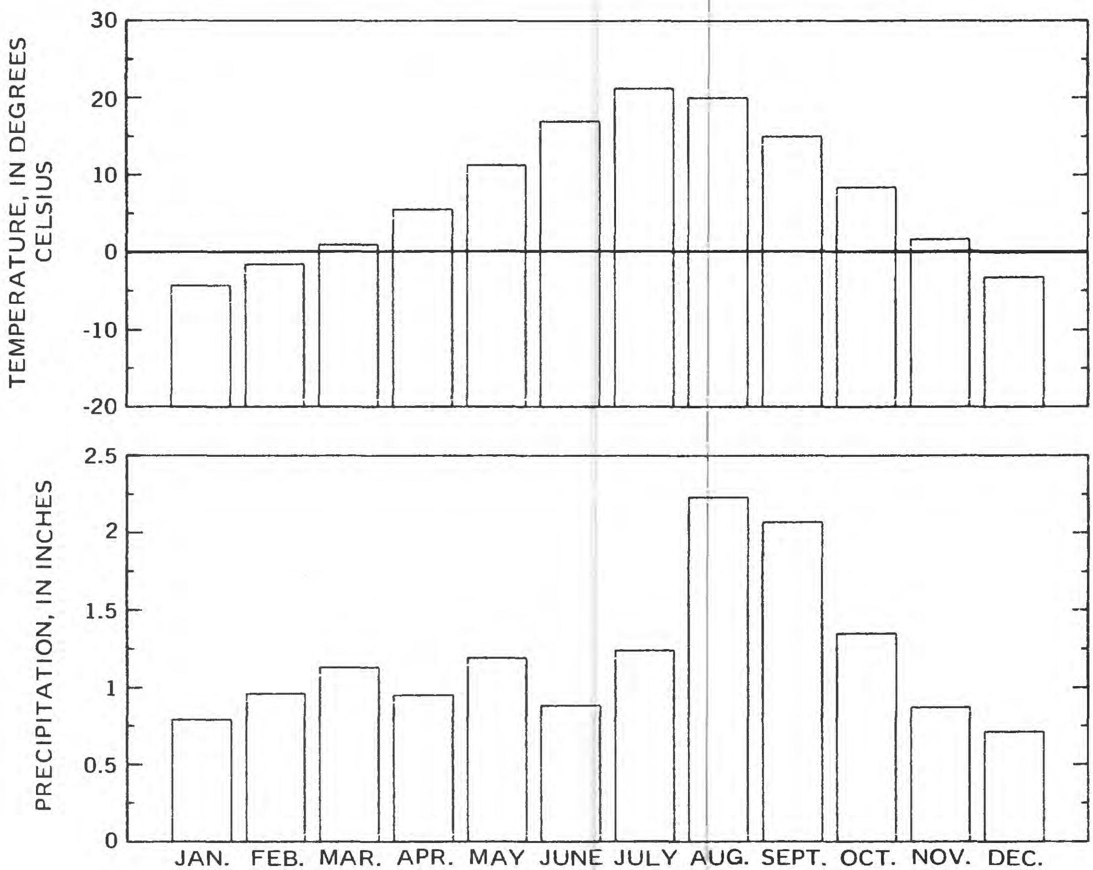

Figure 6.—Mean monthly temperature and precipitation at Sunnyside, 1958-85 (data from U.S. Weather Bureau, 1958-66; U.S. Environmental Science Services Administration, Environmental Data Service, 1967-70; and National Oceanic and Atmospheric Administration, Environmental Data Service, 1971-85).

Vegetation

At the higher altitudes above the cliffs, groves of quaking aspen (Populus tremuloides) are scattered among the sagebrush (Artemesia tridentata) and Douglas hawthorn (Crataegus Douglasii). Along the drainages (fig. 4), Douglas-fir (Abies concolor), yellow pine (Pinus ponderosa), bigtooth maple (Acer grandidentatum), and box elder (Acer negundo) are common. Along the drainages in the lower part of the study area, phreatophytes such as willows (Salix sp.) form dense thickets. At the base of the cliffs, pinyon (Pinus edulis) and juniper (Juniperus communis) are common.

Land Use

Much of the land in the study area is used for livestock grazing during the summer months. Recreational uses of the area include hunting. Coal is mined at the Soldier Canyon Mine to the east of the coal-lease tract.

Hydrology

Surface Water

All of the drainages in the study area (fig. 3, pl. 1) contain intermittent streams that discharge into Coal and Soldier Creeks, tributaries of the Price River. Chemical analyses, discharge, and suspended-sediment concentrations for a streamflow site (site ACSW2) near the Alkali Creek coal-lease tract are presented in table 3.

Streamflow after snowmelt runoff is sustained by springflow into mid-summer. Short reaches of the streams near springs may be perennial and provide a year-round water supply to wildlife. These flows commonly seep underground and disappear within 200 feet of the spring.

There are no continuous records of flow for the small streams within the study area; however, the periods of peak flow in these streams are probably early spring and late summer, the same as at site ACSW1 on Soldier Creek. A hydrograph of daily streamflow at site ACSW1 for water years 1978-84 is shown in figure 7. Peak flows in Soldier Creek occur in March or April in response to snowmelt and in the late summer in response to thunderstorms. In some years, peak flow from a thunderstorm is greater than the peak flow from snowmelt. The peak flow for the period of record was 472 ft^3/s on September 23, 1981; the maximum daily flow was 88 ft^3/s on May 25, 1983.

Thunderstorm runoff can greatly increase the streamflow in the Price River basin. Although streamflow was not measured immediately after a storm, a reach of the stream upstream from site ACSW2 (pl. 1) was visited the day after a thunderstorm in July 1985. The stream channel was about 1 foot wide when observed and the flow at site ACSW2 was 0.11 ft^3/s. Sediment deposited on the sides of the stream channel indicated the stream had been about 10 feet wide during the storm runoff. Mundorff (1972, p. 20) described the effects of an intense summer thunderstorm on streamflow at Drunkards Wash at State Highway 10, about 20 miles southwest of the coal-lease tract; streamflow at 9:20 a.m. on August 29, 1969 was 2.5 ft^3/s and about 3 hours later was 150 ft^3/s.

Peak and average streamflow can be estimated for the small drainages using regression equations developed for the area by Thomas and Lindskov (1983, tables 5 and 6) and Christensen and others (1986, table 3). The equations used to compute peak and average streamflow for streams in a basin with a mean altitude of less than 8,000 feet are listed in table 1. Refer to table 5 of Thomas and Lindskov (1983) for sites in basins with a mean altitude that exceeds 8,000 feet. The variables needed for the equations are the contributing drainage area, mean basin altitude, mean annual precipitation, and main-channel slope.

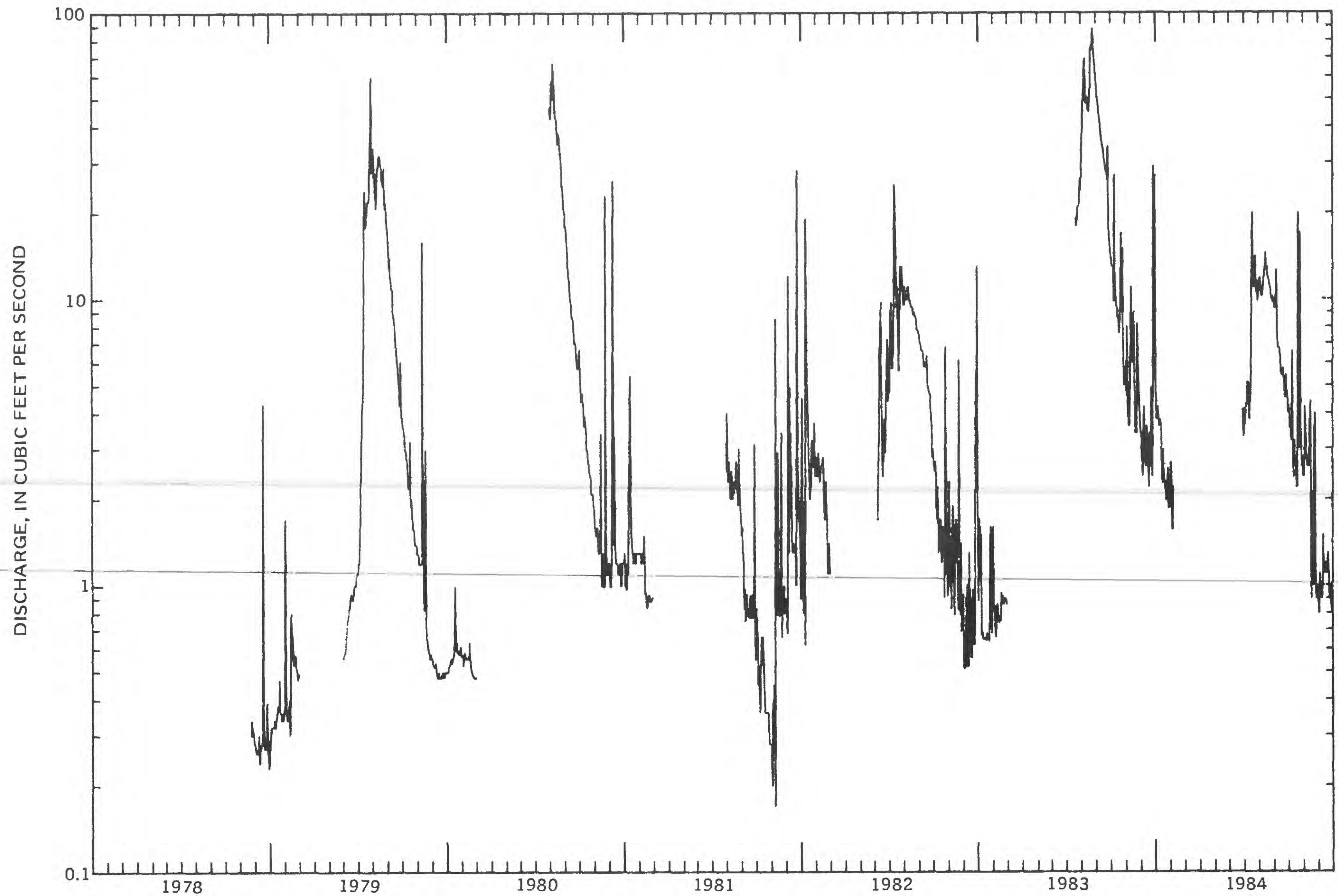

Figure 7.—Daily mean discharge at site ACSW1, Soldier Creek below mine, near Wellington, water years 1978-84. Station generally not operated during winter months.

Table 1.—Regression equations used to compute peak and average streamflow from ungaged tributaries of the Alkali Creek area

[Q, streamflow, in cubic feet per second; A, drainage area, in square miles; E, mean basin altitude, in thousands of feet; P, mean annual precipitation, in inches; and S, main-channel slope, in feet per mile]

Recurrence interval, in years	Equation
	Peak streamflow (Thomas and Lindskov, 1983, table 6)
10	$Q = 23{,}700A^{0.433}E^{-2.23}$
50	$Q = 61{,}000A^{0.375}E^{-2.19}$
100	$Q = 83{,}100A^{0.356}E^{-2.17}$
	Average streamflow (Christensen and others, 1986, table 3)
-	$Q = 0.000208A^{0.709}P^{1.46}S^{0.544}$

The contributing drainage area in square miles, A, is determined by planimetry using a topographic map. The mean basin altitude, in thousands of feet, E, is determined by using a transparent grid over the map. The altitude of a minimum of 20 equally spaced points is tabulated and the average altitude of the points is determined. The mean annual precipitation, in inches, P, is obtained from U.S. Weather Bureau (1963). The main-channel slope, in feet per mile, S, is the slope between two points at 10 and 85 percent of the maximum distance from the stream site to the drainage divide. It is computed by dividing the difference in altitude, in feet, by the distance, in miles, between the two points.

The average flow and the 10-year peak flow at site ACSW2 were computed to demonstrate the use of the equations in table 1. The contributing drainage area (A) was computed to be 3.57 mi^2, and the mean basin altitude (E) was computed to be 7.63 thousand feet. The mean annual precipitation (P) is 12 to 14 inches, and the main-channel slope (S) was computed to be 500 ft/mi. These values were substituted into the appropriate equation from table 1 and the 10-year peak flow was estimated to be 443 ft^3/s and the average flow was estimated to be between 0.57 and 0.71 ft^3/s.

Ground Water

The ground-water system in the Alkali Creek study area was principally defined using data from springs and coal-exploration holes. In the summer of 1986, the U.S. Bureau of Land Management and the U.S. Geological Survey drilled two coal-exploration holes in the study area. Results of chemical analyses and discharge measurements of springs and mines are given in tables 4, 5 and 6. Location of the springs and exploration holes are shown on plate 1.

Aquifer characteristics

Ground water in the Book Cliffs coal field area occurs in perched aquifers and in a regional aquifer in the Blackhawk Formation. Little is known about the hydraulic characteristics of aquifers in the Alkali Creek area. The Flagstaff Limestone contains a perched aquifer. The Flagstaff probably is a cavernous aquifer with a small storage coefficient (Waddell and others, 1986, p. 28). Springs discharge from the Flagstaff at the contact with the North Horn Formation.

The potentiometric surface in the North Horn Formation is several hundred feet above that in underlying formations (Waddell and others, 1986, p. 41), which indicates that it also is perched. Two springs in the Alkali Creek area discharge from the North Horn Formation at the contact with the Price River Formation. Exploration hole AC-2 first encountered water at a depth of 375 feet, near the contact between the North Horn and Price River Formations, which indicates that the upper few hundred feet of the North Horn is unsaturated.

No springs discharge from the Price River Formation in the Alkali Creek study area. Therefore, the Price River Formation is probably unsaturated in the study area even though exploration hole AC-1 encountered some moisture in the Price River Formation at a depth of 140 feet (at a contact between sandstone and shale). About 4 miles east of the coal-lease tract, the Price River Formation is saturated, and the potentiometric surface at well (D-13-12)11dad-2 is at an altitude of about 7,085 feet. Waddell and others (1986, p. 41) conducted a slug test using this well and estimated that the transmissivity in the formation is about 0.07 ft^2/day.

Two springs in the Alkali Creek coal-lease tract discharge from the Castlegate Sandstone. About 3 to 5 miles east of the coal-lease tract, the Castlegate is saturated; the altitude of the potentiometric surface at well (D-13-12)10abb-1, completed in the upper Castlegate, is 7,381 feet and at well (D-13-12)24daa-1, completed in the lower Castlegate, it is 7,017 feet. Waddell and others (1986, p. 41) conducted slug tests on these wells and estimated that the transmissivity in the upper Castlegate is 0.02 ft^2/day and in the lower Castlegate it is 0.003 ft^2/day.

Much of the Blackhawk Formation is saturated and forms a regional aquifer in parts of the Book Cliffs coal field; however, the local topography probably controls the flow in the Blackhawk in the Alkali Creek coal-lease tract. Water discharges from coal beds in the Blackhawk into the Soldier Canyon Mine and other mines in the Book Cliffs and Wasatch Plateau coal fields. Several springs discharge from the Blackhawk in the Alkali Creek area. Water in the Blackhawk at some sites is under artesian pressure and discharges through fractures in other formations. The Blackhawk was unsaturated near the cliff face at sites AC-1 and AC-2 (pl. 1) in August 1986.

Aquifer-test data are not available; however, hydraulic diffusivity, the ratio of transmissivity to storage coefficient (T/S), can be estimated from records of spring discharge. The time required for spring discharge to decrease to 0.1 of the original discharge is called the recession index and is inversely related to the hydraulic diffusivity (T/S) and directly related to the recharge area. For a spring at site ACS12, the time is greater than 365 days (Waddell and others, 1986, p. 27-28); thus the hydraulic diffusivity is small or the recharge area is large or both.

Recharge

The principal sources of recharge to the aquifers in the study area are snow and rainfall on outcrops and local alluvium. Waddell and others (1986, p. 43) calculated the recharge rate to the Flagstaff Limestone in an area a few miles east of the coal-lease tract. They assumed that recharge to the Flagstaff was equal to discharge, which is about 9 percent of the annual precipitation on the outcrop area. In the Alkali Creek coal-lease tract, the outcrop area of the Flagstaff is about 275 acres. The average annual precipitation on the Flagstaff is 12 to 14 inches; thus, the annual recharge to the Flagstaff from precipitation is estimated to be about 25 to about 30 acre-ft.

Annual recharge directly from precipitation on the Blackhawk Formation in the study area also is small. The Blackhawk Formation crops out in about 810 acres, but the rate at which precipitation infiltrates into the Blackhawk may be slow. Thus, the volume of recharge to the Blackhawk in the coal-lease tract probably is less than the volume of recharge to the Flagstaff Limestone.

Total recharge to all other aquifers in the Alkali Creek area is probably not much larger than recharge to the Flagstaff Limestone. Annual recharge from precipitation on the coal-lease tract can be estimated if two assumptions are made: (1) Recharge equals discharge, and (2) the ratio of discharge per unit area from the Flagstaff to discharge per unit area from the Blackhawk Formation and other formations is 7.5, or the same in the coal-lease tract as in the Dugout Creek drainage as discussed later under the heading "Discharge". If these assumptions are used, total annual recharge directly from precipitation in the coal-lease tract to the Blackhawk and other formations, except the Flagstaff, is estimated to be about 23 to about 26 acre-ft and for all formations it is estimated to be about 48 to about 56 acre-ft.

Annual recharge by downward percolation to the aquifers that underlie the Flagstaff Limestone and North Horn Formation is probably negligible. The shale layers in the North Horn may have small values of hydraulic conductivity, thus forming effective barriers to downward movement of water. In the Alkali Creek area, there may be practically no recharge to the Blackhawk Formation from the overlying formations. In other areas to the northeast near faults, recharge from above could be larger because of fractures and jointing that allow downward movement of water from upper aquifers.

Seepage from intermittent streams may recharge formations exposed in the stream channels. Seepage from Soldier Creek recharges the Price River Formation and Castlegate Sandstone; Waddell and others (1986, p. 43-44) measured seepage losses where Soldier Creek crosses outcrops of these formations.

Movement

A contour map of the potentiometric surface of the aquifer in the Blackhawk Formation could not be prepared because of the limited water-level data. Water levels for three sites described by Waddell and others (1986, p. 41) indicate that the gradient is northward away from the Book Cliffs and averages 42 ft/mi. The discharge point of the water moving away from the Book Cliffs is not known. At some locations near the coal-lease tract, water in the Blackhawk Formation is under artesian pressure and where fractures exist the water can move upwards into overlying formations or to the land surface. In the Alkali Creek area, the gradient may be towards deeply incised canyons where water is discharged to springs or towards the active mine workings where the Blackhawk Formation is being dewatered.

Water moves slowly through the Blackhawk Formation. This is indicated by the fact that Waddell and others (1986, p. 27) determined little seasonal change in discharge from a spring at site ACS12. The average velocity of the ground-water movement can be calculated from the hydraulic gradient, hydraulic conductivity, and porosity of the aquifer material. Values of hydraulic conductivity and porosity are not available for the Blackhawk in the Alkali Creek area; however, Lines (1985, p. 13) presents a range of values of hydraulic conductivity and porosity for the Blackhawk in the Trail Mountain area. If the gradient of 42 ft/mi and the range of porosity and hydraulic conductivity values for the Trail Mountain area are used, then the average velocity of the ground-water would range from near zero to about 1 ft/yr.

Chemical data indicate the rate of ground-water movement is less than 290 ft/yr. The concentration of tritium indicates water in the Blackhawk Formation in the Soldier Canyon Mine has been in the ground more than 50 years. The nearest recharge area on the face of the Book Cliffs is about 2.75 miles away from where the water sample was collected; thus, the maximum velocity is about 290 ft/yr.

Water in the Flagstaff Limestone generally travels only short distances from the recharge site before discharging. The downward movement of water is blocked by less permeable beds of shale or mudstone in the North Horn Formation. Springs discharging from the Flagstaff have a large seasonal fluctuation in discharge, which indicates that water moves rapidly through the formation, or the springs are near recharge areas, or both.

Discharge

Spring discharge was measured and water-quality data were collected at all discharging springs (table 4). The location of all springs where data were collected are shown on plate 1. Most of the springs are near formation contacts, which indicates that the contacts mark the boundary between formations with different permeability. Springs in the study area generally issue from the base of large sandstone cliffs. Springs discharging from the Blackhawk Formation are commonly in stream channels.

The measured spring discharges ranged from 0.2 to 53.5 gal/min. In late July 1985, the total measured discharge from all the springs in the coal-lease tract was 9 gal/min. If this value is assumed to be the average rate for the entire year, the annual discharge from the coal-lease tract would be only about 14 acre-ft.

All or most of the water discharged from the springs in the study area in July 1985 was either consumed by evapotranspiration or lost to infiltration before reaching Coal or Soldier Creeks. It is not known if all the water discharged from the spring at site ACS1 at that time, 3.2 gal/min, was lost before reaching Soldier Creek.

As coal is mined in the Soldier Canyon Mine, water from the Blackhawk Formation seeps in along the active face; however, inflow ceases soon afterwards. The ceiling of most of the mine was observed to be dry in January 1986. Discharge from a bolt hole in the mine, on the border between sections (D-13-11)1 and (D-13-11)12, ranged from 1.2 to 2.8 gal/min from June 1985 to August 1986 (David Stillman, Soldier Creek Coal Company, oral commun., September 1986). Excess water from the mine is discharged into Soldier Creek. On June 2, 1986, at site SC the mine discharge was 367 gal/min. The average discharge from the mine is about 100 gal/min or an annual discharge of about 160 acre-ft (Thomas Paluso, Soldier Creek Coal Company, oral commun., January 1986).

Soldier Creek gains where it crosses the North Horn and Blackhawk Formations, indicating that water from these formations is entering the stream (Waddell and others, 1986, p. 43-44). An unknown proportion of the water that enters the stream as it crosses the North Horn is actually from the Blackhawk, which is under artesian pressure and discharges through fractures in the North Horn.

Waddell and others (1986, table 10) estimated streamflow for the Dugout Creek drainage, which is about 4 miles southwest of the Alkali Creek coal-lease tract. The estimated ground-water contribution to streamflow during runoff for the water year 1980 was 1,000 acre-ft from the Flagstaff Limestone and 200 acre-ft from the Blackhawk Formation and other formations. Outcrops of the Flagstaff cover about 40 percent of the Dugout Creek drainage and outcrops of the Blackhawk and other formations cover the other 60 percent. Thus, the discharge per unit area from the Flagstaff is about 7.5 times greater than the discharge per unit area from the Blackhawk and other formations.

Ground-Water/Surface-Water Relations

Springflow from the Flagstaff Limestone sustains streamflow after snowmelt runoff in some drainages in the study area. The discharge-recession curves for streamflow at site ACSW2 and springflow at site ACS1 are plotted in figure 8 and are based on miscellaneous measurements; the shapes of the curves are similar in both 1985 and 1986. The similar shape of the curves of the stream and the spring indicate that discharge from the Flagstaff is the principal source of water in the stream. The spring at site ACS1 discharges from the Flagstaff. The stream at site ACSW2 was dry about 3 weeks after the last plotted measurements in 1985 and 1986 (fig. 8, table 3). In midsummer, after discharge from the Flagstaff has decreased, the discharge from formations underlying the Flagstaff is not sufficient to maintain streamflow. The decrease in slope of the 1985 stream-recession curve was caused by storm runoff.

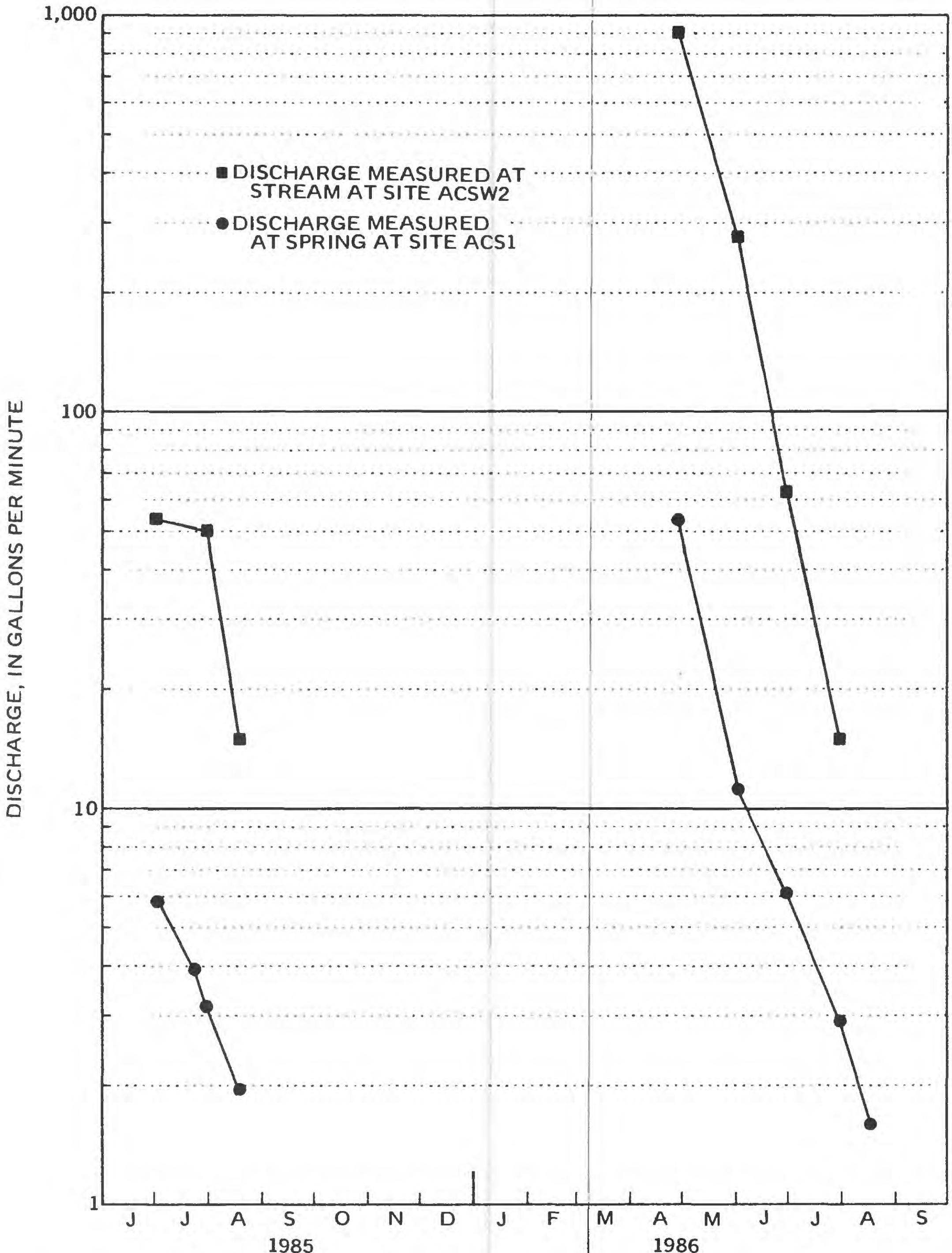

Figure 8.—Discharge-recession curves of stream at site ACSW2 and spring at site ACS1.

Waddell and others (1986, p. 29) determined that most flow in Soldier Creek in early summer is from springs issuing from the Flagstaff Limestone. By about the middle of August, discharge from the Flagstaff has receded, and the majority of the base flow in Soldier Creek is from underlying formations.

Water Quality

Surface water

Samples of streamflow were analyzed for chemical quality and suspended sediment. These two aspects of water quality are discussed in the following sections.

Chemical quality.--The chemical quality of streamflow at site ACSW2 changes as streamflow decreases. The smallest specific conductance, 645 µS/cm, was measured during spring runoff. Throughout the spring and summer, specific conductance increased as the streamflow decreased (fig. 9 and table 3). This reflects the effects of: (1) Evapotranspiration; (2) an increasing percentage of ground-water inflow as opposed to snowmelt; and (3) an increasing percentage of more saline water from older formations as discharge from the Flagstaff becomes a progressively smaller component of streamflow.

The greatest specific conductance, 1,850 µS/cm, was measured in water from melting snow in January 1986. This large value of specific conductance probably was due to dissolution of salt efflorescence. Water reaching land surface from formations that contain considerable salt, such as the Mancos Shale, evaporates and leaves a salt crust, or efflorescence. During storm or snowmelt runoff, the first flush of water dissolves the salt, and the runoff would be more saline than normally expected.

Chemical composition of the water at site ACSW2 changes as discharge decreases. The principal chemical constituents were magnesium, calcium, bicarbonate plus carbonate (alkalinity)[1], and sulfate (pl. 1) in April 1986 during spring runoff. The principal constituents were magnesium, calcium, sulfate, and bicarbonate during July 1985 when the discharge was much less. Bicarbonate was the dominant anion from the Flagstaff, and sulfate is the dominant anion in water from springs discharging from older formations. As discharge at ACSW2 decreased, sulfate became the dominant anion, which further indicates that older formations contributed increasing proportions of the streamflow.

Suspended sediment.--The suspended-sediment concentrations in streamflow are greatest during thunderstorm runoff. Waddell and others (1986, p. 19) reported the effects of the source of runoff on sediment discharge in Soldier Creek at site ACSW1. Discharge at site ACSW1 from a thunderstorm on July 19, 1979, was about 17 ft^3/s and the suspended-sediment concentration was about 37,000 mg/L. Discharge of 50 ft^3/s during snowmelt runoff on May 14, 1980, had a suspended-sediment concentration of about 650 mg/L. At site ACSW2,

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[1]Alkalinity (as calcium carbonate) listed in tables 3 and 5 consists primarily of bicarbonate; therefore, bicarbonate is used in subsequent discussions of chemical composition.

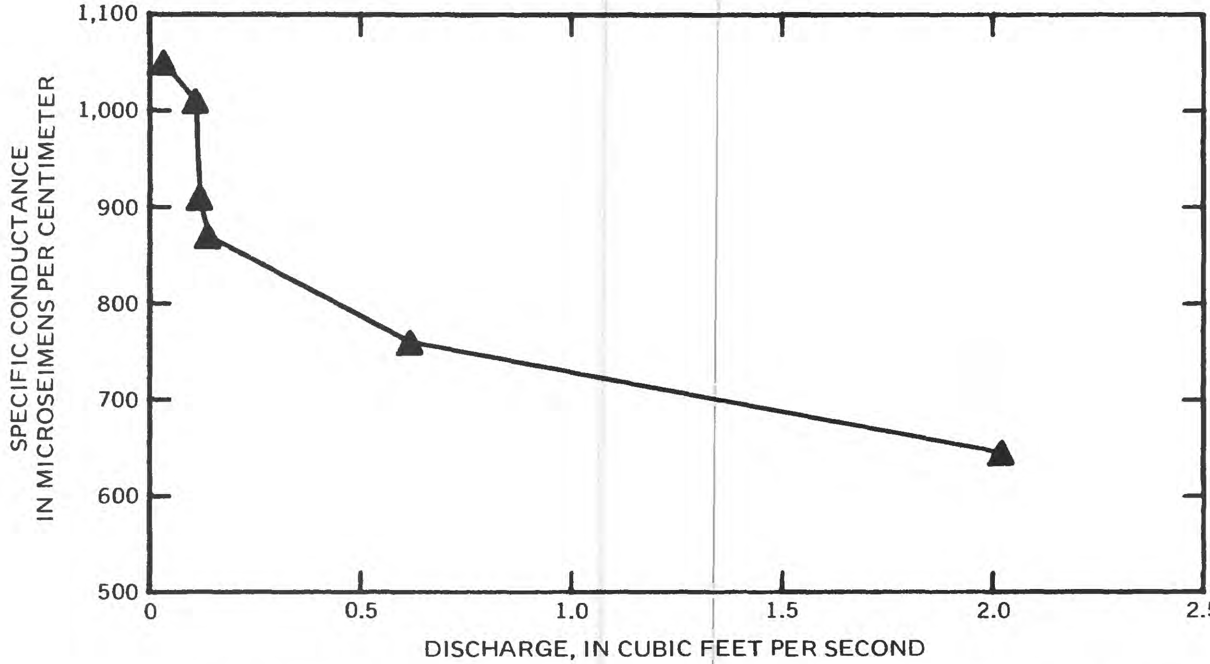

Figure 9.—Relationship between stream discharge and specific conductance at site ACSW2.

snowmelt runoff of 2.02 ft^3/s had a suspended-sediment concentration of 136 mg/L. During low flow, 0.12 ft^3/s, the suspended-sediment concentration was only 17 mg/L. No suspended-sediment samples were collected at site ACSW2 during thunderstorm runoff for this study.

Ground water

Samples of ground water from springs and mines were analyzed for chemical quality. The chemical characteristics of water from these two sources are discussed in the following sections.

Springs.—Water from 13 springs in the Alkali Creek area was analyzed for chemical composition (tables 4 and 5). The least mineralized water discharges from the Flagstaff Limestone and the most mineralized from the Blackhawk Formation and Quaternary unconsolidated deposits. The dissolved-solids concentration (residue at 180 °C) in three samples from springs issuing from the Flagstaff Limestone, sites ACS1 and ACS6, ranged from 273 to 386 mg/L (table 5). The predominant ions in these samples were calcium and bicarbonate. The water composition was similar to that of springs discharging from the Flagstaff Limestone throughout the Book Cliffs and Wasatch Plateau coal fields (Waddell and others, 1986, pl. 1).

Dominant ions in springwater from the North Horn Formation and the Castlegate Sandstone were magnesium, calcium, bicarbonate, and sulfate. Dissolved-solids concentrations in the springwater from these formations ranged from 796 to 1,380 mg/L.

The chemical composition of water from the Blackhawk Formation is variable. Dissolved-solids concentrations in samples collected from the Blackhawk Formation ranged from 657 to 5,210 mg/L (table 5). Springwater from site ACS12, which discharges into Soldier Creek, was dominated by sodium and bicarbonate. The spring orifice was surrounded by a slimy precipitate, and there was a strong odor of hydrogen sulfide gas. The spring discharges from massive sandstone in the North Horn Formation, but the water probably has its source in a coal seam in the Blackhawk Formation and reaches the land surface through a joint or fracture. Water from the Blackhawk in the Soldier Canyon Mine also is dominated by sodium and bicarbonate. Water in the Blackhawk probably is under artesian pressure near site ACS12. The bicarbonate in the spring water probably is associated with sulfate reduction.

Two springs issuing from the Blackhawk Formation near Coal Creek, sites ACS5 and ACS6, had dissolved-solids concentrations that ranged from 1,230 to 1,400 mg/L (table 5). Springwater from site ACS5 was dominated by magnesium, bicarbonate, and sulfate. Springwater from site ACS6 was dominated by magnesium and bicarbonate (pl. 1).

Water from different zones in the Blackhawk Formation may be mixing through fractures. Springwater from site ACS6 had larger sodium and bicarbonate concentrations compared to springwater from site ACS5. The composition of springwater from site ACS6 probably results from mixing a sodium bicarbonate water, similar to that from site ACS12, with water of similar composition to that from site ACS5. The molar increases in sodium and bicarbonate were nearly equal. Further evidence that the spring at site ACS6 has its source in a coal seam is the presence of a strong odor of hydrogen sulfide gas and slimy precipitate similar to that present at site ACS12.

The most mineralized water, containing 4,960 to 5,210 mg/L dissolved solids, was from springs at sites ACS10 and ACS11, which issue from the lower Blackhawk Formation or Quaternary unconsolidated deposits near the lower Blackhawk (pl. 1). The dominant ions were magnesium and sulfate. The Mancos Shale intertongues with the lower Blackhawk Formation in this area (Nethercott, 1985) and may be affecting the chemical quality of the springwater.

The Mancos Shale is a major natural source of salinity. No springs in the Mancos were sampled. However, Bowles and others (1982, p. 41) described the chemical composition of salt efflorescence resulting from evaporation of formation water. The predominant constituents were sodium and sulfate.

The measured strontium concentrations were much greater in the Blackhawk Formation than in the Flagstaff Limestone. The strontium concentration in the springwater at site ACS1 was 140 μg/L (table 6). Water from the Blackhawk Formation at site ACS12 and in the Soldier Canyon Mine (site SCI) had strontium concentrations ranging from 760 to 1,100 μg/L (table 6).

Mines.--Water from active and inactive areas of the Soldier Canyon Mine had changes in water composition, including decreased pH and increased mineralization in the inactive areas after abandonment. In both areas, the sampled water was dominated by sodium and bicarbonate. Water collected from a bolt hole in an active part of the mine at site SCA had a dissolved-solids concentration of 657 mg/L and sulfate concentration of 15 mg/L (table 5). Water collected from an inactive part of the mine at site SCI had a dissolved-solids concentration of 824 mg/L, and a sulfate concentration of 85 mg/L—more than five times greater than that for the active part of the mine.

Calcium sulfate (gypsum) commonly is used in coal mines for dust control, and its dissolution might contribute some to the measured increase in sulfate. Gypsum dissolution will result in an equimolar increase in calcium and sulfate. Gypsum probably isn't the major source of sulfate because the molar increase in sulfate was about 3.5 times greater than the molar increase in calcium.

In both the inactive and active parts of the Soldier Canyon Mine, the barium concentrations were much larger than would be expected based on the solubility of barium sulfate (barite). Barite is almost insoluble and the solubility of barium likely is controlled by the concentration of sulfate (Hem, 1985, p. 137). At site SCA, in the active part of the mine, the sulfate concentration was 15 mg/L and the measured barium concentration was 4,100 µg/L; the expected barium concentration would be about 700 µg/L. At site SCI, in the inactive part of the mine, the sulfate concentration was 85 mg/L and the measured barium concentration was 500 µg/L; the expected concentration would be about 100 µg/L. The geochemical model PHREEQE (Parkhurst and others, 1980) was used to calculate the expected barium concentration of water in equilibrium with barite. A KSP value of 1.05×10^{-10} for barite was used.

Water from the Flagstaff Limestone also was supersaturated with barite. The barium concentration in water from the spring at site ACS2, which discharges from the Flagstaff, was 290 µg/L; the expected concentration would be about 100 µg/L.

The concentration of some radioisotopes in ground water can be used to estimate the age of the water. A sample of water from a bolt hole in the ceiling of the Soldier Canyon Mine was analyzed for tritium, a radioisotope of hydrogen with an atomic weight of 3. The sample contained less than 1.0 pCi/L. Prior to testing of nuclear weapons in the early 1950's, natural tritium concentrations in precipitation were about 26 pCi/L (Thatcher and others, 1977, p. 8). Tritium concentrations reached a peak in the northern hemisphere in 1963 when concentrations in the atmosphere exceeded the natural concentration by about three orders of magnitude (Thatcher and others, 1977, p. 8). Tritium has a half-life of only 12.26 years and, assuming natural concentrations of 26 pCi/L, the water must have been isolated from the atmosphere for more than 4.7 half lives for the tritium concentration to decay to less than 1.0 pCi/L. Therefore, the water in the mine must have entered the ground-water system more than 50 years ago.

Erosion and Sediment Yield

Most of the sediment discharged by streams in arid and semiarid areas is transported during a short period each year. A large part of the sediment yield in semiarid areas also is from only a small part of the drainage area where such factors as sparse vegetation, steep slopes, gullys, and erodible soils result in accelerated erosion relative to surrounding areas. The largest concentrations of suspended sediment usually occur as a result of runoff from thunderstorms. Sediment concentration in streamflow during snowmelt runoff is much larger than during base flow, but is small compared to that in runoff from thunderstorms.

Wilson and others (1975, p. 52-53) describe the hydrologic characteristics of soils in the study area. The soils belong to the Badlands-Rock Land Association, which is mainly bare rock outcrops with some thin soils over bedrock. Runoff is rapid and the sediment yield is large.

The Pacific Southwest Inter-Agency Committee method, as modified by Frickel and others (1975), was used to estimate source-area sediment yield from the Alkali Creek coal-lease tract. A number of factors, such as surface geology, climate, and ground cover are given a numerical rating. The numbers assigned to factors are summed, and the total rating value is used to obtain an estimate of the source-area sediment yield. By this method the estimated annual source-area sediment yield from the study area is about 0.5 acre-ft/mi^2. Insufficient sediment data were obtained during this investigation to verify the estimated sediment yields.

On the basis of measured sediment accumulation in small reservoirs, King and Mace (1953) computed an annual sediment yield of about 0.4 acre-ft/mi^2 in a small drainage about 10 miles south-southeast of the Alkali Creek study area. McCormack and others (1984, pl. 2) estimated the annual sediment yield from the Alkali Creek area to be between 0.5 and 1.0 acre-ft/mi^2.

CASTLE VALLEY RIDGE STUDY AREA

Physical Setting

The location of the Castle Valley Ridge coal-lease tract is shown in figure 10 and on plate 2. The tract is west of Price on the boundary between Carbon and Emery Counties along Castle Valley Ridge. The tract covers about 3,360 acres and is adjacent to an area actively mined (1987) at the King Mine complex and Plateau Mine.

Topography

Land-surface altitudes in the coal-lease tract range from about 10,100 feet in the south part to about 8,320 feet in the east-central part (pl. 2). The Castle Valley Ridge, which traverses nearly the length of the coal-lease tract (fig. 10), has only a few hundred feet change in altitude in several miles (fig. 11). The steepest sustained slope, about 39 degrees, is located in the southeast part of the study area in an area appropriately called 'The Steeps'. Vertical sandstone cliffs exceeding 50 feet are found in drainages on both sides of the study area.

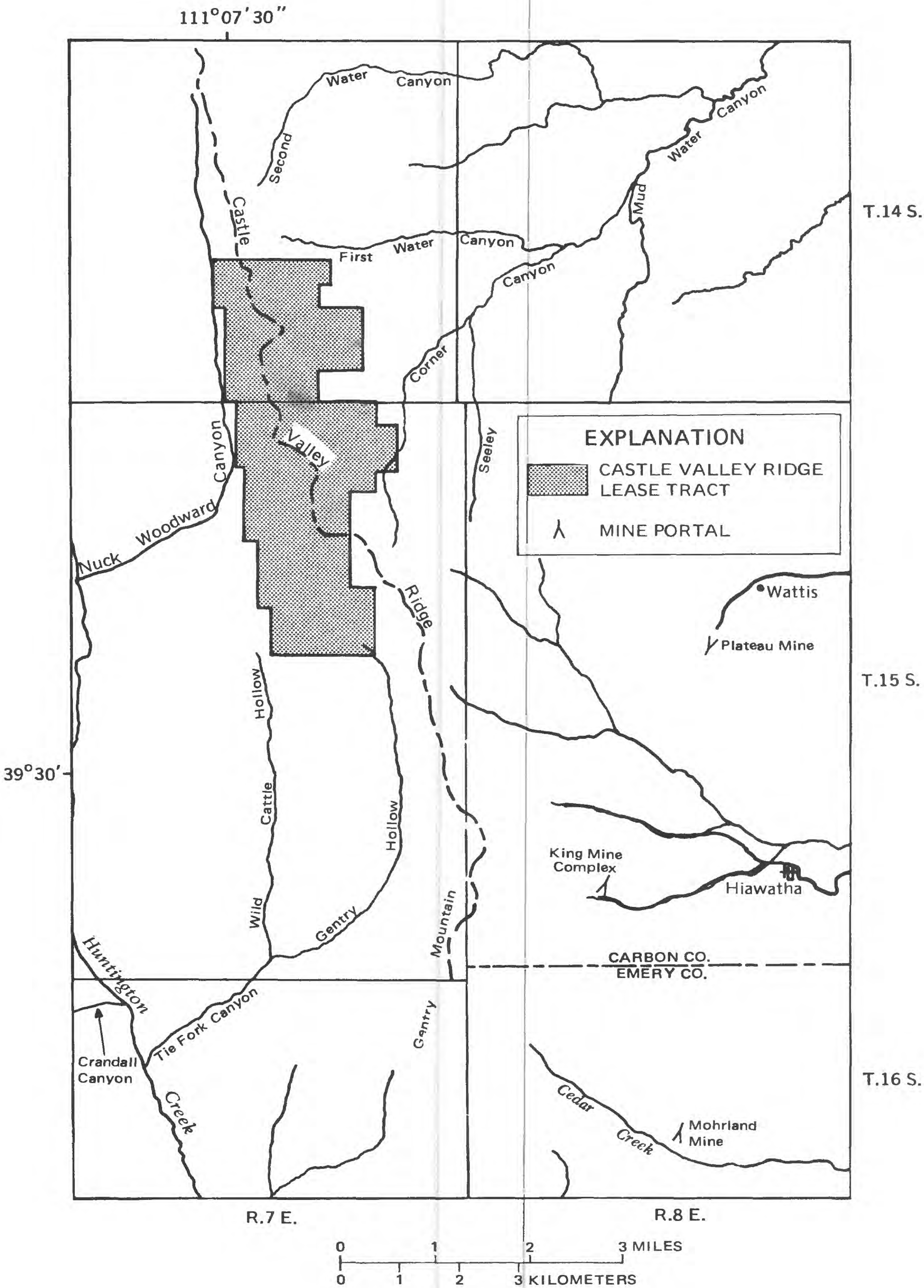

Figure 10.—Location of Castle Valley Ridge lease tract.

Figure 11.—View (facing south) of part of the Castle Valley Ridge lease tract showing topography and vegetative cover.

Geologic Structure

Descriptions of the stratigraphic units, and structure of the Castle Valley Ridge area are given in Spieker (1931) and Doelling (1972). All the stratigraphic units have been subjected to major deformational forces and are extensively jointed and faulted.

The dominant structural features are north-trending fault complexes. These faults were formed during the middle-Tertiary and are superimposed on an older set of folds that are probably related to the formation of the San Rafael Swell, about 55 miles south-southeast of the study area (Courtney Williamson, written commun., 1986). The regional dip is 2 to 5 degrees to the west-northwest. Evidence from recently drilled coal-exploration holes indicates that rotation has occurred in some of the fault blocks causing local dips within the different blocks to differ from the regional dip (Courtney Williamson, written commun., 1986).

Climate

The Castle Valley Ridge study area is semiarid to subhumid with precipitation generally increasing with altitude. Mean annual precipitation is about 25 to 30 inches, with about 8 inches during May-September (U.S. Weather Bureau, 1963). Free water-surface evaporation is about 35 in/yr (Farnsworth and others, 1982).

In the Castle Valley Ridge area, the intensity of a 1-hour storm with a recurrence interval of 2 years is about 0.60 in/h, and the intensity of a 1-hour storm with a 100-year recurrence interval is about 1.6 in/h (Miller and others, 1973, table 11 and figs. 19, 24, 25, 30). Intense thunderstorms are frequent in late summer and early fall; however, the vegetation cover and thick soil mantle absorb the water quickly and flashflooding is uncommon.

The mean monthly air temperature and precipitation about 14 miles north of the Castle Valley Ridge coal-lease tract at the Scofield Dam weather station are presented in figure 12. During November-March, the mean monthly temperature is below freezing. January usually is the month with the greatest precipitation.

Vegetation

The many beautiful trees and shrubs make the Castle Valley Ridge area especially scenic. On the ridge, Engelman spruce (Picea Engelmannii), subalpine fir (Abies lasiocarpa), and quaking aspen (Populus tremuloides) are common. Gooseberry (Ribes montigenum) is a common shrub. In the drainages, rocky mountain maple (Acer glabrum), red-osier dogwood (Cornus stoloniferum), and elderberry (Sambucus caerulea) are common near the streams. Gambel's oak (Quercus Gambelii) is common in the lower more sunny parts of the drainages. Brittle fern (Cystopteris fragilis) is abundant in shady moist areas.

Land Use

Castle Valley Ridge is part of the Manti-La Sal National Forest, and a detailed description of land use is given by U.S. Department of Agriculture, Forest Service (1986). The land is managed for multiple use, including recreation, grazing, and minerals development. Much of the land in the study area is used for livestock grazing during the summer months. Recreation pursuits include wood gathering, sightseeing, camping, or just relaxing in the forest environment. Recreation use is especially intense during the big-game hunting season when many deer are harvested.

The King Mine complex (U.S. Fuel Company) and Plateau Mine (Getty Minerals Company) are active underground coal mines near the study area. The Mohrland Mine is part of the King Mine underground complex (fig. 10) and is no longer active.

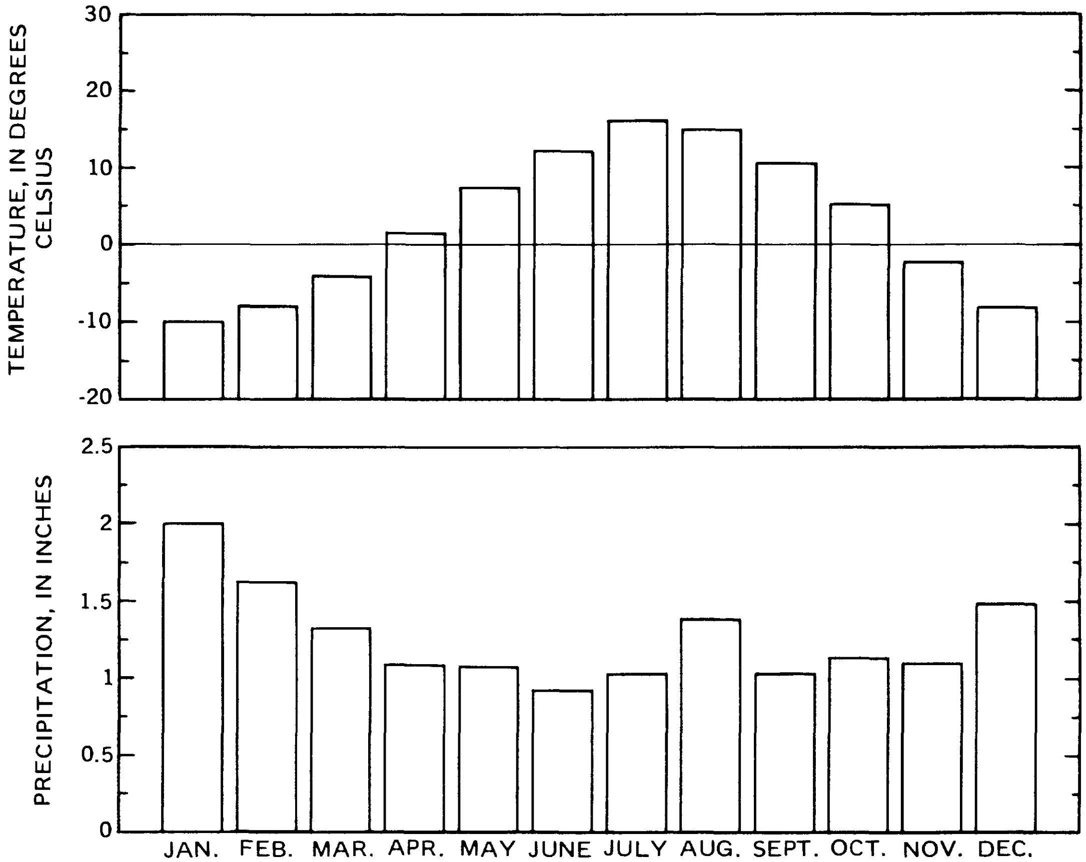

Figure 12.—Mean monthly temperature and precipitation at Scofield Dam, 1951-80 (data from National Oceanic and Atmospheric Administration, Environmental Data Service, 1983).

Hydrology

Surface Water

All streams on the west side of the Castle Valley Ridge coal-lease tract are intermittent and drain to Nuck Woodward Creek, a tributary of Huntington Creek in the San Rafael River basin. On the east side of the ridge, the drainages contribute to Corner Canyon Creek and First Water Creek, which eventually drain to the Price River by way of Gordon Creek. South Fork Corner Canyon Creek is the only perennial stream in the study area. Short reaches of the intermittent streams downstream from springs are perennial and provide a year-round water supply for livestock and wildlife. Chemical analyses, discharge, and suspended-sediment concentrations for South and North Forks Corner Canyon Creek, sites CVSW2 and CVSW3 (pl. 2), are presented in table 3.

Continuous streamflow records are not available for any of the streams that drain the study area; however, the time of peak daily mean streamflow is probably similar to that at site CVSW1, Crandall Canyon Creek, southwest of the coal-lease tract (fig. 13). The peak flow of Crandall Canyon Creek is during late May or early June. Peak daily mean flow from summer thunderstorms generally is less than from snowmelt runoff. Flow in intermittent streams after snowmelt is sustained by springs into midsummer.

The estimated average and peak flows for the small drainages can be computed using regression equations developed for the area by Thomas and Lindskov (1983, table 5) and Christensen and others (1986, table 1). The equations used to compute peak and average flow are listed in table 2. Methods for computing the needed variables are discussed earlier in this report. The 10-year peak flow of South Fork Corner Canyon Creek (site CVSW2 on plate 2) is estimated to be 60 ft^3/s and the average flow is estimated to be 0.74 ft^3/s.

Ground Water

The ground-water system in the Castle Valley Ridge study area was principally defined using data from springs and coal-exploration holes. Results of chemical analyses and discharge measurements of springs and mines are given in tables 4, 5 and 6. Water levels in exploration holes are given in table 7. Locations of the exploration holes and springs are shown on plate 2.

Aquifer characteristics

Ground water in the Wasatch Plateau occurs in regional and localized aquifers. The Blackhawk Formation and Star Point Sandstone form a regional aquifer, the Blackhawk-Star Point aquifer, in the southern part of the Wasatch Plateau (Lines, 1985). The Blackhawk-Star Point aquifer is a localized aquifer in the Castle Valley Ridge area and many springs discharge from this aquifer on the east side of Castle Valley Ridge. All exploration holes drilled in the Blackhawk on Castle Valley Ridge encountered water.

There also may be perched aquifers in the upper part of the Blackhawk Formation. During drilling, water was encountered at depths of less than 200 feet in hole CST-3; the water level in a piezometer completed in the hole was about 500 feet below land surface. Lines (1985, table 3) made laboratory determinations of the hydraulic conductivity of rocks from the Blackhawk Formation and Star Point Sandstone from the Trail Mountain area of the Wasatch Plateau, about 17 miles south of the study area. One shale layer was impermeable to water even at a pressure of 5,000 lbs/in^2. Such an impermeable shale would stop any downward movement of water.

Lines (1985) conducted several aquifer tests using pumped wells in the Trail Mountain area. The computed transmissivity ranged from 2 to 100 ft^2/day in wells completed in the Blackhawk-Star Point aquifer. The value of 100 ft^2/day is greater than would be expected on the basis of laboratory determinations of porosity and hydraulic conductivity of the aquifer material and probably is a result of secondary permeability from fractures. The storage coefficient of unconfined parts of the Blackhawk-Star Point aquifer in the Trail Mountain area probably averages about 0.05 (Lines, 1985, p. 15).

The younger formations contain localized perched aquifers. One spring on Castle Valley Ridge at site CVS13, discharges from the Castlegate Sandstone, and a nearby spring at site CVS12 discharges from the Price River Formation. Lines (1985, p. 14) conducted an aquifer test on a perched aquifer in the Price River Formation in the Trail Mountain area. The computed transmissivity was 0.8 ft^2/day.

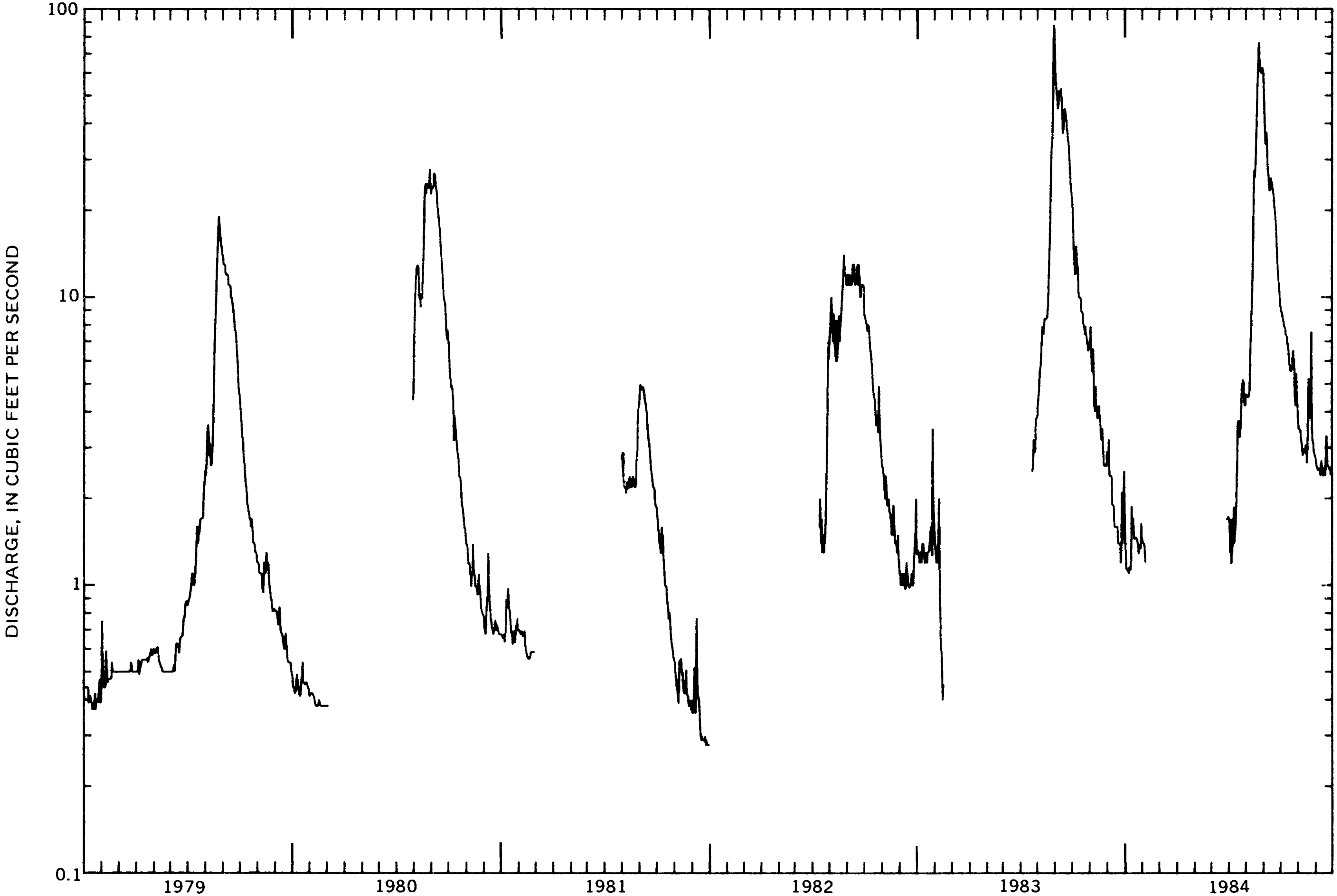

Figure 13.—Daily mean discharge at site CVSW1, Crandall Canyon at mouth, near Huntington, water years 1979-84. Station generally not operated during winter months.

Table 2.—Regression equations used to compute peak and average streamflow from ungaged tributaries of Castle Valley Ridge area

[Q, streamflow, in cubic feet per second; A, drainage area, in square miles; E, mean basin altitude, in thousands of feet]

Recurrence interval, in years	Equation
	Peak streamflow (Thomas and Lindskov, 1983, table 5)
10	$Q = 680A^{0.706}E^{-1.30}$
50	$Q = 64{,}200A^{0.651}E^{-3.03}$
100	$Q = 347{,}000A^{0.631}E^{-3.68}$
	Average streamflow (Christensen and others, 1986, table 1)
-	$Q = 1.39 \times 10^{-5}A^{1.06}E^{4.67}$

There are many springs issuing from the North Horn Formation in the southern end of the Castle Valley Ridge study area. The existence of shale layers in the North Horn indicates that water in this formation may be perched. Lines (1985, p. 14) computed the transmissivity of a perched aquifer in the North Horn to be 10 ft^2/day.

Recharge

The principal source of recharge to the aquifers in the study area is snowmelt and rainfall on outcrops. Danielson and others (1981, p. 24) compared concentrations of deuterium in snow, rain, spring, and mine water in the upper Huntington and Cottonwood Creek drainages, which include the western part of the Castle Valley Ridge study area. They concluded that most, if not all, of the recharge to the ground water is derived from snow.

The quantity of recharge to the Blackhawk Formation is not known but may be substantial. The Blackhawk crops out in about 2,100 acres in the north and central part of the coal-lease tract (pl. 2). A sinkhole, probably caused by the stoping of rock above a fault or large fracture system, was observed a few hundred yards to the southwest of coal-exploration hole CST-2 (Courtney Williamson, written commun., 1986). Sinkholes and other surface features which intercept surface runoff increase recharge to the aquifer.

The quantity of recharge to the North Horn Formation also is unknown. The North Horn is exposed in nearly flat areas in the southern part of the study area where the gentle relief slows the snowmelt runoff and allows the water to percolate through the soil to the water table.

Movement

A contour map of the potentiometric surface of the Blackhawk-Star Point aquifer could not be prepared because of the limited water-level data. Flow in the Blackhawk-Star Point aquifer in the Castle Valley Ridge coal-lease tract probably is controlled by the Bear Canyon fault on the east side of the ridge and by local topography on the west side. The hydraulic head within the Blackhawk-Star Point aquifer on Trail Mountain decreases with depth indicating downward movement of water (Lines, 1985, p. 15).

Faults may be major conduits and control the movement of ground water. At coal-exploration hole CST-2 (pl. 2), drillers encountered a void at a depth of 405 feet which caused the drill stem to drop about 4 feet (Courtney Williamson, written commun., 1986). From a depth of 540 to 597 feet, an extremely oxidized and extensively fractured sandstone was encountered. The presence of faults and voids indicate water can move rapidly through this part of the aquifer.

Discharge

Ground water discharges at formation contacts, between zones of differing permeability within a formation, near faults, and into mines. Springs issuing from the North Horn Formation generally are located in slight depressions near recharge areas. Site CVS13 is a seep located at the top of the Blackhawk Formation; however, the probable source of its water is the Castlegate Sandstone. Several springs issuing from the Blackhawk-Star Point aquifer and Mancos Shale are located at the base of sandstone cliffs. Several springs issuing from the Blackhawk discharge near the Bear Canyon fault.

Water from the Blackhawk Formation enters mines adjacent to the study area through faults, bolt holes, and along the working faces of the mine. Between May 9 and October 11, 1979, about 140 gal/min entered the King Mine about 1.5 miles southeast of the study area through a fault (Danielson and others, 1981, p. 32). Discharge from the Mohrland Mine portal (site MP) ranged from 350 to 1,100 gal/min during 1975-78 (Danielson and others, 1981, p. 32).

The measured discharge of springs in the Castle Valley Ridge study area ranged from 0.2 to 29.3 gal/min. The greatest measured discharges were those of springs issuing from the North Horn Formation. The discharge of a spring at site CVS18 which issues from the North Horn was 29.3 gal/min on June 3, 1986, and receded to less than 10 percent of this discharge in less than 2 months (fig. 14). The spring probably is perennial and is sustained by recharge from rainfall in summer and early fall.

Discharge was measured at site CVS13 (fig. 14), a seep which discharges from the Castlegate Sandstone through the upper Blackhawk Formation. After the first measurement, the discharge was nearly constant at 4.8 gal/min. The first measured discharge might have been affected by inflow from snowmelt; snow remains in parts of the study area until mid-summer. If 4.8 gal/min is assumed to be the mean annual discharge, then the annual discharge from the Castlegate through this spring is about 7.7 acre-ft.

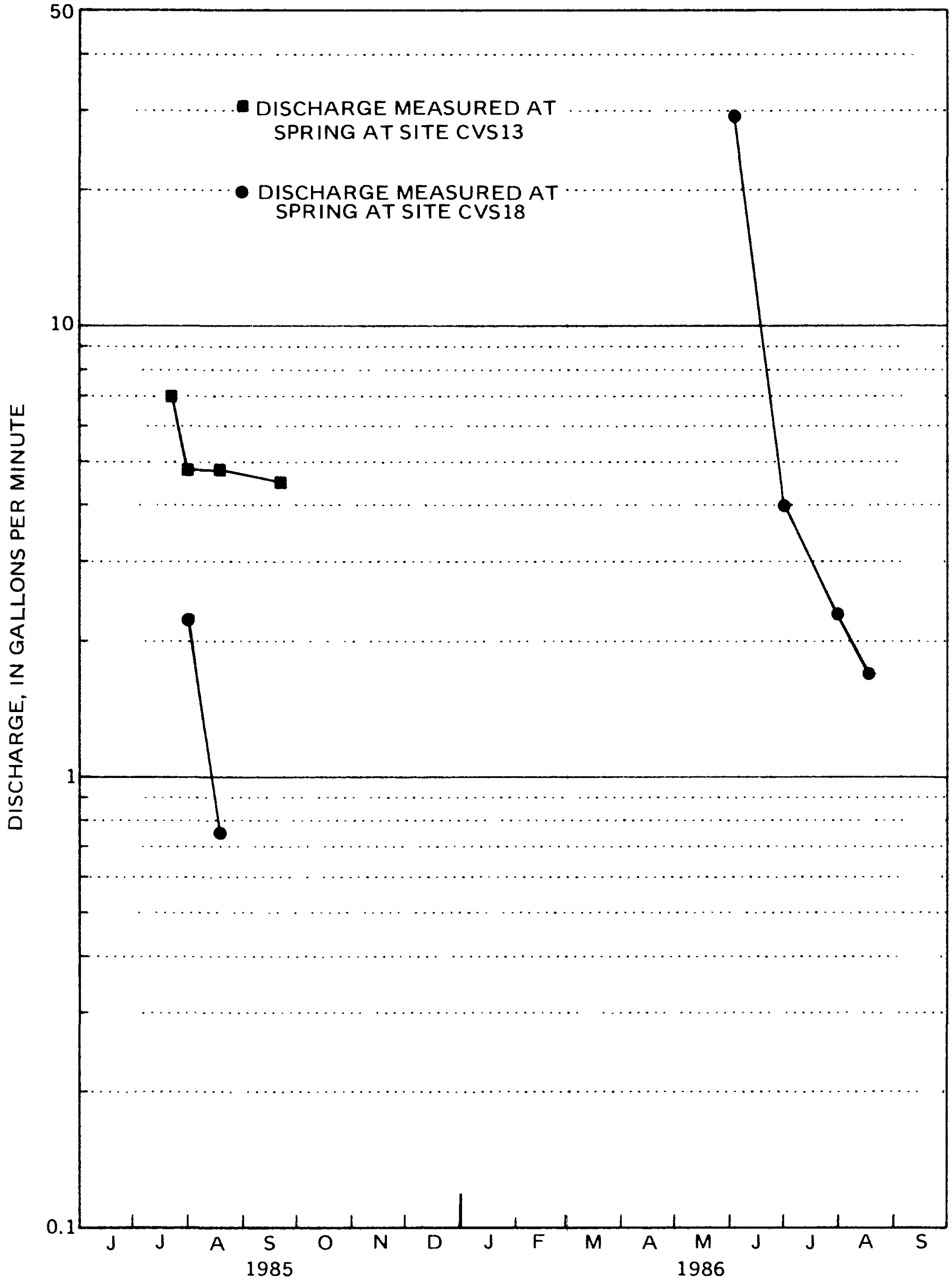

Figure 14.—Discharge-recession curves of springs at sites CVS13 and CVS18.

Measured discharges of springs in the Blackhawk Formation ranged from 0.2 to 12.9 gal/min (table 4). No springs issuing from the Blackhawk were measured on a regular basis. Discharge from some springs issuing from the Blackhawk, however, is perennial as indicated by the hydrophytic vegetation growing in the channel downstream from the spring.

Water Quality

Surface water

Samples of surface-water were analyzed for chemical quality and suspended sediment. These two aspects of water quality are discussed in the following sections.

Chemical quality.--The chemical quality of streamflow at site CVSW2 generally changes as streamflow decreases. Site CVSW2 is on South Fork Corner Canyon Creek, which is the only perennial stream that drains from the coal-lease tract. As streamflow decreases, the concentration of the major ions and the proportion of magnesium and sulfate increases (fig. 15).

During snowmelt runoff in June 1986 at site CVSW2 (fig. 15), the predominant constituents were magnesium, calcium, and bicarbonate. The dissolved-solids concentration was 458 mg/L (table 3). Two analyses were made in October 1980 and the predominant constituents were magnesium, calcium, bicarbonate, and sulfate. On July 17, 1981, the predominant constituents were magnesium, calcium, and sulfate, and the dissolved-solids concentration was 1,400 mg/L (table 3). As noted in figure 15, the flow at site CVSW2 was not recorded on July 17, 1981, however, it probably was less than that measured in October 1980. The discharges at nearby continuous-record gaging stations on Coal Creek, Soldier Creek, Tie Fork Canyon Creek, and several other creeks were less in July 1981 than in October 1980.

The changing chemical composition of water probably is caused partly by inflow of ground water from different formations. As the relative contribution of base flow to the stream from different formations changes, the chemical composition of the streamflow will change. However, no springs were discovered in the study area that discharged water of similar composition. Evaporation of streamflow also can change the chemical composition by increasing the ionic strength and causing calcite precipitation. Evaporation of springwater from site CVS3 (pl. 2) could result in water like that sampled at site CVSW2.

At site CVSW3 on North Fork Corner Canyon Creek, the dissolved-solids concentration was 645 mg/L in June 1986 (table 3). The predominant constituents were calcium, magnesium, sulfate, and bicarbonate.

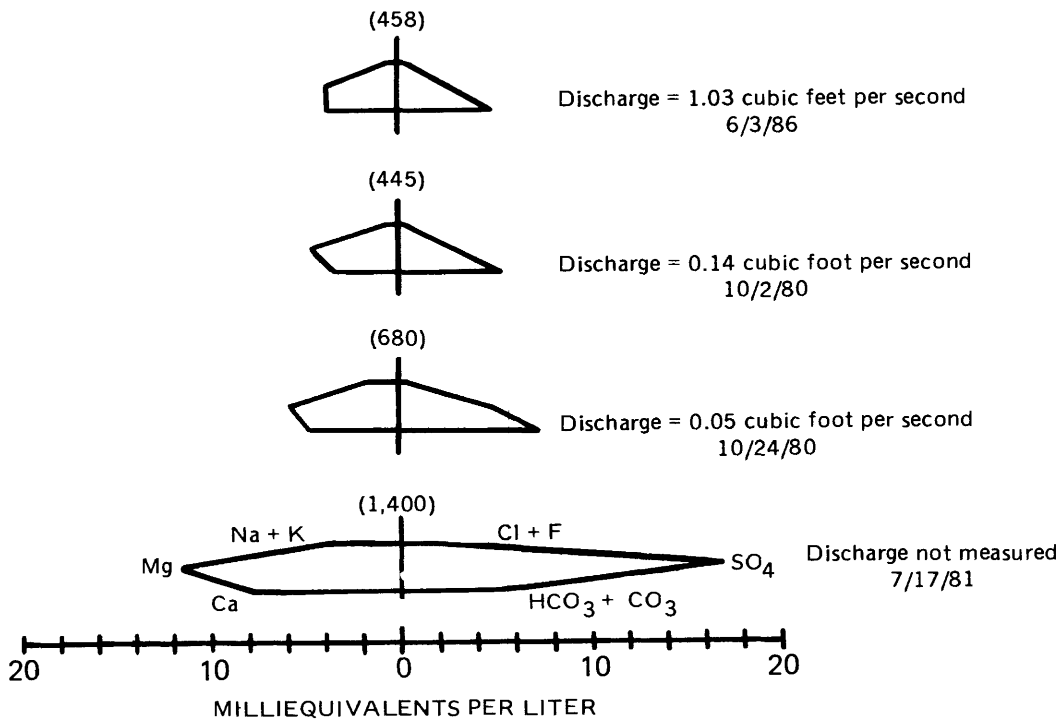

Figure 15.—Diagrams of the chemical quality of water from site CVSW2 (analyses from 1980-81 by U.S. Fuels Company). [Number in parentheses is dissolved-solids (residue) concentration in milligrams per liter.]

Suspended sediment.—The suspended-sediment concentration was 154 mg/L at site CVSW2 on June 3, 1986, during snowmelt runoff (table 3). At site CVSW3, the suspended-sediment concentration was 382 mg/L (table 3). The drainages upstream from these sites are natural with dense vegetative cover; thus, sediment yields are small. Larger drainages near the study area also have relatively small sediment yields. The suspended-sediment concentration of 14 samples collected from Tie Fork Canyon Creek (fig. 10) between August 1978 and September 1981 ranged from 2 to 648 mg/L; corresponding stream discharge ranged from 0.41 to 26 ft^3/s.

Ground Water

Samples of ground water from springs and mines were analyzed for chemical quality. The chemical characteristics of water from these two sources are discussed in the following sections.

Springs.--Water samples from 17 springs were analyzed for chemical quality. The smallest concentrations of dissolved solids, 208 to 242 mg/L, were in water from springs issuing from the North Horn Formation, Castlegate

Sandstone, and Price River Formation (table 5). The predominant ions in the water from springs issuing from these formations were calcium and bicarbonate (pl. 2).

The concentration of dissolved solids in water from the Blackhawk Formation ranged from 277 to 371 mg/L (table 5), the larger concentrations generally being in the springs that discharge from the lower, older strata of the Blackhawk. The predominant constituents in water from the Blackhawk were calcium, magnesium, and bicarbonate. Calcium was the predominant cation in water from springs east of the Bear Canyon fault; however, magnesium and calcium were codominant in water from springs west of the fault.

Water in springs issuing from the Star Point Sandstone contained the largest dissolved-solids concentrations, ranging from 383 to 579 mg/L (table 5). The chemical composition of water from two of these springs issuing from the Star Point was similar to that from most of the other springs in the study area; however, the chemical composition of water from site CVS3 was different from that of any other spring. The predominant constituents of the water were magnesium, calcium, bicarbonate, and sulfate. Danielson and others (1981) sampled about 140 springs in the upper drainages of Huntington and Cottonwood Creeks and sampled two springs with chemical composition similar to that from site CVS3. Both springs, (D-16-7)22bbb-S1 and (D-17-7)27abc-S1, issue from the Star Point Sandstone.

Site CVS4 is a spring that issues from the Mancos Shale and is at the base of a large sandstone cliff. The water had a dissolved-solids concentration of 427 mg/L, and the predominant constituents were calcium, magnesium, and bicarbonate. The chemical composition was similar to that of spring (D-15-6)13dad-S1, which also discharges from the Mancos (Danielson and others, 1981, p. 78).

Mines.--Chemical analyses of water from active and inactive mines near the study area indicate that changes in the chemical quality of water in the mines may be due to oxidation of minerals in the collapsed roof materials. In particular, increased sulfate concentrations and decreased pH are probably caused by oxidation of sulfide minerals. Some, but not all, of the increase in sulfate may be from dissolution of gypsum that is used in the mine for dust control. Water from the ceiling of an active part of the King Mine No. 4 (site KMA) had a pH of 7.8 and a sulfate concentration of 19 mg/L (table 5). Where roof collapse had occurred in a nearby inactive section of the mine (site KMI), the water had a pH of 7.2 and a sulfate concentration of 140 mg/L (table 5), more than seven times greater than in the active part of the mine. Concentrations of dissolved-solids were 256 mg/L at site KMA in the active part of the mine and 472 mg/L in the inactive part at site KMI (table 5).

Water quality changes occur soon after part of a mine is abandoned. Chemical-quality diagrams of water from active and inactive mine areas are shown in figure 16. A water sample from an active part of the King Mine No. 4 was collected at site KMA, and the water is similar in quality to springwater from the Blackhawk Formation. A water sample was collected from a part of the mine, site KMI, that was abandoned only about 2 years before the sample was collected (Robert Eccli, U.S. Fuels Company, oral commun., January, 1986). The roof has collapsed in this part of the mine and the ground-water inflow forms ponds. The water from this part of the mine is more acidic, more

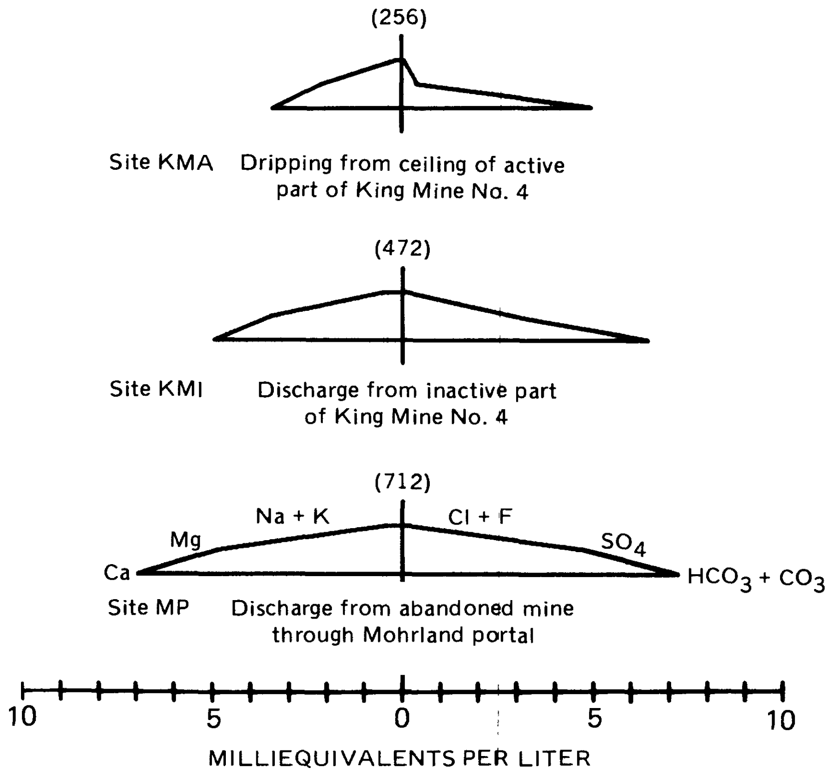

Figure 16.—Diagrams of the chemical quality of water from active and inactive mines in the Castle Valley Ridge area. [Number in parentheses is dissolved-solids (residue) concentration in milligrams per liter.]

mineralized, and contains a greater concentration of sulfate compared with water from the active part of the mine.

The composition of water from the recently abandoned part of King Mine No. 4 resembles that of water discharging from a nearby mine that has been abandoned for more than 30 years. Thus, water quality may not return to its original state for a long time after mining has caused the quality to change. Coal mining through the Mohrland Mine portal at site MP ceased in the 1950's. The dissolved-solids concentration of water discharging from site MP was 712 mg/L and the pH was 7.1 in 1985. The chemical composition of the water had not changed significantly from 1975 to 1985.

Strontium concentrations are much greater in water from formations affected by mine roof collapse than in water from undisturbed formations. The strontium concentrations of water from undisturbed parts of the Blackhawk Formation are relatively small; 73 µg/L in spring water from site CVS11 in 1985 and 150 µg/L in water dripping from the ceiling in the King Mine No. 4 at site KMA in 1986 (table 6). In water from the inactive part of this mine where the roof had collapsed, the strontium concentration was 1,400 µg/L in

1986, and in water from the Mohrland Mine portal (site MP) it was 1,000 µg/L in 1985 (table 6).

The strontium concentration in water from the North Horn Formation is small; 99 µg/L in springwater from site CVS18 in 1985 (table 6). This indicates that the strontium does not come from overlying aquifers through subsidence-caused fractures, or through faults and natural fractures. Geochemical changes resulting from roof collapse after abandonment may increase the solubility of strontium minerals present in the Blackhawk Formation.

A sample of water seeping from the ceiling of the King Mine No. 4 at site KMA was analyzed for the concentration of tritium as discussed earlier in the report. The sample contained 8.02 pCi/L. Although exact dating of the water using this tritium concentration is not possible, some of the mine water must have been recharged to the aquifer after atmospheric testing of nuclear weapons began in 1952.

Erosion and Sediment Yield

Wilson and others (1975, p. 10) described the hydrologic characteristics of the soils in the study area. The soils belong to the Argic Cryoborolls-Pachic Cryoborolls Paleborolls Association. The soils are moderately to somewhat excessively drained and the permeability is slow to rapid. The runoff is medium to slow and the sediment yield is moderately low.

The Pacific Southwest Inter-Agency Committee method, as modified by Frickel and others (1975), was used to estimate source-area sediment yield from the Castle Valley Ridge coal-lease tract. By this method (discussed earlier in the report) the estimated annual source-area sediment yield is about 0.3 acre-ft/mi^2. Insufficient sediment data were obtained within the study area to verify the estimated sediment yields.

The head of a gully at (D-15-7)11a was staked in late September 1985. Nine months later, the site was revisited but there had been no measurable advance of the headcut. The area around the gully headcut is covered with dense grass, which decreases the rate of gully-headcut advance. The greatest rate of headcut advance probably occurs from July to October during runoff from thunderstorms.

POTENTIAL EFFECTS OF COAL MINING

Land Subsidence above Coal Mines

Subsidence above abandoned coal mines can have a profound effect on both surface and ground water and can be the greatest effect a mine has on the hydrology of an area. Determination of the potential effects of mine-related land subsidence on the hydrologic systems in the Alkali Creek and Castle Valley Ridge study areas is needed to predict the long-term hydrologic effects of coal mining.

Subsidence-caused fractures can divert flow to lower strata or into mine workings by intercepting streamflow or draining perched aquifers. Subsidence features reaching the land surface could divert and decrease streamflow available for downstream use. Water could be diverted from one drainage to another through underground fractures. Interception of perched aquifers by subsidence fractures could cause the aquifers to drain into the underlying mine workings. Surface depressions caused by subsidence also can pond water and increase recharge to the ground-water system.

Subsidence fractures can extend from the roof of a mine to the land surface or into a perched aquifer several hundred feet above the mine. Several reports have documented surface expressions of subsidence above coal mines in central Utah. Dunrud (1976, fig. 9) reported subsidence fractures and compression arches in a massive sandstone 900 feet above mine workings in the Book Cliffs coal field in the Geneva Mine area, about 19 miles southeast of the Alkali Creek coal-lease tract. In the Wasatch Plateau coal field, about 43 miles south-southwest of Castle Valley Ridge, subsidence has caused tension cracks in the soil 800 feet above mine workings in the SUFCo (Southern Utah Fuel Company) Mine (Danielson and Sylla, 1983, p. 32).

Even small fractures can greatly increase the hydraulic conductivity of the aquifer. Craft and Hawkins (1959, p. 283) stated that an open fracture only 0.001 inch wide has a hydraulic conductivity of about 132 ft/day. For comparison, the hydraulic conductivity of shale ranges from about 3×10^{-5} to 3×10^{-8} ft/day (Freeze and Cherry, 1979, p. 29). It is possible that plastic flow in mudstones eventually would close fractures and prevent flow from above entering the mined area. Nevertheless, perched aquifers could drain and springflow sustained by the aquifers could cease if subsidence fracturing occurs.

Dunrud (1984, p. 171) stated that the most important factors controlling the area, magnitude, rate, and duration of subsidence in the western United States are the geotechnical properties of the coal and rock above and below the coal being mined, the topography and slope angle of the land surface, the mine geometry, and mining method. Dunrud (1984, p. 161, 164) presented equations to predict the duration of subsidence and the extent of a mined-out area that would cause maximum land-surface subsidence. Predictions of the area and duration of subsidence are beyond the scope of this report.

Predicted Effects in the Study Areas

Land-surface subsidence after the mines are abandoned will potentially have the greatest effect on the hydrology of the areas because subsidence-caused fractures divert surface- and ground-water flow to the mine workings. This could eventually result after mining the coal of the Alkali Creek and Castle Valley Ridge coal-lease tracts, because subsidence fractures have been observed above coal mines near both tracts. The discharge from some springs could decrease or cease if perching layers are fractured. Springs are the major source of water to both stock and wildlife in both areas.

Mining of the Castle Valley Ridge coal-lease tract could result in transbasin stream capture; all discharge from the King and Plateau Mines is presently (1987) into the Price River basin. Runoff from parts of the coal-lease tract that now discharges into Huntington Creek in the San Rafael River basin could be transferred through mine workings to the Price River basin. This could affect downstream water rights.

Ground water and surface water that now discharge to Coal Creek from parts of the Alkali Creek coal-lease tract could be intercepted by subsidence-caused fractures on the tract and diverted through the mine workings to the Soldier Creek drainage. It is possible that no water will discharge from abandoned mines on the Alkali Creek coal-lease tract. During the study, no water was observed discharging from the Knight Ideal Mine; the water may pond in abandoned workings.

After the mine is abandoned, quality of the mine water probably will change. For example, the dissolved-solids concentration increased about 25 percent and the sulfate concentration increased more than 500 percent in water in a part of the Soldier Canyon Mine after it was abandoned. The dissolved-solids concentration almost doubled and the sulfate concentration was seven times greater after a part of the King Mine No. 4 was abandoned. Even with increased mineralization, however, the water may still meet Utah's drinking-water standards. Some of the water discharging from the Mohrland Mine portal is used by the community of Hiawatha (Danielson and others, 1981, p. 32).

The size of the disturbed area and the increase in sediment yield caused by mining in the Alkali Creek and Castle Valley Ridge coal-lease tracts will depend on the construction needed for new surface facilities. If new portals and transportation facilities are not needed, then the increase in sediment yield probably will be limited to that caused by the construction of new ventilation shafts.

NEEDED STUDIES AND MONITORING

Additional geochemical studies of the water in the mines near the Alkali Creek and Castle Valley Ridge coal-lease tracts are needed to provide a better understanding of the effects of mining on the chemical quality of ground water. For example, the causes of the increased strontium concentrations in the King Mine No. 4 after part of the mine was abandoned are not known. Also, the concentration of barium in water from Soldier Canyon Mine is much greater than expected.

A better understanding of the hydrology of the study areas would be possible if spring discharge measurements were made at regular intervals after mining begins so changes in the rate at which spring discharge recedes following periods of recharge could be detected. Deviation of the rate of recession from rates measured during this study could indicate changes in the ground-water system caused by coal mining.

SUMMARY

The Alkali Creek coal-lease tract includes about 2,150 acres in the Book Cliffs coal field in central Utah, and the Castle Valley Ridge coal-lease tract includes about 3,360 acres in the Wasatch Plateau coal field, also in central Utah. Both lease tracts have intermittent streams in which flow after snowmelt runoff is locally sustained into midsummer by springflow. The only perennial stream is South Fork Corner Canyon Creek in the Castle Valley Ridge area. Peak flow in both areas generally is from snowmelt runoff; however, peak flow from thunderstorm runoff in the Alkali Creek area can exceed that from snowmelt runoff. Surface-water quality in both areas changes as streamflow decreases.

Estimated annual source-area sediment yield was 0.5 acre-ft/mi^2 in the Alkali Creek coal-lease tract and it was 0.3 acre-ft/mi^2 in the Castle Valley Ridge coal-lease tract.

Ground water in the Alkali Creek area occurs in perched aquifers in the Flagstaff Limestone and in other formations above the coal-bearing Blackhawk Formation. Local topography probably controls the flow in the Blackhawk in the Alkali Creek coal-lease tract but in some parts of the Book Cliffs coal field the Blackhawk is a regional aquifer. Annual recharge to the Flagstaff Limestone in the Alkali Creek coal-lease tract is estimated to be about 25 to about 30 acre-ft and total annual ground-water recharge in the coal-lease tract is estimated to be about 48 to about 56 acre-ft. Most of the springs in the area are at formation contacts.

Ground water in the Castle Valley Ridge area occurs in perched aquifers. The Blackhawk Formation and Star Point Sandstone form a regional aquifer in the southern Wasatch Plateau coal field; however, this aquifer is a localized aquifer in the Castle Valley Ridge area. The principal source of recharge to the aquifers is snowmelt on outcrops. Faults may be major conduits and control the movement of ground water. Ground water discharges at formation contacts, between zones of differing permeability within a formation, near faults, and into mines.

Water sampled from 13 springs in the Alkali Creek area had concentrations of dissolved solids ranging from 273 to 5,210 mg/L. The least mineralized water issued from the Flagstaff Limestone and the most mineralized from the Blackhawk Formation or Quaternary unconsolidated deposits. Ionic composition of water from the Flagstaff is dominated by calcium bicarbonate and water from some springs discharging from the Blackhawk is dominated by sodium bicarbonate. Springwater from other formations is dominated by magnesium, calcium, sulfate, and bicarbonate.

Water sampled from 17 springs in the Castle Valley Ridge area had concentrations of dissolved-solids ranging from 208 to 579 mg/L. The major dissolved constituents in water from most of the springs were calcium and bicarbonate. The most mineralized water is from a spring in the Star Point Sandstone where the water composition is unlike that of any other springwater in the study area.

Analyses of water from active and inactive mines in the Book Cliffs and Wasatch Plateau coal fields indicate that increased mineralization, decreased pH, and change in water composition occur soon after a section of mine is abandoned. The composition of water from a recently abandoned part of an active mine in the Wasatch Plateau closely resembles that of water discharging from a nearby mine that was abandoned more than 30 years ago, hence, water quality may not return to pre-mining quality for a long time.

Subsidence above the proposed mines on the Alkali Creek and Castle Valley Ridge coal-lease tracts probably will have the greatest effect on the hydrology of the areas studied. Fractures caused by subsidence could divert surface- and ground-water flow to lower strata or to the mine workings. Subsidence caused by mining could cause spring discharge to decrease or cease and disrupt the major source of water to livestock and wildlife in both areas.

Mining of the Alkali Creek and Castle Valley Ridge coal-lease tracts likely will result in mineralization of the water that enters the mines. Mining fractures the rock and increases the surface area exposed to oxygen. This results in decreased pH and increased concentration of dissolved solids. Even after mining, the water, especially in the Castle Valley Ridge area, may still meet Utah's drinking-water standards.

Increased sediment yield caused by mining probably will be minimal if the only new surface facilities are ventilation shafts. If new portals and coal-processing facilities are built, especially in the Alkali Creek area, an increase in sediment yield is anticipated.

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Table 3.—Discharge, suspended sediment, and

[Values for site CVSW2, South Fork Corner Canyon Creek, 1980-81, are from
Alkalinity and pH values obtained in the field except those

Site identifier	Stream	Drainage area (mi²)	Date	Discharge (ft³/s)	Suspended sediment concentration (mg/L)	Temperature (°C)	Specific conductance (µS/cm)	pH (Standard units)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)
<u>ALKALI CREEK AREA</u>										
ACSW2	Unnamed tributary to Soldier Creek	3.57	07-02-85	0.12	17	21.5	910	-	-	-
			07-31-85	.11	-	24.0	1,010	8.7	79	82
			08-19-85	.033	-	-	-	-	-	-
			09-11-85	0	-	-	-	-	-	-
			01-14-86	.026	-	1.0	1,850	-	-	-
			04-29-86	2.02	136	13.0	645	8.8	55	44
			06-02-86	.62	-	20.5	760	-	-	-
			06-30-86	.14	-	23.0	870	-	-	-
			07-31-86	.033	-	14.5	1,050	-	-	-
			08-18-86	0	-	-	-	-	-	-
<u>CASTLE VALLEY RIDGE AREA</u>										
CVSW2	South Fork Corner Canyon Creek	1.84	10-02-80	0.14	-	5	680	7.2	67	56
			10-24-80	.05	-	0	1,030	7.6	96	71
			11-10-80	.3	-	-	750	9.6	81	55
			05-27-81	.2	-	11	490	8.0	36	72
			06-16-81	.1	-	15	690	8.3	18	84
			07-17-81	-	-	-	2,150	-	160	142
			06-03-86	1.03	154	9.5	715	8.5L	74	46
CVSW3	North Fork Corner Canyon Creek	1.39	06-03-86	.43	382	11.0	930	8.3L	100	57

[1]See plates 1 and 2 for location.

chemical quality of surface water, 1980-81, 1985-86

U.S. Fuels Co., and are on file in the offices of Utah Division of Oil, Gas and Mining.
marked with an L which were measured in the laboratory]

Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Alka-linity (mg/L as $CaCO_3$)	Sulfate, dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as SiO_2)	Dis-solved solids, residue at 180 °C (mg/L)	Dis-solved solids, sum of consti-tuents (mg/L)	Hard-ness (mg/L as $CaCO_3$)	Manga-nese, dis-solved (µg/L as Mn)	Iron, dis-solved (µg/L as Fe)
-	-	-	-	-	-	-	-	-	-	-	-
32	6.2	294	300	9.9	0.4	7.5	700	690	530	15	17
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
19	2.4	226L	110	6.3	0.3	5.9	363	380	320	2	15
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
13	3.7	270L	136	8.8	-	-	-	445	400	-	59
34	12	368L	229	15	-	-	-	680	530	-	37
14	3.2	280L	160	8.6	-	-	-	490	430	-	20
39	4.0	264L	183	24	-	-	-	515	390	-	<1
50	3.4	286L	193	20	-	-	-	559	390	-	10
83	9.3	262L	810	59	-	-	-	1,400	980	-	210
12	2.7	249L	130	12	0.3	6.9	458	430	370	2	22
21	3.2	246L	260	22	0.3	6.4	645	620	480	10	22

Table 4.—Discharge, temperature of water, and specific conductance from selected springs and mines

Geologic unit: Qp, unconsolidated deposits; Tf, Flagstaff Limestone; TKnh, North Horn Formation; Kpr, Price River Formation; Kcg, Castlegate Sandstone; Kb, Blackhawk Formation; Ksp, Star Point Sandstone; Km, Mancos Shale

Site identifier	Location (See page 5)	Altitude (feet)	Geologic unit	Date	Discharge (gal/min)	Temperature (°C)	Specific conductance (µS/cm)
ALKALI CREEK AREA							
ACS1	(D-13-11) 1cca-S1	8,040	Tf	07-03-85	5.8	-	-
				07-24-85	3.9	-	-
				07-30-85	3.2	15.0	580
				08-19-85	2.0	-	-
				04-29-86	53.5	13.0	470
				06-02-86	11.2	12.0	590
				06-30-86	6.1	10.0	585
				07-31-86	2.9	12.5	570
				08-18-86	1.6	12.0	470
ACS2	1dab-S1	7,940	Tf	07-31-86	8.6	9.5	650
ACS3	2cdc-S1	7,320	TKnh	07-30-85	1.2	11.0	1,370
ACS4	10aaa-S1	7,040	Kcg	07-30-85	.3	14.0	1,120
ACS5	10bac-S1	6,640	Kb	08-29-85	2.0	10.0	1,700
ACS6	10bac-S2	6,600	Kb	10-01-85	-	6.0	1,910
				07-04-85	-	14.0	1,950
ACS7	11acb-S1	7,240	Kcg	07-30-85	1.1	15.0	1,750
ACS8	11cbd-S1	7,000	Kb	07-30-85	.8	11.0	1,320
ACS9	12bcc-S1	7,600	TKnh	07-31-85	.2	11.0	1,750
ACS10	13bdd-S1	6,800	Kb	07-31-85	1.3	11.0	4,800
ACS11	15bad-S1	6,460	Qp	07-30-85	.8	15.0	4,800
ACS12	(D-13-12) 5cbc-S1	6,930	Kb	01-14-86	-	9.0	1,020
				06-02-86	1.8	9.5	1,080
ACS13	7aba-S1	7,160	Kcg	07-02-85	.3	-	1,920
SCI	7b	6,500	Kb	01-15-86	-	16.0	1,290
SCA	8b	5,000	Kb	01-15-86	4.5	15.0	1,150
SC	18aac	6,700	Kb	06-02-86	367	14.0	1,340

Table 4.—Discharge, temperature of water, and specific conductance from selected springs and mines—Continued

Site identifier	Location (See page 5)	Altitude (feet)	Geologic unit	Date	Discharge (gal/min)	Temperature (°C)	Specific conductance (µS/cm)
CASTLE VALLEY RIDGE AREA							
CVS1	(D-14- 7)34abc-S1	9,350	Kb	07-03-86	2.9	5.5	500
CVS2	35dbc-S1	8,450	Ksp	07-01-86	-	6.5	810
CVS3	(D-15- 7) 1bcc-S1	8,640	Ksp	08-29-85	4.6	7.0	890
CVS4	1bcd-S1	8,400	Km	09-24-85	-	5.0	710
CVS5	2cbc-S1	9,120	Kb	08-27-85	.2	8.0	555
CVS6	2cda-S1	9,360	Kb	08-29-85	1.3	7.0	530
CVS7	2cdb-S1	9,600	Kb	08-29-85	.3	12.0	540
CVS8	2ddc-S1	8,720	Ksp	08-28-85	1.1	6.0	680
CVS9	3daa-S1	8,960	Kb	08-27-85	1.1	8.0	645
CVS10	3dbb-S1	8,640	Kb	08-27-85	1.1	8.0	645
CVS11	10aca-S1	8,640	Kb	09-23-85	2.5	5.0	600
CVS12	11aca-S1	9,700	Kpr	09-23-85	.4	8.5	360
CVS13	11acc-S1	9,420	Kcg	07-23-85	7.0	6.0	430
				08-01-85	4.8	6.0	420
				08-19-85	4.8	6.5	-
				09-22-85	4.5	-	-
CVS14	11bdc-S1	9,200	Kb	09-23-85	12.9	5.5	520
CVS15	11cba-S1	9,360	Kb	09-23-85	4.7	2.5	500
CVS16	13adc-S1	9,990	TKnh	10-02-80	-	8.0	355
CVS17	14aad-S1	9,840	TKnh	06-03-86	28.9	3.0	325
CVS18	14acd-S2	9,800	TKnh	08-01-85	2.2	6.0	400
				08-19-85	.7	7.0	-
				06-03-86	29.3	9.0	360
				07-01-86	4.0	5.0	440
				07-31-86	2.3	6.0	430
				08-18-86	1.7	6.5	435
CVS19	15aad-S1	9,640	TKnh	08-01-85	-	-	430
				08-19-85	1.0	8.0	-
KMI	(D-15- 8)18ccc	8,320	Kb	01-14-86	-	9.5	805
KMA	19bbb	8,300	Kb	01-14-86	-	8.5	500
MP	(D-16- 8) 8dad-S1	7,800	Kb	10-15-85	-	12.0	1,020
				07-01-86	-	12.0	1,000

Table 5.—Chemical analyses of water

[All pH, specific conductance, and alkalinity values were obtained in

Geologic unit: Qp, unconsolidated deposits; Tf, Flagstaff Limestone; TKnh, North Horn Formation; Kpr, Km, Mancos Shale

Site identifier	Location (See page 5)	Geologic unit	Date	Temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
ALKALI CREEK AREA									
ACS1	(D-13-11) 1cca-S1	Tf	07-30-85	15.0	580	8.3	100	21	8.0
			04-29-86	13.0	470	8.2	74	15	5.6
ACS2	1dab-S1	Tf	07-31-86	9.5	650	7.3	85	30	14
ACS3	2cdc-S1	TKnh	07-30-85	11.0	1,370	7.6	65	120	92
ACS4	10aaa-S1	Kcg	07-30-85	14.0	1,120	8.7	89	88	27
ACS5	10bac-S1	Kb	08-29-85	10.0	1,700	7.6L	140	150	55
ACS6	10bac-S2	Kb	10-01-85	6.0	1,910	7.1	130	140	110
ACS7	11acb-S1	Kcg	07-30-85	15.0	1,750	7.6	130	110	39
ACS8	11cbd-S1	Kb	07-30-85	11.0	1,320	7.4	150	100	24
ACS9	12bcc-S1	TKnh	07-31-85	11.0	1,750	8.1	190	150	41
ACS10	13bdd-S1	Kb	07-31-85	11.0	4,800	7.6	400	720	93
ACS11	15bad-S1	Qp	07-30-85	15.0	4,800	7.3	390	440	130
ACS12	(D-13-12) 5cbc-S1	Kb	07-31-80	8.7	1,060L	7.5	30	28	180
SCI	7b	Kb	01-15-86	16.0	1,290	7.8	39	32	240
SCA	8b	Kb	01-15-86	15.0	1,150	8.0	46	35	180
CASTLE VALLEY RIDGE AREA									
CVS1	(D-14- 7)34abc-S1	Kb	07-03-86	5.5	500	7.4	76	21	3.8
CVS2	35dba-S1	Ksp	07-01-86	6.5	810	7.6	93	45	11
CVS3	(D-15- 7) 1bcc-S1	Ksp	08-29-85	7.0	890	8.3L	77	68	14
CVS4	1bcd-S1	Km	09-24-85	5.0	710	7.7L	86	40	6.5
CVS5	2cbc-S1	Kb	08-27-85	8.0	555	8.5	70	31	4.3
CVS6	2cda-S1	Kb	08-29-85	7.0	530	8.1L	72	31	3.8
CVS7	2cdb-S1	Kb	08-29-85	12.0	540	7.8L	68	26	5.1
CVS8	2ddc-S1	Ksp	08-28-85	6.0	680	7.8	85	38	4.8
CVS9	3daa-S1	Kb	08-27-85	8.0	645	8.1	82	38	5.7
CVS10	3dbb-S1	Kb	08-27-85	8.0	645	8.2	72	43	7.7
CVS11	10aca-S1	Kb	09-23-85	5.0	600	8.8	67	40	7.4
CVS12	11aca-S1	Kpr	09-23-85	8.5	360	7.3	50	16	2.2
CVS13	11acc-S1	Kcg	08-01-85	6.0	420	8.4	60	21	3.3
CVS14	11bdc-S1	Kb	09-23-85	5.5	520	8.1	69	26	4.0
CVS15	11cba-S1	Kb	09-23-85	2.5	500	8.5	65	26	5.2
CVS18	14acd-S2	TKnh	08-01-85	6.0	400	7.8	53	23	1.5
			06-03-86	9.0	360	8.1L	59	12	1.2
CVS19	15aad-S1	TKnh	08-01-85	-	430	7.5	74	11	3.4
KMI	(D-15- 8)18ccc	Kb	01-14-86	9.5	805	7.2	100	42	6.4
KMA	19bbb	Kb	01-14-86	8.5	500	7.8	69	26	2.5
MP	(D-16- 8) 8dad-S1	Kb	09-18-75	12.5	940	7.3	150	55	7.0
			10-12-77	6.0	1,150	6.9	130	59	6.5
			10-15-85	12.0	1,020	7.1	140	59	7.2

from selected springs and mines
the field except those marked L which were measured in the Laboratory]

Price River Formation; Kcg, Castlegate Sandstone; Kb, Blackhawk Formation; Ksp, Star Point Sandstone;

Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids, residue at 180 °C (mg/L)	Dissolved solids, sum of constituents (mg/L)	Hardness (mg/L as $CaCO_3$)	Manganese, dissolved (µg/L as Mn)	Iron, dissolved (µg/L as Fe)
1.7	306	22	5.6	0.2	8.4	312	350	340	3	<3
1.6	237L	16	5.4	0.2	6.1	273	270	250	<1	7
1.1	262L	22	8.3	0.4	7.8	386	330	340	<1	<3
4.9	564	270	17	0.5	8.8	934	920	660	8	3
5.6	258	330	47	0.6	9.3	796	750	580	8	12
11	535L	460	36	0.7	16	1,230	1,200	970	<1	<3
12	664L	420	75	0.8	9.0	1,400	1,300	900	16	13
8.9	532	520	34	0.4	11	1,300	1,200	780	64	20
8.0	423	370	24	0.8	13	976	940	790	3	4
7.0	456	680	21	0.4	9.6	1,380	1,400	1,100	35	580
51	551	3,200	52	0.9	14	5,210	4,900	4,000	20	40
20	503	2,600	99	0.5	15	4,960	4,000	2,800	20	40
4.2	480L	39	49	0.5	8.1	-	629	190	-	<10
1.9	677L	85	33	1.8	8.3	824	850	230	19	15
16	657L	15	18	1.3	7.8	657	720	260	<1	<3
0.7	251L	13	3.3	0.3	7.1	285	280	280	<1	10
3.3	329L	95	11	0.3	8.0	474	460	420	<1	6
4.2	275L	190	29	0.4	9.3	579	560	470	2	<3
2.3	336L	45	8.0	0.2	8.0	427	400	380	<1	4
1.7	267L	22	5.9	0.2	7.6	319	300	300	2	6
1.6	240L	42	4.8	0.2	7.5	325	310	310	17	5
0.8	243L	20	7.3	0.2	6.3	277	280	280	22	<3
1.8	307L	45	4.7	0.2	7.7	383	370	370	5	13
1.2	309L	25	4.9	0.2	9.5	366	350	360	2	8
1.2	306L	26	9.6	0.3	9.3	357	350	360	1	4
1.7	276L	37	9.6	0.2	8.2	371	340	330	3	8
1.0	174L	7.3	3.4	0.1	7.0	217	190	190	<1	8
0.4	210	13	4.3	0.2	7.0	242	240	240	<1	3
0.8	257L	19	4.7	0.1	7.0	290	280	280	<1	4
1.1	231L	32	5.1	0.2	6.4	297	280	270	<1	5
0.8	217	4.0	1.4	0.2	4.3	232	220	230	<1	4
0.9	197L	2.8	0.3	<0.1	3.7	208	200	200	4	12
1.5	212	6.1	3.0	0.1	6.8	234	230	230	8	4
8.2	323L	140	3.4	0.4	7.1	472	500	420	47	72
1.3	249L	19	2.1	0.1	6.5	256	280	280	16	18
5.0	353	230	3.4	0.2	8.4	-	670	600	-	20
4.8	360	210	4.3	0.2	9.3	-	640	570	40	30
4.6	362L	230	5.5	0.2	9.2	712	670	590	20	<3

Table 6.--Chemical analyses for dissolved metals and radioisotopes in water from selected springs and mines in the Alkali Creek and Castle Valley Ridge areas

[All concentrations are in micrograms per liter except for tritium which is in picocuries per liter]

Site identifier	Location (See page 5)	Date	Barium, dissolved (as Ba)	Cadmium, dissolved (as Cd)	Cobalt, dissolved (as Co)	Copper, dissolved (as Cu)	Lead, dissolved (as Pb)	Lithium, dissolved (as Li)	Molybdenum, dissolved (as Mo)	Strontium, dissolved (as Sr)	Zinc, dissolved (as Zn)	Tritium
ALKALI CREEK AREA												
ACS1	(D-13-11) 1cca-S1	04-29-85	-	-	-	-	-	-	-	140	-	-
ACS2	1dab-S1	07-31-86	290	-	-	-	-	-	-	-	-	-
ACS12	(D-13-12) 5cbc-S1	07-31-80	-	-	-	-	-	20	-	960	<3	-
SCI	7b	01-15-86	500	<1	<3	<10	<10	180	<10	760	13	-
SCA	8b	01-15-86	4,100	<1	<3	<10	<10	180	<10	1,100	12	<1.0
CASTLE VALLEY RIDGE AREA												
CVS11	(D-15- 7)10aca-S1	09-23-85	-	-	-	-	-	-	-	73	-	-
CVS18	14acd-S2	06-03-85	-	-	-	-	-	-	-	99	-	-
KMI	(D-15- 8)18ccc	01-14-86	79	<1	<3	<10	<10	33	<10	1,400	34	-
KMA	19bbb	01-14-86	86	<10	<3	<10	<10	11	<10	150	40	8.02
MP	(D-16- 8) 8dad-S1	10-15-85	47	<1	<3	<10	<10	29	<10	1,000	20	-

Table 7.—Records of coal-exploration holes in the Castle Valley Ridge area

Finish: X, uncased; P, perforated—depth of hole or upper and lower limits of perforations given in feet below land surface.
Water Level: Measured water levels given in feet and decimal fractions; water levels from resistivity logs are given in whole numbers.

Site identifier	Location (See page 5)	Finish	Altitude of land surface	Date of measurement	Water Level
CST-5	(D-14- 7)22dcc- 1	X 677	9,560	10-15-85	450
CST-3	27acd- 1	P 716-756	9,660	10-01-85	513.7
CST-3C	27acd- 2	X 756	9,660	10-04-85	480
CST-4	27dac- 1	X 835	9,684	09-22-85	680
CST-2	35bca- 1	X 756	9,613	09-10-85	565