HYDROLOGIC ANALYSIS OF THE U.S. BUREAU OF MINES' UNDERGROUND OIL-SHALE RESEARCH-FACILITY SITE PICEANCE CREEK BASIN, RIO BLANCO COUNTY, COLORADO

U.S. GEOLOGICAL SURVEY

Water Resources Investigations 78-28

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16. Abstracts

The U.S. Bureau of Mines plans to develop an underground oil-shale research facility near the center of Piceance Creek basin. The oil-shale zone, which is to be penetrated by a shaft, is overlain by 1,400 feet of sedimentary rocks, primarily sandstone and marlstone, consisting of two aquifers separated by a confining layer. Three test holes were drilled by the U.S. Bureau of Mines to obtain samples of the oil shale, and to test the hydraulic properties of the two aquifers. The data collected during construction of the test holes were used to update an existing ground-water-flow computer model. The model was used to estimate the maximum amount of water that would have to be pumped to dewater the shaft during its construction. Based on the model, it is estimated that it would be necessary to pump as much as 3,080 gallons per minute to keep the shaft dry. Disposal of waste water and rock are the principal hydrologic problems associated with constructing the shaft.

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CONVERSION TABLE

U.S. customary units in this report may be expressed as metric units by use of the following conversion factors:

To convert U.S. customary unit	*Multiply by*	*To obtain metric unit*
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	.3048	meter
foot per day (ft/d)	.3048	meter per day
cubic foot per day	.02832	cubic meter per day
foot squared per minute	.0929	meter squared per minute
foot squared per day (ft^2/d)	.0929	meter squared per day
gallon per minute (gal/min)	.06309	liter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer

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ABSTRACT

The U.S. Bureau of Mines plans to develop an underground oil-shale research facility near the center of Piceance Creek basin. The rocks underlying the site consist of more than 800 feet of kerogen-rich marlstone (oil shale) that is overlain by 1,400 feet of sedimentary rocks, primarily sandstone and marlstone. The overburden section of 1,400 feet consists of two aquifers separated by a confining layer.

Three test holes have been drilled by the U.S. Bureau of Mines as part of the exploratory work prior to the development of the research facility. The test holes were drilled to obtain samples of the oil shale, and to test the hydraulic properties of the two aquifers. Results of two aquifer tests made during the drilling of the test holes indicate that the upper aquifer has a transmissivity of 2,600 feet squared per day, and the lower aquifer has a transmissivity of 210 feet squared per day.

The water discharged from the upper aquifer and the upper part of the lower aquifer during the drilling of the test holes had about the same chemical quality as the water from Piceance Creek during low flow. The water discharged from a point near the base of the lower aquifer had a higher concentration of dissolved constituents. This condition is caused by the dissolution of soluble minerals in the marlstone.

One of the problems related to constructing a shaft through the aquifers is that a large amount of water may have to be pumped to keep the working area dry. A digital ground-water model of the Piceance basin was used to determine the maximum amount of water that would have to be pumped. Based on the model, it is estimated that it would be necessary to pump as much as 3,080 gallons per minute to keep the shaft dry.

Saline-water production and erosion of wastes by dewatering discharge are the principal hydrologically related problems associated with constructing the shaft. The problems are created not by the construction but by the disposal of waste water and rock from the shaft. The leaching of soluble minerals from shaft waste and the erosion of fine-grained sediments from the waste are the expected problems that would need resolution at any such waste-disposal site.

INTRODUCTION

As part of their energy resource and development program, the U.S. Bureau of Mines plans to develop an underground oil-shale research facility on a site near the center of Piceance Creek basin (fig. 1). At the site, the rocks consist of more than 800 ft of oil-shale deposits occurring at a depth of 1,400 ft below the land surface. The oil-shale deposits will be reached by a vertical shaft, and various methods of obtaining oil shale will be tested.

Two hydrologic problems are anticipated in association with the construction and operation of the facility. The first problem is a shaft-drainage problem. During the sinking of the shaft, two aquifers will be penetrated, and a large volume of water may have to be pumped to dewater the shaft during its construction. The second problem is a waste-disposal problem. This includes both the disposal of saline water that may be pumped during the construction of the shaft and the disposal of tailings, a part of which contain water-soluble minerals.

From the conception of the underground oil-shale research-facility project, the U.S. Geological Survey has cooperated with the U.S. Bureau of Mines on the selection of the site for the facility. The richer oil shale occurs near the center of the basin, where the overburden is the thickest and the shaft-dewatering problem is the greatest. The site selected was a compromise between obtaining the maximum richness of the oil shale and the minimum adverse hydrologic changes.

Four potential sites for the facility were considered, and a single site was selected based on criteria developed from a site-selection study (Ege and others, 1978). The site was selected using available data only, because no test drilling had been done prior to the site selection. The oil-shale richness was based on data from nearby test holes, and the hydrologic effects were simulated using a large-scale digital model of the entire basin developed by Weeks, Leavesley, Welder, and Saulnier (1974).

After the selection of the facility site, three test holes were drilled in order to verify the richness of the oil shale and to verify the hydraulic properties of the aquifers. The first test hole was drilled in an unnamed tributary to Ryan Gulch, herein called Fault Draw (fig. 2). During the drilling of this hole, a large amount of water was produced, indicating that the upper aquifer was very permeable. Because of faults and high permeability, the site was abandoned. The drilling equipment was moved about 1.5 mi north to Horse Draw, where two test holes were drilled. During the test drilling in Horse Draw, cores were collected from the oil-shale zone and two aquifer tests were made to determine the hydraulic properties of the aquifers.

The purpose of this report is to present the hydrologic data collected during the test drilling and to document refinements of the estimated hydrologic changes, based on the data collected, that may occur as a result of the construction of the facility.

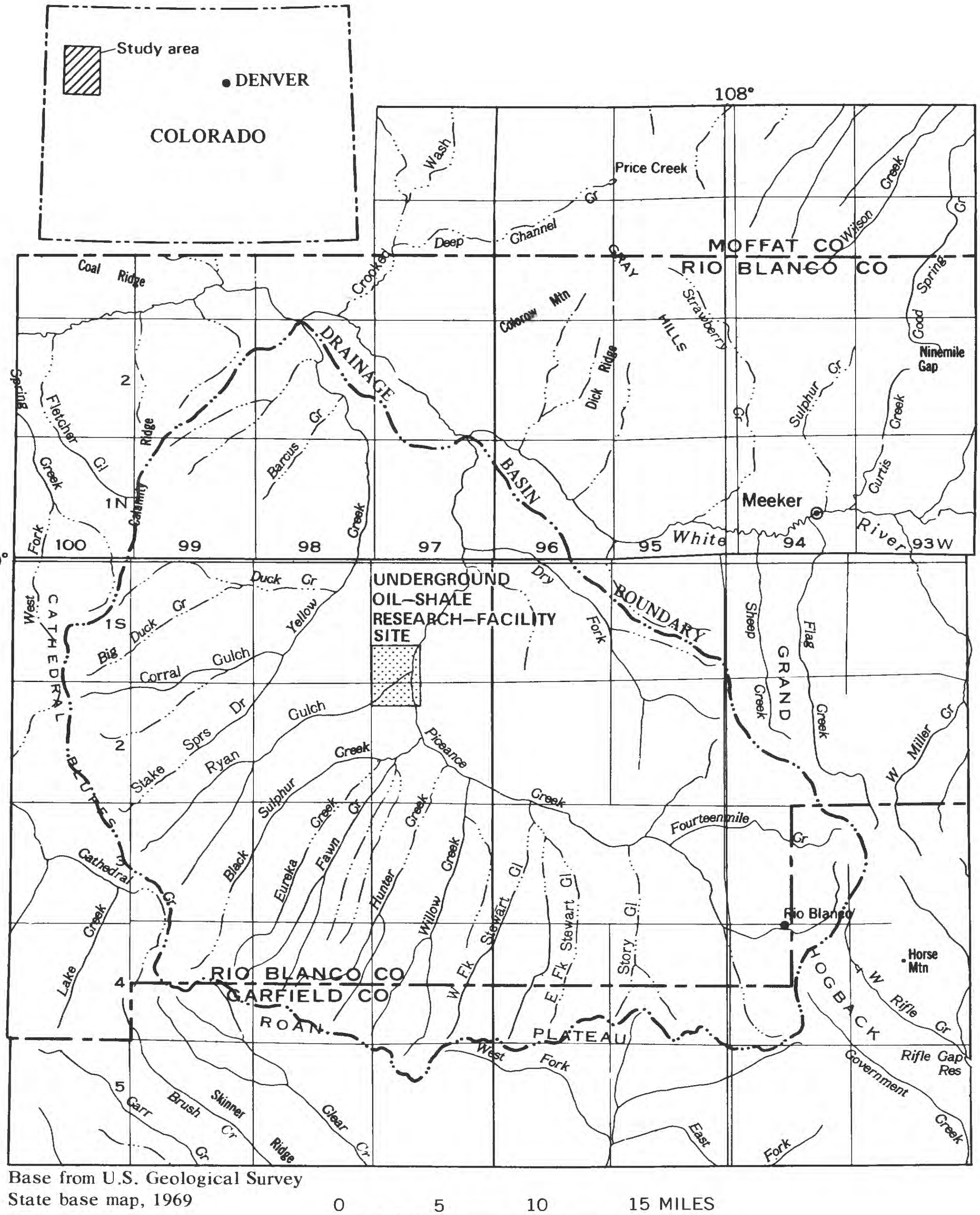

Figure 1.--Location of the underground oil-shale research-facility site. Details of the site are shown on figure 2.

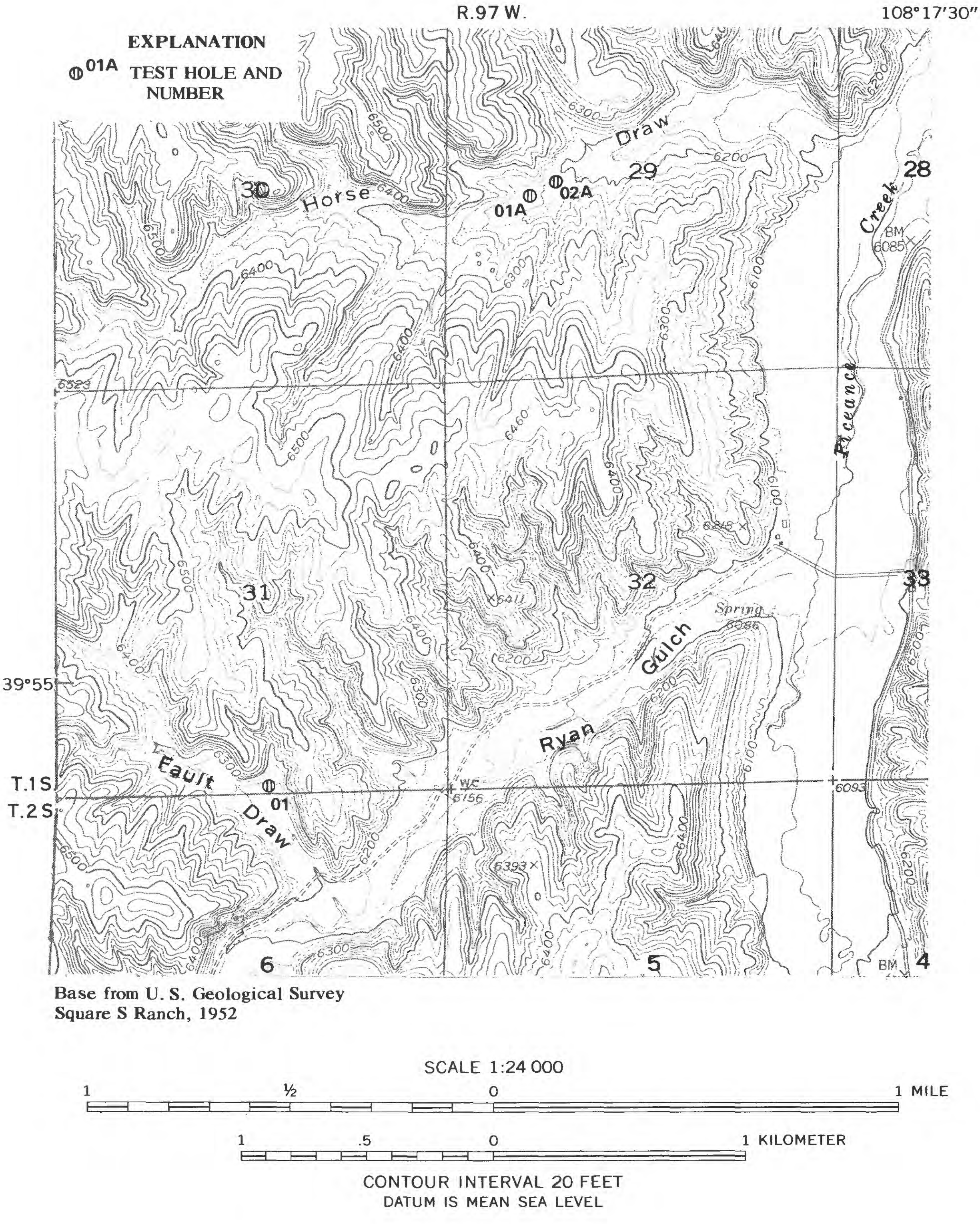

Figure 2.--Underground oil-shale research-facility site showing location of test holes 01, 01A, and 02A.

GEOHYDROLOGIC FRAMEWORK

The oil-shale zone is contained in the lower part of the Parachute Creek Member of the Green River Formation of Eocene age (fig. 3). The Parachute Creek Member consists of dolomitic marlstone, the soluble saline minerals nahcolite and halite, and a solid hydrocarbon called kerogen. If the marlstone is rich in kerogen, it is called oil shale. The Parachute Creek Member is the oil-shale-bearing part of the section. The richest oil-shale intervals are the Mahogany zone and the high-resistivity or saline zone (fig. 3).

The Uinta Formation of Eocene age directly overlies the Parachute Creek Member. The Uinta Formation consists primarily of sandstone and marlstone. The unit does not contain appreciable amounts of soluble minerals or kerogen.

The significant permeability of the rocks is due to fracturing of the sedimentary rocks, caused by gentle regional folding and by local faulting. The fracturing occurs in the kerogen-free rocks, whereas the kerogen-rich rocks tend to undergo plastic deformation. The fractures permit the entry and movement of water through the rocks, an action that dissolves and removes the soluble minerals and causes a further increase in permeability. Thus, the sandstones and kerogen-free marlstones have relatively high permeability, and the rocks richest in kerogen have relatively low permeability.

From a hydrologic point of view, the geologic section, from top to bottom, consists of an upper aquifer, a confining layer, a lower aquifer, and the oil-shale zone (fig. 3). The upper aquifer is about 900 ft thick, and consists, for the most part, of sandstone and marlstone. The confining layer, about 200 ft thick, consists of an oil-shale section called the Mahogany zone of the Parachute Creek Member. The lower aquifer is about 300 ft thick, and consists of marlstone and oil shale that have been leached of soluble minerals. The lower aquifer is sometimes described as the leached zone. The oil-shale zone is more than 800 ft thick, and consists of oil shale and saline minerals. This zone is sometimes described as the high-resistivity zone or the saline zone and is virtually impermeable.

TEST-DRILLING PROGRAM

Three test holes were drilled within the boundaries of the facility site to determine the hydraulic properties of the aquifers and to obtain core samples of the oil shale. The first hole (01) was drilled and cored at Fault Draw, and the other two holes (01A and 02A) were drilled and cored at Horse Draw (fig. 2).

Drilling Procedures

From land surface to a depth of about 200 ft, each test hole was drilled with a tricone bit, and mud was used to lift the drill cuttings to the

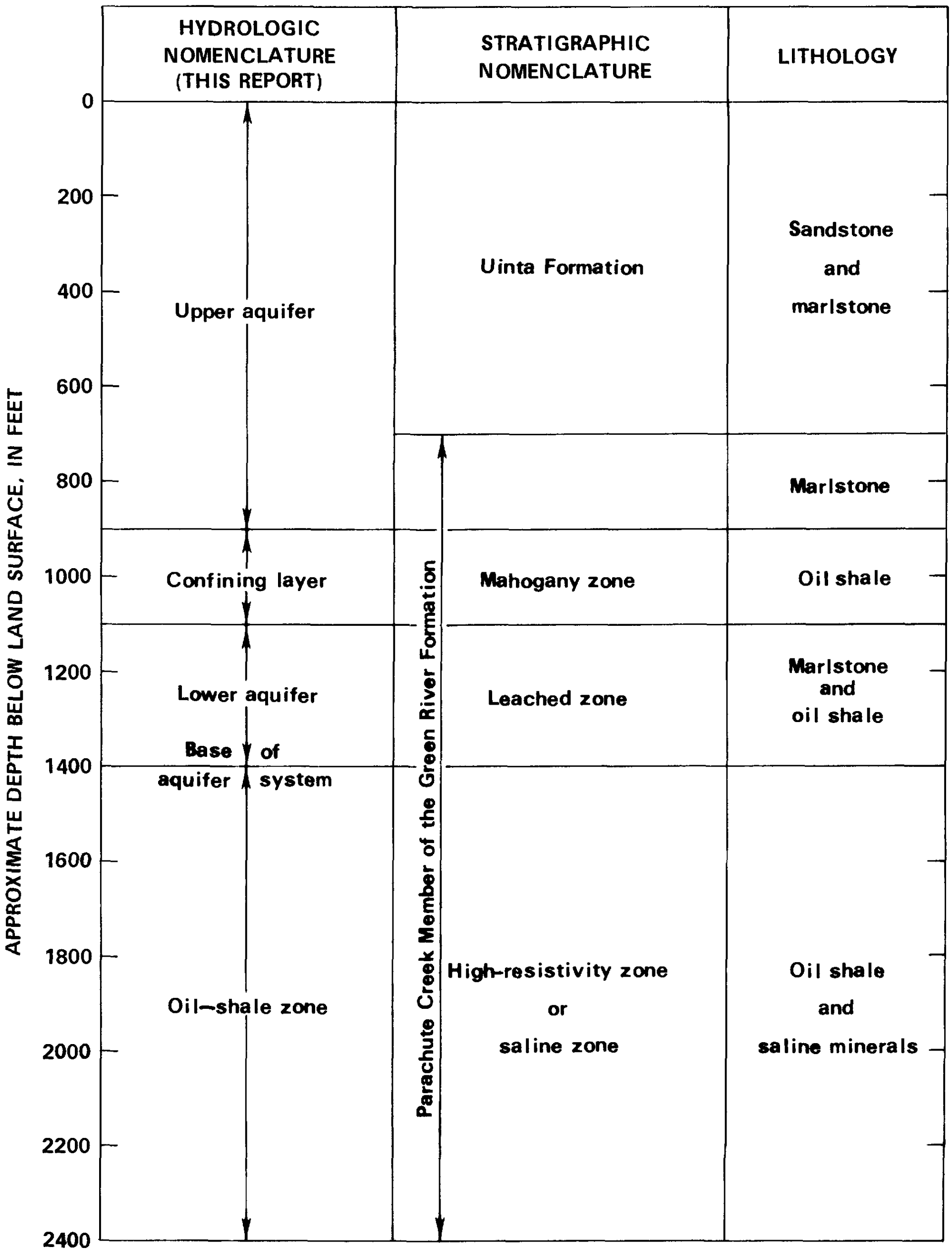

Figure 3.--Correlation between hydrologic and stratigraphic nomenclature.

surface. When the depth of each hole was about 200 ft, casing was cemented in place. After cementing, drilling was continued, generally using either a tricone bit or a 7 7/8-in. diamond-core bit, depending on the type of geologic and hydrologic information required.

At depths greater than 200 ft, air was used to remove the drill cuttings from the hole. In this method, a large amount of air is pumped down the drill pipe, causing the cuttings and the ground water to be blown out of the hole. If there was not enough ground water available, some drilling water was added, but, for the most part, the discharged fluid was ground water.

Data Collected During Drilling

The quantity and specific conductance of water produced during drilling and coring was recorded during the construction of each test hole. The quantity of water produced is an index of the permeability of the aquifers, and the specific conductance of water produced is useful in estimating the variation in chemical quality of the water with depth.

Test-Hole Construction

The casing installation, cementing, and casing-perforation procedures were different for each hole, depending on whether the test hole was to be completed as a production well or an observation well. Test hole 01 was initially drilled as a production well, but was converted to an observation well. Test hole 01A was drilled as an observation well, and test hole 02A was drilled as a production well.

Test hole 01 was drilled to a depth of 160 ft with a 15-in. tricone bit, and 160 ft of 10 3/4-in. casing was cemented in place (fig. 4). The depth interval from 160 to 750 ft was drilled with a tricone rock bit, and the depth interval from 750 to 2,382 ft was cored with a diamond-core bit. More than 1,000 gal/min of water was blown out of the hole while drilling through the upper aquifer, indicating high permeability. In addition, evidence of faulting was recognized in the core samples obtained. Because of the combination of high permeability and faulting, the decision was made to abandon the Fault Draw site. The well was subsequently filled with mud to a depth of 1,200 ft, and then a cement plug was placed in the depth interval between 800 and 1,200 ft. Test hole 01 was left open to the upper aquifer for use as an observation well.

Test hole 01A was drilled and completed in a manner so that the hydraulic head could be measured in both the upper and lower aquifer (fig. 5). The test hole was drilled to a depth of 184 ft, cased with 13 5/8-in. casing, and cemented. The depth interval from 184 to 830 ft was drilled with a tricone bit; the depth interval from 830 to 2,548 ft was cored with a diamond-core

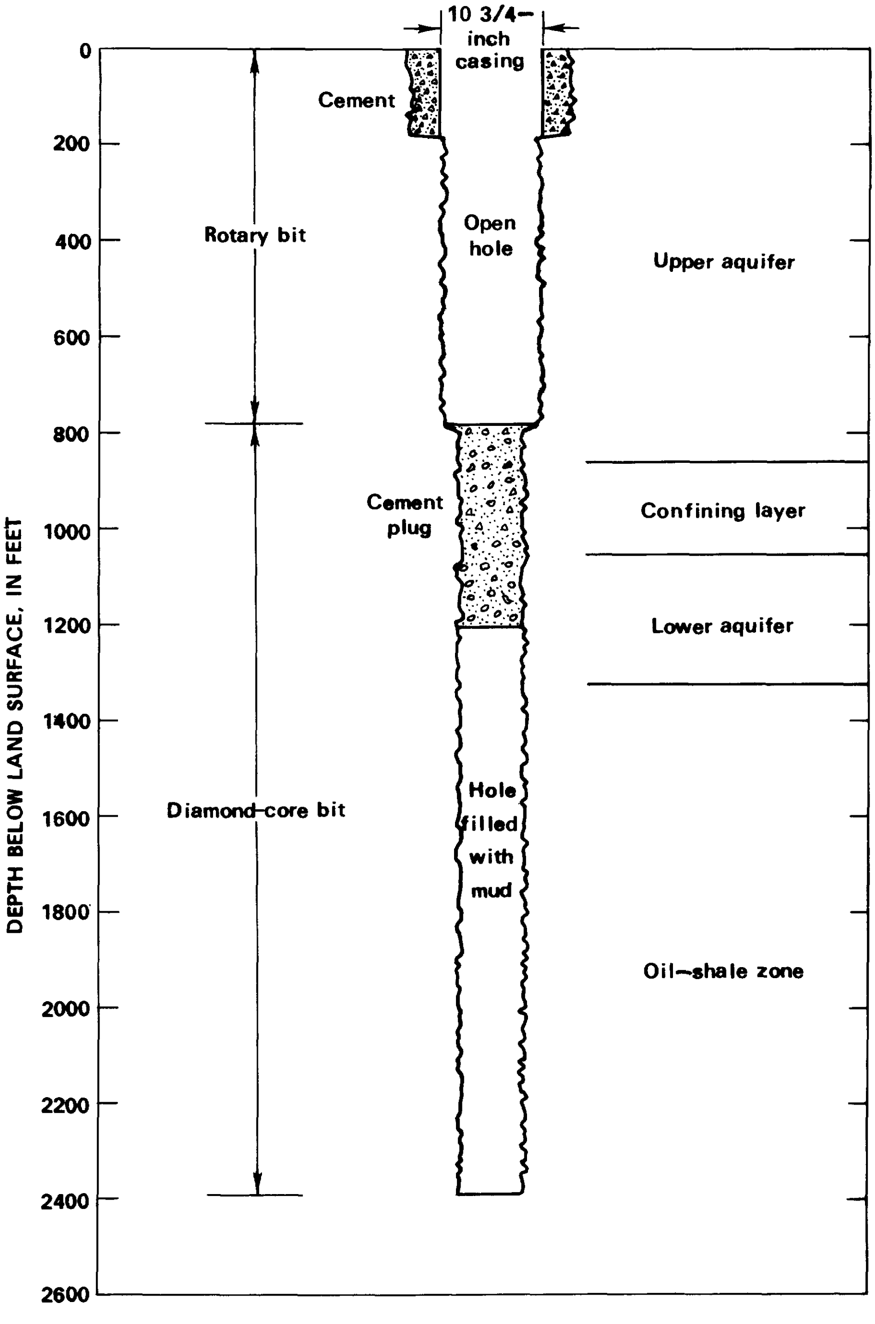

Figure 4.--Construction diagram of test hole 01.

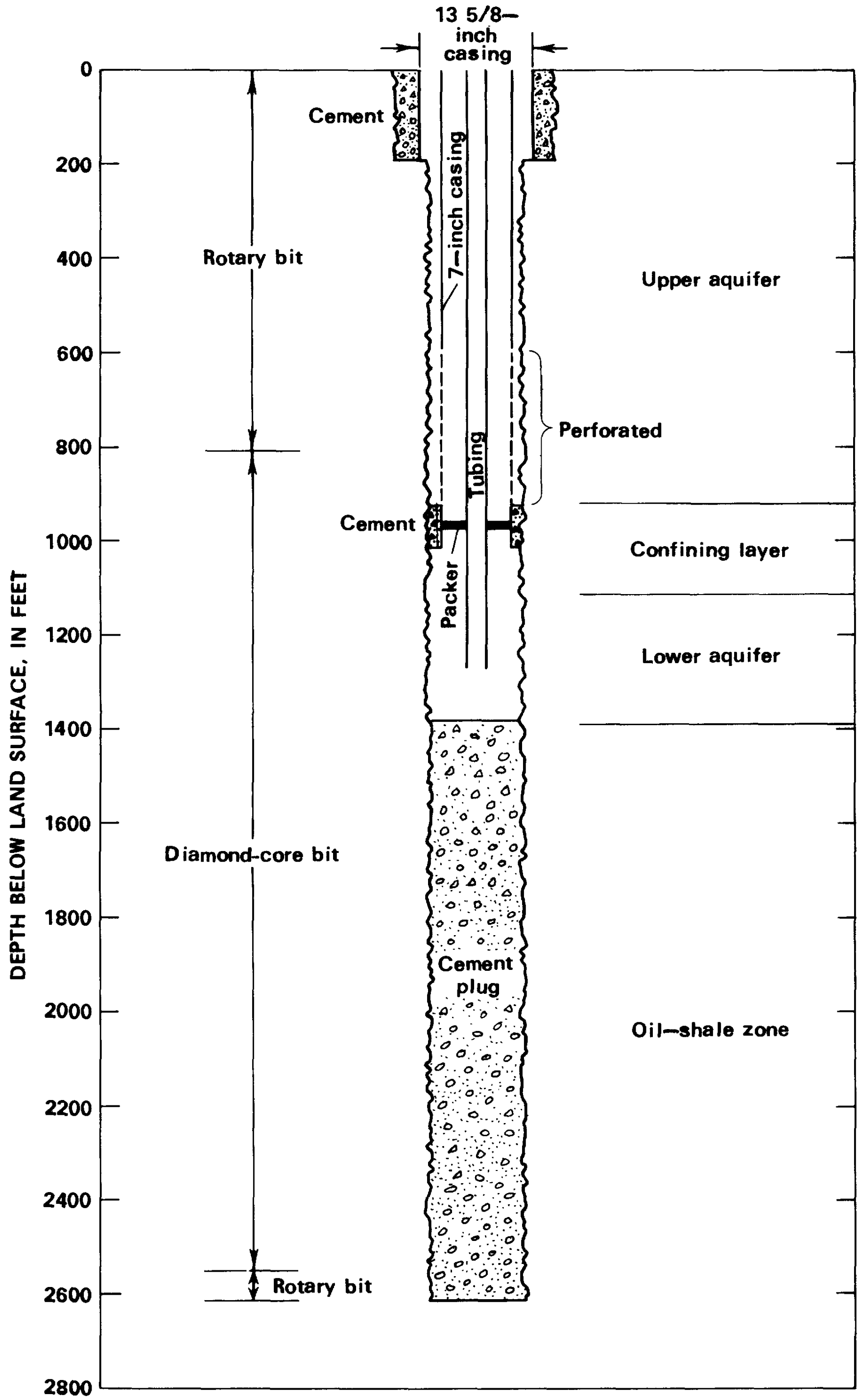

Figure 5.--Construction diagram of test hole 01A.

bit; and the depth interval from 2,548 to 2,610 ft was drilled with a tricone bit. The hole was then backfilled with cement to the top of the oil-shale zone at a depth of 1,400 ft. Next, the hole was reamed to a depth of 1,040 ft, and 7-in. casing was installed and cemented into the confining layer in the depth interval 920 to 1,040 ft. The 7-in. casing was then perforated in the upper aquifer in the depth intervals of 600 to 700 ft and 800 to 900 ft. Two and three-eighths-inch tubing was placed inside the 7-in. casing. The tubing extended below the bottom of the casing to a depth of 1,276 ft, and a packer was placed between the tubing and 7-in. casing at 959 ft. This installation makes it possible to measure the hydraulic head in the upper aquifer in the annular space between the tubing and the 7-in. casing, and to measure the hydraulic head in the lower aquifer in the tubing.

Test hole 02A, designed to be pumped for aquifer testing, was drilled in three separate stages. The first stage (fig. 6) was completed for the testing of the upper aquifer; the second stage (fig. 7) was completed for the testing of the lower aquifer, and the third stage (fig. 8) for recovering samples of the oil-shale zone.

During the first stage (fig. 6), the test hole was drilled to a depth of 197 ft, and 20-in. casing was cemented into place. The depth interval from 197 to 980 ft was then cored with a diamond-core bit. Following the coring, a test of the upper aquifer was made.

During the second stage (fig. 7), the test hole was reamed and 13 3/8-in. casing was placed in the hole to a depth of 844 ft. Originally it was planned to extend the casing to a depth of 980 ft, but the casing became stuck and could not be placed at that depth. Therefore, to seal off the lower part of the upper aquifer, the depth interval from 740 to 980 ft was filled with cement. After hardening, the cement was drilled out with a rock bit to a depth of 975 ft; the depth interval from 975 to 1,451 ft was cored with a diamond-core bit. Following the coring, a test of the lower aquifer was made.

During the third stage (fig. 8), drilling of test hole 02A was primarily for the recovery of samples from the oil-shale zone. The test hole was reamed and a 9 5/8-in. liner was cemented in place in the depth interval from 740 to 1,450 ft. The depth interval from 1,450 to 2,260 ft was then cored with a diamond-core bit.

AQUIFER PROPERTIES

The rate of water discharge required to keep the shaft dry depends, in part, on the transmissivity and the storage coefficient of the aquifer. Transmissivity is a measure of the rate of flow of water through a unit width of the aquifer under a unit hydraulic gradient. The storage coefficient is a measure of the water released from or taken into storage per unit surface area of the aquifer per unit change in hydraulic head.

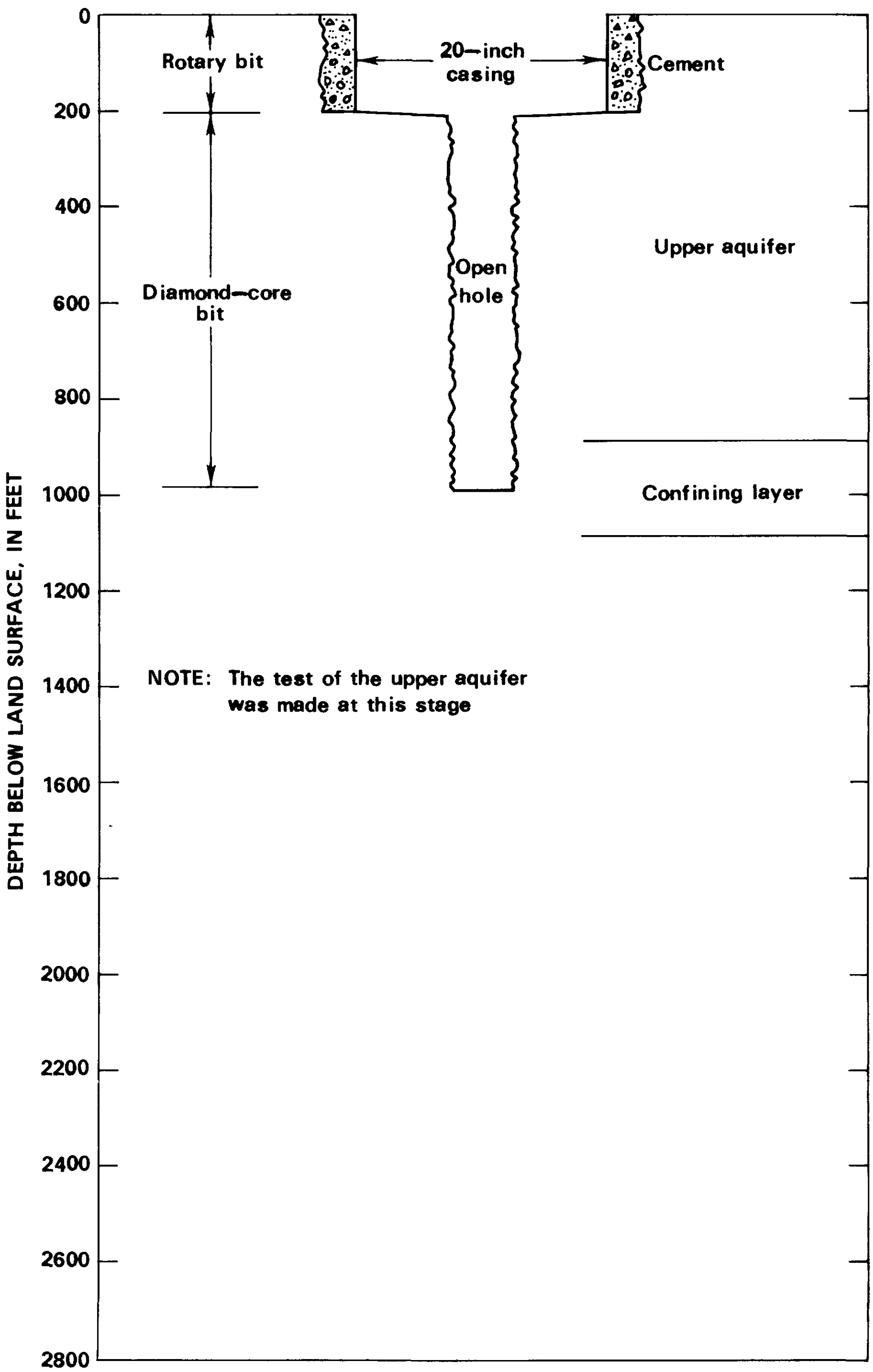

Figure 6.--Construction diagram of test hole 02A, first stage.

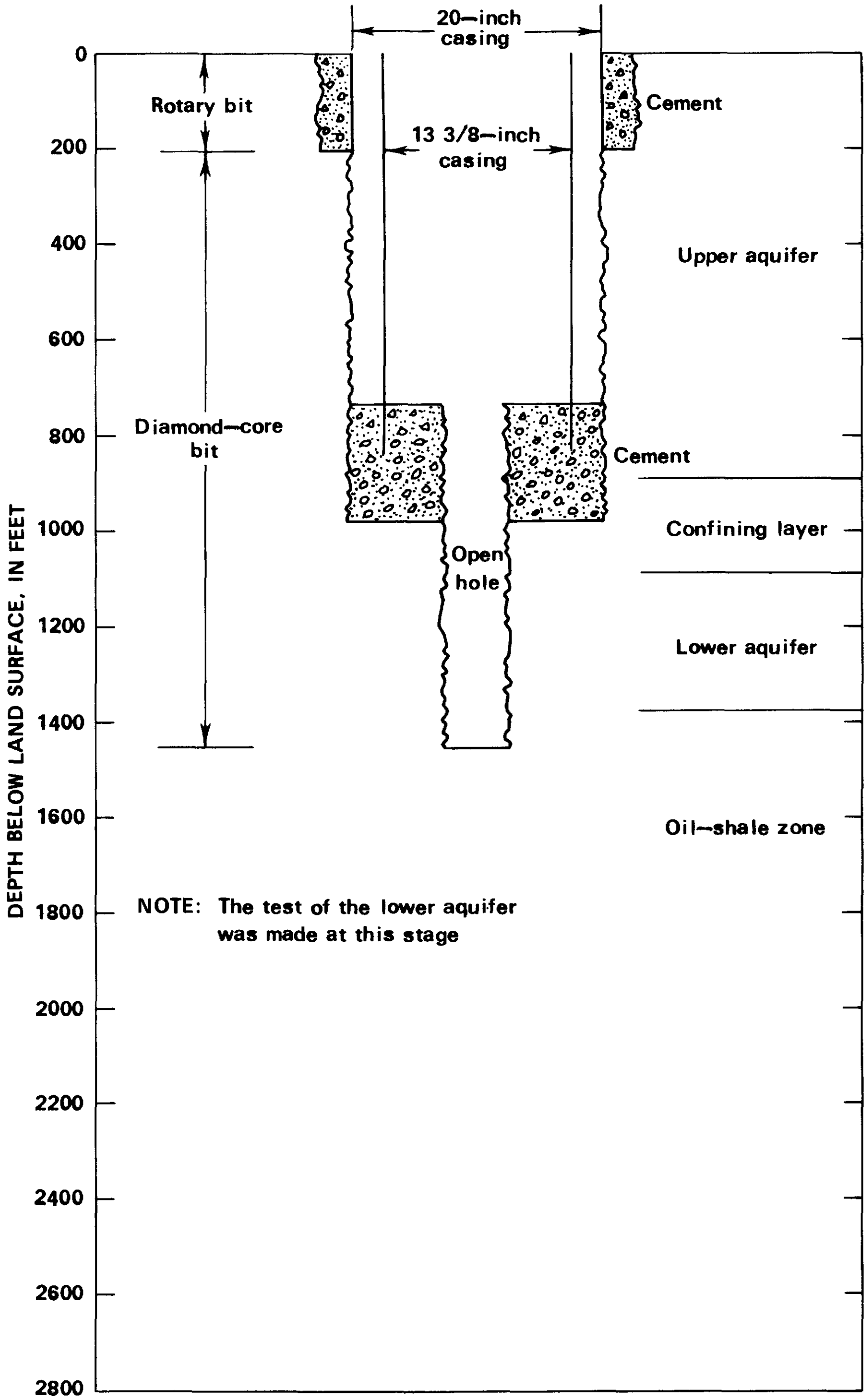

Figure 7.--Construction diagram of test hole 02A, second stage.

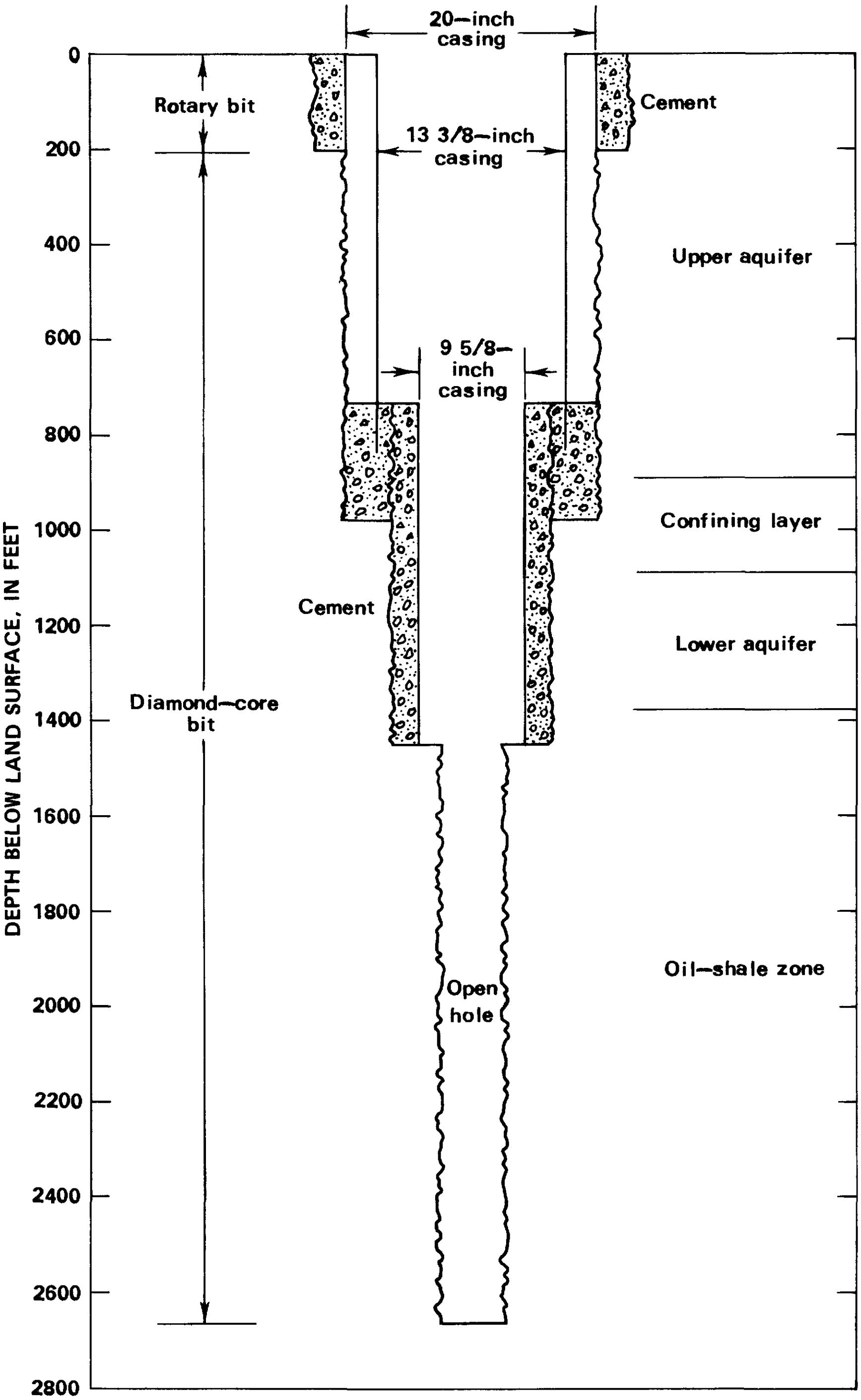

Figure 8.--Construction diagram of test hole 02A, third stage.

Aquifer Tests

Two aquifer tests were made to determine the aquifer properties at the Horse Draw site. The first test was made to determine the properties of the upper aquifer, and the second test was made to determine the properties of the lower aquifer. The first test was made following the first stage of drilling test hole 02A, and the second test was made following the second stage of drilling test hole 02A. In both tests, test hole 02A was pumped, and hydraulic-head measurements were made in test holes 01A and 02A.

The data from the aquifer tests were analyzed using the Theis (1935) method. In this method, the drawdown (s) is graphed against the square of the distance to the observation point divided by time (r^2/t). A type curve is superimposed over the data points and the functions u and $W(u)$ are transferred to the graph. Transmissivity (T), in feet squared per day, is determined from the formula:

$$T = \frac{Q}{4\pi s} W(u),$$

where Q is the pumping rate, in cubic feet per day, and s is the drawdown, in feet. The storage coefficient (S) is determined from the formula:

$$S = \frac{4Tu}{1{,}440(r^2/t)},$$

where r^2/t is measured in feet squared per minute. The reader is directed to Ferris, Knowles, Brown, and Stallman (1962) for more complete explanations on the theory and use of this approach.

In the analysis of the aquifer tests it was assumed that the pumped wells had a radius of 1 ft. In practice, the wells had radii less than 1 ft, but this difference causes only a small change in the value of S, and does not affect the value of T.

Upper Aquifer

The pumping rate for the test of the upper aquifer averaged 280 gal/min for 900 minutes. After 900 minutes, the drawdown in the pumped test hole (02A) was about 10 ft, and the drawdown in hole 01A was a little more than 1 ft. Based on the data from the pumped hole 02A, the transmissivity of the upper aquifer is 2,600 ft^2/d (fig. 9). Based on the data from hole 01A, the transmissivity is 7,940 ft^2/d, and the storage coefficient is 2.5×10^{-3} (fig. 10).

The time-drawdown data from test hole 02A also were analyzed by the methods presented by Raghavan, Cady, and Ramey (1972). The analysis resulted in the same value of transmissivity at hole 02A as did the Theis method. In

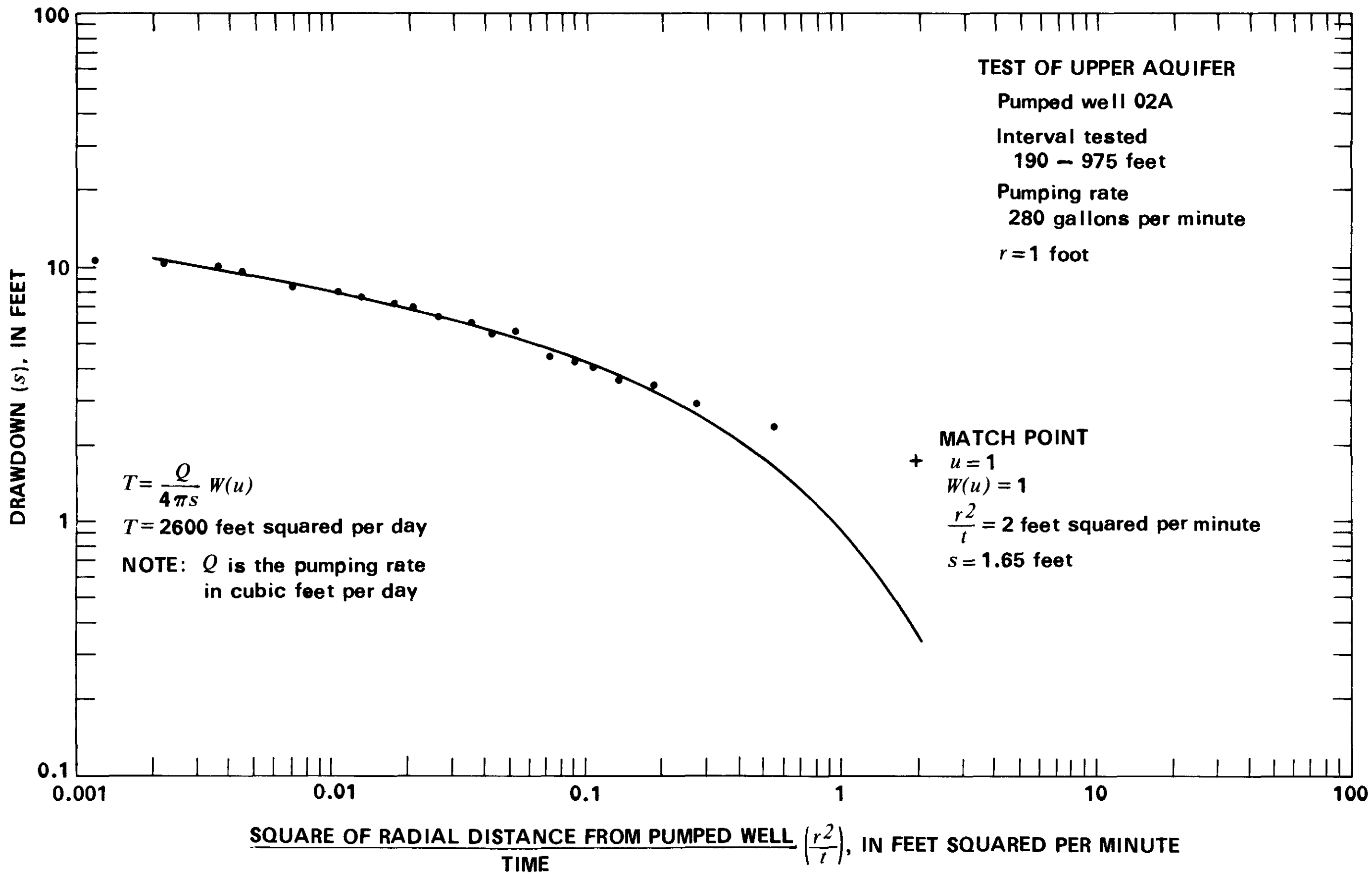

Figure 9.-- Analysis of test of upper aquifer, test hole 02A.

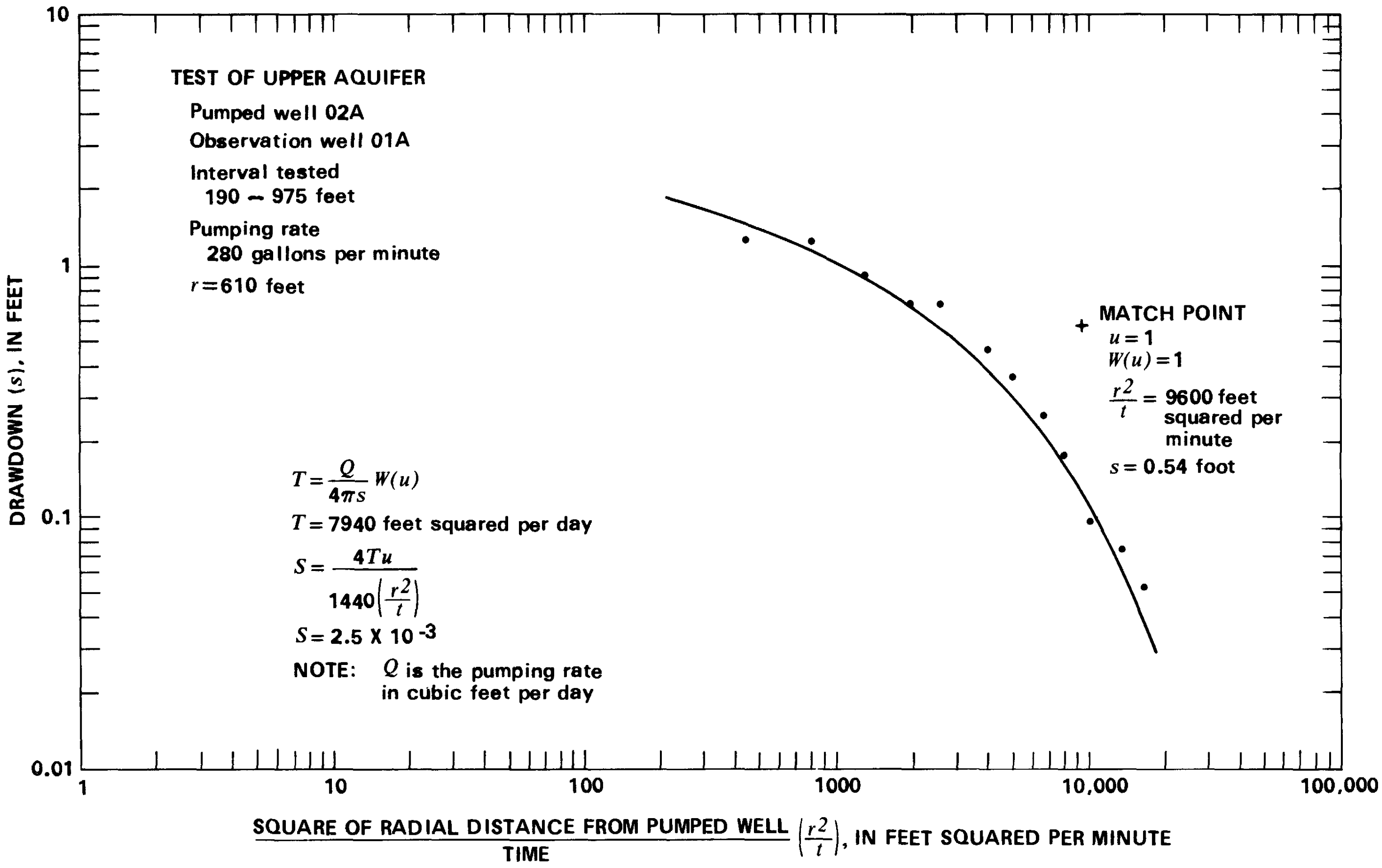

Figure 10.--Analysis of test of upper aquifer, test hole 01A.

addition, the analysis showed that the data from hole 02A are typical of data from a well completed in a vertically fractured porous medium, indicating that test hole 02A may be in the fracture zone of a near-vertical fault. Because the aquifer is fractured marlstone rather than a homogeneous medium and because the aquifer may be faulted and highly anisotropic, the difference in the values of transmissivity derived from the two tests is not unexpected; and the transmissivity of 2,600 ft^2/d, based on the data from test hole 02A, was assumed to be the most representative of the regional transmissivity of the upper aquifer at the Horse Draw site. The larger value of transmissivity based on the data from hole 01A is undoubtedly the result of local nonhomogeneous and anisotropic conditions.

Lower Aquifer

The test of the lower aquifer was very short because the minimum capacity of the pump exceeded the capacity of the well to yield water. An attempt was made to reduce the pumping rate to obtain a longer pumping period. However, it was determined that the necessary reduction in pumping rate to achieve a longer pumping period could have damaged the pump. A smaller capacity pump was not available; therefore, it was decided that a short-duration test would be made to estimate the transmissivity of the lower aquifer.

The rate of pumping from the well ranged between 196 gal/min at the beginning of the test and 164 gal/min after 10 minutes of pumping. The pumping rate from the lower aquifer (fig. 11) was computed as the measured pumping rate from the well minus the amount of water withdrawn from the well bore. During the first 2 minutes, most of the water pumped came from storage in the well bore, and only a small amount came from the aquifer. Therefore, for this analysis it was assumed that pumping from the aquifer commenced 2 minutes after the pump was turned on. It was further assumed that the rate of pumping from the aquifer was a constant 154 gal/min, the average rate from the aquifer for the 3d through the 15th minutes of pumping (fig. 11).

The pumping period was so short that the drawdown cone did not reach observation test hole 01A; therefore, the estimated transmissivity is based on the drawdown in the pumped well 02A (fig. 12). The transmissivity based on these data is 210 ft^2/d. Although the transmissivity of the lower aquifer was estimated using data from a very short duration aquifer test, the resulting value is quite small and consistent with the rapid rate of drawdown measured during the test. The storage coefficient was not computed, because the measured drawdown includes unknown hydraulic-head losses associated with the pumping well and difficult to account for; the storage coefficient is usually determined only when an observation well is available.

WATER QUALITY

Water-quality data were collected at the test-drilling sites. Field measurements were made of the specific conductance of the water discharged

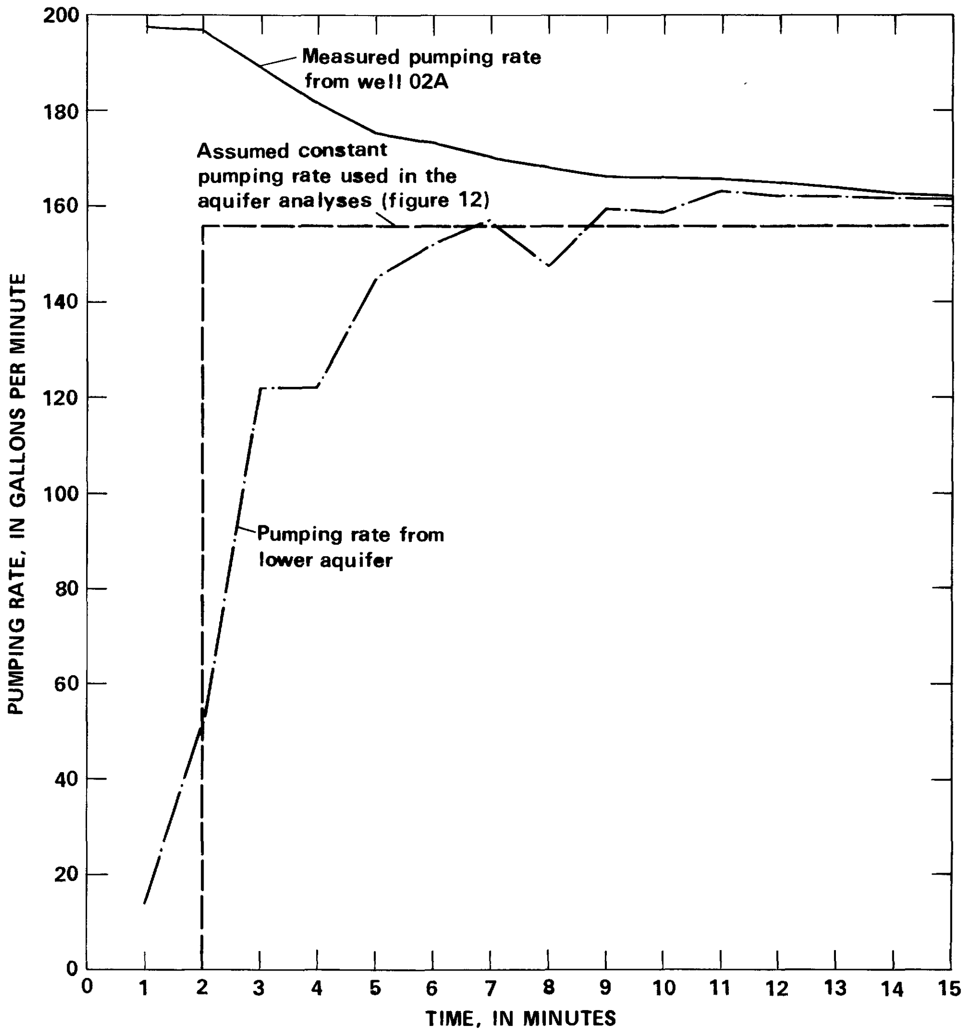

Figure 11.--Pumping rate from the lower aquifer during the aquifer test.

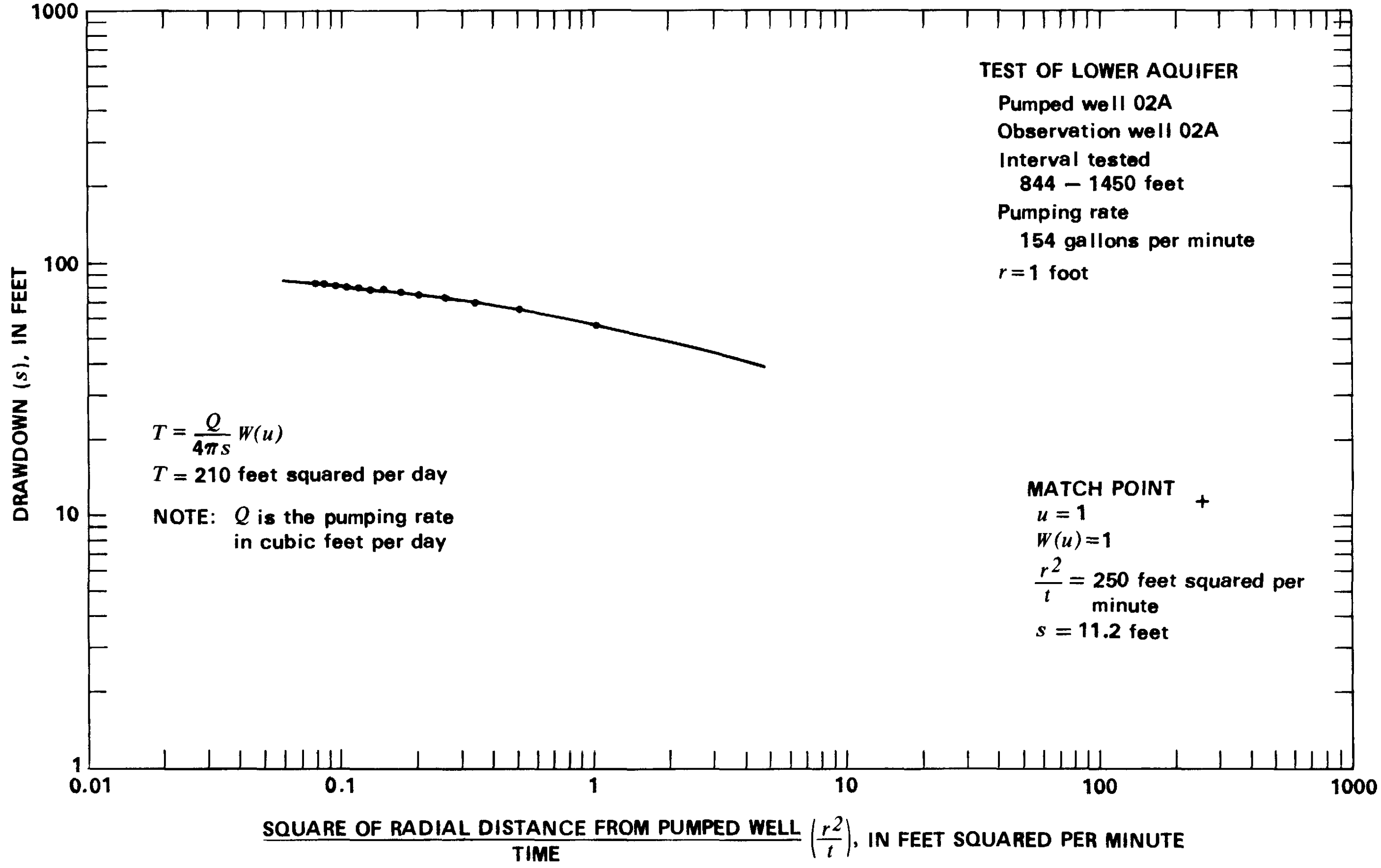

Figure 12.--Analysis of test of lower aquifer, test hole 02A.

during drilling, and water samples for chemical analysis in the laboratory were collected during drilling, coring, and aquifer testing.

The concentration of dissolved chemical constituents may be estimated from the specific conductance of the water. The specific conductance of pure water is virtually zero. At small dissolved-solids concentrations, the specific conductance increases in an approximately linear manner with an increase in dissolved chemical constituents. If specific conductance is measured in micromhos per centimeter at 25°C, the specific conductance is about 1.5 times the concentration of dissolved solids measured in milligrams per liter. Specific-conductance measurements made during the drilling of each test hole are shown in figure 13.

A total of 15 water samples were collected for chemical analyses during the drilling, coring, and aquifer testing of the test holes. The analyses are presented in tables 1, 2, and 3. The open interval of the test hole at the time each sample was collected and the specific conductance of the samples are included in the tables. In general, the specific conductance of the samples is about 1.5 times the concentration of dissolved solids given in tables 1, 2, and 3.

The graph of the principal dissolved cations and anions (fig. 14) summarizes how the ground-water quality varies with depth. Samples are arranged from left to right in order of increasing test-hole depth. The extreme left sample is from Piceance Creek, and was collected during a low-flow period at the confluence of Horse Draw and Piceance Creek (Weeks and others, 1974, p. 21). The other samples, from the test holes, are numbered with the test-hole number, followed by a hyphen, followed by the hole depth at the time the sample was collected. The complete analysis for each of the samples is listed in either tables 1, 2, or 3. The shallowest sample, 01-260, is of about the same quality as Piceance Creek. In the interval from 501 ft to 1,451 ft, the water is of noticeably better quality. This series of samples is from both the upper and lower aquifers. Sample 01A-2175 was collected when the hole was being drilled in the oil-shale zone. The change in water quality at this depth is due primarily to an increase in sodium and chloride.

The water in the upper aquifer and the upper part of the lower aquifer has a concentration of dissolved constituents of about 1,500 mg/L (milligrams per liter), and a specific conductance of about 2,000 micromhos per centimeter at 25°C. This is about the same dissolved-solids concentration as the water from Piceance Creek during the low flow that was measured near the confluence of Horse Draw and Piceance Creek (Weeks and others, 1974, p. 21). In this reach of Piceance Creek, low flow is maintained by ground-water discharge (Weeks and others, 1974, p. 70).

The section near the base of the lower aquifer contains enough soluble minerals to cause an increase in the specific conductance of the water with depth. However, analysis of sample 02A-1451 (fig. 14), which was collected

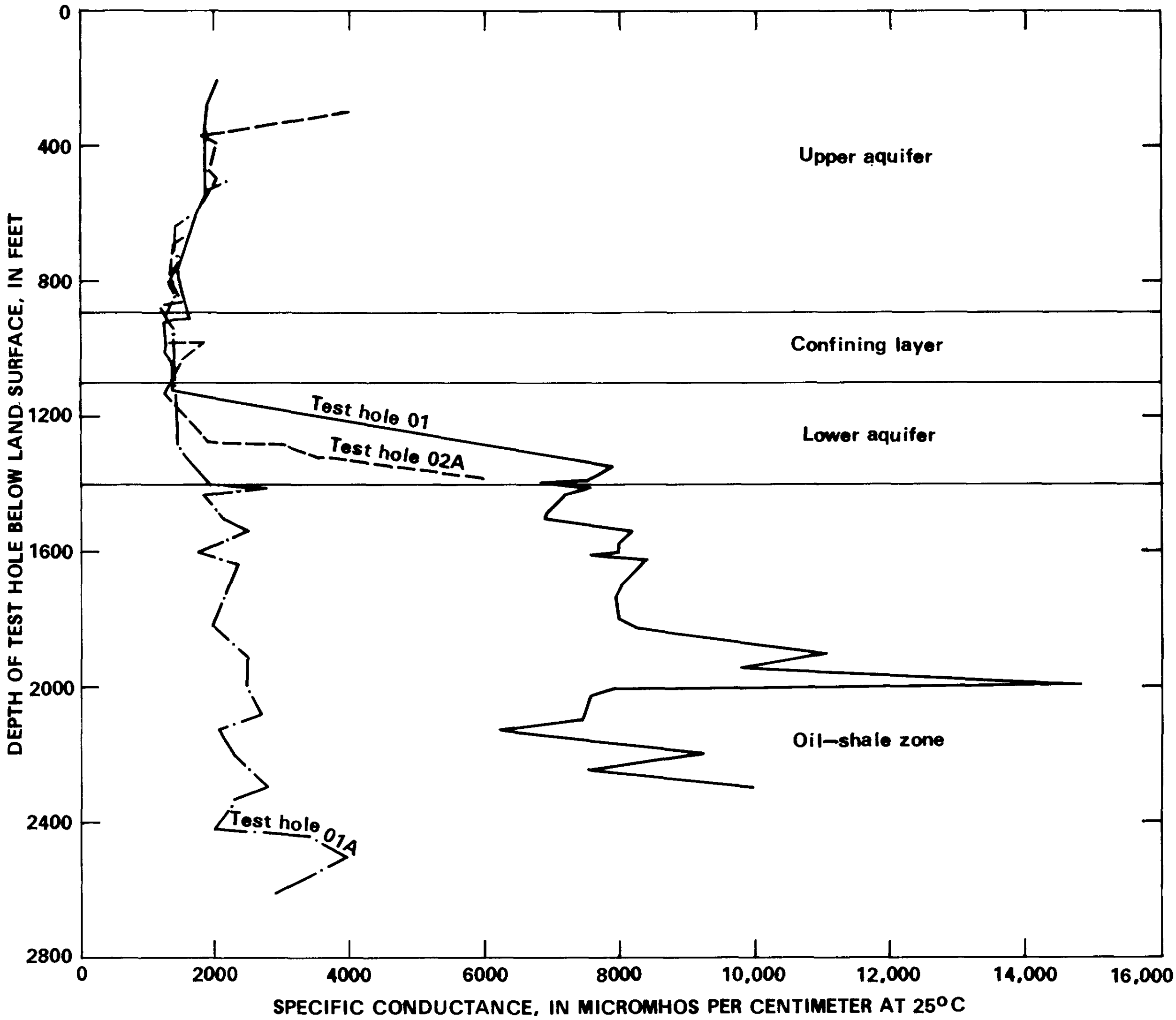

Figure 13.--Specific conductance of ground water discharged during drilling.

Table 1.--*Chemical analyses of water samples from test hole 01*
(U.S. Geological Survey station number 395447108192100)

[MG/L=milligrams per liter; UG/L=micrograms per liter]

DATE	TIME	DEPTH TO TOP OF SAMPLE INTER-VAL (FT)	DEPTH TO BOT-TOM OF SAMPLE INTER-VAL (FT)	DIS-SOLVED SILICA (SIO2) (MG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)
OCT 1975										
08...	1605	160	260	26	30	0	50	71	140	230
11...	2030	150	836	16	10	60	10	21	48	250
16...	0015	150	1053	17	10	50	0	17	39	280
18...	0230	160	1207	16	50	50	10	16	36	1000
20...	1115	150	1420	12	20	130	10	15	34	1800
24...	2125	150	1967	12	20	420	0	18	37	2400
28...	0600	150	2382	9.8	0	660	20	45	36	3300

DATE	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	ALKA-LINITY AS CACO3 (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED FLUO-RIDE (F) (MG/L)	BROMIDE (BR) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED ORTHO. PHOS-PHORUS (P) (MG/L)
OCT 1975										
08...	.9	631	0	518	670	11	.3	.1	.00	.01
11...	.5	449	0	368	410	7.3	1.6	.1	.00	.01
16...	.4	491	0	403	400	7.0	1.9	.0	.01	.02
18...	2.0	2400	0	1970	370	72	3.9	.1	.02	.15
20...	2.3	4490	0	3680	340	150	6.0	.3	.00	.26
24...	3.3	4620	286	4270	370	720	5.7	.9	.01	.00
28...	3.8	4930	981	5680	390	960	6.2	1.3	.01	.01

Table 1.--*Chemical analyses of water samples from test hole 01*--Continued
(U.S. Geological Survey station number 395447108192100)

DATE	DIS-SOLVED SOLIDS (SUM OF CONSTI-TUENTS) (MG/L)	HARD-NESS (CA,MG) (MG/L)	NON-CAR-BONATE HARD-NESS (MG/L)	SODIUM AD-SORP-TION RATIO	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	TEMPER-ATURE (DEG C)	DIS-SOLVED ARSENIC (AS) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
OCT 1975										
08...	1470	770	250	3.6	1900	8.4	13.5	1	0	170
11...	990	250	0	7.2	1300	8.3	19.0	6	0	230
16...	1010	210	0	8.6	1380	8.1	18.0	4	0	290
18...	2700	190	0	32	3500	8.1	20.0	3	300	630
20...	4580	180	0	59	5900	8.3	20.0	6	400	890
24...	6140	200	0	74	9000	8.4	20.0	20	500	1300
28...	8170	260	0	89	11800	8.1	20.5	13	600	1600

DATE	DIS-SOLVED CAD-MIUM (CD) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	DIS-SOLVED LITHIUM (LI) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED STRON-TIUM (SR) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
OCT 1975									
08...	2	8	0	130	.0	3	0	12000	10
11...	0	0	0	110	.0	2	0	3300	10
16...	0	0	3	100	.0	1	0	2500	10
18...	0	0	2	170	.0	2	0	2500	30
20...	0	0	2	250	.0	5	0	2200	7
24...	2	0	8	250	.0	66	0	2500	10
28...	0	0	4	270	.0	50	0	2300	10

Table 2.--*Chemical analyses of water samples from test hole 01A*

(U.S. Geological Survey station number 395600108184600)

[MG/L=milligrams per liter; UG/L=micrograms per liter]

DATE	TIME	DEPTH TO TOP OF SAMPLE INTER-VAL (FT)	DEPTH TO BOT-TOM OF SAMPLE INTER-VAL (FT)	DIS-SOLVED SILICA (SIO2) (MG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)
NOV 1975										
06...	1720	188	501	33	20	10	6	20	34	230
07...	0410	188	830	16	0	0	170	55	95	230
12...	1445	188	1313	12	20	10	20	14	19	340
13...	1440	188	1429	12	20	20	10	12	19	430
18...	1230	188	2175	15	30	0	20	9.3	15	820
22...	1900	188	2547	10	20	70	5	8.5	12	2400
APR 1976										
04...	1420	--	--	--	--	--	--	--	--	--

DATE	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	ALKA-LINITY AS CACO3 (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED FLUO-RIDE (F) (MG/L)	BROMIDE (BR) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED ORTHO. PHOS-PHORUS (P) (MG/L)
NOV 1975										
06...	.6	487	0	399	300	9.3	.4	.1	.03	.03
07...	1.0	700	0	574	420	6.5	4.2	.0	.11	.01
12...	.7	780	0	640	170	11	7.6	.1	.08	.02
13...	.6	1020	0	837	170	21	1.0	.1	.03	.04
18...	.7	1150	0	943	140	570	1.0	.9	.18	.06
22...	1.2	1950	0	1600	110	2500	8.9	4.0	.08	.04
APR 1976										
04...	--	--	--	--	540	48	1.5	--	--	--

Table 2.--*Chemical analyses of water samples from test hole 01A*--Continued
(U.S. Geological Survey station number 395600108184600)

DATE	DIS-SOLVED SOLIDS (SUM OF CONSTI-TUENTS) (MG/L)	HARD-NESS (CA,MG) (MG/L)	NON-CAR-BONATE HARD-NESS (MG/L)	SODIUM AD-SORP-TION RATIO	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	TEMPER-ATURE (DEG C)	DIS-SOLVED ARSENIC (AS) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
NOV 1975										
06...	868	190	0	7.3	2100	8.4	13.0	2	100	200
07...	1190	540	0	4.4	1280	8.0	15.5	3	100	150
12...	962	120	0	14	1400	8.1	18.0	14	200	160
13...	1170	110	0	18	1800	8.2	18.5	14	100	320
18...	2140	87	0	39	4700	8.0	18.0	14	200	400
22...	6020	72	0	124	--	8.1	18.0	17	100	460
APR 1976										
04...	--	--	--	--	1410	7.2	--	--	--	--

DATE	DIS-SOLVED CAD-MIUM (CD) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	DIS-SOLVED LITHIUM (LI) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED STRON-TIUM (SR) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
NOV 1975									
06...	0	0	1	100	.0	8	0	300	8
07...	0	2	0	130	.0	51	0	11000	20
12...	3	1	4	80	.0	20	0	1700	30
13...	0	0	2	100	.0	24	0	1700	0
18...	0	0	1	90	.0	31	1	1200	10
22...	1	1	5	80	.0	15	0	1100	10
APR 1976									
04...	--	--	--	--	--	--	--	--	--

Table 3.--*Chemical analyses of water samples from test hole 02A*

(U.S. Geological Survey station number 395601108184000)

[MG/L=milligrams per liter; UG/L=micrograms per liter]

DATE	TIME	DEPTH TO TOP OF SAMPLE INTER-VAL (FT)	DEPTH TO BOT-TOM OF SAMPLE INTER-VAL (FT)	DIS-SOLVED SILICA (SIO2) (MG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED MAN-GANESE (MN) (UG/L)	DIS-SOLVED CAL-CIUM (CA) (MG/L)	DIS-SOLVED MAG-NE-SIUM (MG) (MG/L)	DIS-SOLVED SODIUM (NA) (MG/L)
DEC 1975 19...	0745	190	975	17	20	0	20	27	42	270
JAN 1976 08...	1715	844	1451	8.6	40	250	20	5.8	6.9	410

DATE	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	ALKA-LINITY AS CACO3 (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED FLUO-RIDE (F) (MG/L)	BROMIDE (BR) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED ORTHO. PHOS-PHORUS (P) (MG/L)
DEC 1975 19...	1.6	550	30	501	310	12	4.8	.1	.06	.30
JAN 1976 08...	2.5	991	0	813	110	13	10	.1	.07	1.5

Table 3.--*Chemical analyses of water samples from test hole 02A*--Continued

(U.S. Geological Survey station number 395601108184000)

DATE	DIS-SOLVED SOLIDS (SUM OF CONSTI-TUENTS) (MG/L)	HARD-NESS (CA,MG) (MG/L)	NON-CAR-BONATE HARD-NESS (MG/L)	SODIUM AD-SORP-TION RATIO	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH (UNITS)	TEMPER-ATURE (DEG C)	DIS-SOLVED ARSENIC (AS) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
DEC 1975										
19...	991	240	0	7.6	1200	7.8	15.0	14	200	200
JAN 1976										
08...	1060	44	0	27	1600	8.3	15.0	9	100	290

DATE	DIS-SOLVED CAD-MIUM (CD) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	DIS-SOLVED LITHIUM (LI) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	DIS-SOLVED MOLYB-DENUM (MO) (UG/L)	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED STRON-TIUM (SR) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)
DEC 1975									
19...	0	0	1	90	1.0	41	0	3500	10
JAN 1976									
08...	0	0	1	10	.0	11	0	510	20

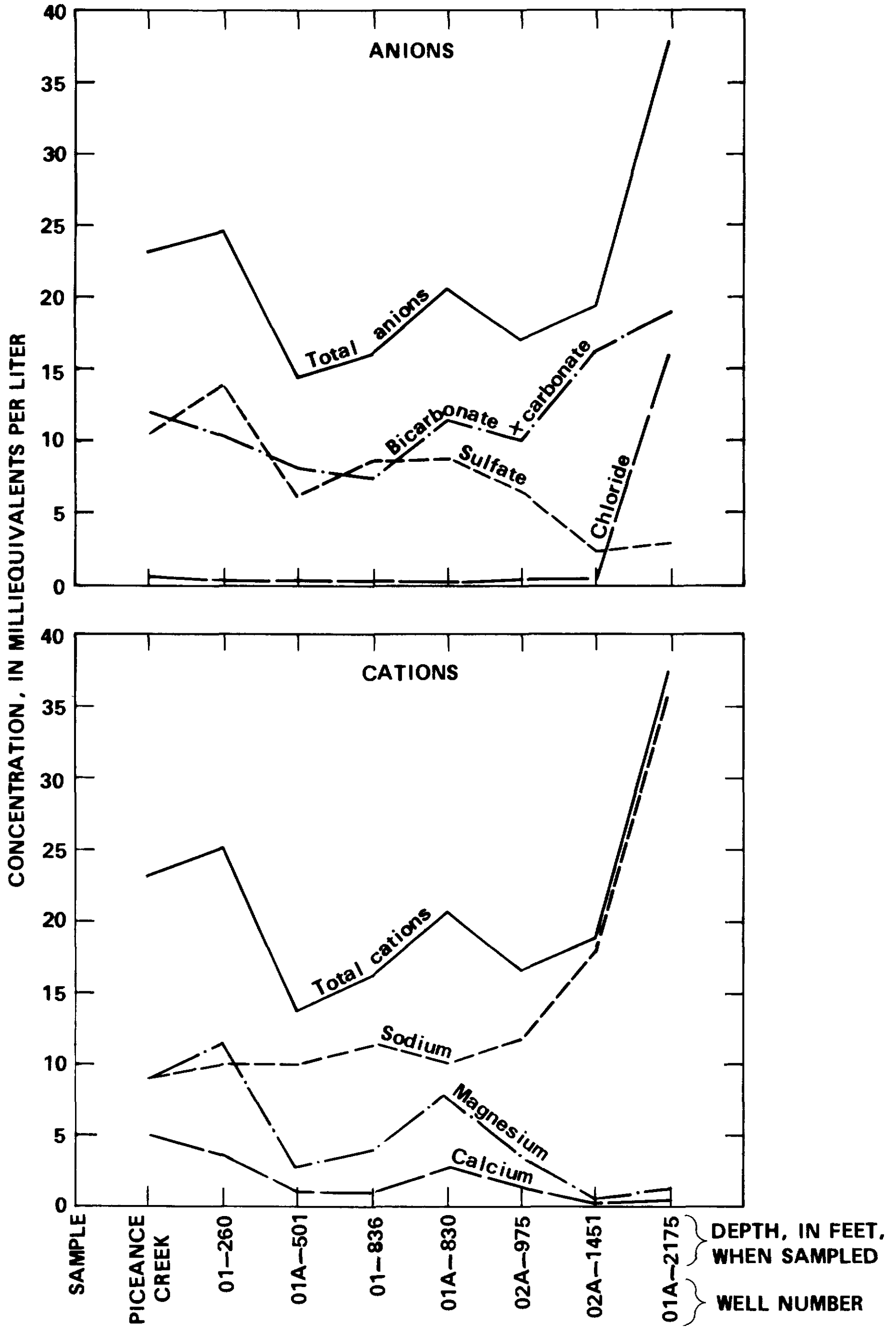

Figure 14.--Principal dissolved constituents in the ground water and water from Piceance Creek during low flow.

during the test of the lower aquifer, shows that the sampled water is similar in quality to samples from the upper aquifer. Probably, the sample reflects the condition that most of the water that was discharged during the test originated in the upper part of the lower aquifer. If so, the upper part of the lower aquifer may be more permeable than the lower part.

In the oil-shale zone, the rocks are virtually impermeable, and the small amount of water that may exist in this zone must be highly saline and in chemical equilibrium with the soluble minerals. The specific conductance of the water discharged during the drilling of the oil-shale zone depends on the rate of drilling and the amount of soluble minerals available for dissolution. Note that test hole 01A shows very little change in specific conductance with depth, whereas test hole 01 shows a large increase in specific conductance in the oil-shale zone (fig. 13). The difference in specific conductance with depth probably is related to the rate of drilling of the two test holes. During the drilling of the oil-shale zone in hole 02A, the driller reported that water was added to the hole at about the same rate as it was being discharged. Therefore, no ground water was being discharged, and the permeability of the oil-shale zone must be small.

ESTIMATED GROUND-WATER PUMPAGE REQUIRED TO DEWATER THE SHAFT

A large amount of ground water may have to be pumped during the sinking of the shaft in order to keep the working area dry. The shaft will be constructed through the two aquifers. During construction, the water levels in the shaft will be lowered by pumping. By the time the oil-shale zone is reached, the water level in the shaft will have been drawn down 1,300 ft from the initial water level that existed prior to start of construction. This large drawdown in the shaft will cause the water to flow into the shaft at a rapid rate.

The dewatering of the shaft will be a problem only during the construction phase. The completed shaft will probably be lined with reinforced concrete that is strong enough to withstand the 1,300-ft head at the bottom of the shaft.

The water flow into the shaft will increase with the depth of the shaft in a manner similar to the increase in discharge rates (pumping) during the drilling of the test holes. The discharge rates measured during the drilling of test holes 01 and 01A are shown in figure 15. The first 100 ft of material below land surface is unsaturated, and a hypothetical shaft will be dry to a depth of 100 ft. After the saturated zone is reached, ground water will start to flow into the shaft. As the shaft is deepened and the incoming water is pumped out, the aquifer's hydraulic gradient and pumping cone around the shaft will increase; this causes an increase in the flow of water into the shaft. Based on the discharge rates during the drilling of the test holes (fig. 15), the depth interval between 100 and 300 ft will produce only a small amount of inflow. At a depth of 300 ft, the rate of inflow will increase, and the maximum rate of inflow will occur near the base of the lower aquifer.

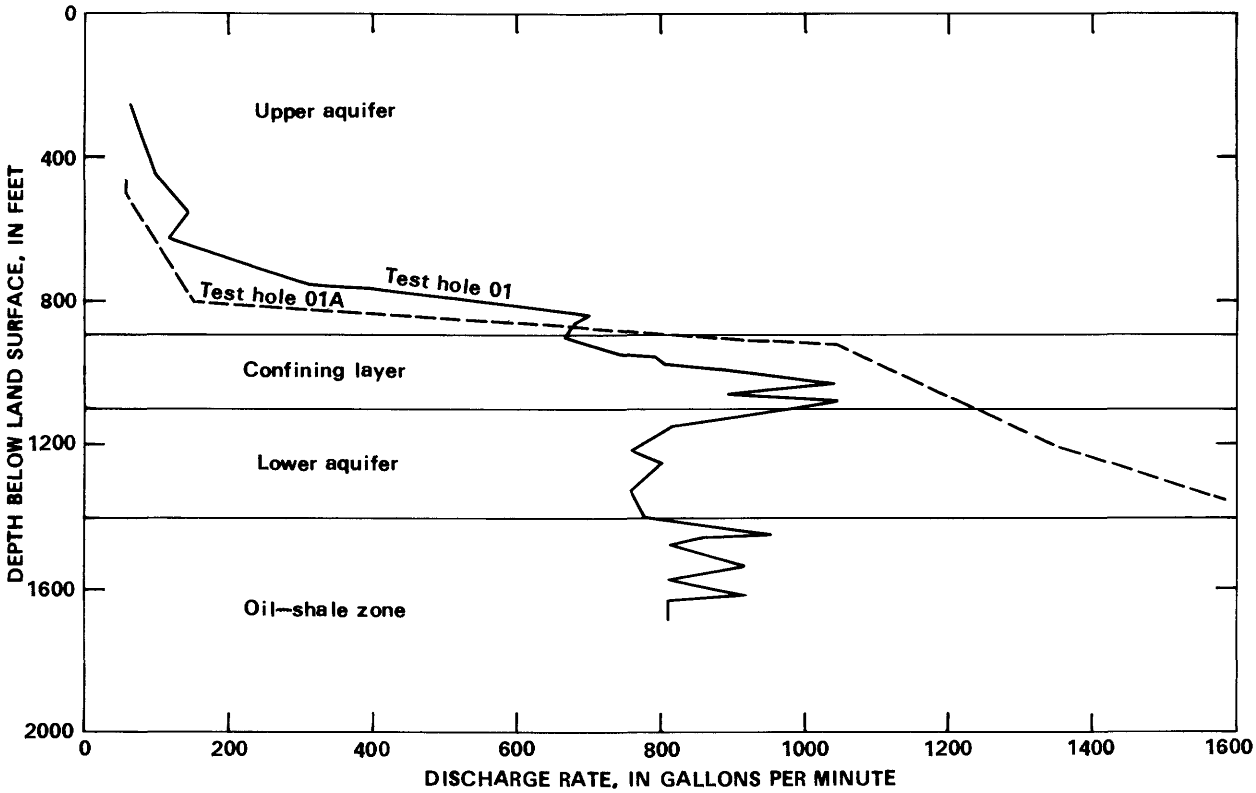

Figure 15.--Ground–water discharge rate during the drilling of test holes 01 and 01A.

Simulation of Shaft Dewatering

A digital model of the ground-water system (Weeks and others, 1974) was used to estimate the discharge that would be produced during the construction of a vertical shaft, 20 ft in diameter, at the Horse Draw site. The shaft would penetrate the upper and lower aquifers and terminate in the oil-shale zone (fig. 3). The model analysis assumed that the shaft was deepened at the rate of 20 ft/d and that water was pumped from the shaft at a rate sufficient to dewater the shaft.

All of the parameters used in the model were the same as those used in the previous modeling report (Weeks and others, 1974), with the exception of the transmissivity values used at the shaft site. For this simulation, the values of transmissivity used at the shaft site were 2,600 ft^2/d for the upper aquifer and 210 ft^2/d for the lower aquifer. The boundary conditions, transmissivity and leakance values, storage coefficients, recharge rates, and initial heads used in the digital model are discussed by Weeks, Leavesley, Welder, and Saulnier (1974).

The shaft was simulated by a single node in each layer of the digital model. The hydraulic head at the node representing the shaft in the upper aquifer was made to decline at the rate of 20 ft/d until the head declined to the top of the Mahogany zone (fig. 3), after which a constant head was maintained in the upper aquifer equal to the altitude of the top of the Mahogany zone. When the simulated shaft penetrated the bottom of the Mahogany zone, the head in the lower aquifer was drawn down to the bottom of the Mahogany zone and made to decline at the rate of 20 ft/d until the shaft reached the oil-shale zone.

The flow rate into the shaft was calculated by applying Darcy's law between the nodes representing the shaft and adjacent nodes in the model. No attempt was made to simulate grouting or other methods of preventing or retarding water inflow to the shaft during construction. Consequently, the flow rates computed by the model represent conditions of unretarded flow into the shaft.

The node spacing used in the model represents 1 mi between nodes. This results in larger flow rates to the shaft than would result using a smaller grid spacing. Thus, the magnitude of the computed discharge is larger than that expected for a shaft 20 ft in diameter and must be corrected.

To determine the effects of node spacing on the computed discharge rate, dewatering in the upper aquifer was tested, using two different one-dimensional radial-flow models. The first model had a node spacing of 20 ft, and the second model had a node spacing of 1 mi. The ratio of the discharge from the first model to the discharge from the second model ranged between 0.20 and 0.27, and averaged 0.24. Based on this modeling experiment, it was assumed that the discharge into the 20-ft diameter shaft will be 0.24 times the discharge computed by the model of the Piceance basin, which has 1-mi node spacing. There is some error introduced by comparing the results of the radial-flow model to the rectangular-grid model, but for all practical purposes the error introduced is small. The error would be of the order of magnitude of the difference of pumpage from a square shaft 20 ft on a side as compared to a 20-ft diameter well.

The computed discharge rates, adjusted for node spacing, are given in table 4. The discharge rate increases with depth to a maximum of 3,080 gal/min when the entire saturated section has been penetrated by the shaft. Based on the computed discharge rates, a total of 350 acre-ft may need to be pumped during construction of the shaft.

Table 4.--*Computed discharge rate for selected depths*

Depth (feet)	Discharge rate (gallons per minute)	Horizon
320	375	----------------------
900	1,370	Base of upper aquifer.
1,100	2,500	Top of lower aquifer.
1,400	3,080	Base of lower aquifer.

The simulated time required to construct and dewater the shaft was 70 days. During this time, the cone of depression caused by dewatering extended to a radial distance of more than 5 mi from the shaft. The drawdown (change in hydraulic head) in the aquifers is shown in figure 16; there is less than 1 ft of drawdown beyond 5 mi in the upper aquifer and 6 mi in the lower aquifer.

Quality of the Pumped Ground Water

The ground water pumped during the drilling of the shaft will be virtually the same quality as that collected during the test drilling (tables 1, 2, and 3), because most of the water will come from the immediate vicinity of the shaft. Although the drawdown extends for a radial distance of more than 5 mi from the shaft (fig. 16), most of the volume of water that will be pumped is within a radial distance of less than 500 ft from the shaft. It is unlikely that there will be appreciable water-quality changes within that distance.

Water will be originating principally from within the upper aquifer during the construction of the shaft to the base of the confining layer. During this period of construction, 170 acre-ft of water will be discharged that will have a similar chemical quality to the water from Piceance Creek at low flow (fig. 14), which contains less than 1,500 mg/L dissolved solids.

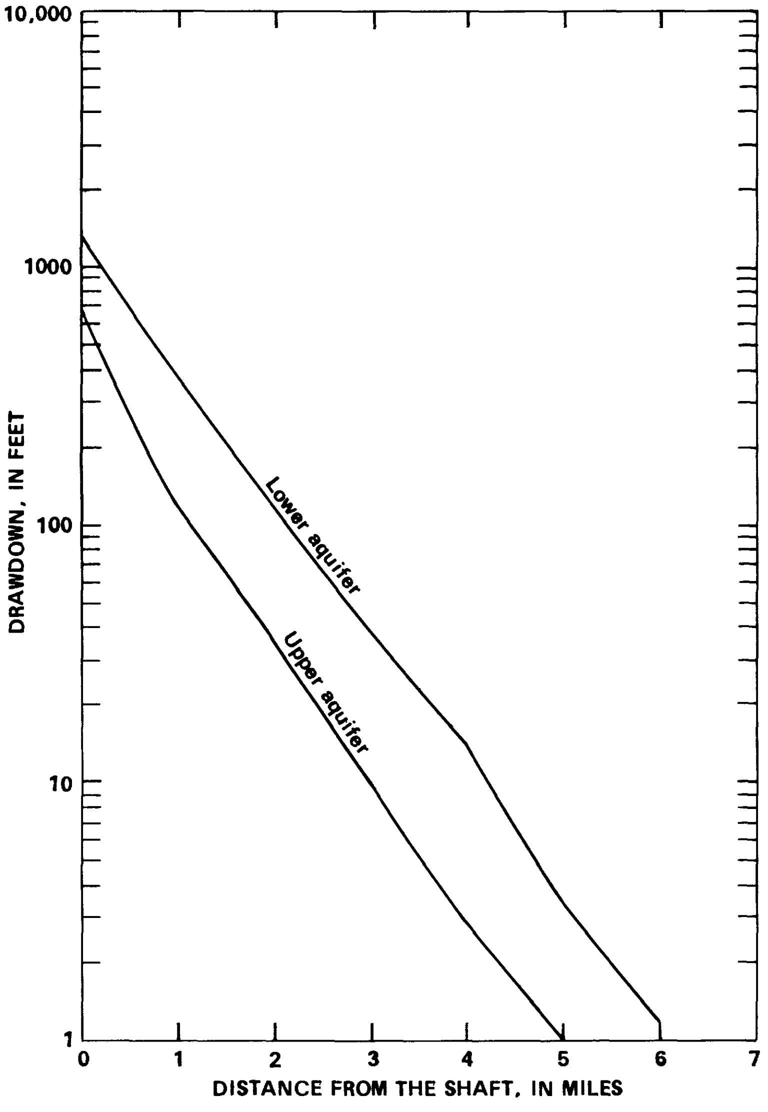

Figure 16.--Simulated drawdown after 70 days of dewatering.

Once the lower aquifer is penetrated, about 60 percent of the flow will be coming from the lower aquifer and an additional 180 acre-ft of water will be pumped during the normal course of construction. Near the top of the lower aquifer, the quality of the water is similar to that in the upper aquifer. However, the water becomes saline with depth. Based on the specific-conductance data presented in figure 13, the concentration of dissolved solids in the discharge from the shaft will be less than 4,000 mg/L at a depth of about 1,400 ft. When the shaft penetrates the oil-shale zone, saline minerals will be dissolved, and the concentration of dissolved solids in the water discharged probably will increase greatly.

OTHER HYDROLOGIC CONSIDERATIONS

Control of runoff from facility and waste-disposal sites and disposal of waste water from the shaft are important considerations in the development of the facility. Erosion, sedimentation, and chemical-quality degradation are all surface-water problems to be anticipated with the construction. Erosion and sedimentation can be minimized with proper control structures and development practices. Chemical-quality degradation of surface waters can be minimized by treatment to improve the quality of discharge to surface streams or by discharging to storage ponds, where the water could be evaporated. These considerations have been discussed in the site-selection report (Ege and others, 1978).

SUMMARY

Three test holes were drilled near the U.S. Bureau of Mines' underground oil-shale research-facility site. These holes penetrated an upper aquifer, a confining layer, a lower aquifer, and the oil-shale zone.

Aquifer tests were made on the two aquifers. The transmissivity of the upper aquifer was determined to be 2,600 ft^2/d, and the transmissivity of the lower aquifer was 210 ft^2/d. The storage coefficient of the upper aquifer was determined to be 2.5×10^{-3}.

The water pumped from the upper aquifer and the upper part of the lower aquifer contained less than 1,500 mg/L dissolved solids. This is about the same concentration as the water in Piceance Creek adjacent to the site during low flow. At the base of the lower aquifer, the salinity of the water increases because of the availability of soluble minerals.

The digital ground-water model of the Piceance basin (Weeks and others, 1974) was used to simulate potential ground-water discharge that would occur during the construction of a 20-ft diameter shaft to the oil-shale zone. If no attempt were made to prevent the inflow of water to the shaft, it was estimated that a pumping rate of as much as 3,080 gal/min would be required to dewater the shaft. The total amount of water that would have to be pumped from the shaft during construction is about 350 acre-ft.

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