The Ground-Water System and Possible Effects of Underground Coal Mining in the Trail Mountain Area, Central Utah

United States Geological Survey Water-Supply Paper 2259

Prepared in cooperation with the U.S. Bureau of Land Management

The Ground-Water System and Possible Effects of Underground Coal Mining in the Trail Mountain Area, Central Utah

By Gregory C. Lines

Prepared in cooperation with the
U.S. Bureau of Land Management

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2259

DEPARTMENT OF THE INTERIOR
WILLIAM P. CLARK, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1985

For sale by the Branch of Distribution
U.S. Geological Survey
604 South Pickett Street
Alexandria, VA 22304

Library of Congress Cataloging in Publication Data

Lines, Gregory C.
The ground-water system and possible effects of underground coal mining in the Trail Mountain area, central Utah.

(Geological Survey water-supply paper 2259)
"Prepared in cooperation with the U.S. Bureau of Land Management."
Bibliography 32 p.
Supt. of Docs. No.: I 19.13:2259
1. Water, Underground—Utah—Wasatch Plateau. 2. Coal mines and mining—Environmental aspects—Utah—Wasatch Plateau. I. Title. II. Title: Trail Mountain area, central Utah. III. Series.

GB1025.U8L558 1985 553.7'9'09792563 84-600083

CONTENTS

FIGURES

FIGURES

TABLES

CONVERSION FACTORS AND RELATED INFORMATION

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

Multiply	By	To obtain
acre	0.4047	square hectometer
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.09290	meter squared per day
gallon per day (gal/d)	3.785	liter per day
gallon per minute (gal/min)	3.785	liter per minute
inch (in.)	2.540	centimeter
micromhos per centimeter at 25° Celsius (umho)	1.000	microsiemens per centimeter at 25° Celsius
mile (mi)	1.609	kilometer
pound per square inch (lb/in^2)	6.895	kilopascal
square mile (mi^2)	2.590	square kilometer
ton (short, 2,000 pounds)	0.9072	metric ton

Chemical concentration and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter. Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.

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

$$°F=1.8(°C)+32$$

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, is referred to as sea level in this report.

The Ground-Water System and Possible Effects of Underground Coal Mining in the Trail Mountain Area, Central Utah

By Gregory C. Lines

Abstract

The ground-water system was studied in the Trail Mountain area in order to provide hydrologic information needed to assess the hydrologic effects of underground coal mining. Well testing and spring data indicate that water occurs in several aquifers. The coal-bearing Blackhawk-Star Point aquifer is regional in nature and is the source of most water in underground mines in the region. One or more perched aquifers overlie the Blackhawk-Star Point aquifer in most areas of Trail Mountain.

Aquifer tests indicate that the transmissivity of the Blackhawk-Star Point aquifer, which consists mainly of sandstone, siltstone, and shale, ranges from about 20 to 200 feet squared per day in most areas of Trail Mountain. The specific yield of the aquifer was estimated at 0.05, and the storage coefficient is about $1x10^{-6}$ per foot of aquifer where confined.

The main sources of recharge to the multiaquifer system are snowmelt and rain, and water is discharged mainly by springs and by leakage along streams. Springs that issue from perched aquifers are sources of water for livestock and wildlife on Trail Mountain.

Water in all aquifers is suitable for most uses. Dissolved-solids concentrations range from about 250 to 700 milligrams per liter, and the predominant dissolved constituents generally are calcium, magnesium, and bicarbonate.

Future underground coal mines will require dewatering when they penetrate the Blackhawk-Star Point aquifer. A finite-difference, three-dimensional computer model was used to estimate the inflow of water to various lengths and widths of a hypothetical dewatered mine and to estimate drawdowns of potentiometric surfaces in the partly dewatered aquifer. The estimates were made for a range of aquifer properties and premining hydraulic gradients that were similar to those on Trail Mountain. The computer simulations indicate that mine inflows could be several hundred gallons per minute and that potentiometric surfaces of the partly dewatered aquifer could be drawn down by several hundred feet during a reasonable life span of a mine. Because the Blackhawk-Star Point aquifer is separated from overlying perched aquifers by an unsaturated zone, mine dewatering alone would not affect perched aquifers. Mine dewatering would not significantly change water quality in the Blackhawk-Star Point aquifer.

Subsidence will occur above future underground mines, but the effects on the ground-water system cannot be quantified. Subsidence fractures possibly could extend from the roof of a mine into a perched aquifer several hundred feet above. Such fractures would increase downward percolation of water through the perching bed, and spring discharge from the perched aquifer could decrease. Flow through subsidence fractures also could increase recharge to the Blackhawk-Star Point aquifer and increase inflows to underground mines.

INTRODUCTION

Trail Mountain is in the Wasatch Plateau coal field in central Utah. (See figure 1.) The Wasatch Plateau is Utah's most developed coal field, and production was about 14 million tons during 1982. All coal was recovered with underground mining from a number of beds in the Blackhawk Formation of Cretaceous age. During 1982, there were 21 producing mines and about 60,000 acres of Federal land leased for coal mining in the Wasatch Plateau (T.F. Abing, U.S. Bureau of Land Management, written commun., 1983). There was one producing coal mine on Trail Mountain, and much of the Federally owned coal was unleased.

Data from previous hydrologic studies in the Wasatch Plateau (Danielson and others, 1981; Waddell and others, 1981; and Danielson and Sylla, 1983) indicate that the coal-bearing Blackhawk Formation and other geologic units contain water. Inflows of water to most underground mines in the Wasatch Plateau are sufficiently large to require mine dewatering. Aquifer characteristics, the degree of aquifer interconnection, recharge and discharge relationships, and the directions of ground-water movement usually are inadequately defined to accurately assess the hydrologic effects of mine dewatering. Data generally are not available to assess the hydrologic effects of subsidence associated with the underground mining.

Scope and Objectives

From March 1981 to September 1983, the U.S. Geological Survey in cooperation with the U.S. Bureau of Land Management studied ground-water conditions in the Trail Mountain area in order to provide hydrologic information needed to assess the hydrologic effects of coal mining. Trail Mountain was selected for study because of its apparent geologic and hydrologic similarities to much of the Wasatch Plateau and because of the availability of U.S. Geological Survey coal-test holes that could be used to construct wells for aquifer testing.

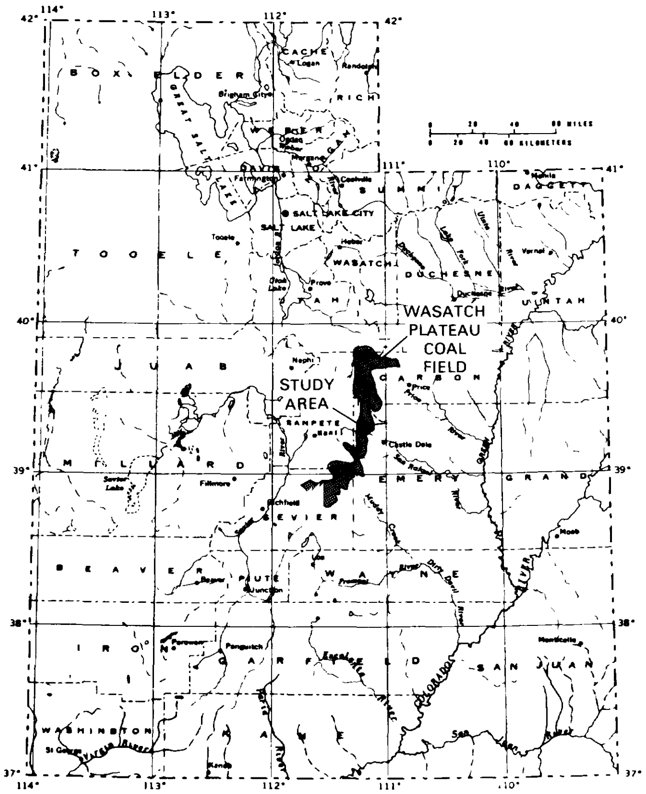


Figure 1. Location of study area in the Wasatch Plateau coal field.

The primary objective of the study was to determine aquifer characteristics, hydraulic connection between aquifers and with streams, recharge and discharge relationships, and chemical quality of water within, above, and immediately below the coal-bearing Blackhawk Formation. A second objective was to predict, quantitatively where possible, the effects of underground mining on the ground-water system.

Methods of Investigation

Fieldwork included the construction and testing of five wells on the south end of Trail Mountain; an extensive spring inventory; base-flow measurements along streams; and sampling of water from springs, wells, and underground mines for chemical analyses. Water discharged from the underground Trail Mountain Mine by pumping and by the ventilation system also was monitored.

A three-dimensional computer model was used to develop curves that may be used to estimate inflow to various lengths and widths of underground mine for various hydrologic conditions. Curves also were developed to estimate drawdowns at various distances from a mine that has been dewatered for various lengths of time.

Acknowledgments

The writer expresses his gratitude to Natomas Trail Mountain Coal Co. for allowing access to the mine property for data-collection activities and for supplying unpublished maps and data. Special thanks are given to Kerry Willardson who kept records on times of pumping from the Trail Mountain Mine and to Allen Childs who served as a guide underground.

Well-, Spring-, and Site-Numbering System

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The 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 uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants. Numbers designating the township and range (in that order) follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section, and it 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 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-17-6) 24bdc-1 designates the first well constructed or visited in the SW¼SE¼NW¼ sec. 24, T. 17 S., R. 6 E., and (D-17-6) 24ab-S designates a spring known only to be in the NW¼NE¼ of the same section. 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.

GEOLOGIC SETTING

Consolidated rocks exposed in the Trail Mountain area range in age from Cretaceous to Tertiary. Various types of unconsolidated deposits of Quaternary age also are

[1]Although the basic land unit, the section, is theoretically 1 mi^2, many sections are irregular. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is added to or subtracted from the tracts along the north and west sides of the section.

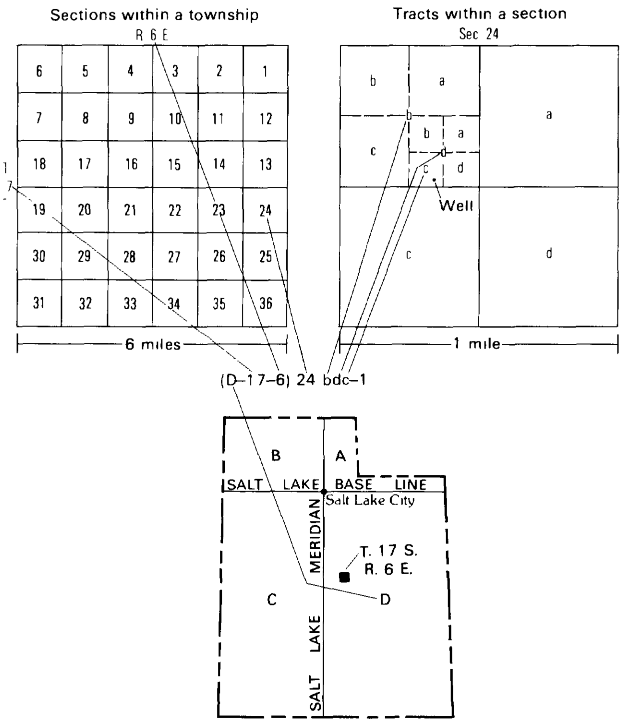


Figure 2. Well-, spring-, and site-numbering system used in Utah.

exposed in the area. The unconsolidated deposits are relatively thin and mainly consist of clay, sand, gravel, and boulders. Outcrop areas of geologic units are shown in figure 3.

The oldest geologic unit exposed in the area is the Masuk Member of the Mancos Shale of Cretaceous age. The Masuk consists of gray marine shale that is sandy in some places. About 600 ft of the Masuk is exposed at the base of Trail Mountain near the confluence of Straight Canyon and Cottonwood Creek. (See figure 4.) The Masuk is not fully exposed in the study area, therefore, total thickness is unknown.

The Star Point Sandstone of Cretaceous age is exposed in the lowermost cliffs on the southeast end of Trail Mountain. The Star Point consists of massive beds of tan medium-grained sandstone, and it intertongues with several thin shale beds of the Masuk. Where the unit is exposed on Trail Mountain, it is about 500 ft thick. The altitude of the top of the Star Point is shown in figure 5.

The coal-bearing unit in the Wasatch Plateau is the Blackhawk Formation. The Blackhawk consists of gray sandstone, gray to black siltstone and shale, and coal. Sediments in the Blackhawk were deposited in marine, flood-plain, deltaic, and lagoonal environments. Sandstone beds are lenticular, and individual beds can be traced only for short distances in the outcrop area. The sandstones mainly are fine grained, and lithologic logs of test holes on Trail Mountain indicate that the Blackhawk is 50 to 60 percent sandstone (Davis and Doelling, 1977, p. 23-54). The Blackhawk ranges in thickness from about 800 to 1,100 ft on Trail Mountain.

Most of the coal is in the lower one-half of the Blackhawk Formation. The Hiawatha coal bed, the thickest of the coal beds on Trail Mountain, is within a few feet of the base of the Blackhawk and has a maximum thickness of about 12 ft. The Hiawatha bed was mined along Straight Canyon at the Oliphant and Black Diamond Mines (fig. 7) from about the turn of the 20th century into the 1950's (Doelling, 1972, p. 87 and 90). Mining from the Hiawatha bed began in 1946 at the Trail Mountain Mine along Cottonwood Creek, and the mine was still operating in 1983. A view of the surface facilities at the Trail Mountain Mine is shown in figure 6.

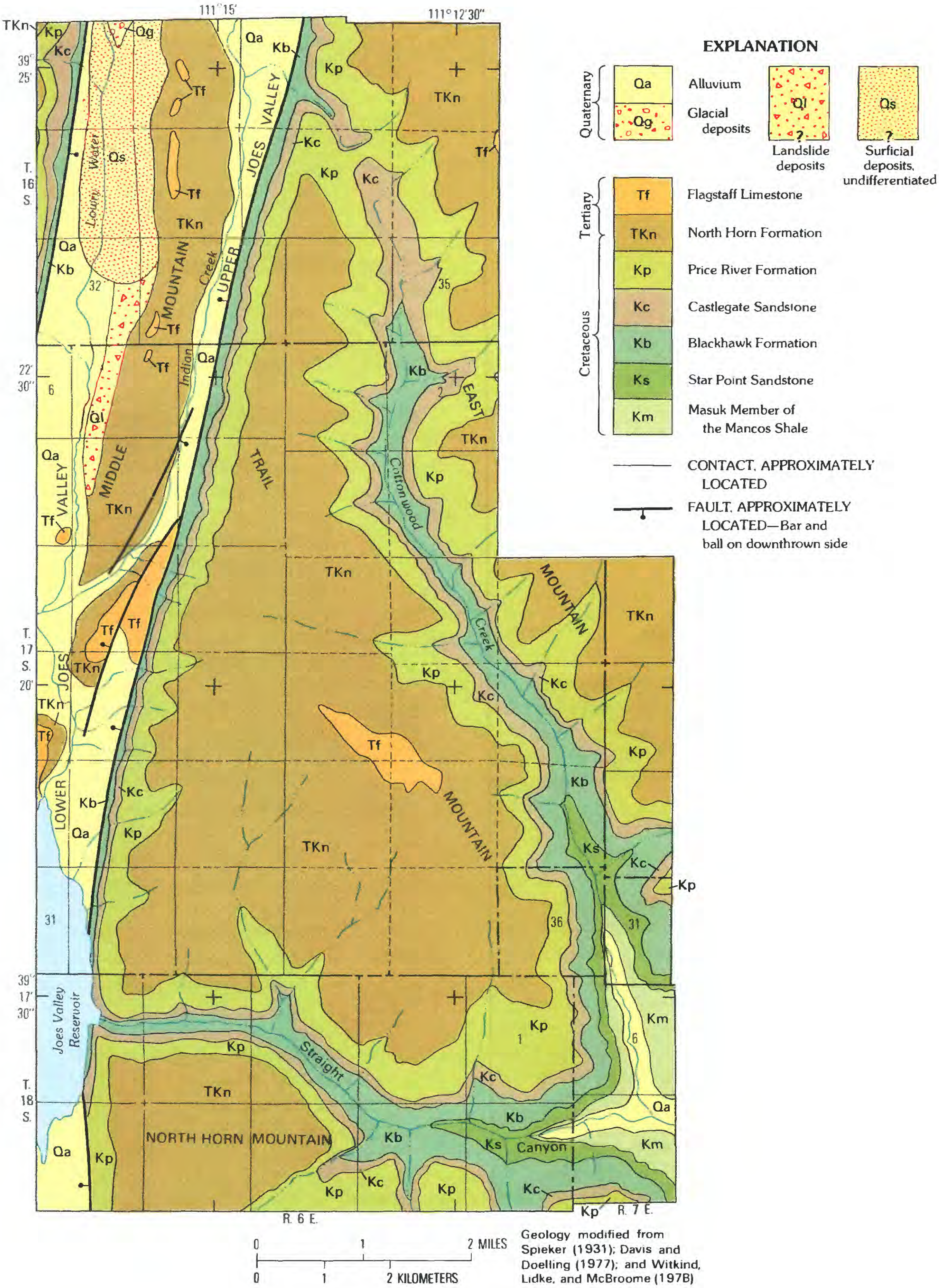
The Castlegate Sandstone of Cretaceous age overlies the Blackhawk, and it forms cliffs similar to those shown in figure 4 along most of its outcrop. The Castlegate consists of gray, tan, and yellowish brown sandstone. The sandstone beds are massive, and the sandstones mostly are medium to coarse grained and conglomeratic in places. The Castlegate is about 170 ft thick along a section measured in sec. 20, T. 17 S., R. 6 E. on the west side of Trail Mountain (Davis and Doelling, 1977, p. 6). The Castlegate is about 200 ft thick at well (D-17-6) 27bda-1.

The Price River Formation of Cretaceous age crops out on steep slopes above the cliffs of the Castlegate Sandstone. The Price River Formation mainly consists of gray, tan, and brown sandstone and a few thin beds of conglomerate and shale. The sandstones mainly are medium to coarse grained. The unit is about 700 ft thick on Trail Mountain.

Exposures of the North Horn Formation of Cretaceous and Tertiary age cover about 56 percent of the surface of Trail Mountain. The North Horn generally forms gentle slopes that are hummocky in places. The unit mainly consists of shale, but it has some thin beds of sandstone and limestone. The shales are various shades of pink, green, purple, gray, and brown. The North Horn is about 980 ft thick along a section measured in secs. 21 and 22, T. 17 N., R. 6 E. (Davis and Doelling, 1977, p. 6).

The Flagstaff Limestone of Tertiary age is as much as 1,000 ft thick in other areas of the Wasatch Plateau, but only 100 ft remains atop the south end of Trail Mountain. The Flagstaff mainly consists of white and light gray limestone and some thin beds of shale and volcanic ash. The limestones are lacustrine in origin and are thin bedded.

The Joes Valley fault breaks the continuity of geologic units along the west edge of Trail Mountain. Davis and Doelling (1977, p. 9) estimate about 2,300 ft of vertical displacement along the fault in this area. The Joes Valley fault is the eastern fault boundary of a graben, approximately



Geology modified from Spieker (1931); Davis and Doelling (1977); and Witkind, Lidke, and McBroome (1978)

Figure 3. Surficial geology.

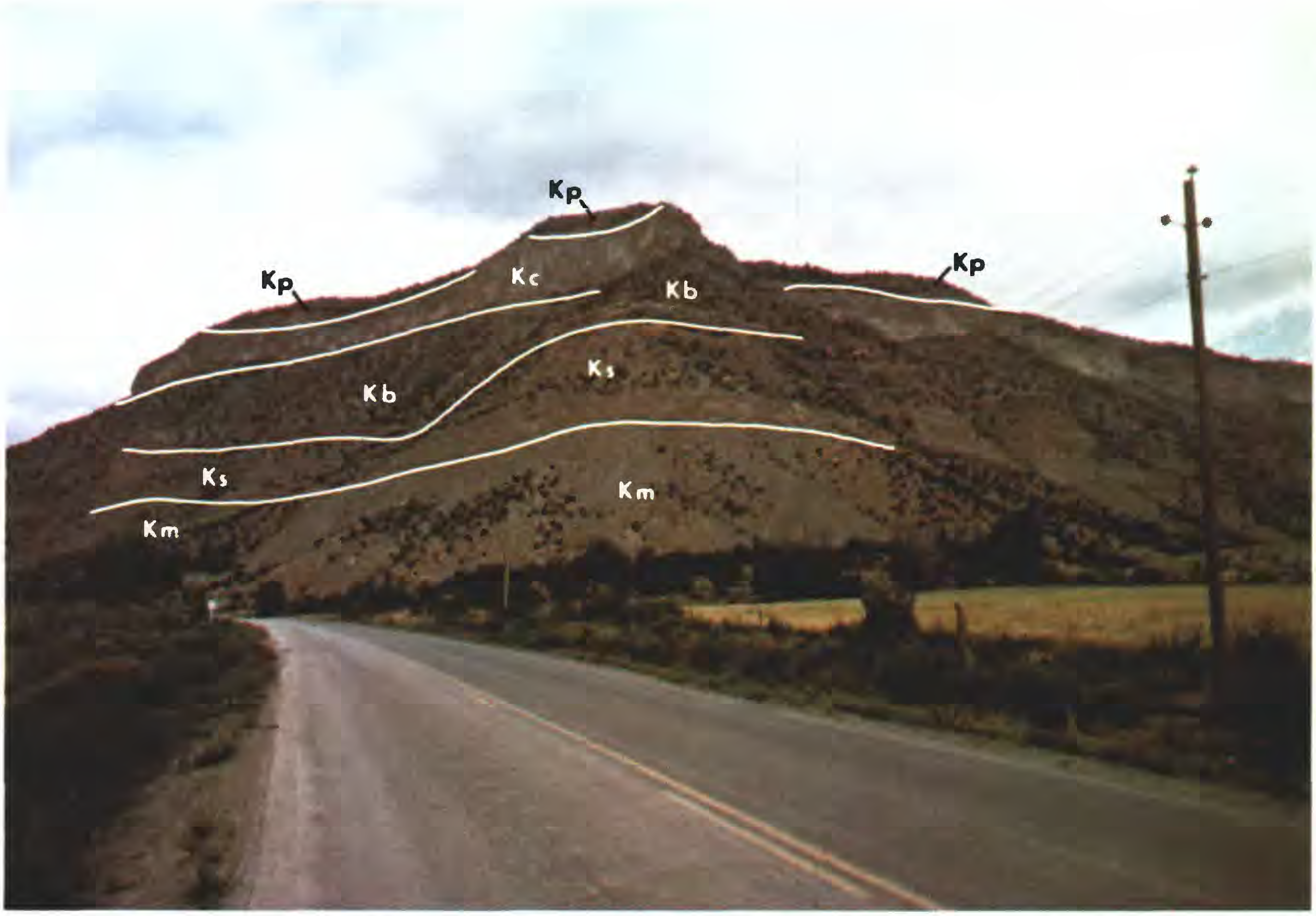


Figure 4. View of geologic units exposed on the southeast slopes of Trail Mountain. (Km, Masuk Member of the Mancos Shale; Ks, Star Point Sandstone; Kb, Blackhawk Formation; Kc, Castlegate Sandstone; Kp, Price River Formation.)

2 mi wide, that extends at least 20 mi north of Trail Mountain and at least 40 mi south.

Strata are gently folded into the Flat Canyon anticline in the northern part of Trail Mountain. Southward, the strata dip gently into the Straight Canyon syncline. (See figure 5.) Both structures trace about north 50° east and plunge to the southwest. The dip of strata on Trail Mountain generally is 2° or 3° and rarely exceeds 5°.

GROUND-WATER SYSTEM

The ground-water system in the Trail Mountain area was defined principally using data from wells and springs. Records of wells in the Trail Mountain area are listed in table 1, and spring records are listed in table 2. Location of the wells, springs, mines, and other data-collection sites is shown in figure 7.

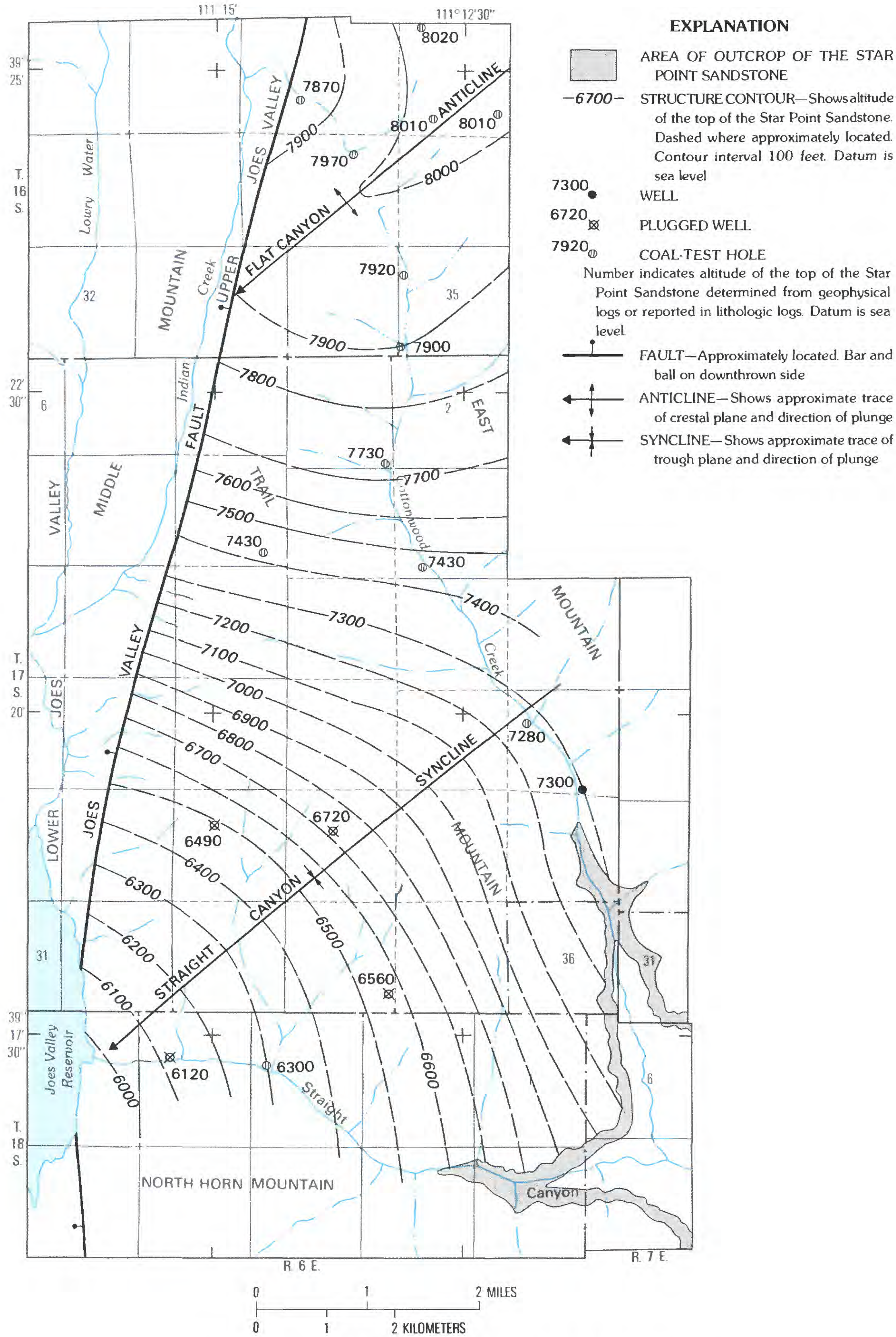


Figure 5. Altitude of the top of the Star Point Sandstone.

Figure 6. View of the Trail Mountain Mine along Cottonwood Creek. The stream has been diverted into the culvert to decrease sediment yields from the surface facilities of the mine.

Occurrence of Ground Water

The occurrence of ground water in Trail Mountain is depicted in the generalized block diagram in figure 8. Most of the Blackhawk Formation and Star Point Sandstone are saturated, except where they are drained naturally near the edges of deeply incised canyons. This saturated zone comprises the Blackhawk-Star Point aquifer, which extends throughout most of the Wasatch Plateau coal field. This regional aquifer is the source of most of the water in underground mines in the coal field.

Although the Masuk Member of the Mancos Shale probably is saturated beneath the Blackhawk-Star Point aquifer, it is not considered a part of the aquifer. Except where extensively fractured, less-permeable shales in the Masuk will transmit relatively small quantities of water compared to most rocks in the Blackhawk-Star Point aquifer.

Where strata that overlie the Blackhawk-Star Point aquifer are several hundred feet above the bottoms of canyons, as is the case for most of Trail Mountain, aquifers in the overlying strata are perched[2]. As depicted in figure 8, perched aquifers in the North Horn and Price River Formations are separated from each other and from the Blackhawk-Star Point aquifer by an unsaturated zone. Both of the perched aquifers have water tables that are several hundred feet above the regional water table in the Blackhawk-Star Point aquifer.

The perched aquifers are the source of most of the spring water consumed by livestock and wildlife on Trail Mountain. In some areas of the Wasatch Plateau, most of the base flow of streams originates as discharge from perched aquifers (Danielson and Sylla, 1983, p. 15).

The Castlegate Sandstone is depicted in figure 8 as being above the regional water table and containing no

[2]As defined by Lohman and others (1972, p. 7), "*Perched ground water* is unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a *perched water table.* It is held up by a *perching bed* whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure."

Table 1. Records of wells

Altitude of land surface: Interpolated from U.S. Geological Surgey topographic maps.
Casing: Depth—Depth to top of perforations or first opening; P, depth to bottom of expandable packer in open hole.
Water-bearing zone(s): Kb, Blackhawk Formation; Kc, Castlegate Sandstone; Kp, Price River Formation; Ks, Star Point Sandstone; Qa, alluvium; TKn, North Horn Formation.
Use(s) of well: A, aquifer test; D, domestic supply; M, water-level monitoring.
Remarks and other data available: A, aquifer test summarized in table 4 and data in files of U.S. Geological Survey, Salt Lake City, Utah; C, chemical analysis in table 6; T, analysis of dissolved trace metals in table 7.
Units: ft, feet; in., inches; gal/min, gallons per minute.

Well No.	Owner or user	Year constructed	Altitude of land surface above sea level (ft)	Depth of well (ft)	Casing Diameter (in.)	Casing Depth (ft)	Water-bearing zone(s)	Water level above (+) or below land surface (ft)	Discharge (gal/min)	Date	Use(s) of well	Remarks and other data available
(D-17-6)24dcd-1	Utah Power and Light Co.	1978	7,440	280	4	100	Kb,Ks	46	5.0	9-18-79	A,M	A
27bda-1	U.S. Geological Survey	1982	9,130	2,500	4	1,910P	Kb,Ka	1,484	6.5	10-20-82	A	First water at 130 ft in the North Horn Formation. 4-in. casing to 1,400 ft; 3-in. casing to 1,490 ft; and 3-in. open hole below. Plugged after testing. A,C,T
						2,420P	Ks	1,505	4.7	10-18-82		
28bad-1	do.	1982	8,920	664	4	50	TKn	49	.1	10-28-82	A	Casing perforated at 50-90 and 550-580 ft. Both perforated intervals tested with an expandable packer. Plugged after testing.
						550	TKn	Dry	---	10-26-82		
28bad-2	do.	1982	8,920	1,220	4	1,030	Kp	816	2.0	10-30-82	A	Casing perforated at 1,030-1,080 ft. Plugged after testing. A,C,T
29cbb-1	Jack World	1982	7,100	120	6	80	Qa	73	---	8-10-82	D	C,T
34dda-1	U.S. Geological Survey	1982	8,460	1,945	4	55	TKn	40	1.5	9-23-82	A	Casing perforated at 55-100; 722-742; 1,446-1,466; and 1-882-1,897 ft. Each perforated interval tested with an expandable packer. Plugged after testing. A
						722	Kc	Dry	---	9-25-82		
						1,446	Kb	1,414	.1	10- 6-82		
						1,882	Kb	1,478	.2	10- 9-82		
(D-18-6)4bac-1	do.	1981	6,800	696	4	85	Kb,Ks	+20	9.3	6-22-82	A	First water reported at 45 ft. in the Blackhawk Formation. Casing perforated at 85-410 ft. and 3-in. open hole below. Plugged after testing. A,C,T
5abd-1	U.S. Bureau of Reclamation	1980	7,010	188	.5	174	Kb	122	---	9- 3-82	M	Porous-tube piezometer.
5abd-2	do.	1980	7,010	160	.5	148	Kb	107	---	9- 3-82	M	Do.
5abd-3	do.	1980	7,010	154	.5	135	Kb	67	---	9- 3-82	M	Do.
5abd-4	do.	1980	7,010	132	.5	120	Kb	56	---	9- 3-82	M	Do.

Table 2. Records of springs

Altitude of land surface: Interpolated from U.S. Geological Surgey topographic maps.
Water-bearing zone: Kb, Blackhawk Formation; Kc, Castlegate Sandstone; Kp, Price River Formation; TKn, North Horn Formation.
Units: ft, feet; gal/min, gallons per minute; μmho, micromhos per centimeter at 25 degrees Celsius; °C, degrees Celsius.

Spring No.	Altitude of land surface above sea level (ft)	Water-bearing zone	Date	Discharge (gal/min)	Specific conductance (μmho)	Water temperature (°C)
(D-16-6)21ddd-S1	8,570	TKn	6-22-79	9.4	650	6.0
			9-19-79	.5	---	10.0
22cda-S1	8,900	Kb	7-16-81	6.1	660	6.5
			7-29-81	5.0	690	6.0
			8-20-81	5.2	600	5.5
			9-23-81	4.8	560	6.0
			5-21-82	14.5	580	6.0
			6-23-82	13.7	600	6.5
			7-17-82	13.0	620	6.5
			8-10-82	10.4	600	6.5
			9- 2-82	10.9	600	6.5
22ddb-S1	9,400	Kp	6-28-79	3.8	540	5.5
27aaa-S1	9,460	Kp	6-19-79	9.4	430	3.5
27add-S1	9,180	Kc	6-20-79	.6	420	6.0
27bcd-S1	9,580	Kp	8-23-79	.8	400	6.0
27dcc-S1	9,480	Kp	8- 1-79	4.8	510	4.5
33bcd-S1	8,380	TKn	10- 1-80	13.0	580	7.0
34abd-S1	9,280	Kp	8- 1-79	.05	580	7.0
34acc-S1	9,560	TKn	6-20-79	13.0	440	5.0
34bdc-S1	9,700	TKn	6-20-79	17.1	470	5.0
34cad-S1	9,400	Kp	9- 6-78	.5	560	8.5
34dda-S1	8,760	Kp	8- 1-79	3.2	560	7.5
(D-17-6)3aac-S1	9,360	Kp	7-19-79	.8	560	7.5
3aac-S2	9,360	Kp	7-19-79	.4	500	8.0
3acb-S1	8,960	Kp	6-21-79	60	530	6.0
3adc-S1	8,960	Kc	10-14-77	26	540	7.0
			7- 4-79	24	550	7.5
3add-S1	8,760	Kc	7- 4-79	7.1	550	7.5
3bab-S1	9,640	TKn	6-20-79	.2	490	7.0
3bad-S1	9,440	Kp	7-19-79	1.3	490	6.5
3bda-S1	9,040	Kp	6-21-79	50	520	6.0
3cbd-S1	9,400	TKn	7-31-79	.6	470	7.0
3ddc-S1	8,700	Kc	7- 4-79	13	560	---
4bcc-S1	8,190	TKn	6-15-79	29	620	5.0
4cbb-S1	8,200	TKn	6-15-79	147	600	5.0
14bcb-S1	9,080	TKn	6-27-79	.6	470	---
			7-14-81	Dry	---	---
14ddd-S1	7,770	Kb	7-14-81	80	650	8.5
			7-30-81	76	640	8.0
			8-20-81	73	640	8.0
			9-24-81	76	660	8.0
			5-20-82	80	---	---
			6-23-82	76	670	8.0
			7-17-82	98	670	7.5
			8-10-82	98	660	8.5
			9- 8-82	110	600	8.5
15adc-S1	9,080	TKn	6-27-79	1.6	490	7.0

Spring No.	Altitude of land surface above sea level (ft)	Water-bearing zone	Date	Discharge (gal/min)	Specific conductance (μmho)	Water temperature (°C)
(D-17-6)15cad-S1	8,840	TKn	7- 5-79	1.0	560	8.5
			7-29-81	.2	690	6.0
15cbd-S1	8,950	TKn	7-13-79	1.2	680	13.5
			7-29-79	Dry	---	---
15dda-S1	8,520	Kp	7- 5-79	1.5	650	8.0
21abb-S1	9,340	TKn	6-26-79	3.2	550	5.5
			7-14-81	.6	630	7.5
21dcd-S1	9,040	TKn	7-10-79	32	520	6.0
			7-14-81	12.4	560	7.0
			7-30-81	10.3	580	6.5
			8-20-81	7.6	600	7.0
			9-23-81	7.6	580	6.5
			5-21-82	44	570	6.5
			6-23-82	28	580	6.5
			7-15-82	20	580	6.0
			8-10-82	12.6	620	7.0
			9- 2-82	13.5	600	7.0
21dcd-S2	9,100	TKn	7-10-79	4.0	560	6.0
22cdc-S1	9,220	TKn	7-14-81	5.0	495	8.0
			7-30-81	6.1	520	8.0
			8-20-81	5.3	540	6.0
			9-23-81	5.1	520	6.5
			5-21-82	40	520	6.5
			6-23-82	28	510	6.5
			7-15-82	23	520	6.0
			8-10-82	11.2	600	6.5
			9- 2-82	12.4	510	7.0
23bcb-S1	8,860	TKn	7-13-79	14	620	4.0
23bcb-S2	8,780	Kp	7-13-79	24	630	4.5
26cba-S1	9,200	TKn	6-27-79	6.3	560	8.0
			7-14-81	1.1	600	11.0
26cbb-S1	9,180	TKn	7-18-79	4.0	580	6.0
			7-14-81	1.3	640	7.5
			7-30-81	1.3	660	7.5
			8-20-81	1.1	720	7.0
			9-23-81	1.2	650	7.5
			5-21-82	5.0	660	7.0
			6-23-82	5.0	670	6.5
			7-15-82	4.8	660	6.0
			8-10-82	3.6	640	7.5
			9- 2-82	2.6	660	7.5
26ccb-S1	8,960	TKn	7-18-79	18	700	5.0
27bbd-S1	9,050	TKn	8-16-79	4.0	500	6.5
27cbb-S1	8,800	TKn	8-16-79	3.2	650	7.0
			7-15-81	2.3	680	7.0
27ccc-S1	8,760	TKn	8-16-79	4.0	700	8.0
			7-15-81	1.7	660	7.5
27ccd-S1	8,800	TKn	8-16-79	3.2	620	7.5
			7-15-81	.6	710	8.5
28bac-S1	8,800	TKn	7-16-81	.8	740	10.0
28bbc-S1	8,500	TKn	8-29-79	6.0	800	8.0

Table 2 Records of springs—Continued

Spring No.	Altitude of land surface above sea level (ft)	Water-bearing zone	Date	Discharge (gal/min)	Specific conductance (μmho)	Water temperature (°C)
(D-17-6)28bbc-S2	8,340	Kp	8-29-79	6.0	540	9.0
			7-16-81	.8	600	10.5
32acb-S1	7,600	Kp	8-31-79	---	790	---
33cbb-S1	8,400	TKn	8-30-79	0.1	950	12.0
35cbb-S1	8,720	TKn	7-11-79	.9	750	8.0
			7-15-81	.2	780	12.0
35ccb-S1	8,720	TKn	7-12-79	5.1	560	6.5
			7-15-81	2.6	700	7.5
			7-30-81	2.5	740	7.0
			8-20-81	2.2	740	8.5
			9-23-81	2.6	720	8.0
			5-21-82	9.7	680	6.5
			6-23-82	6.4	690	7.5
			7-15-82	5.3	700	7.0
			8-10-82	5.0	690	7.5
			9- 2-82	4.4	700	8.0
(D-18-6)2bbd-S1	8,120	TKn	7-12-79	.5	940	8.0
			7-15-81	.6	1,140	9.0
4bab-S1	7,200	Kc	11- 9-77	6.7	660	2.0
4bbc-S1	7,000	Kb	8-31-79	1.6	800	12.5
			7-13-81	.6	870	17.0
			7-30-81	1.0	870	15.0
			8-20-81	1.1	920	15.0
			5-20-82	.1	900	12.5
			6-23-82	Dry	---	---
5abd-S1	6,920	Kb	5-21-82	200	410	3.0
			10-28-82	180	425	3.0

perched aquifer. This is an accurate depiction for most of the area. Four springs do issue from the Castlegate on the northeast slopes of Trail Mountain. The source of water for the Castlegate springs probably is a perched aquifer as the springs are several hundred feet higher in altitude than Cottonwood Creek, which is ephemeral in its upper reaches.

No springs issue from the small outcrop area of the Flagstaff Limestone on Trail Mountain. Most water recharged on the outcrop of the Flagstaff probably leaks downward into the perched aquifer in the North Horn Formation.

Despite the large quantity of rock with negligible permeability, there is hydraulic connection between aquifers. Most of the exchange of water probably occurs along fractures in perching beds where there is unsaturated flow downward. Leakage from overlying aquifers is a significant source or recharge to the Blackhawk-Star Point aquifer, and it is discussed in a following section of the report.

Occurrence of ground water as depicted in figure 8 is consistent with spring and test-hole data for other areas in the Wasatch Plateau. Danielson and Sylla (1983, figs. 10 and 11) completed an extensive spring inventory on North Horn, South Horn, and Ferron Mountains 2 to 20 mi south of Trail Mountain. Most of the springs in these areas issue from the North Horn and Price River Formations, and few springs issue from the Castlegate Sandstone and older rocks. Elsewhere in the Wasatch Plateau where the Flagstaff Limestone has an extensive outcrop area, they inventoried a large number of springs that issue from the Flagstaff. Danielson and Sylla (1983, p. 22) concluded from test-hole data that the Star Point Sandstone and Blackhawk Formation contain water in most areas of the southern Wasatch Plateau.

Aquifer Characteristics

Porosity was determined in the laboratory for eight core samples that are representative of lithologies in the Blackhawk-Star Point aquifer. The core samples were obtained while drilling the hole for well (D-17-6) 27bda-1. Hydraulic conductivity was determined in the horizontal direction in seven of the samples and in the vertical direction in six. The

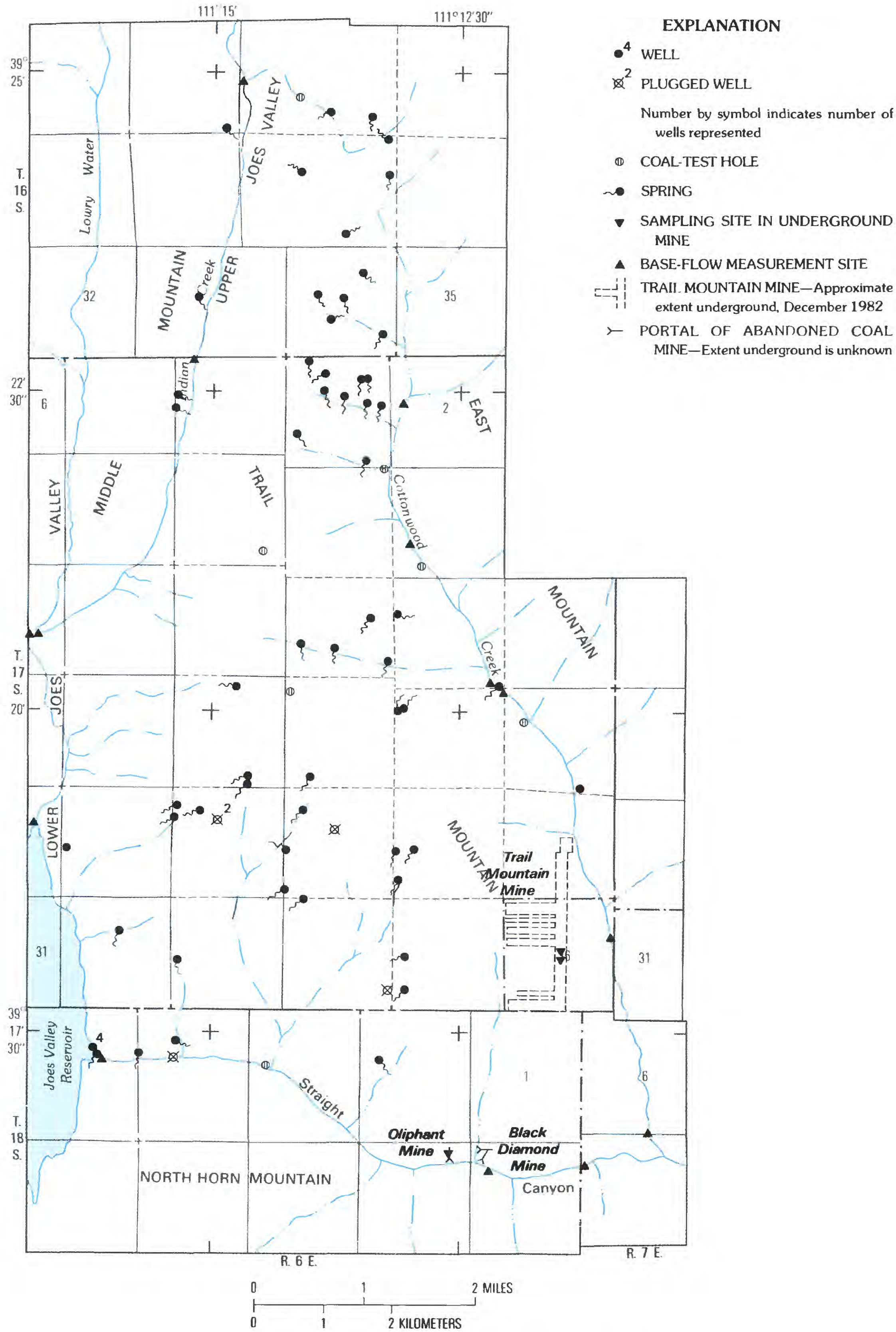


Figure 7. Data-collection sites and coal mines.

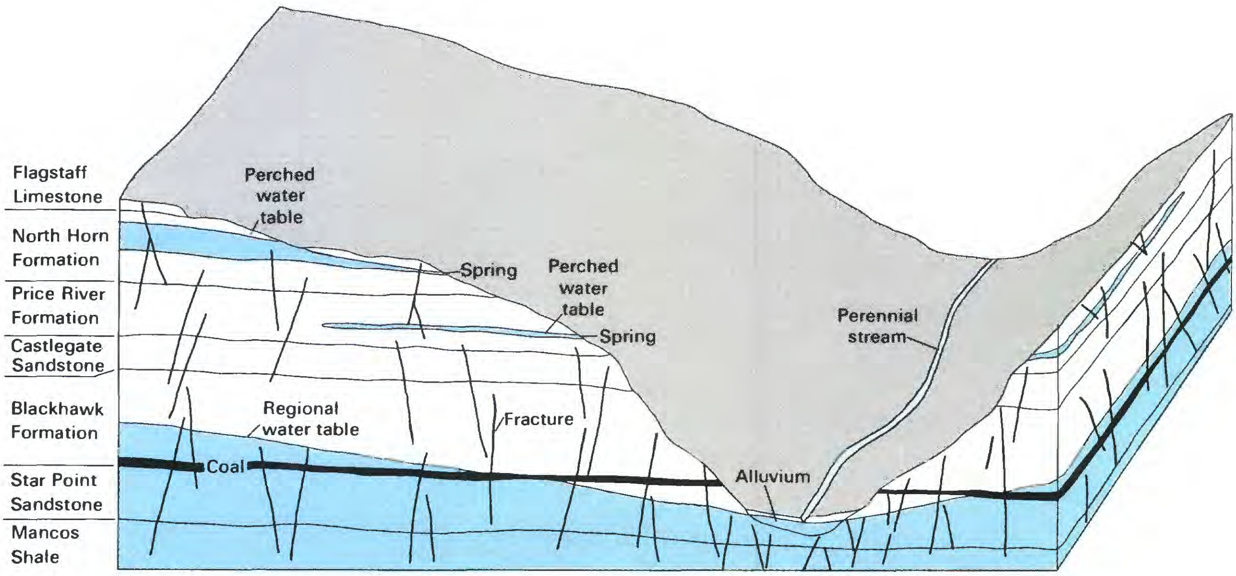


Figure 8. Generalized block diagram showing occurrence of ground water.

Table 3. Laboratory determinations of porosity and hydraulic conductivity of core samples from well (D-17-6)27bda-1

[Determinations by Core Laboratories, Inc., Dallas, Texas]

Lithology: Sh, shale; Slt, siltstone; Ss, sandstone; f, fine grained; m, medium grained.
Hydraulic conductivity: I, impermeable to water even at a pressure of 5,000 pounds per square inch.

Geologic unit	Lithology	Depth below land surface (feet)	Porosity (percent)	Hydraulic conductivity (feet per day)	
				Horizontal	Vertical
Blackhawk Formation	Ss, f	1,521	14	$1.5x10^{-2}$	$3.7x10^{-3}$
	Slt	1,545	3	$9.3x10^{-8}$	$1.2x10^{-7}$
	Sh	1,786	2	I	I
	Ss, f	1,792	14	$1.1x10^{-2}$	$3.9x10^{-3}$
	Sh	2,170	4	$1.1x10^{-8}$	---
	Slt	2,265	2	$2.0x10^{-7}$	$2.2x10^{-6}$
Star Point Sandstone	Ss, m	2,466	17	$3.1x10^{-2}$	$1.1x10^{-2}$
	Ss, m	2,493	11	$1.5x10^{-2}$	$6.6x10^{-3}$

laboratory determinations, listed in table 3, indicate a large variation in both porosity and hydraulic conductivity. Porosity of sandstone samples ranged from 11 to 17 percent, and hydraulic conductivity ranged from $3.7x10^{-3}$ to $3.1x10^{-2}$ ft/d. Horizontal hydraulic conductivities of all sandstone samples were greater than vertical hydraulic conductivities, but the differences were less than one order of magnitude. Porosity of the finer grained siltstone and shale samples ranged from 2 to 4 percent, and hydraulic conductivity ranged from $1.1x10^{-8}$ to $2.2x10^{-6}$ ft/d. One shale sample was effectively impermeable to water even at a pressure of 5,000 lbs/in^2. Unlike the sandstone samples, vertical hydraulic conductivities of the two siltstone samples were greater than the horizontal hydraulic conductivities.

Aquifer tests were conducted at five wells on Trail Mountain, and the results are summarized in table 4. No observation wells were available for the tests, and recovery in the discharge wells are used to compute transmissivity. A constant-drawdown test (Lohman, 1972, p. 23-26) also was conducted at well (D-18-6) 4bac-1, which flowed at the land surface. An expandable packer was used in wells (D-17-6) 27bda-1 and 34 dda-1 to isolate various zones for testing.

None of the test wells fully penetrated the Blackhawk-Star Point aquifer, and the transmissivity values in table 4 probably are most representative of the transmissivities of those parts of the aquifer open to the wells. Some transmissivity values computed from the tests agree fairly well with what would be expected from hydraulic conductivities determined

Table 4. Summary of aquifer tests, 1979–82

Method of test analysis: C, constant-drawdown method (Lohman, 1972, p. 23-26); R, straight-line recovery method (Lohman, 1972, p. 26 and 27).
Units: ft, feet; min, minutes; gal/min, gallons per minute; ft^2/d, feet squared per day.

Well No.	Water-bearing zone(s)	Interval tested (ft below land surface)	Duration of test (min)	Discharge (gal/min)	Transmissivity (ft^2/d)	Method of test analysis
(D-17-6)24dcd-1	Blackhawk Formation and Star Point Sandstone	100-280	43	5.0	2	R
27bda-1	Blackhawk Formation and Star Point Sandstone	1,910-2,500	300	6.5	8	R
	Star Point Sandstone	2,420-2,500	350	4.7	6	R
28bad-2	Price River Formation	1,030-1,080	130	2.0	.8	R
34dda-1	North Horn Formation	55-100	150	1.5	10	R
	Blackhawk Formation	1,882-1,897	270	.2	.7	R
(D-18-6)4bac-1	Blackhawk Formation and Star Point Sandstone	85-696	200	---	100	C
			200	9.3	100	R

in the laboratory (table 3.) At well (D-18-6) 4bac-1, the computed transmissivity of 100 ft^2/d is greater than would be expected from the laboratory data. This is believed due to secondary permeability in the form of fractures; much of the core from this hole was fractured. Transmissivity of the full thickness of the Blackhawk-Star Point aquifer probably ranges from about 20 to 200 ft^2/d in most of Trail Mountain.

One aquifer test was conducted in each of the perched aquifers in the North Horn and Price River Formations. Computed transmissivities for these two tests, 10 and 0.8 ft^2/d, are indicative of the low-permeability rock in most of the Cretaceous and Tertiary section on Trail Mountain.

Water is unconfined in the upper few tens of feet of the Blackhawk-Star Point aquifer and in the perched aquifers. Water is released from storage in unconfined aquifers mainly by gravity drainage, and the storage coefficient is virtually equal to specific yield. No tests were conducted that allowed for accurate estimates of storage coefficients. Other studies (Johnson, 1967), however, have found that specific yield ranges from about 0.01 in shales to about 0.1 in sandstones that are similar to those on Trail Mountain. Because the Blackhawk-Star Point aquifer consists of sandstone and finer grained shales and siltstones, the storage coefficient in the unconfined parts of the aquifer probably averages about 0.05.

Water in most of the Blackhawk-Star Point aquifer is confined under pressure between shale and siltstone beds within the aquifer. Water is released from storage from confined aquifers mainly by compression of the sandstones and less permeable confining beds as pressure in the aquifer declines. The quantity of water that can be released from storage is dependent on the storage coefficient, which is about 1×10^{-6} per foot of thickness for most confined aquifers (Lohman, 1972, p. 8).

Potentiometric Surfaces

Hydraulic head varies both areally and with depth in the Blackhawk-Star Point aquifer. The potentiometric surface (the altitude at which water stands in tightly cased wells) of the aquifer at approximately the level of the Hiawatha coal bed is shown in figure 9. The Hiawatha bed contains water in other areas of Trail Mountain, but data permit contouring of the potentiometric surface only on the south end of the mountain. Water moves horizontally through the aquifer at approximately right angles to the potentiometric contours shown in figure 9.

Water also moves vertically through the Blackhawk-Star Point aquifer as indicated by changes in altitude of the potentiometric surface with depth. At well (D-17-6) 27bda-1, an expandable packer was used to isolate various intervals of an open hole. With the packer set at a depth of 2,420 ft (a few feet below the Hiawatha coal bed) and the bottom 80 ft of the hole open to the testing string, the water level was 1,505 ft below land surface. With the packer set at a depth of 1,910 ft in the same hole, the water level was 1,484 ft below land surface. Similarly, the water level in well (D-17-6) 34dda-1 was 1,478 ft below land surface when the perforated interval from 1,882 to 1,897 ft (opposite the Hiawatha bed) was isolated for testing, and the water level was 1,414 ft when the interval from 1,446 to 1,466 ft was isolated. At these two wells, the potentiometric surface decreased in altitude with increased depth in the aquifer, and water was moving downward. This is probably the case elsewhere on Trail Mountain where the Blackhawk-Star Point aquifer is recharged by downward percolation of water.

In natural discharge areas, such as along most of Straight Canyon and Cottonwood Creek, the altitude of the potentiometric surface in the Blackhawk-Star Point aquifer probably increases with depth. When the hole was being drilled for well (D-18-6) 4bac-1 in Straight Canyon, the water table in the Blackhawk-Star Point aquifer was penetrated at a depth of about 45 ft at about the level of the stream. Water flowed from the drill hole at land surface when the hole had penetrated the Hiawatha coal bed at a depth of about 670 ft. On June 22, 1982, shut-in water pressure at the well was 20 ft above land surface. Had the well been constructed so that it was open only to the Hiawatha bed, the shut-in pressure probably would have been greater.

Similarly, water flowed from an oil-test hole along Cottonwood Creek in the NE¼SW¼NE¼ sec. 14, T. 17 S., R. 6 E. when 370 ft of the Blackhawk Formation had been drilled (H.E. Patterson, Vortt Exploration Co., Inc., written commun., 1981). In an abandoned 65-foot deep "rat hole" at the same site, the water level was 17 ft below land surface on May 20, 1982.

Four porous-tube piezometers in Straight Canyon near Joes Valley Reservoir, (D-18-6) 5abd-1, 2, 3, and 4 in table 1, are open at various depths in the upper part of the Blackhawk-Star Point aquifer. During 1982, water levels in the piezometers decreased in altitude with increased depth in the aquifer. Recharge from the reservoir probably was inducing downward movement of water through the upper part of the aquifer in this area.

The approximate configuration of the perched water table in the North Horn Formation during 1982 is shown in figure 10. The water-table map mainly is based on the altitude of springs that issue from the aquifer and on some water levels measured in wells and coal-test holes.

Water moves through the perched aquifer in the North Horn Formation approximately at right angles to the water-table contours. Comparison of the water-table map (fig. 10) and the land-surface contours in figure 11 indicates that the configuration of the perched water table closely approximates the configuration of the land surface. The differences between the altitude of the perched water table in the North Horn and the potentiometric surface of the Blackhawk-Star Point aquifer at the level of the Hiawatha

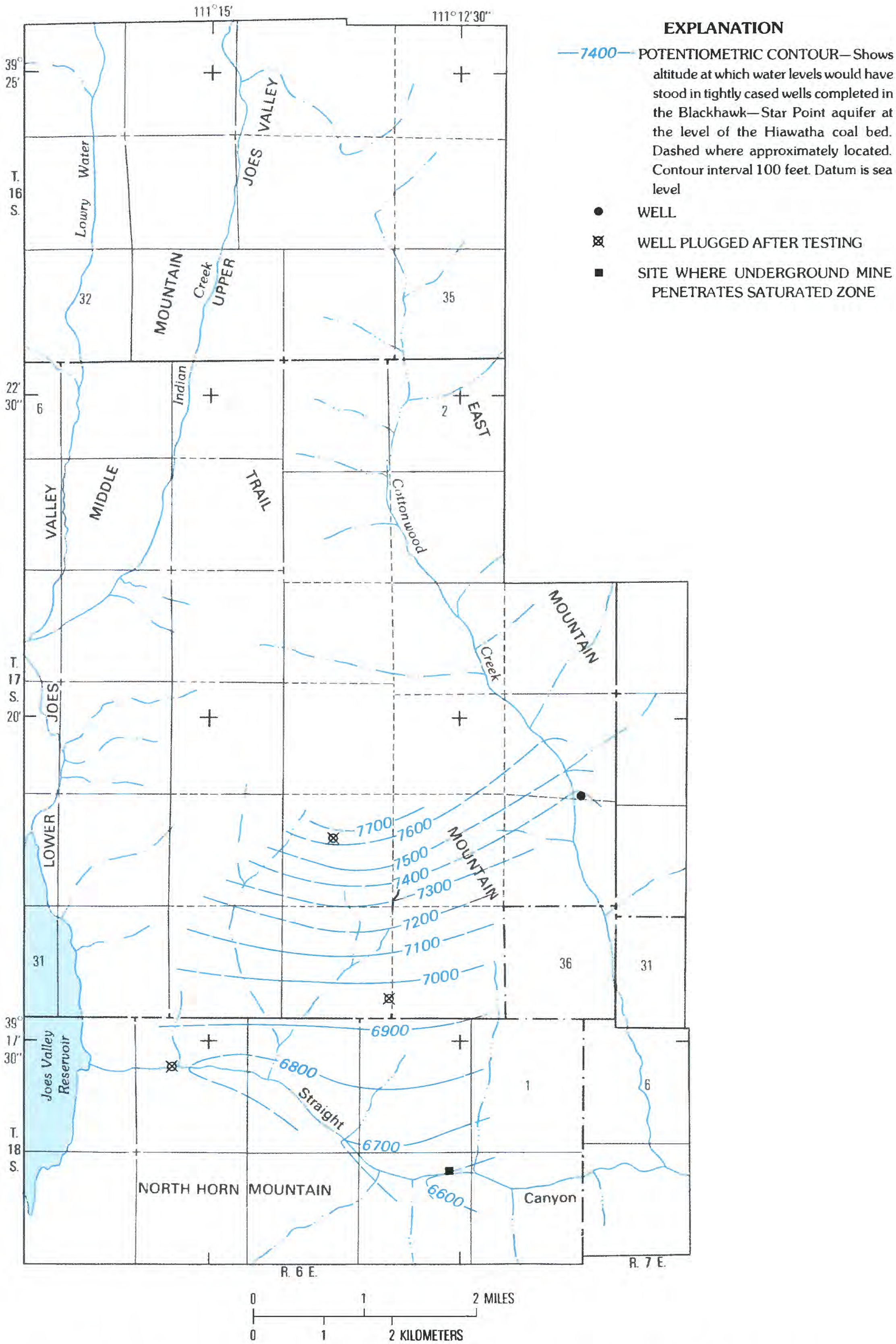


Figure 9. Potentiometric surface of the Blackhawk-Star Point aquifer at the level of the Hiawatha coal bed, 1982.

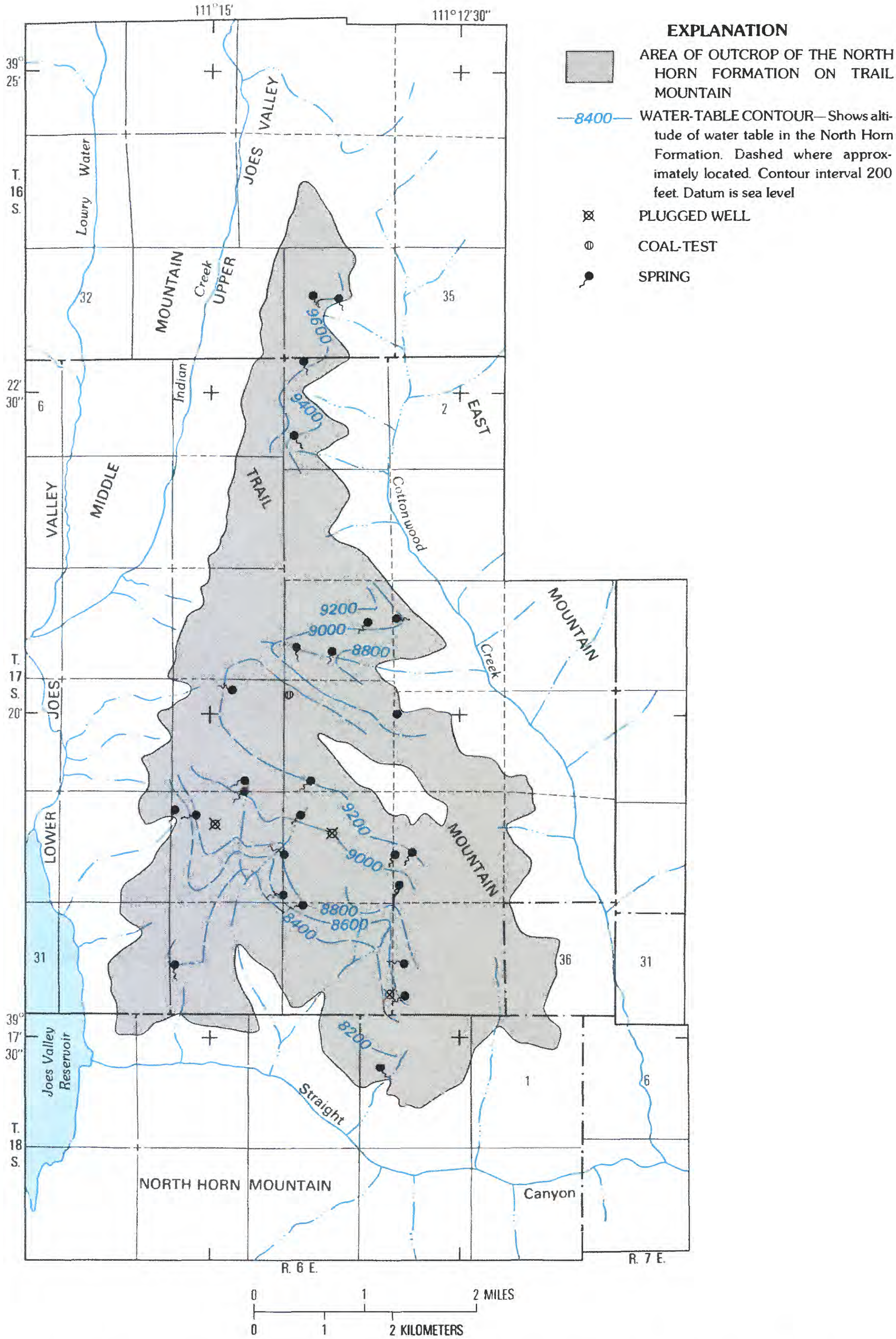
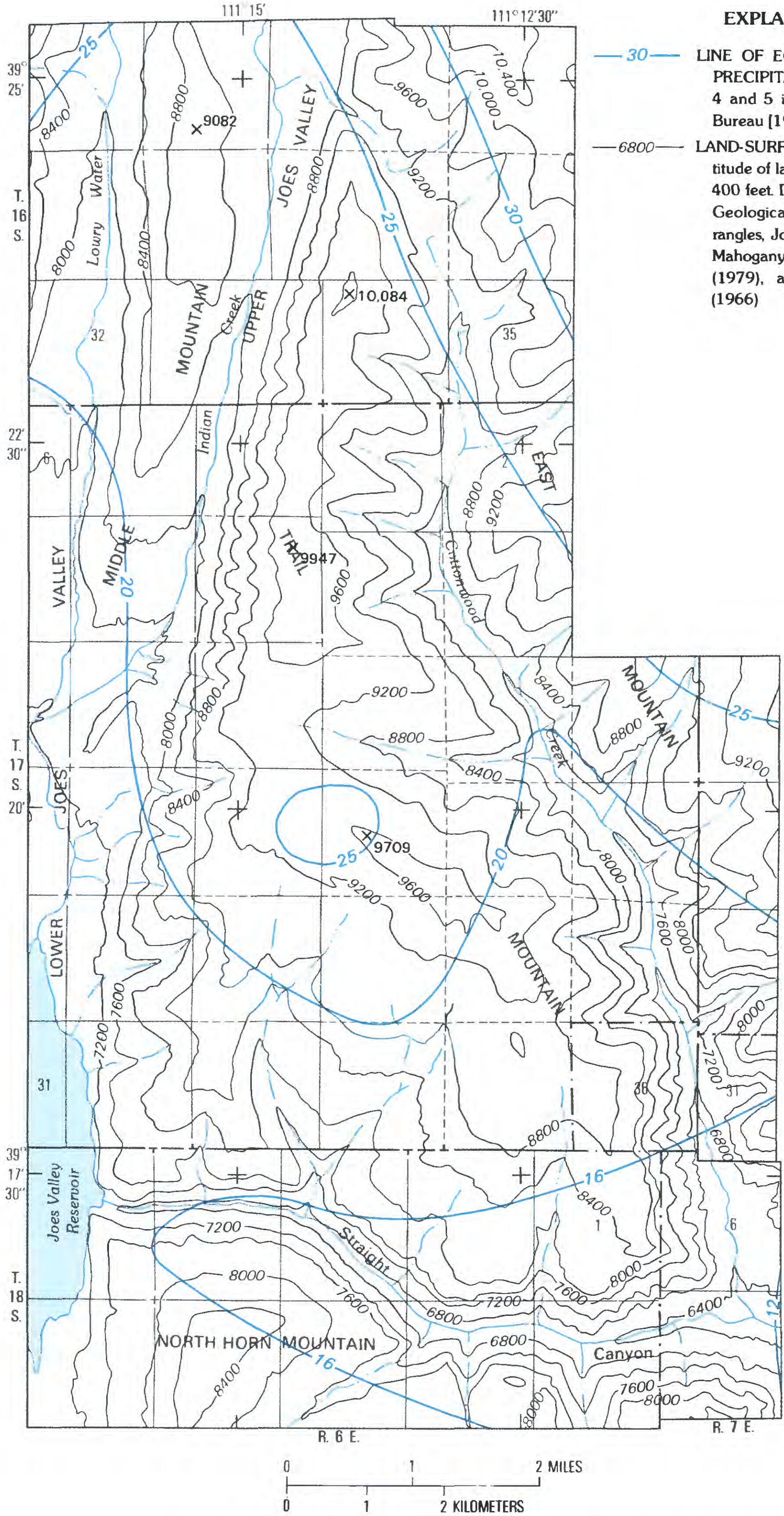


Figure 10. Altitude of the water table in the North Horn Formation on Trail Mountain, 1982.



EXPLANATION

—30— LINE OF EQUAL NORMAL ANNUAL PRECIPITATION (1931–60)—Interval 4 and 5 inches. From U.S. Weather Bureau [1963]

—6800— LAND-SURFACE CONTOUR—Shows altitude of land surface. Contour interval 400 feet. Datum is sea level. From U.S. Geological Survey 1:24,000 quadrangles, Joes Valley Reservoir (1966), Mahogany Point (1979), Rilda Canyon (1979), and South Tent Mountain (1966)

Figure 11. Normal annual precipitation and altitude of land surface.

coal bed range from about 1,000 to 1,700 ft on the south end of Trail Mountain.

It is apparent from the distribution of springs that a perched aquifer exists in most of the outcrop area of the North Horn. The perched aquifer probably exists in other areas of the North Horn outcrop that are not contoured in figure 10, but hydrologic data are not available to precisely define the extent of the aquifer. Sufficient data are not available to define the extent of other perched aquifers, such as in the Price River Formation or Castlegate Sandstone, or to define the configuration of their water tables.

Recharge and Discharge

Snowmelt and rain are the main sources of recharge to the ground-water system in Trail Mountain. Normal annual precipitation ranges from about 12 to 25 in. as shown in figure 11, and it occurs about equally as rain and snow.

Much of the recharge from precipitation is discharged by springs close to original recharge areas. The estimated total annual discharge of springs that issue from each geologic unit, expressed as a percentage of normal annual precipitation on the outcrop area, ranges from zero for three geologic units with no springs and relatively small outcrop areas to 18 percent for the Blackhawk Formation. (See table 5.) For those geologic units with outcrop areas greater than a fraction of a square mile, the percentages increase with increased geologic age. This reflects, in part, the relative permeabilities of geologic units and the relative ease with which they accept recharge. It probably also reflects significant downward percolation of water from overlying aquifers. The percentage is large for the Blackhawk also because of recharge from Joes Valley Reservoir, which is believed to be a large part of the water discharge at spring (D-18-6) 5abd-S1 in Straight Canyon.

The discharge of two springs that issued from the North Horn Formation is shown in figure 12 for parts of 1981 and 1982. Discharge of the springs varied markedly. The perched aquifer in the North Horn Formation receives most of its recharge from snowmelt and rain during late spring, and discharges of springs generally are largest during this period. Following the recharge period during late spring, the discharges of springs recede until the aquifer again receives a significant quantity of recharge, which may come as rain during the following summer and fall. A view of a typical spring that issues from the North Horn in a shallow depression on the upper slopes of Trail Mountain is shown in figure 13. The photograph was taken in late May of 1982, and most of the snow had melted on south-facing slopes. Discharge at spring (D-17-6) 22cdc-S1 was 40 gal/min (table 2).

The discharge of two springs that issue from the Blackhawk Formation is shown in figure 14. Like springs that issue from the North Horn, the discharges of Blackhawk springs vary markedly from season to season and from year to year. It is interesting to note that the discharge of spring (D-17-6) 14ddd-S1 was larger during the summer of 1982 than during late spring of the same year. The increase in discharge was undoubtedly due to recharge from summer rains, but it is unknown why the discharge of this spring increased while others that were measured did not. Perhaps summer rains were more intense in the recharge area of this spring than in other areas of Trail Mountain.

As mentioned earlier, water levels in piezometers near the head of Straight Canyon indicate that the Blackhawk-Star Point aquifer probably is recharged by Joes Valley Reservoir. Spring (D-18-6) 5abd-S1, shown in figure 15, is a short distance downstream from the dam on the reservoir, and it was the largest spring that issued from the Blackhawk-Star Point aquifer on Trail Mountain during 1982. Discharges of 200 and 180 gal/min were measured at the spring during 1982 (table 2), and a large part of the recharge to the Blackhawk-Star Point aquifer from the reservoir probably was discharged by the spring. According to Clyde Sherman (Emery Water Conservancy District, oral commun., 1982)

Table 5. Outcrop area, normal annual precipitation, and total annual discharge of springs for geologic units exposed on Trail Mountain

Geologic unit	Outcrop area (square miles)	Normal annual precipitation on outcrop (acre-feet)	Total annual discharge of springs: Acre-feet	Total annual discharge of springs: Percent of normal annual precipitation on outcrop
Flagstaff Limestone	0.35	410	0	0
North Horn Formation	15	16,000	200	1.2
Price River Formation	5.9	6,100	160	2.6
Castlegate Sandstone	2.2	2,300	80	3.5
Blackhawk Formation	2.6	2,500	450	18
Star Point Sandstone	.37	380	0	0
Masuk Member of the Mancos Shale	.25	190	0	0
Total (rounded)	27	28,000	890	

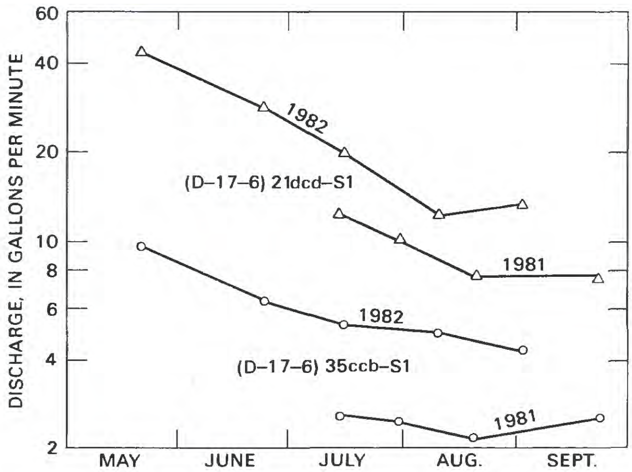


Figure 12. Discharge of two springs that issue from the North Horn Formation.

and other local residents, a spring issued from this location prior to construction of the dam, and a larger spring existed a few hundred feet upstream from the dam. The latter spring also issued from the Blackhawk-Star Point aquifer, but it was inundated by the reservoir. Thus, the head of Straight Canyon was a major discharge area for the Blackhawk-Star Point aquifer during 1982 and prior to construction of the dam in 1965.

Another source of discharge from the ground-water system was the dewatering of underground coal mines. A small quantity of water drained from the abandoned underground workings of the Oliphant Mine in Straight Canyon. On July 13, 1981, 1.0 gal/min was draining from the mine portal, and Sumsion (1979, p. 21) measured the discharge from the Oliphant Mine at 0.2 gal/min on June 1, 1977. The extent of the underground workings is unknown, but they probably intersect the regional water table in the Blackhawk-Star Point aquifer.

Discharge of water from the Trail Mountain Mine during 1982 was much larger than from the Oliphant Mine, although most of the water was derived from the unsaturated zone rather than from the Blackhawk-Star Point aquifer. Most of the Trail Mountain Mine was dry during 1982, except for a few areas where water dripped from the roof and where water had accumulated on the floor. An estimated 10 gal/min was pumped from Cottonwood Creek for use underground for dust suppression and for cooling of conveyor belts (J.R. Vasques, Natomas Trail Mountain Coal Co., oral commun., 1981). About 600 gal/d (0.4 gal/min) was pumped from a sump in the mine during 1982, and an average of

Figure 13. View of spring (D-17-6) 22cdc-S1 that issues from the perched aquifer in the North Horn Formation.

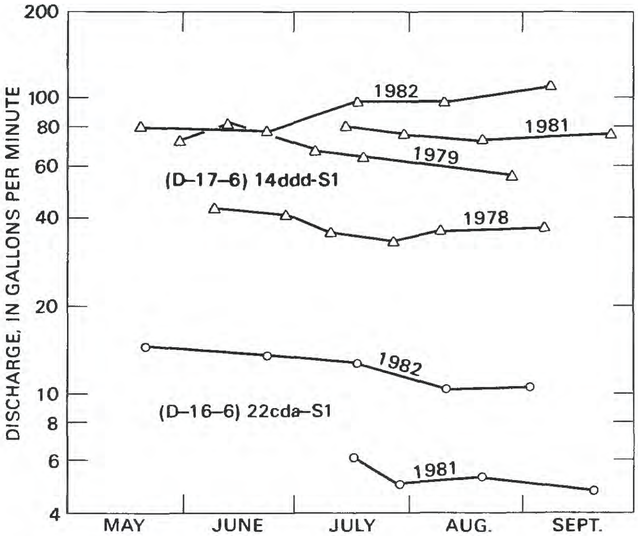


Figure 14. Discharge of two springs that issue from the Blackhawk Formation.

about 40 gal/min was removed by the mine ventilation system, which moved 159,000 ft^3 of air per minute. Water removed by the ventilation system was estimated by using wet- and dry-bulb thermometer readings to compute the water content of air entering the mine at the portal and exiting the mine at the exhaust fan. Measurements made on July 29 and September 1, 1982, and on February 11, 1983, indicate that about 13, 40, and 74 gal/min were removed by the ventilation system on those dates.

Very little water probably enters Trail Mountain through the Blackhawk-Star Point aquifer underlying Straight Canyon and the lower reaches of Cottonwood Creek. The streams are perennial in these areas, and ground water moving toward the streams from each side of the deeply incised canyons probably is discharged along the streams.

Streamflow measurements were made along streams that border Trail Mountain during two periods of base flow during 1981 and 1982 in order to determine ground-water discharge along the streams. Except for the discharge of spring (D-18-6) 5abd-S1 and water draining from the Oliphant Mine, ground-water discharge could not be detected along Straight Canyon. Discharge of the stream in Straight Canyon was about 60 ft^3/s on September 24, 1981, and about 50 ft^3/s on October 28, 1982, at the measurement sites shown in figure 7. The measurements were rated as "fair" (having an error of as much as 8 percent) due to flow conditions in the

Figure 15. View of spring (D-18-6) 5abd-S1 that issues from the Blackhawk Formation in Straight Canyon a short distance downstream from the dam on Joes Valley Reservoir. Photograph was taken from the top of the dam; spring issues from dark-colored lower slopes in the bottom center of photograph.

measured sections. Ground-water discharge would have had to have been 4 to 5 ft^3/s in order to be greater than the error inherent in the streamflow measurements, and it was not. Using Darcy's law (Ferris and others, 1962, p. 73) and assuming a transmissivity of 100 ft^2/d and a hydraulic gradient of 250 ft/mi, an estimated 1 ft^3/s was discharged along 4.4 mi of Straight Canyon from that part of the Blackhawk-Star Point aquifer underlying Trail Mountain.

As indicated in figure 16, streamflow in Cottonwood Creek increased by about 0.5 ft^3/s on September 24, 1981, and by about 0.6 ft^3/s on September 8, 1982, across the outcrops of the Blackhawk Formation and Star Point Sandstone. The streamflow measurements were rated as "good" (having an error of as much as 5 percent), and ground-water discharge exceeded the error inherent in the measurements. Probably about one-half of the water was discharged from that part of the Blackhawk-Star Point aquifer underlying Trail Mountain, and the other one-half was discharged by the aquifer beneath East Mountain.

There were small gains and losses in streamflow along Indian Creek on September 25, 1981, and on September 9, 1982; flow increased by 1.9 and 3.2 ft^3/s along the lower reaches of Lowry Water on these same days. (See figure 17.) Some of the water discharged by the alluvium along these streams could be due to leakage from the Blackhawk-Star Point aquifer along the Joes Valley fault, but most of the water probably originates as recharge from snowmelt and rain on the alluvium in Upper and Lower Joes Valley. There are few springs on the west side of Trail Mountain near the Joes Valley fault. This could be due to increased fracture permeability that may allow water to move more readily downward through the system and into the alluvium rather than being retarded by perching beds and discharged by springs on the upper slopes of the mountain.

Also, some water may enter or leave the ground-water system by subsurface flow in the area of the Flat Canyon anticline (figure 5). As along the Joes Valley fault, however, subsurface flow in this area cannot be verified because of a lack of potentiometric-surface data.

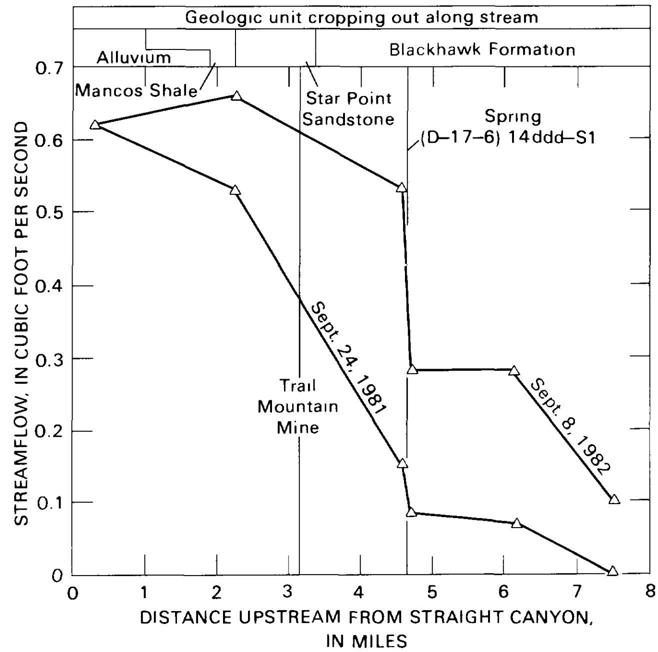


Figure 16. Streamflow in Cottonwood Creek during two periods of base flow. (Location of measurement sites shown in figure 7.)

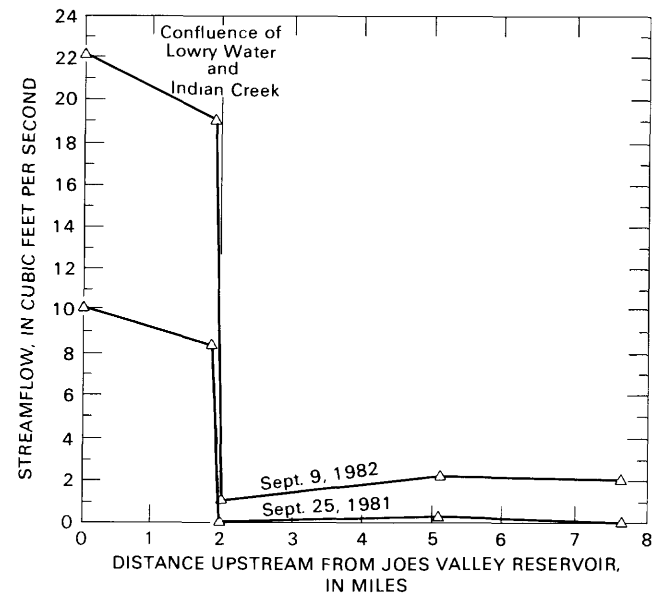


Figure 17. Streamflow in Indian Creek and in the lower reaches of Lowry Water during two periods of base flow. (Location of measurement sites shown in figure 7.)

Water Quality

Chemical analyses of selected ground-water samples collected on Trail Mountain are listed in table 6, and concentrations of selected dissolved trace metals are listed in table 7. The analyses indicate that the water is suitable for most uses.

Dissolved-solids concentrations ranged from 278 to 570 mg/L in seven water samples collected from the Blackhawk-Star Point aquifer. In two water samples that were collected from drips from the roof of the Trail Mountain Mine, dissolved-solids concentrations were 262 and 255 mg/L. (See (D-17-6) 36acc and 36dbb in table 6.) A small perched body of water in the Blackhawk probably was the source of the water dripping from the mine roof. In comparison, water in perched aquifers in the North Horn Formation, Price River Formation, and Castlegate Sandstone contained 254 to 695 mg/L of dissolved solids. The dissolved-solids concentrations in the perched aquifer in the North Horn during 1979-81 are shown in figure 18; the dissolved solids generally increased in the direction of ground-water flow. (See water-table contours in fig. 10.) No such pattern was apparent to the author when studying dissolved-solids

Table 6. Chemical analyses of water from selected wells, springs, and underground mines

Water-bearing zone(s): Kb, Blackhawk Formation; Kc, Castlegate Sandstone; Kp, Price River Formation; Ks, Star Point Sandstone; Qa, alluvium; TKn, North Horn Formation.
Units: °C, degrees Celsius; μmho, micromhos per centimeter at 25° Celsius.

Well, spring, or site No.	Water-bearing zone(s)	Date	Water temperature (°C)	pH (units)	Specific conductance (μmho)	Milligrams per liter: Dissolved calcium (Ca)	Dissolved magnesium (Mg)	Dissolved sodium (Na)	Dissolved potassium (K)	Alkalinity (as $CaCO_3$)	Dissolved sulfate (SO_4)	Dissolved chloride (Cl)	Dissolved boron (B)	Dissolved silica (SiO_2)	Hardness (as $CaCO_3$)	Non-carbonate hardness (as $CaCO_3$)	Dissolved solids (calculated sum)
(D-16-6)22cda-S1	Kb	10-14-77	---	7.2	600	64	27	4.8	1.0	250	15	4.8	<0.02	7.7	270	17	278
34bdc-S1	TKn	6-20-79	5.0	7.6	470	64	19	3.6	.6	220	25	3.5	<.02	5.2	240	18	254
34cad-S1	Kp	9- 6-78	8.5	7.6	560	87	22	3.7	1.8	290	86	3.8	.05	7.2	310	78	350
34dda-S1	Kc	10-14-77	6.5	7.4	560	54	30	4.8	1.6	300	14	4.4	<.02	7.5	260	0	299
(D-17-6)3acb-S1	Kp	6-21-79	6.0	7.6	530	75	23	6.2	1.1	270	17	4.4	.03	6.5	280	12	296
3add-S1	Kc	11-10-77	6.5	7.5	600	79	32	6.6	1.2	300	29	5.9	.03	7.2	330	26	344
3cbd-S1	TKn	7-31-79	7.0	7.4	470	81	21	7.5	.6	290	20	4.4	.03	5.5	290	0	315
14ddd-S1	Kb	7-14-81	8.5	7.3	650	67	39	15	1.8	280	65	9.3	.01	7.0	330	48	373
15cbd-S1	TKn	7-13-79	13.5	7.4	680	85	36	18	1.4	350	43	11	.04	8.4	360	11	414
15dda-S1	Kp	7- 5-79	8.0	7.8	650	66	42	17	.9	310	46	23	.04	8.1	340	28	390
21abb-S1	TKn	7-14-81	7.5	7.4	630	54	27	56	1.7	320	1.0	24	.02	6.5	250	0	363
21dcd-S1	TKn	7-14-81	7.0	7.4	560	41	34	18	.7	230	.7	28	.02	6.3	240	12	267
22cdc-S1	TKn	7-14-81	8.0	7.5	495	44	31	17	1.1	240	1.1	11	.01	6.5	240	0	256
26cba-S1	TKn	7-14-81	11.0	7.6	600	53	37	19	.8	290	10	9.3	.03	7.6	280	0	312
26cbb-S1	TKn	7-14-81	7.5	7.5	640	38	34	42	.8	300	.8	8.4	.03	8.1	230	0	313
27bda-1	Ks	10-16-82	12.0	7.9	570	27	21	67	4.0	287	10	9.7	.21	8.8	150	0	570
	Kb,Ks	10-20-82	11.5	8.0	550	25	18	70	4.2	286	<5	7.6	.19	8.2	140	0	550
27cbb-S1	TKn	7-15-81	7.0	7.7	680	48	35	49	.8	320	1.2	21	.02	8.2	260	0	356
27ccc-S1	TKn	7-15-81	7.5	7.7	660	50	34	49	1.0	320	2.4	21	.02	8.2	270	0	358
27ccd-S1	TKn	7-15-81	8.5	7.6	710	47	44	41	.7	330	5.4	22	.02	8.1	300	0	367
28bac-S1	TKn	7-16-81	10.0	7.7	740	60	52	40	.7	360	1.9	29	.03	8.5	360	4	409
28bad-2	Kp	10-30-82	8.0	7.8	730	51	29	44	26	288	70	22	.09	5.5	250	0	422
28bbc-S2	Kp	7-16-81	10.5	7.6	600	59	36	17	.8	240	59	19	.00	6.4	300	56	342
29cbb-1	Qa	8-10-82	9.0	8.4	850	61	71	51	2.8	239	170	67	.07	7.1	440	210	575
35cbb-S1	TKn	7-15-81	12.0	7.7	780	38	40	78	1.1	330	13	40	.05	7.2	260	0	416
35ccb-S1	TKn	7-15-81	7.5	7.6	700	43	40	47	1.2	270	40	34	.03	6.9	270	2	375
36acc	Kb	8-21-81	11.0	8.0	480	26	14	54	8.6	240	1.0	3.7	.36	8.5	120	0	262
36dbb	Kb	8-21-81	11.0	7.9	470	23	14	54	7.0	240	1.0	3.2	.27	9.1	120	0	255
(D-18-6)2bbd-S1	TKn	7-15-81	9.0	7.5	1,140	67	45	120	1.5	350	190	52	.07	8.9	350	3	695
4bac-1	Kb,Ks	10-25-81	13.5	7.6	510	45	32	16	3.7	260	11	8.1	.04	9.3	240	0	282
4bbc-S1	Kb	7-13-81	17.0	7.1	870	97	53	15	2.4	320	100	20	.02	7.8	460	140	488
11aac	Kb	7-13-81	9.5	7.5	600	53	36	20	3.7	220	100	6.6	.09	8.9	280	61	361

Table 7. Concentrations of selected dissolved trace metals in water from wells, springs, and underground mines

Water-bearing zone(s): Kb, Blackhawk Formation; Kp, Price River Formation; Ks, Star Point Sandstone; Qa, alluvium; TKn, North Horn Formation.

Well, spring, or site No.	Water bearing zone(s)	Date	Micrograms per liter																
			Aluminum (Al)	Arsenic (As)	Barium (Ba)	Cadmium (Cd)	chromium (Cr)	Hexa-valent chromium	Cobalt (Co)	Copper (Cu)	Iron (Fe)	Lead (Pb)	Lithium (Li)	Manga-nese (Mn)	Mercury (Hg)	Nickel (Ni)	Sele-nium (Se)	Silver (Ag)	Zinc (Zn)
(D-17-6)14ddd-S1	Kb	7-14-81	0	0	90	<1	0	0	<3	2	60	0	20	<1	0.0	2	1	0	10
21abb-S1	TKn	7-14-81	0	0	100	<1	1	0	<3	1	20	0	30	<1	.1	1	4	0	8
22cdc-S1	TKn	7-14-81	0	1	200	<1	12	0	<3	1	<10	0	20	2	.0	1	2	0	6
26cba-S1	TKn	7-14-81	0	0	200	<1	1	0	<3	1	<10	0	30	<1	.1	1	1	0	4
27bda-1	Ks	10-18-82	20	10	400	<1	<1	<1	6	3	3,000	9	39	140	<.1	16	1	<1	190
	Kb,Ks	10-20-82	50	2	230	<1	<1	<1	2	4	350	5	30	130	.2	5	<1	<1	54
27ccc-S1	TKn	7-15-81	0	0	100	<1	0	0	<3	0	<10	1	30	<1	.0	1	1	0	10
28bac-S1	TKn	7-16-81	0	0	200	<1	0	0	<3	1	<10	0	30	<1	.1	2	0	0	6
28bad-2	Kp	10-30-82	30	2	240	<1	<1	<1	1	200	73	7	38	120	<.1	41	<1	<1	13
29cbb-1	Qa	8-10-82	10	1	28	<1	<1	<1	1	1	<3	3	33	170	<.1	1	3	<1	440
35ccb-S1	TKn	7-15-81	0	0	90	<1	0	0	<3	1	<10	0	30	<1	.0	0	3	0	<3
36acc	Kb	8-21-81	20	0	760	<1	0	0	<3	2	30	3	28	5	.0	1	0	0	57
36dbb	Kb	8-21-81	20	0	990	<1	0	0	<3	2	11	4	29	3	.0	1	0	0	14
(D-18-6)2bbd-S1	TKn	7-15-81	10	1	50	<1	2	0	<3	0	<10	0	50	3	.1	0	2	0	3
4bac-1	Kb,Ks	10-25-81	<10	0	220	<1	<1	<1	<3	4	<10	2	29	9	.0	2	<1	1	28
4bbc-S1	Kb	7-13-81	10	0	40	<1	0	0	<3	1	<10	0	30	30	.1	3	0	0	30
11aac	Kb	7-13-81	10	0	60	<1	1	0	<3	2	<10	0	40	<1	.1	2	0	0	6

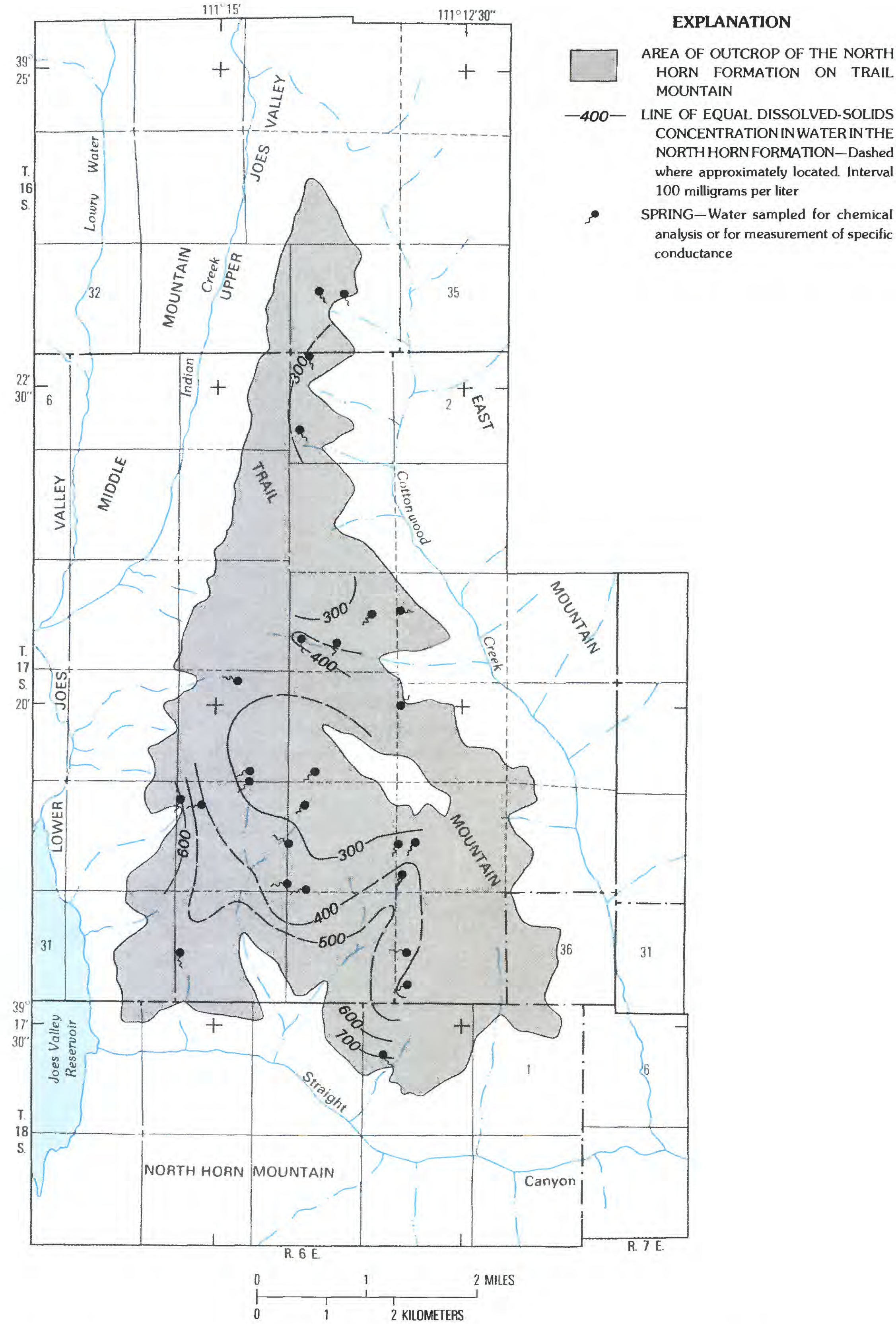


Figure 18. Concentration of dissolved solids in water in the North Horn Formation, 1979–81. (Map is based, in part, on chemical analyses listed by Danielson and others, 1981, p. 80 and 81.)

concentrations in the Blackhawk-Star Point aquifer, and this is believed due to differences in the quantity and quality of water that percolates downward into the aquifer from overlying perched zones.

Calcium and magnesium were the predominant cations in most of the water samples; sodium generally was the predominant cation in the more mineralized samples. In all samples, the pH and the alkalinity concentration indicated that bicarbonate was the predominate anion. Comparison of trace-metal concentrations in table 7 indicates that water in the Star Point and Blackhawk consistently contained larger concentrations of aluminum, iron, and zinc than water in the perched aquifer in the North Horn.

Other chemical analyses of ground water from the area are included in reports by Sumsion (1979, p. 22 and 23) and by Danielson and others (1981, p. 80 and 81).

HYDROLOGIC EFFECTS OF UNDERGROUND MINING

Effects of Mine Dewatering

Future underground coal mines in the Trail Mountain area will require dewatering when they penetrate the Blackhawk-Star Point aquifer. Water produced in the mines will be derived primarily from a decrease in storage in the aquifer. Several hundred feet of aquifer above the mines could be dewatered, and the cone of depression could extend several miles from the mines after a few years. Because the Blackhawk-Star Point aquifer is separated from overlying perched aquifers by an unsaturated zone, mine dewatering alone would not affect the perched aquifers. Mine dewatering would not significantly change water quality in the Blackhawk-Star Point aquifer.

A finite-difference, three-dimensional computer model (McDonald and Harbaugh, 1984) was used to analyze the effects of dewatering various lengths and widths of a hypothetical underground mine in the Hiawatha coal bed on the Blackhawk-Star Point aquifer. The model was used to compute mine inflow and drawdowns around the mine for a range of aquifer properties and premining hydraulic gradients that were similar to those on Trail Mountain. It was beyond the scope of this study to evaluate the effects of every possible mine configuration; nor did the lack of historic water-level and mine-discharge data allow for the calibration and verification of a model that simulated hydrologic boundaries in every possible position with respect to future mining. Rather, the model was used to simulate the aquifer in a simplified manner in order to make order-of-magnitude estimates of mine inflow and drawdown. Although the estimates of mine inflow and drawdown can be used with less confidence than those made for a specific mine plan and set of boundary conditions using a calibrated and verified model, the estimates are more reliable than those that could be made with other more simplified analytical techniques.

The Blackhawk-Star Point aquifer was simulated with three model layers as shown diagrammatically in figure 19. Layers 1 and 2 were used to simulate the Blackhawk and layer 3 to simulate the Star Point. The total number of active cells varied depending mainly on the saturated thickness of the simulated aquifer, but it averaged about 1,200. The model area was 11.5 mi long and 23 mi wide; but since the effects of mine dewatering were very small at the model boundaries, an aquifer of infinite areal extent was in effect simulated.

Boundaries in the model were simulated as impermeable except for the upper surface where constant and uniform recharge was applied. The impermeable model boundaries are similar to ground-water divides or edges of the aquifer where the saturated thickness approaches zero. Recharge to the upper surface represented recharge from precipitation on the outcrop area and from downward percolation of water from overlying perched aquifers. Along one side of the model, the heads in layer 3 were held constant. This row of constant-head cells acted as the natural discharge area for the aquifer and was similar to discharge along a stream. By applying recharge to the upper surface of the model and discharging the water along the row of constant-head cells in layer 3, steady-state hydraulic gradients were simulated that were similar to those in the Blackhawk-Star Point aquifer on Trail Mountain.

The steady-state flow system was then stressed by simulating the dewatering of a hypothetical horizontal underground mine in the Hiawatha coal bed at the base of the Blackhawk Formation. Dewatering of the mine was simulated by lowering and holding constant the potentiometric surface of layer 2 at an altitude of 1 ft above the base of the layer in the appropriate mine cells. Flow rates into the constant-head mine cells and drawdowns around the dewatered mine were then calculated for various aquifer properties, premining horizontal hydraulic gradients, mine lengths and widths, and lengths of time.

The calculated steady-state mine inflow to various mine lengths (M_l) and widths (M_w) for three premining horizontal hydraulic gradients (I) is shown in figure 20. The premining horizontal gradient is the slope of the potentiometric surface of layer 2 in the mine area. (See fig. 19.) For these simulations, the hydraulic conductivities of the Blackhawk Formation (K_b) and the Star Point Sandstone (K_s) were 0.01 and 0.02 ft/d, and both units were simulated as isotropic. Considering the relative proportions of sandstone and finer grained rocks in each unit and the laboratory hydraulic conductivities (table 3), these hydraulic conductivities probably are representative of the units where they are not extensively fractured. With hydraulic conductivities of 0.01 and 0.02 ft/d, the Blackhawk-Star Point aquifer would have a transmissivity of about 20 ft^2/d where both units are fully saturated. By increasing the hydraulic conductivities one order of magnitude to 0.1 and 0.2 ft/d, the computed steady-state mine inflow would be one order of magnitude larger than those in figure

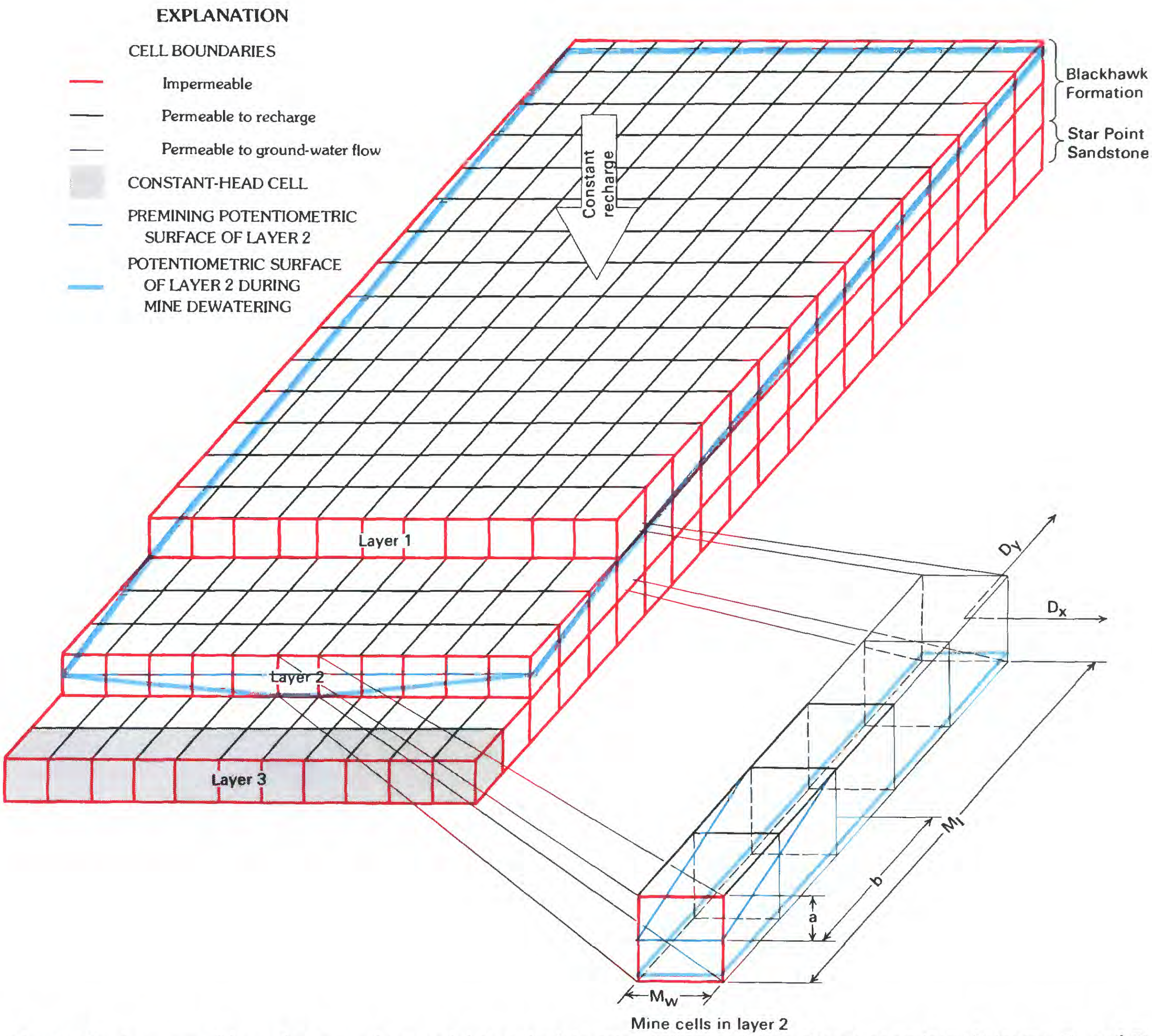


Figure 19. Layers and boundaries used in model to calculate mine inflow and drawdowns at various distances D_x and D_y from a hypothetical dewatered horizontal mine at the base of the Blackhawk Formation. (M_w, mine width; M_1, mine length; I=a/b, premining horizontal hydraulic gradient.)

20, as long as premining horizontal hydraulic gradients are the same as those shown.

The drawdowns produced at distances D_x and D_y (fig. 19) from a dewatered mine that is 1,000 ft wide and as much as 10,000 ft long after the system reaches steady state are shown in figure 21 for three premining horizontal hydraulic gradients. The drawdowns in figure 21 were computed for layer 2 of the model, and they are declines that could be expected in the potentiometric surface of the Blackhawk-Star Point aquifer at the level of the Hiawatha coal bed. The steady-state drawdowns in figure 21 were calculated for hydraulic conductivities of 0.01 and 0.02 ft/d for the Blackhawk Formation and Star Point Sandstone. The steady-state drawdowns would be the same as those shown in figure 21 for any combination of hydraulic conductivities where the Star Point is twice as permeable as the Blackhawk, as long as premining horizontal hydraulic gradients are the same as those shown.

Curves in figure 22 indicate not only that mine inflow increases with increased hydraulic conductivity, but that a large part of the water that flows into a mine will be derived from ground water stored in the aquifer. Also, the quantity of mine inflow derived from ground-water storage is dependent on the specific yield (Sy). For example, the top curves (where K_h=0.01 ft/d, K_s=0.02 ft/d, and Sy=0.05) indicate that total mine inflow after 100 years would be about 0.5 ft^3/s, of which about 0.4 ft^3/s would be derived from ground-water storage. The remaining 0.1 ft^3/s would be derived from a decrease in natural discharge from the aquifer. Similarly, the bottom curves (where K_h=0.1 ft/d, K_s=0.2

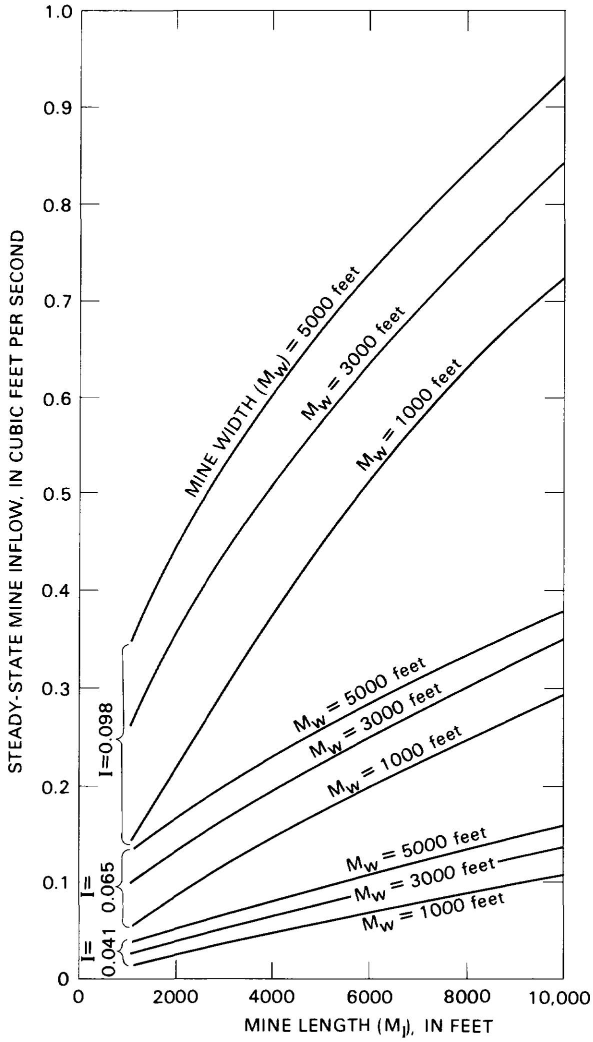


Figure 20. Families of curves for three premining horizontal hydraulic gradients (I) showing steady-state inflow to specified lengths and widths of a hypothetical horizontal underground mine at the base of the Blackhawk Formation. (Hydraulic conductivity of the Blackhawk Formation, 0.01 foot per day; hydraulic conductivity of the Star Point Sandstone, 0.02 foot per day.)

ft/d, and Sy=0.01) indicate that total mine inflow after 100 years would be about 3 ft^3/s, of which about 0.8 ft^3/s would be derived from ground-water storage. The remaining 2.2 ft^3/s would be derived from a decrease in natural discharge from the aquifer. The curves also indicate that the larger the specific yield, the greater the proportion of mine inflow that initially will be derived from ground-water storage and the longer the time it will take for the system to reach steady state. In the transient model simulations that were used to develop the curves in figure 22, a storage coefficient (S) of 1x10^{-6}/per foot was used for the confined parts of the aquifer.

Drawdowns at distances D_x and D_y from a mine that has been dewatered for various lengths of time are shown in figure 23. The drawdowns were computed for layer 2, and they are declines that could be expected in the potentiometric surface of the Blackhawk-Star Point aquifer at the level of the Hiawatha coal bed. One pair of curves is for hydraulic conductivities of the Blackhawk (K_b) and Star Point (K_s) of 0.01 and 0.02 ft/d and the other pair is for hydraulic conductivities of 0.1 and 0.2 ft/d. In both cases, the premining horizontal hydraulic gradient (I) was 0.065, specific yield (Sy) was 0.05, and the storage coefficient (S) was 1x10^{-6} per foot of confined aquifer. Comparison of the two pairs of curves indicates that when hydraulic conductivities are increased by one order of magnitude, the potentiometric surface is drawn down about 10 times as quickly. Drawdowns of several hundred feet can be expected around a dewatered underground mine within 50 years (a reasonable life span of a mine), and the cone of depression will extend several miles from the mine after a few years unless a hydrologic boundary is intercepted. It would take 10,000 years for the aquifer to reach steady state.

The curves in figures 20–23 may be used to evaluate the effects of dewatering a mine in the Hiawatha coal bed, but calculated mine inflows and drawdowns need to be considered as order-of-magnitude estimates. The curves are based on calculations that assume that the aquifer is isotropic and, for all practical purposes, infinite in areal extent in three directions from the simulated mine. In actuality, boundaries could limit the continuity of the Blackhawk-Star aquifer around a mine, in one or more directions, to distances varying from a few feet to a few miles. When the time-drawdown curves in figure 23 indicate that the cone of depression will intercept a boundary and that the drawdown at the boundary cannot be considered as negligible, use of the curves in figures 20–23 may be precluded. When an aquifer boundary can be treated as an abrupt vertical discontinuity, the curves in figures 21 and 23 can be used with image theory to estimate drawdown. Image theory is discussed in detail by Ferris and others (1962, p. 144-161).

Further errors will be introduced if the computed mine inflows and drawdowns in figures 20–23 are applied to a mine that dips more than a few degrees from the horizontal. For example, computed steady-state inflows to a mine that dips 5° downward were about two times greater than those computed for a horizontal mine, and steady-state drawdowns were about 50 percent greater. Similarly, computed steady-state inflows to a mine that dips 5° upward were about one-half those computed for a horizontal mine, and steady-state drawdowns were about 50 percent less. The curves do not account for increased downward movement of water from overlying perched aquifers or increased permeability in the Blackhawk-Star Point aquifer that could result from subsidence above underground mines.

Effects of Subsidence Above Underground Mines

Subsidence is the movement or deformation that occurs in overburden above all underground mines, and it needs to be considered when evaluating the effects of mining

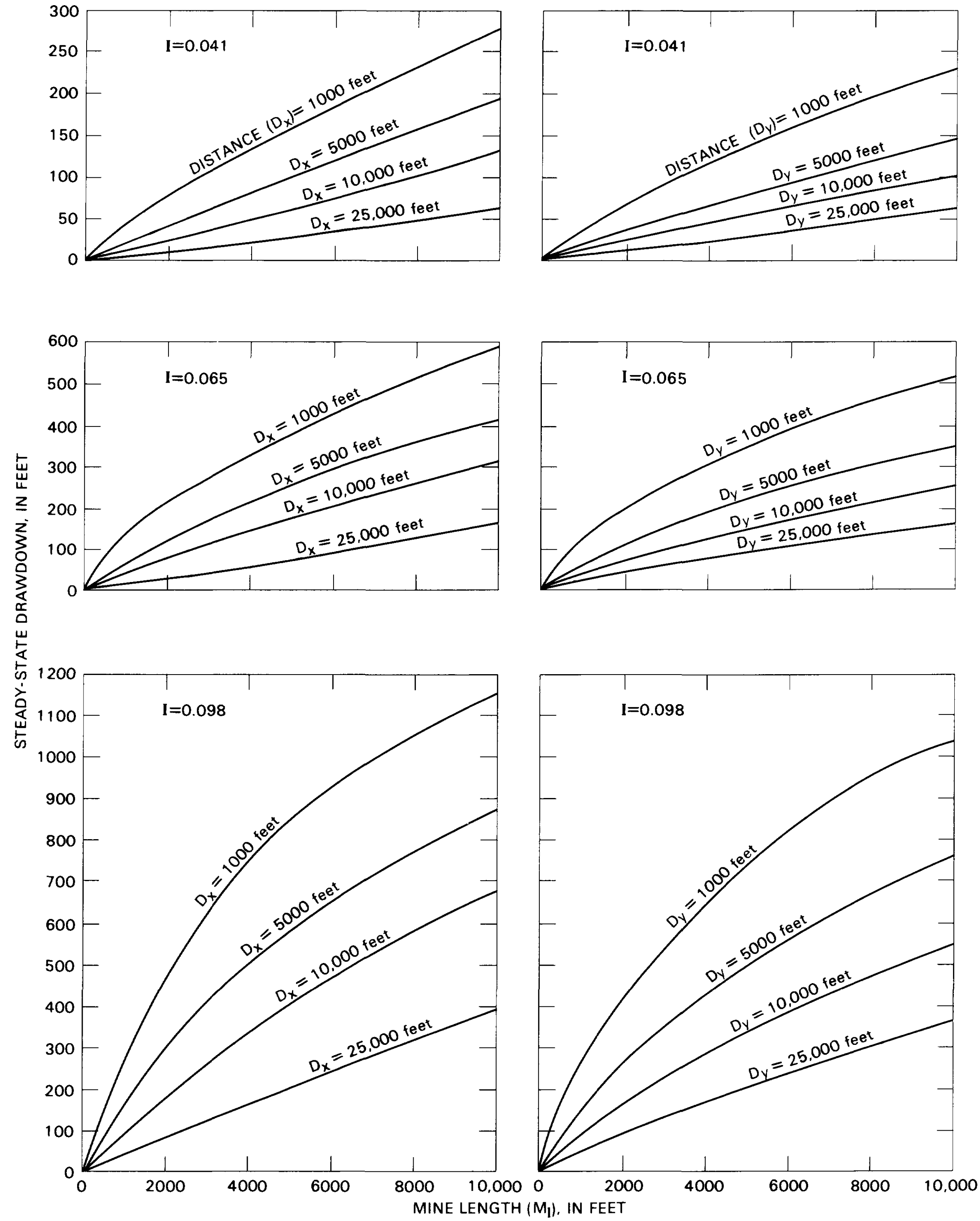


Figure 21. Families of curves for three premining horizontal hydraulic gradients (I) showing steady-state drawdown produced at various distances from the specified lengths of a hypothetical horizontal underground mine at the base of the Blackhawk Formation. (Mine width, 1,000 feet; hydraulic conductivity of the Blackhawk Formation, 0.01 foot per day; hydraulic conductivity of the Star Point Sandstone, 0.02 foot per day.)

on a ground-water system. Subsidence includes fracturing and downwarping of overburden, and its effects may reach the land surface. Dunrud (1976, p. 34–36) points out that subsidence is related to: (1) The geometry of mine workings, (2) the lithology, structure, and thickness of overburden, (3) the direction of dip of the mined coal bed relative to its outcrop, and (4) the proximity of mine workings to the coal outcrop. Dunrud also points out that the type and rate of coal extraction affects subsidence. Unfortunately, the degree of subsidence cannot be predicted, nor can the effects on

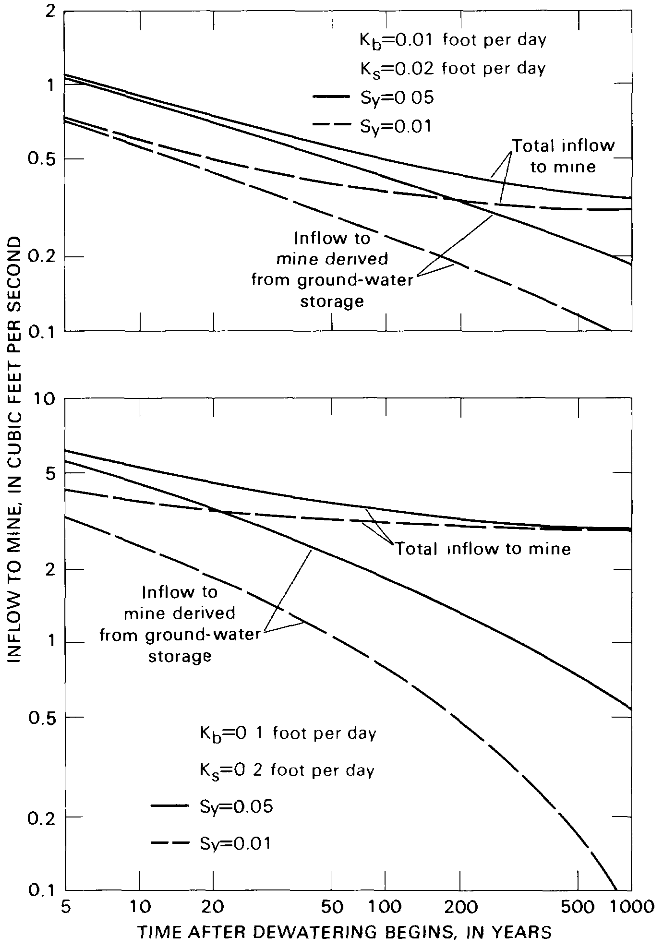


Figure 22. Logarithmic curves for various specific yields (Sy) and hydraulic conductivities of the Blackhawk Formation (K_b) and Star Point Sandstone (K_s) showing total mine inflow and that part of the inflow derived from a decrease in ground-water storage at the specified times after dewatering begins in a hypothetical horizontal underground mine at the base of the Blackhawk Formation. (Premining horizontal hydraulic gradient, 0.065; mine width, 1,000 feet; mine length, 10,000 feet; storage coefficient, 1×10^{-6} per foot of confined aquifer.)

the ground-water system be quantified. Mines can be planned, however, to keep subsidence at a minimum.

In the Book Cliffs coal field about 50 mi northwest of Trail Mountain, subsidence fractures have formed in the Price River Formation at the land surface about 900 ft above an underground mine in the Blackhawk Formation. The fractures are as much as 3 ft wide at the land surface and according to Dunrud (1976, p. 9) "These cracks divert all surface- and ground-water flow in this area to lower strata or to the mine workings."

It is possible that subsidence fractures could extend from the roof of a mine in the Hiawatha coal bed into a perched aquifer several hundred feet above. Such fractures would increase hydraulic connection between the perched aquifer and the unsaturated zone and would increase downward percolation through the perching bed. The discharge of springs that issue from the perched aquifer could decrease. Some of the water that flows through the perching bed along subsidence fractures could reach the Blackhawk-Star Point aquifer. Thus, recharge to the Blackhawk-Star Point aquifer and inflow to the mine could increase.

Because water quality is similar in all aquifers in Trail Mountain, subsidence would not significantly change water quality in the ground-water system. Water quality could improve slightly in the Blackhawk-Star Point aquifer if increased permeability due to subsidence fractures increased flow rates through the aquifer and decreased time that water is in contact with the rock.

SUMMARY

Ground water occurs in several aquifers in Trail Mountain. The coal-bearing Blackhawk-Star Point aquifer is regional in nature and is the source of most water in underground mines in the Wasatch Plateau coal field. In Trail Mountain, the Blackhawk-Star Point aquifer is overlain by one or more perched aquifers in the North Horn and Price River Formations, and in the Castlegate Sandstone.

Snowmelt and rain are the main sources of recharge to this multiaquifer system. The Blackhawk-Star Point aquifer also is recharged by Joes Valley Reservoir. Water is discharged from the system mainly by springs and by leakage along streams. Springs that issue from the perched aquifers are sources of water for livestock and wildlife on Trail Mountain. About 40 gal/min was discharged from the Trail Mountain Mine during 1982 mainly by the mine ventilation system. Some of this mine water was pumped from Cottonwood Creek for use underground, but most of the water was evaporated from the unsaturated zone in the Blackhawk Formation.

Water in all aquifers in Trail Mountain is suitable for most uses. Dissolved-solids concentrations range from about 250 to 700 mg/L, and the predominant dissolved constituents are usually calcium, magnesium, and bicarbonate.

Future underground mines that penetrate the Blackhawk-Star Point aquifer will require dewatering as mine inflows probably will be several hundred gallons per minute. Initially, most of the mine inflow will be derived from ground water in storage in the partly dewatered aquifer; some of the water will be derived from a decrease in natural discharge from the aquifer. Potentiometric surfaces in the partly dewatered aquifer could be drawn down several hundred feet during a reasonable life span of a mine. Because the Blackhawk-Star Point aquifer is separated from overlying perched aquifers by an unsaturated zone, mine dewatering alone would not affect the perched aquifers. Most dewatering would not significantly change water quality in the Blackhawk-Star Point aquifer.

The degree of subsidence above underground mines cannot be predicted, nor can the effects on the ground-water system be quantified. It is possible that subsidence

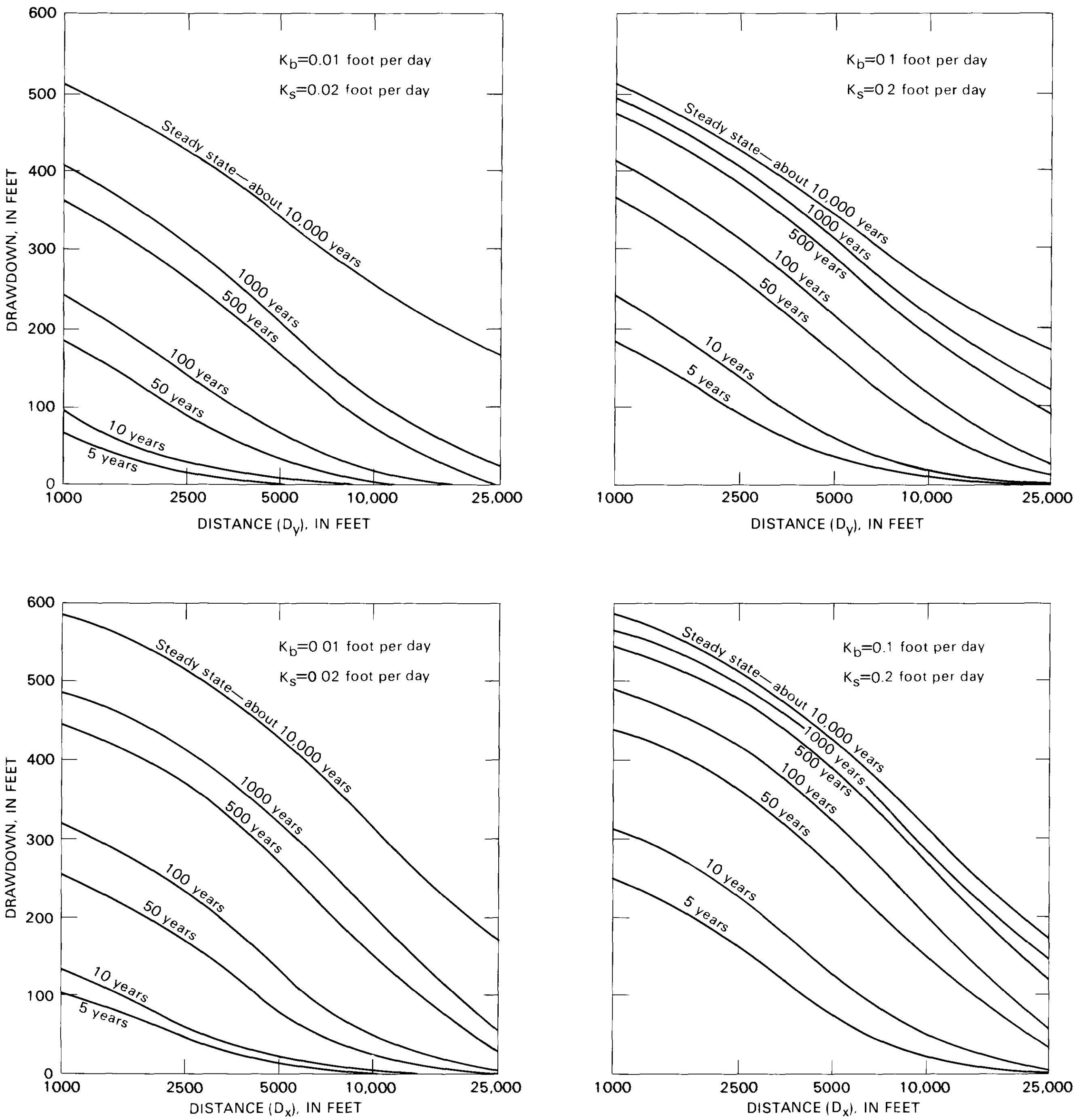


Figure 23. Semilogarithmic curves for various hydraulic conductivities of the Blackhawk Formation (K_b) and Star Point Sandstone (K_s) showing drawdown produced at specified distances from a hypothetical horizontal underground mine at the base of the Blackhawk Formation that has been dewatered for various lengths of time. (Premining horizontal hydraulic gradient, 0.065; mine width, 1,000 feet; mine length, 10,000 feet; specific yield, 0.05; storage coefficient, $1x10^{-6}$ per foot of confined aquifer.)

fractures could extend from the roof of a mine into an overlying perched aquifer. Such fractures would increase downward percolation through the perching bed, and spring discharge from the perched aquifer could decrease. Some of the water that flows through the perching bed along subsidence fractures could reach the Blackhawk-Star Point aquifer.

REFERENCES CITED

Danielson, T.W., ReMillard, M.D., and Fuller, R.H., 1981, Hydrology of the coal-resource areas in the upper drainages of Huntington and Cottonwood Creeks, central Utah: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-539, 85 p.

Danielson, T.W., and Sylla, D.A., 1983, Hydrology of coal-resource areas in the southern Wasatch Plateau, central Utah: U.S. Geological Survey Water-Resources Investigations Report 82-4009, 66 p.

Davis, F.D., and Doelling, H.H., 1977, Coal drilling at Trail Mountain, North Horn Mountain, and Johns Peak areas, Wasatch Pleateau, Utah: Utah Geological and Mineral Survey Bulletin 112, 90 p.

Doelling, H.H., 1972, Central Utah coal fields: Sevier-Sanpete, Wasatch Plateau, Book Cliffs and Emery: Utah Geological and Mineralogical Survey Monograph 3, 571 p.

Dunrud, C.R., 1976, Some engineering geologic factors controlling coal mine subsidence in Utah and Colorado: U.S. Geological Survey Professional Paper 969, 39 p.

Ferris, J.G., Knowles, D.B., Brown, R.H., and Stallman, R.H., 1962, Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536-E, 174 p.

Johnson, A.I., 1967, Specific yield—Compilation of specific yields for various materials: U.S. Geological Survey Water-Supply Paper 1662-D, 74 p.

Lohman, S.W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Lohman, S.W., and others, 1972, Definitions of selected ground-water terms—Revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

McDonald, M.G., and Harbaugh, A.W., 1984, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Open-File Report 83-875, 528 p.

Spieker, E.M., 1931, The Wasatch Plateau coal field, Utah: U.S. Geological Survey Bulletin 819, 210 p.

Sumsion, C.T., 1979, Selected coal-related ground-water data, Wasatch Plateau-Book Cliffs area, Utah: U.S. Geological Survey Open-File Report 79-915 (duplicated as Utah Hydrologic-Data Report 32), 25 p.

U.S. Weather Bureau, [1963], Normal annual and May-September precipitation (1931-60) for the State of Utah: Map of Utah, scale 1:500,000.

Waddell, K.M., Contratto, P.K., Sumsion, C.T., and Butler, J.R., 1981, Hydrologic reconnaissance of the Wasatch Plateau-Book Cliffs coal-fields area, Utah: U.S. Geological Survey Water-Supply Paper 2068, 45 p.

Witkind, I.J., Lidke, D.J., and McBroome, L.A., 1978, Preliminary geologic map of the Price 1° x 2° Quadrangle, Utah: U.S. Geological Survey Open-File Report 78-465, scale 1:250,000, 2 sheets.

☆ U S GOVERNMENT PRINTING OFFICE 1985—578-187