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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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Federal Center, Lakewood, Colorado 80225

HYDRAULIC TESTING AND SAMPLING OF
HOLES RB-E-01 AND RB-D-01, PROJECT RIO BLANCO,
RIO BLANCO COUNTY, COLORADO

(Rio Blanco-1)
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HYDRAULIC TESTING AND SAMPLING OF
HOLES RB-E-01 AND RB-D-01, PROJECT RIO BLANCO,
RIO BLANCO COUNTY, COLORADO

By

J. E. Weir, Jr.

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ABSTRACT

At the request of the U.S. Atomic Energy Commission, the U.S. Geological Survey monitored the discharge of water during drilling of two holes (RB-E-01 and RB-D-01) at the Rio Blanco site in western Colorado. Recovery of water level was measured following periods of water withdrawal from hole RB-D-01.

Two intervals of hole RB-D-01 were tested. Zone 1, from 245 to 845 feet below land surface, has a transmissivity of about 4,600 gallons per day per foot and a static water level of 59.90 feet below land surface. Zone 2, from 882 to 1,651 feet below land surface, has a transmissivity of about 200 gallons per day per foot and a static water level of 39.63 feet below land surface. There is potential at hole RB-D-01 for flow of water upward from zone 2 to zone 1; however, differences in quality of water in the two zones indicate that water probably does not circulate freely between the zones.

INTRODUCTION

The U.S. Geological Survey, at the request of the U.S. Atomic Energy Commission, and in collaboration with CER Geonuclear Corp., monitored the discharge of water during drilling of two holes (RB-E-01 and RB-D-01) at the Rio Blanco site in western Colorado. The Rio Blanco site is in the northwestern part of sec. 14, T. 3 S., R. 98 W., 6th prime meridian (fig. 1). The holes considered in this

Figure 1.-- Location of Rio Blanco site and generalized potentiometric contours for part of Piceance Creek basin, Colorado.

report are on the west side of Fawn Creek at the mouth of a small side canyon. Data and interpretations are presented from tests in part of hole RB-E-01, the emplacement hole, and in hole RB-D-01, the documentation hole, which is about 108 feet north of hole RB-E-01. In addition, recovery of water level was measured following periods of water withdrawal from hole RB-D-01.

The objectives of testing and sampling holes RB-E-01 and RB-D-01 were to: (1) determine the vertical distribution of static heads, (2) collect samples of water for chemical and radiochemical analysis, and (3) determine the transmissivities of the rocks in selected intervals of the boreholes. These objectives were designed to provide some information which could be used in an evaluation of the groundwater system in the vicinity of the Rio Blanco site, and provide background water-quality data.

Regional Geologic Setting

The site of Project Rio Blanco is in the Piceance Creek basin, an elongated structural downwarp trending northwest-southeast. Folding was contemporaneous with lake deposition during Eocene time and continued after the lake had disappeared.

The Wasatch Formation of Eocene(?) age underlies the Green River Formation of Eocene age. The basal units of the Wasatch contain gas, are not water saturated based on geophysical logs, and have low permeability. The Mesaverde Formation of Cretaceous age underlies and is similar to the Wasatch Formation. The lower Wasatch is coarsely clastic, in part, and probably is correlative with a part of the Fort Union Formation (Donnell, 1961, p. 844).

General lithology of the lower part (about 2,000 feet) of the Green River Formation consists of marlstone and shale with a few beds of sandstone. These rocks contain some organic debris and hydrocarbons, including gas, and some evaporite minerals, predominantly in the central parts of the basin. The upper part (about 1,000 feet) of the Green River Formation consists of the Evacuation Creek Member and Parachute Creek Member, and is mainly clastic with some marlstone (Donnell, 1961, p. 847-857).

Alluvium occurs near the Rio Blanco site in the stream valleys and consists of sand, gravel, and clay eroded mainly from the Green River Formation.

General Water-Yielding Characteristics

According to Coffin, Welder, and Glanzman (1971), there are three principal aquifers in the Piceance Creek basin: 1) Parachute Creek Member of the Green River Formation, 2) Evacuation Creek Member of the Green River Formation, and 3) alluvium. Rocks underlying these aquifers probably have low permeability; some contain natural gas and probably are not water saturated.

The Parachute Creek Member includes a high resistivity zone (Coffin, Welder, and Glanzman, 1971) and the Mahogany ledge zone, both of which have low permeability. The Parachute Creek also has a leached zone at some places which contains water under artesian pressure. The transmissivity of the leached zone is reported to be as much as 20,000 gpd per ft (gallons per day per foot) in the center of the basin, and estimated yields are reported to be as much as 1,000 gpm (gallons per minute).

Water in the Evacuation Creek Member is reported (Coffin, Welder, and Glanzman, 1971) to move through fractures in beds of sandstone. This unit may yield as much as 100 gpm to tested wells.

Alluvium, although of small areal extent, has the highest transmissivity of all rocks in the basin. According to Coffin, Welder, and Glanzman (1971), transmissivity of the alluvium ranges from 20,000 to 150,000 gpd per ft, and reported yields are as much as 1,500 gpm.

HISTORY OF DRILLING IN SEPTEMBER AND OCTOBER, 1971

Testing and preliminary evaluation of hydraulic characteristics of rocks during the drilling of holes RB-E-01 and RB-D-01 were done by techniques suited to air drilling. Discharge of water during air drilling was measured with Parshall flumes, and heads were measured with surface-recording downhole pressure gages, steel tapes, or other measuring devices.

Hole RB-E-01

Hole RB-E-01, begun on September 28, 1971, penetrated about 105 feet of alluvium, 290 feet of the Evacuation Creek Member, and 450 feet of the Parachute Creek Member. The hole was drilled using air-mist as the circulating fluid to a depth of 65 feet, after which 7 $\frac{5}{8}$ -inch casing was installed to that depth and the annulus filled with cement. Little hydraulic data were collected during drilling of this part of the hole. Although air-mist was used for the circulating fluid, the material drilled formed a slurry and reliable data could not be obtained. Loss of water from the hole prior to cementing of casing indicates that the zone of aeration and possibly the upper 20 feet of the saturated alluvium are at least moderately permeable.

Drilling was resumed with a $6\frac{3}{4}$ -inch-diameter bit. Water was evident in the air returns when a depth of 67 feet (just below the casing shoe) was reached. Discharge of water was estimated to be 5 gpm during drilling of the interval from 67 to 76 feet. The discharge increased to 30 gpm during the drilling from 76 to 86 feet.

The original plans were to drill the upper 845 feet of RB-E-01 with air so that hydraulic data could be obtained, but problems developed at a depth of 86 feet. An attempt to jet water from the hole was unsuccessful and a decision was made to drill the remainder of the hole with mud as the circulating fluid. A static water level of 46.58 feet below land surface was measured prior to adding the mud. After the mud was mixed, the $7\frac{5}{8}$ -inch casing was washed over and removed so the diameter of the hole could be increased. Indirect data from loss of mud are the only other data obtained from the upper part of hole RB-E-01. At a depth of 669 feet, circulation was lost temporarily while drilling a $14\frac{3}{4}$ -inch hole and 100 barrels (42 gallons per barrel) of drilling fluid disappeared into the formation. The interval accepting this mud was not known. While the hole was being reamed to a diameter of 22 inches at a depth of 268 feet, 200 barrels of mud were lost; and at a depth of 576 feet, an additional 30 barrels of mud were lost. The hole was later deepened from 845 to 7,864 feet in preparation for its use as an emplacement hole.

Geophysical logs made in the 22-inch hole consisted of sidewall neutron porosity and compensated formation density logs, both of which were run with accompanying gamma-ray and caliper logs. The logs are not exceptionally good because the hole diameter was larger than the rated maximum for the logging tools used. They do, however, partially correlate with logs made in hole RB-D-01.

Hole RB-D-01

Drilling of hole RB-D-01 was started October 14, 1971, using mud as the circulating fluid to a depth of 244 feet. Drilling was interrupted at this depth and $7\frac{5}{8}$ -inch casing was installed and cemented (fig. 2). The remainder of the hole was drilled using a $6\frac{3}{4}$ -inch-diameter bit and air-mist as the circulating fluid. The yield (fig. 3), conductivity, and temperature of water were monitored continuously during this stage of drilling (table 1). Water samples were collected and depths to water were measured periodically.

Hole RB-D-01 was drilled through rock similar to that penetrated by the upper part of hole RB-E-01. The tops of marker beds, identified from geophysical logs, apparently were 5 to 10 feet lower than the same beds in hole RB-E-01. Hole RB-D-01 was drilled to a total depth of 1,651 feet, penetrating 1,256 feet of the Parachute Creek Member. The hole was bottomed in the Parachute Creek and more than 300 feet beneath the Mahogany ledge zone (fig. 2).

Figure 2.-- Hole RB-D-01 at Rio Blanco site showing construction and stratigraphy.

Figure 3.--Graph of jetted discharge during drilling of hole RB-D-01, Project Rio Blanco, Colorado.

Table 1.--Record of air-jetted discharge and related data from hole RB-D-01

Date	Hour	Depth of hole (feet below land surface)	Dis- charge ^{1/} (gpm)	Temper- ature of water		Field conductance (micromhos per centi- meter at field temperature)	Air-mist injection pressure (psig)	Remarks
				(°C)	(°F)			
10-15-71	1900	256	e8	--	--	--	--	
	1915	286	e30	14.0	57	--	175	
	2000	315	e30	--	--	--	225	
	2100	349	e50	--	--	--	200	
	2200	386	e75	--	--	--	200	
	2300	406	e90	--	--	--	200	
	2400	422	e100	14.0	57	--	200	Discharge pit began to overflow through ditch.
10-16-71	0100	448	92.7	--	--	--	200	
	0200	471	121.8	--	--	--	180	
	0300	495	121.8	--	--	--	180	
	0400	522	207.0	--	--	--	200	
	0500	540	234.0	--	--	--	200	
	0600	547	242.9	--	--	--	200	
	0700	563	292.3	--	--	--	200	
	0800	578	332.7	15.5	60	775	200	
	0900	600	391.0	--	--	--	220	
	1050	634	391.0	16.5	62	975	220	Stage recorder on flume.
	1130	664	449.4	--	--	--	220	
	1234	694	530.2	16.5	62	690	225	
	1347	725	543.6	16.5	62	790	225	Drilling tools dropped at 696 and 715 feet.
	1458	755	557.1	16.5	62	800	260	Drilling tools dropped at 752 feet.

Table 1.--Record of air-jetted discharge and related data from hole RB-D-01--Continued

Date	Hour	Depth of hole (feet below land surface)	Dis-charge ^{1/} (gpm)	Temper-ature of water		Field conductance (micromhos per centi-meter at field temperature)	Air-mist injection pressure (psig)	Remarks
				(°C)	(°F)			
10-16-71 (Continued)	1532	784	615.4	16.5	62	840	260	Very fast drilling.
	1617	815	602.0	--	--	--	260	--
	1655	845	628.9	--	--	--	260	--
	2155	845	644.0	17.0	63	800	--	End of jetting test. Depth to static water level, 59.90 feet below land surface.
10-17-71	0232	877	628.9	--	--	--	300	--
	0312	907	--	--	--	--	325	Board in flume caused washout.
	0524	938	e650	--	--	--	325	Very fast drilling for previous 60 feet.
	0647	968	664.8	--	--	--	325	--
	0746	998	664.8	--	--	--	325	--
	0836	1,028	691.7	--	--	--	325	--
	0922	1,059	691.7	--	--	--	325	--
	1029	1,090	642.4	17.5	64	780	325	--
	1113	1,120	602.0	--	--	--	325	--
	1205	1,151	615.4	--	--	--	325	--
	1420	1,182	615.4	18.5	65	880	325	--
	1530	1,212	615.4	19.0	66	870	325	--
	1705	1,243	628.9	18.0	64	880	325	--
	1843	1,273	602.0	--	--	--	325	--
	1900	1,278	615.4	--	--	--	325	--
	2000	1,287	615.4	--	--	--	325	--
	2100	1,298	642.4	18.0	64	900	325	--

Table 1.--Record of air-jetted discharge and related data from hole RB-D-01--Continued

Date	Hour	Depth of hole (feet below land surface)	Dis-charge ^{1/} (gpm)	Temper-ature of water		Field conductance (micromhos per centi-meter at field temperature)	Air-mist injection pressure (psig)	Remarks
				(°C)	(°F)			
10-17-71 (Continued)	2200	1,303	642.4	18.0	64	910	325	--
	2300	1,305	655.8	--	--	--	325	--
	2400	1,309	615.4	--	--	--	325	--
10-18-71	0600	1,320	664.8	--	--	--	330	--
	0700	1,342	642.4	--	--	--	330	--
	0800	1,362	691.7	18.5	65	1,050	350	--
	1016	1,399	678.3	--	--	--	425	Abrupt air-pressure increase at 1,379 feet and very fast drilling for 7-foot interval.
	1130	1,421	--	21.0	70	2,150	400	
	1141	1,430	664.8	21.0	70	1,950	400	
	1310	1,451	--	21.0	70	1,920	425	--
	1329	1,460	691.7	--	--	--	--	Depth to water 64.1 feet below land surface after ½-hour shutdown.
	1536	1,491	678.3	21.0	70	1,900	475	
	1723	1,522	655.8	--	--	--	400	
	1919	1,552	664.8	21.0	70	1,700	425	
	2257	1,583	664.8	20.0	68	1,800	400	
10-19-71	0309	1,614	655.8	21.0	70	1,850	400	--
	0656	1,645	655.8	20.5	69	1,900	400	--
	0900	1,651	664.8	20.0	68	1,700	400	--

Table 1.--Record of air-jetted discharge and related data from hole RB-D-01--Continued

Date	Hour	Depth of hole (feet below land surface)	Dis-charge ^{1/} (gpm)	Temperature of water		Field conductance (micromhos per centimeter at field temperature)	Air-mist injection pressure (psig)	Remarks
				°C	°F			
10-19-71 (Continued)	1700	1,651	--	--	--	--	--	Depth to water 63.44 feet below land surface after injecting 400 barrels of mud without obtaining circulation.
10-23-71	0800	1,651	--	--	--	--	--	Depth to water 52.13 feet below land surface just prior to jetting test of zone 2.
	1540	1,651	114.4	25.0	77	4,000	--	Near end of jetting test of zone 2.
11-19-71	1300	1,651	--	--	--	--	--	Depth to water 43.20 feet below land surface ^{2/} .

e Estimated.

^{1/} As determined from 6-inch Parshall flume in overflow ditch between discharge pit and reserve pit, unless estimated. Visual average from recorder chart or as observed hourly; corrected for quantities of injected detergent solution.

^{2/} Additional water-level observations after completion of hole: 12-19-71, 1225 hours, 40.70 feet below land surface; 1-22-72, 1415 hours, 39.93 feet below land surface; 1-31-72, 1300 hours, 39.60 feet below land surface; 2-11-72, 1540 hours, 39.63 feet below land surface.

Field measurements of the conductance of water during drilling indicate only minor changes in quality of water jetted from the Green River Formation down to a depth of about 1,400 feet. At this depth, the temperature of discharged fluid increased, and field conductance of discharged fluid more than doubled. When zone 2 was isolated and tested, the field conductance of the water was 4,000 micromhos per cm at the prevailing temperature of 25°C.

Drilling mud was pumped into hole RB-D-01 in preparation for geophysical logging. Following an attempt to circulate mud in the hole before logging, a temperature log (fig. 4) was made to determine at what depths the mud was going into the formation. This log indicated mud was being accepted by several zones in the open hole above a depth of about 1,400 feet. Geophysical logs made included dual induction resistivity with laterolog, sidewall neutron porosity, borehole compensated sonic, and compensated formation density. The latter three were accompanied by gamma-ray and caliper logs.

HYDRAULIC TESTS IN HOLE RB-D-01

The intervals 245 to 845 feet (zone 1) and 882 to 1,651 feet (zone 2) in hole RB-D-01 were tested separately during drilling by air-lifting water (jetting). In order to isolate zone 2 for testing, a 4½-inch casing equipped with an external packer was installed. The packer was placed in the Mahogany ledge zone (generally a confining layer) and the annulus above the packer was filled with cement. The 4½-inch casing was torch-slotted throughout zone 2.

Figure 4.--Temperature logs and tested zones in hole RB-D-01.

Zone 1 was tested when the hole was 845 feet deep. The discharge rate while testing zone 1 was 644 gpm for a period of 125 minutes. A drawdown of 33 feet was measured with a surface-recording, downhole pressure gage. Recovery measurements are plotted on figure 5. They indicate a transmissivity of about 4,600 gpd per ft. Geophysical logs and discharge data obtained during drilling indicate that about 220 feet of zone 1 yields most of the water. The average hydraulic conductivity of this 220-foot thickness is, therefore, about 21 gpd per square foot (equivalent to a permeability of 1,020 millidarcies).

The discharge rate while testing zone 2 was 114 gpm for a period of 261 minutes (a 10-minute shutdown occurred during the test). Drawdown was 319 feet during the jetting period. Transmissivity is about 200 gpd per ft (fig. 6). Discharge data and geophysical logs indicate that about 110 feet of zone 2 yields most of the water. The hydraulic conductivity of the 110-foot thickness is computed to be about 2 gpd per square foot (permeability of 97.5 millidarcies).

The static water levels measured in hole RB-D-01 were 59.90 feet below land surface in zone 1 and 39.63 feet below land surface in zone 2. The greater head in zone 2 indicates that a potential exists for upward movement of water into zone 1. In hole RB-E-01, the depth to static water level in the alluvium was 46.58 feet, which shows a potential for downward flow into zone 1.

Figure 5.--Water-level recovery test of zone 1, hole RB-D-01, October 16, 1971.

Figure 6.--Water-level recovery test of zone 2, hole RB-D-01, October 23-25, 1971.

Ground-Water Velocity and Direction of Motion

Velocity of ground-water movement in the two zones investigated required estimation of effective porosity (a very difficult parameter to determine for fractured rock) as well as hydraulic gradient. The formula for computing velocity is:

$$V = \frac{KI}{\theta_e}$$

where V = velocity, in feet per day;

K = hydraulic conductivity, in gpd per square foot;

I = hydraulic gradient, in feet per foot;

θ_e = effective porosity, as a decimal.

Coffin, Welder, and Glanzman (1971) indicate an average gradient of 100 feet per mile (0.019 foot per foot) at the Rio Blanco site. Southwest (upgradient) from the site the hydraulic gradient is 133 feet per mile (0.025 foot per foot); northeast (downgradient) from the site the gradient is 80 feet per mile (0.015 foot per foot). Effective porosity is estimated to be 15 percent, or about half the weighted-average total porosity derived from the sidewall neutron porosity log of hole RB-D-01. Velocities calculated using these estimated and measured parameters are:

$$\begin{aligned} V \text{ (zone 1)} &= \frac{21 (0.019)}{0.15 (7.48)} \\ &= 0.36 \text{ ft per day, or 130 ft per year, northeastward;} \\ V \text{ (zone 2)} &= \frac{2 (0.019)}{0.15 (7.48)} \\ &= 0.034 \text{ ft per day, or 12 ft per year, northeastward.} \end{aligned}$$

Using the maximum gradient of 133 feet per mile and the minimum porosity (9 percent), as estimated from logs, the velocity of ground-water movement is:

$$\begin{aligned} V \text{ (zone 1)} &= \frac{21 \text{ (0.025)}}{0.09 \text{ (7.48)}} \\ &= 0.78 \text{ ft per day, or 285 ft per year, northeastward;} \\ V \text{ (zone 2)} &= \frac{2 \text{ (0.025)}}{0.09 \text{ (7.48)}} \\ &= 0.07 \text{ ft per day, or 25 ft per year, northeastward.} \end{aligned}$$

The former velocities are considered more reasonable.

Quality of Water

Three samples of water were obtained from hole RB-D-01. The first sample was taken near the end of a jetting test when the hole was 845 feet deep and was open from 244 to 845 feet. The second sample was taken by jetting water from the hole when it was 1,651 feet deep and was open from 244 to 1,651 feet. The third sample was taken near the end of a jetting test when the hole was 1,651 feet deep and open to the formation through slotted casing from 882 to 1,651 feet.

Results of chemical analysis of the samples of water (table 2) indicate that the water is principally a sodium bicarbonate type, that the fluoride content is high (ranging from 20 to 39 mg/l, which greatly exceeds U.S. Public Health Service recommended standards) (U.S. Public Health Service, 1962, p. 41), and that there is a significant difference in amount of mineralization between water in zone 1 and zone 2. General implications derived from these results

Table 2.--Chemical analyses of water from hole RB-D-01,
Project Rio Blanco, Colorado

(Analyses by U.S. Geological Survey. Constituents in
milligrams per liter unless otherwise noted.)

Constituents	Intervals sampled, in feet below land surface		
	244 to 845 ft; October 16, 1971	244 to 1,651 ft; October 19, 1971	882 to 1,651 ft; October 23, 1971
Silica (SiO ₂)	12	12	14
Aluminum (Al)	<.01	.01	.04
Iron (Fe)	<.01	<.01	<.01
Manganese (Mn)	<.01	<.01	<.01
Calcium (Ca)	3.6	5.2	3.6
Magnesium (Mg)	5.3	5.7	9.1
Strontium (Sr)	.76	.70	.39
Sodium (Na)	250	530	1,200
Potassium (K)	.2	1.1	4.6
Lithium (Li)	.03	.20	.52
Bicarbonate (HCO ₃)	579	1,080	2,300
Carbonate (CO ₃)	8	79	210
Sulfate (SO ₄)	28	74	220
Chloride (Cl)	10	44	120
Fluoride (F)	20	27	39
Nitrate (NO ₃)	.2	.2	.3
Phosphate (PO ₄)	<.01	<.01	<.01
Dissolved solids			
Res. on evap. at 180°C	663	1,320	2,850
Calculated	623	1,310	2,950
Hardness as CaCO ₃			
Total	32	38	47
Non-carbonate	0	0	0
Specific conductance (micromhos per cm at 25°C)	997	2,050	4,130
pH	8.5	9.1	9.2

are 1) that water in these formations is in proximity to a source of fluoride and 2) that water probably does not circulate freely between the two zones in the vicinity of Rio Blanco site.

SUMMARY AND CONCLUSIONS

Moderate permeability was indicated by water yield (as much as 30 gpm) while drilling hole RB-E-01 through the alluvium. Losses of circulation while drilling hole RB-E-01 at depths of 268 feet, 576 feet, and 669 feet indicate that other intervals of rock also have significant permeability.

Comparison of data obtained by testing and sampling two intervals in hole RB-D-01 reveals that 1) the transmissivity of the upper interval (zone 1) is significantly greater than that of the lower interval (zone 2), 2) static head is greatest in the lower interval, next greatest in the alluvium (from hole RB-E-01), and least in the upper tested interval, and 3) water in the lower interval is more highly mineralized than water in the upper interval. The vertical distribution of static head shows a potential for movement of water upward from zone 2 to zone 1 and for movement of water downward from the alluvium to zone 1. Observations of conditions during drilling of hole RB-D-01 indicate that an aquiclude probably lies between zones 1 and 2. The difference in quality of water in the two tested intervals in hole RB-D-01 infers that water probably does not circulate freely between zones 1 and 2 under natural conditions in the vicinity of Rio Blanco site.

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