HYDRAULIC TESTS AND CHEMICAL QUALITY OF WATER AT WELL USW VH-1, CRATER FLAT, NYE COUNTY, NEVADA

By William Thordarson and Lewis Howells

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METRIC CONVERSION FACTORS

For those readers who prefer to use inch-pound units rather than metric (International System) units, conversion factors for the terms used in this report are listed below:

Metric unit	*Multiply by*	*To obtain inch-pound unit*
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
millimeter (mm)	0.03937	inch
liter (L)	0.2642	gallon
liter per second (L/s)	15.86	gallon per minute
meter squared per day (m^2/d)	10.76	foot squared per day
cubic meter (m^3)	1.308	cubic yard
kilogram per square meter (kg/m^2)	0.001422	pound per square inch
degree Celsius (°C)	1.8°C+32	degree Fahrenheit
microgram per liter (μg/L)	[1]1.0	part per billion
milligram per liter (mg/L)	[1]1.0	part per million
picocurie per liter (pCi/L)	0.2642	picocurie per gallon

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

[1]Approximate.

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ABSTRACT

Well USW VH-1 was drilled to obtain information about the geologic structure, volcanic stratigraphy, and hydrology of the upper volcanic deposits of Crater Flat, Nye County, Nevada. The well was drilled to a depth of 762 meters. Analyses of aquifer tests provided transmissivity values that range from 450 to 2,200 meters squared per day for the Topopah Spring Member of the Paintbrush Tuff and the Bullfrog Member of the Crater Flat Tuff, both of Miocene age, below a depth of 278 meters. The water is of the sodium bicarbonate type, which is typical of ground water from tuff in this area.

INTRODUCTION

Background

The U.S. Geological Survey has been conducting investigations in cooperation with the U.S. Department of Energy (Interagency Agreement DE-AI08-78ET44802) as part of the Nevada Nuclear Waste Storage Investigations project. These investigations have included geological, geophysical, and hydrological studies to evaluate the suitability of Yucca Mountain, Nevada (fig. 1), as a potential site for a nuclear-waste repository. To obtain the geologic and hydrologic information needed to evaluate conditions west of the potential repository site, several test wells were drilled in Crater Flat in Nye County, Nevada.

Purpose and Scope

This report summarizes the geohydrologic information obtained from test well USW VH-1, which was drilled to: (1) Obtain hydraulic test data from the Tertiary volcanic rocks, (2) determine the volcanic eruption prior to 1.1 million years before present in Crater Flat, (3) determine the cause of aeromagnetic anomalies east of Red and Black Cones (fig. 1), (4) acquire samples of buried volcanic rocks for laboratory tests; and (5) acquire data about stratigraphy and structure in Crater Flat. Only the first objective is addressed in this report.

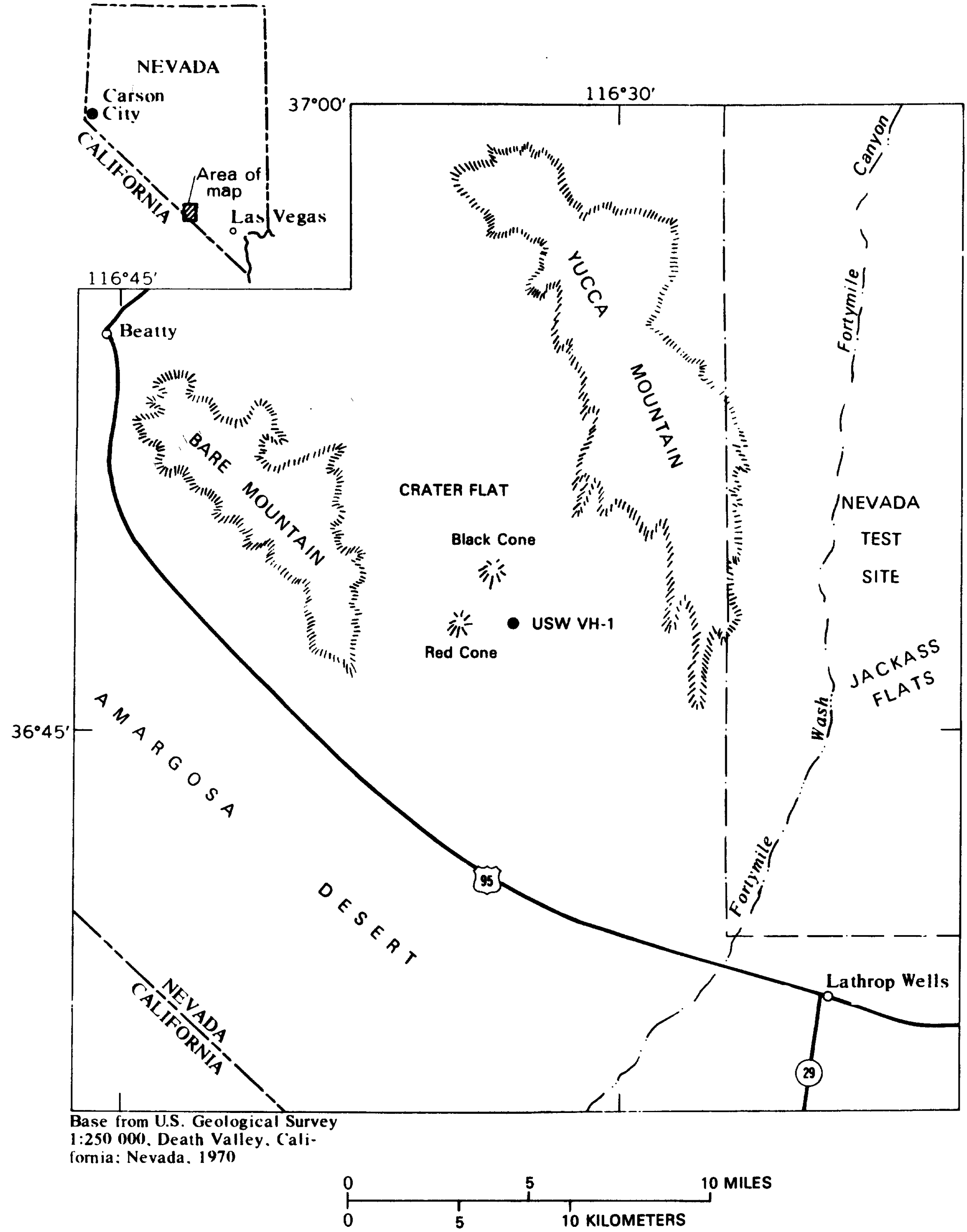

Figure 1.--Location of well USW VH-1 and nearby geographic features in southern Nevada.

Previous Work

Until well USW VH-1 was drilled and tested, the only geohydrologic information available about Crater Flat was based on surface geologic and geophysical maps and regional interpretation of geohydrologic studies of Pahute Mesa (Blankennagel and Weir, 1973) and the south-central Great Basin (Winograd and Thordarson, 1975).

Study Area

Well VH-1 in Crater Flat, southern Nevada, is about 2.3 km (kilometers) east of Red Cone, 2.6 km south-southeast of Black Cone, and about 6 km west of Yucca Mountain (fig. 1). The surveyed coordinates of the location are N. 743,355.81, E. 533, 624.95 (in feet) in the Nevada Central-Zone Coordinate System, and the ground-level elevation[1] at the well is 954.5 m above National Geodetic Vertical Datum of 1929 (NGVD of 1929). Depths in this report refer to ground level as the datum. The well site is 23 km southeast of Beatty (fig. 1).

Drilling Operations

Caving and sloughing of the hole wall of the test well were expected to cause problems during drilling and coring operations, so air foam rather than air or air mist was used as the circulating medium, because air foam gives better support to the wall of the borehole. Caving was an even more severe problem than expected, and a polymer gel was added to the air foam for drilling or coring some intervals.

Well USW VH-1 was drilled from October 28, 1980, to January 16, 1981. A hole 311 mm (millimeters) in diameter was drilled to a depth of 15.8 m, 244-mm casing was set, and the annulus filled with cement to the surface with 3.4 m^3 (cubic meters) of cement slurry (calculated annular volume was 0.42 m^3). Then the hole was drilled to a total depth of 762 m by alternately drilling a 159-mm-diameter hole and cutting 100-mm-diameter cores (the cored sections were reamed to 159-mm diameter). Because of the problems caused by caving of the hole wall during hydrologic tests, the hole was reamed to 222-mm diameter to a depth of 278 m, and a 194-mm-diameter casing was set at 278 m and tack-cemented with 1.4 m^3 of cement slurry. An abridged summary of the well history is presented in table 1.

[1]Altitude, as used in this report, refers to the distance above the N' of 1929.

A summary of the coring is shown below.

Core number	Interval cored (meters)	Interval thickness (meters)	Core recovered (meters)	Core recovered (percent)
1 to 28	33.5 to 89.9	56.4	25.4	45
29 to 170	193.6 to 434.3	240.7	198.0	82
171 to 174	434.7 to 437.4	2.7	1.2	44
175 to 302	438.0 to 762.3	324.3	304.6	94
	Totals	624.1	529.2	85 (average)

Geophysical logs were made at hole depths of 197 and 762 m (table 2). Caving, sloughing, and hole erosion caused problems throughout the drilling but were most severe in the top 275 m of the hole. As shown in the caliper log in figure 2, hole diameter exceeded 0.9 m in at least two intervals (depths of 16 to 18 m and 138 to 142 m). Caving was severe enough during testing to require setting and tack cementing casing to a depth of 278 m so that the hole could be held open during testing (see section "Hydraulic tests").

Hydrogeologic Setting

Geology

Crater Flat is a topographically and structurally complex basin that is partly filled with Tertiary volcanic rocks and alluvium. Major deformation during late Mesozoic and possibly early Tertiary time folded and thrust-faulted the Precambrian and Paleozoic carbonate rocks, siltstone, quartzite, argillite, and shale now exposed on Bare Mountain on the western side of Crater Flat. From middle Oligocene to Pliocene time, a second major episode of deformation accompanied by extensive silicic volcanism resulted in normal block faulting and probable volcanotectonic collapse, and Crater Flat became a greatly depressed block. Preliminary analysis of gravity and magnetometer data (D.B. Snyder and W.J. Carr, U.S. Geological Survey, oral commun., 1981) indicates that Paleozoic rocks may be absent beneath parts of Crater Flat; however, if they are present, Paleozoic rocks are at least 2,600 m below land surface. Remnants of two possible calderas beneath the northern and southern parts of Crater Flat are buried beneath deposits of later volcanic eruptions and alluvium. Volcanic activity in Crater Flat began in middle to late Oligocene time and ended during Pliocene time, except for small basaltic flows which have continued into Quaternary time.

Table 1.--*Summary of well history*

[Abridged from well history prepared by Fenix & Scisson, Inc., Mercury, Nev.; mm, millimeters; m, meters; L, liters; L/s, liters per second]

Date	Activity
1980	
10/27 to 10/29	Moved in drilling rig. Set up rig at site; drilled 311-mm-diameter hole to depth of 15.8 m; set 14.6 m of 244-mm-diameter casing and cemented annulus.
10/30 to 11/2	Cleaned out cement and drilled 159-mm-diameter hole to depth of 33.5 m. Cut core from 33.5 to 89.9 m. Twisted off; fished.[1]
11/2 to 11/6	Reamed hole. Drilled 159-mm-diameter hole to 193.5 m. Cut core from 193.5 to 196.6 m.
11/7 to 11/8	Reamed hole from 193.5 to 196.6 m. Conditioned hole with 9,540 L of high-viscosity bentonite mud. Made geophysical logs.
11/9 to 11/14	Displaced mud with air foam. Cut cores from 196.6 to 247.3 m. Began rig-motor repairs.
11/15 to 11/26	Completed repairs. Cut core from 247.3 to 410.9 m. Began adding polymer gel to drilling fluid.
11/28 to 12/5	Cut core from 410.9 to 434.4 m. Twisted off; fished.[1] Drilled from depths of 434.4 to 434.7 m. Cut core from 434.7 to 437.4 m. Reamed hole from 196.6 to 299.9 m. Twisted off; fished.[1]
12/7 to 12/11	Repaired rig motor. Reamed hole from 299.9 to 437.4 m depth. Drilled from 437.4 to 438.0 m depth. Began rig repairs.
12/12	Completed repairs. Cleaned out hole with high-viscosity mud.
12/13 to 12/24	Completed clean-out. Cut core from 438.0 to 762.3 m depth. Made gyroscopic-multishot survey.
1981	
1/5 to 1/6	Cleaned out hole.
1/7 to 1/13	Reamed hole from 437.4 to 762.3 m depth. Made two attempts to make geophysical logs, but hole had bridged. Made four clean-out trips. Set 114-mm-diameter casing at 304.2 m. Began to make geophysical logs.
1/14 to 1/16	Completed geophysical logs. Lost electric-log probe in bottom of hole. Pulled 114-mm-diameter casing out of hole.
1/17	Set pump and made 2-hour pumping test at discharge of 3.9 L/s; drawdown inadequate for good test. Removed pump.
1/18 to 1/21	Reamed hole to 222-mm diameter from 15.9 to 277.4 m. Cleaned out hole to 757.1 m (top of electric-log tool.)

Table 1.--*Summary of well history*--Continued

Date	Activity
1981--Continued	
1/22 to 1/24	Conditioned hole. Made three attempts to make caliper log, but hole was blocked at 140.5 m. Made two clean-out trips. Set pump (19-L/s capacity) and began test. Pump plugged. Pumping rate ranged from 3 to 15 L/s; removed pump. Made clean-out trip.
1/25 to 2/3	Cleaned out. Twisted off; fished.[1] Hole continued to cave. Made caliper log. Set 194-mm-diameter casing to 277.5 m and tack cemented. Cleaned out hole.
2/4 to 2/12	Set pump and began drawdown and recovery tests at pumping rate of 15.4 L/s. Removed pump.
2/13/2/18	Made clean-out trip. Set 60-mm-diameter tubing to 656.6 m. Rigged down and removed rig from site.

[1]"Twisted off" commonly means a parting of the drilling collars or drill-stem tubing column by torsional shear; "fished" commonly refers to attempts to recover equipment lost in the drill hole.

Table 2.--*Geophysical logs made in well USW VH-1*

Log	Date	Depth below land surface (meters)
Caliper	11-07-80	14.6 to 192.6
--Do	1-13/15-81	265.2 to 755.3
--Do	01-15-81	164.6 to 267.0
--Do	01-16-81	185.9 to 260.6
--Do	01-29-81	6.1 to 251.8
Compensated formation density	11-08-80	0 to 196.6
Borehole-compensated density and neutron	01-15-81	185.3 to 260.3
--Do	01-15-81	304.8 to 747.4
Electric	01-15-81	304.2 to 755.6
--Do	01-16-81	185.9 to 365.8
--Do	01-16-81	185.9 to 257.6
Epithermal-neutron porosity and gamma ray	01-15-81	320.0 to 756.5
--Do	01-16-81	185.9 to 256.0
Gamma ray and neutron	11-07-80	0 to 196.6
--Do	01-15-81	180.8 to 749.2
Gamma ray	01-16-81	185.9 to 257.0
Gyroscopic-multishot survey	12-24-80	0 to 755.9
Induction	11-07-80	14.6 to 196.0
Neutron-neutron and gamma ray	01-15-81	0 to 752.6
--Do	01-16-81	184.7 to 258.2
Nuclear annulus	11-07-81	0 to 196.6
Temperature	11-08-80	0 to 196.3
--Do	01-15-81	304.8 to 749.5
--Do	01-16-81	6.1 to 263.4
3-D velocity	01-15-81	311.5 to 755.6
--Do	01-16-81	179.8 to 257.0
Vibroseis survey	11-07-80	0 to 193.9
--Do	01-16-81	15.2 to 259.1
--Do	01-15-81	0 to 753.8

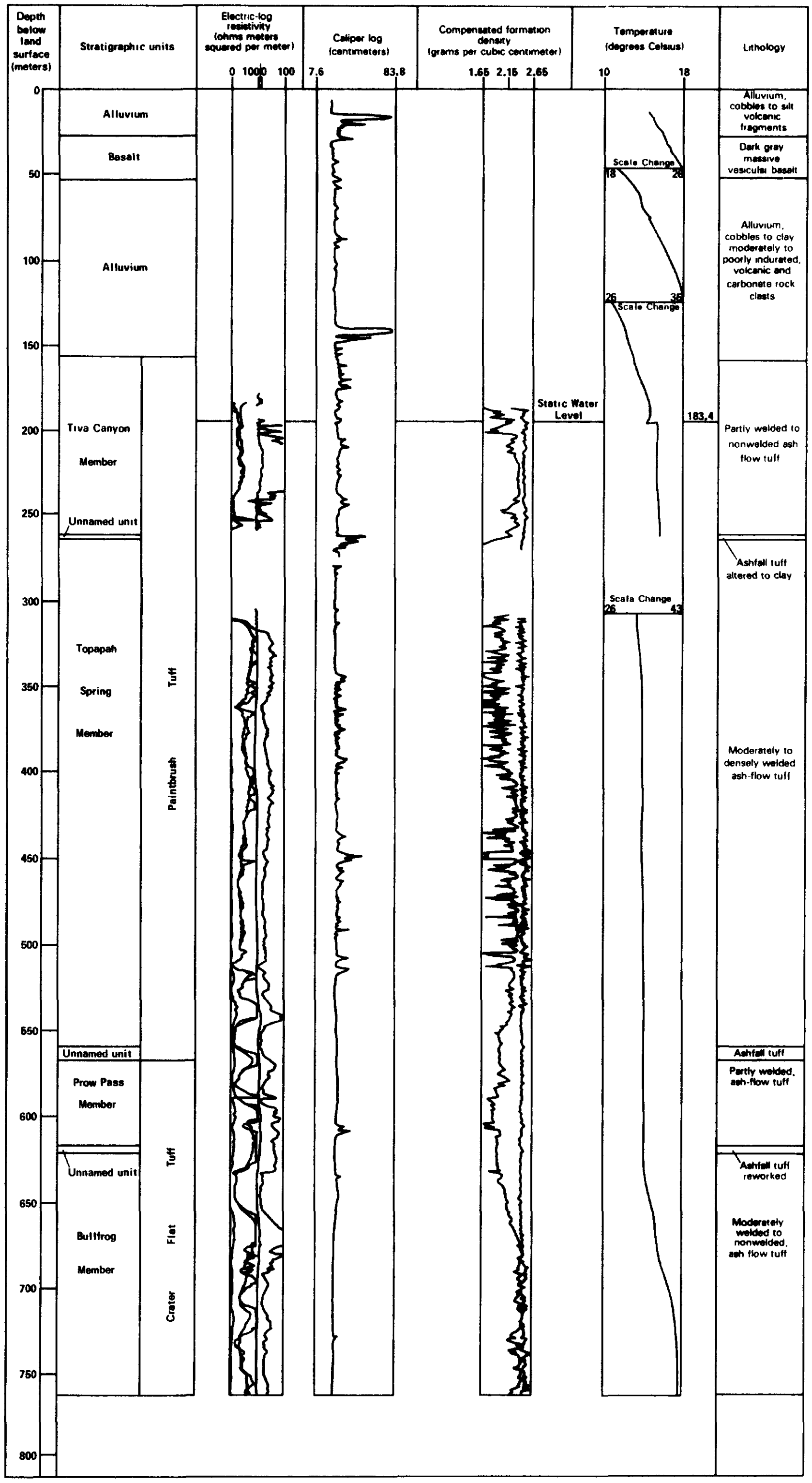

Figure 2.--Selected geophysical logs and general lithology of strata penetrated by well USW VH-1.

Well USW VH-1 was drilled to a total depth of 762.3 m, of which the upper 155.5 m is alluvium that contains a lens of basalt 24.3 m thick; the remaining 606.8 m is volcanic debris that contains a total of 14.7 m of ash-fall tuff and 592.1 m of ash-flow tuff. A summary of the preliminary lithologic log is shown in table 3.

Occurrence of Ground Water

The first indication of water production by well USW VH-1 was during an air-lift test, when the hole was 371 m deep (table 4). Production was 0.008 L/s after 50 minutes and decreased to 0.0008 L/s after 120 minutes. Two hours after completion of the test, the static water level was 181.4 m below land surface. The hole had low productivity to a depth of at least 336 m, as indicated by 14 air-lift tests during drilling from 234.1 to 335.9 m (table 4). After the water-yielding zone at 371 m had been tested by an air-lift test, the static water level was only 181.4 m below land surface and more than 150 m above the top of the uppermost productive zone.

Most of the water pumped came from depth below 626 m, as determined by analyzing the temperature log and the temperature of the discharge at various rates and durations of pumping. From this analysis and from examination of the compensated formation-density (porosity) log, it was tentatively concluded that the major producing zone is the depth interval between 626 and 643 m.

Temperature measurements in the unsaturated zone below a depth of 200 m indicate downward water flow (J. Sass and A. Lachenbruch, U.S. Geological Survey, written commun., 1981).

HYDRAULIC TESTS

Description

A comprehensive program of well testing was planned, but because of adverse borehole conditions, no packer tests or radioactive-tracer surveys could be made. The only tests were six drawdown and recovery tests. After a short initial equipment test, a 4-day drawdown and recovery test was planned; a summary of the testing program follows.

Test 1, the short initial test, was made at a pumping rate of 3.9 L/s. Because the pumping rate was so low, the pump was removed from the well and replaced with a larger-capacity pump. The hole was reamed to 222-mm diameter to a depth of 277.4 m to accommodate the larger pump.

Test 2, made with a pump rated at 19 L/s discharge for the expected pumping lift, was not completed because severe caving of the borehole wall partly blocked the well below the pump and damaged the pump. Following 11 days of hole cleanout and reconditioning, a 194-mm casing was set and tack-cemented to a depth of 277.5 m.

Test 3 lasted 4.17 days (6,000 minutes), had an average discharge of 15.4 L/s (fig. 3), and had a maximum drawdown of 4.41 m (fig. 3). The test was considered acceptable and was used to estimate an aquifer transmissivity.

Table 3.--*Preliminary lithologic and stratigraphic log of well USW VH-1*

[Abridged from W. J. Carr, U.S. Geological Survey, written commun., 1981]

Stratigraphic unit and lithologic description	Depth below land surface (meters)
Alluvium, cobbles to silt, light-brown; fragments of volcanic rocks. Contains some basalt scoria from 22.6 to 28.7 meters.	0 - 28.7
Basalt, dark-gray, massive, fractured. Dark purplish-gray, vesicular from 51.1 to 52.6 meters. Basalt cinders from 52.6 to 53.0 meters.	28.7-53.0
Alluvium, cobbles to clay, light yellowish-brown to light orange-pink, moderately indurated, tuffaceous, clayey; contains angular fragments of tuff and silicic lava with diameters as much as 0.1 meter. Coarser fragments of gray silicic lava and dark-gray dolomite with diameters as much as 0.3 meter from 55.8 to 72.5 meters.	53.0-72.5
Alluvium, gravel to sand, light yellowish-gray, poorly indurated, clayey, abundant calcite. Clasts are tuff and rhyolite, rounded rather than angular. Below 89.9 meters, many of the fragments are of Paleozoic rocks, mostly dolomite; these decrease in abundance downward. A few fragments of a possible ash bed about 155.5 meters.	72.5-155.5
Paintbrush Tuff:	
Tiva Canyon Member	
Tuff, ash-flow, purplish-gray, densely welded, devitrified. Some zones densely fractured but most fractures filled. Moderately welded from 251.2 to 261.5 meters, dark gray to pinkish-orange, matrix locally altered to clay.	155.5-261.5
Unnamed unit	
Tuff, ash-fall, bedded, brown to white, altered to clay.	261.5-264.3
Topopah Spring Member	
Tuff, ash-flow. Nonwelded vapor phase, light gray from 264.3 to 267.9 meters. Moderately to densely welded, purplish-brown, fractured from 267.9 to 270.4 meters. Orange and clayey from 270.4 to 271.0 meters. Densely welded, light purplish-gray, contains large (diameters as much as 0.07 meter) purplish-brown to orange pumice fragments from 271.0 to 497.7 meters. Yellowish-brown, alteration to clay, densely fractured and broken from 497.7 to 499.9 meters. Densely to moderately welded, vitrophyric, light to dark gray and gray-brown, contains pinkish-orange to black pumice, many filled fractures from 499.9 to 525.8 meters. Moderately to slightly welded, grayish-brown, contains pink pumice, black shards, and purple fragments with diameters as much as 0.05 meter from 525.8 to 538.4 meters. Nonwelded, light pinkish-brown to white, contains yellow pumice and abundant purple tuff and lava fragments from 538.4 to 558.7 meters. Base of the Topopah Spring Member is a sharp, irregular contact.	264.3-558.7

Table 3.--*Preliminary lithologic and stratigraphic log of well USW VH-1*--Continued

Stratigraphic unit and lithologic description	Depth below land surface (meters)
<u>Paintbrush Tuff</u>--Continued	
Unnamed unit	
Tuff, ash-fall, very light pinkish- to orange-brown, rather massive. Tight fault dipping about 75° at 560.5 meters. Slickensides indicate right-lateral oblique slip.	558.7-566.9
<u>Crater Flat Tuff</u>:	
Prow Pass Member	
Tuff, ash-flow, nonwelded, vapor phase, light pinkish-gray, zeolitic, and clayey. Slightly welded from 591.3 to 603.5 meters.	566.9-617.2
Unnamed unit	
Tuff, ash-fall, reworked, nonstratified to crudely bedded, pink.	617.2-620.9
Bullfrog Member	
Tuff, ash-flow, nonwelded, light-gray to purplish-brown, becoming densely welded at about 650 meters. A few fractures from 625.8 to 649.3 meters. More abundant fractures from 649.3 to 762.3 meters.	620.9-762.3

Table 4.--*Results of air-lift tests for well USW VH-1*

Date	Depth below land surface (meters)	Remarks
11/13/80	234.1	Dry.
	238.1	Do.
11/14/80	246.0	Do.
11/17/80	252.7	Do.
	254.2	Do.
	257.0	Do.
11/18/80	262.1	Do.
	264.3	Dry; tried air lift for 40 minutes.
	268.5	Air lift for 20 minutes; no water.
11/19/80	282.6	--------------Do------------------
	286.8	Air lift; no water.
11/20/80	299.3	Air lift for 10 minutes; no water.
11/21/80	313.6	Air lift for 40 minutes; no water.
11/22/80	335.9	Air lift with 232,000 kilograms per square meter pressure; no water.
11/24/80	371.0	Air lift for 130 minutes with pipe 9.1 meters above the bottom of the hole. After 50 minutes produced 0.008 L/s, after 120 minutes produced 0.0008 L/s. Static water level measured 181.4 meters below land surface.
11/28/80	410.9	Static water level measured 182.9 meters below land surface.
12/03/80	437.4	Air lift produced estimated 3.9 to 4.3 L/s.
12/07/80	437.4	Static water level measured 183.3 meters below land surface.
01/07/81	762.3 (Total depth)	Air lift during hole cleanout. After 4 hours production estimated (weir in mud pit) as 9.2 L/s; after 25 hours, 13.9 L/s.
01/10/81	762.3 (Total depth)	Air lift during hole cleanout. Produced an estimated 19.6 L/s.
01/17/81	762.3 (Total depth)	Static water level measured 183.4 meters below land surface.

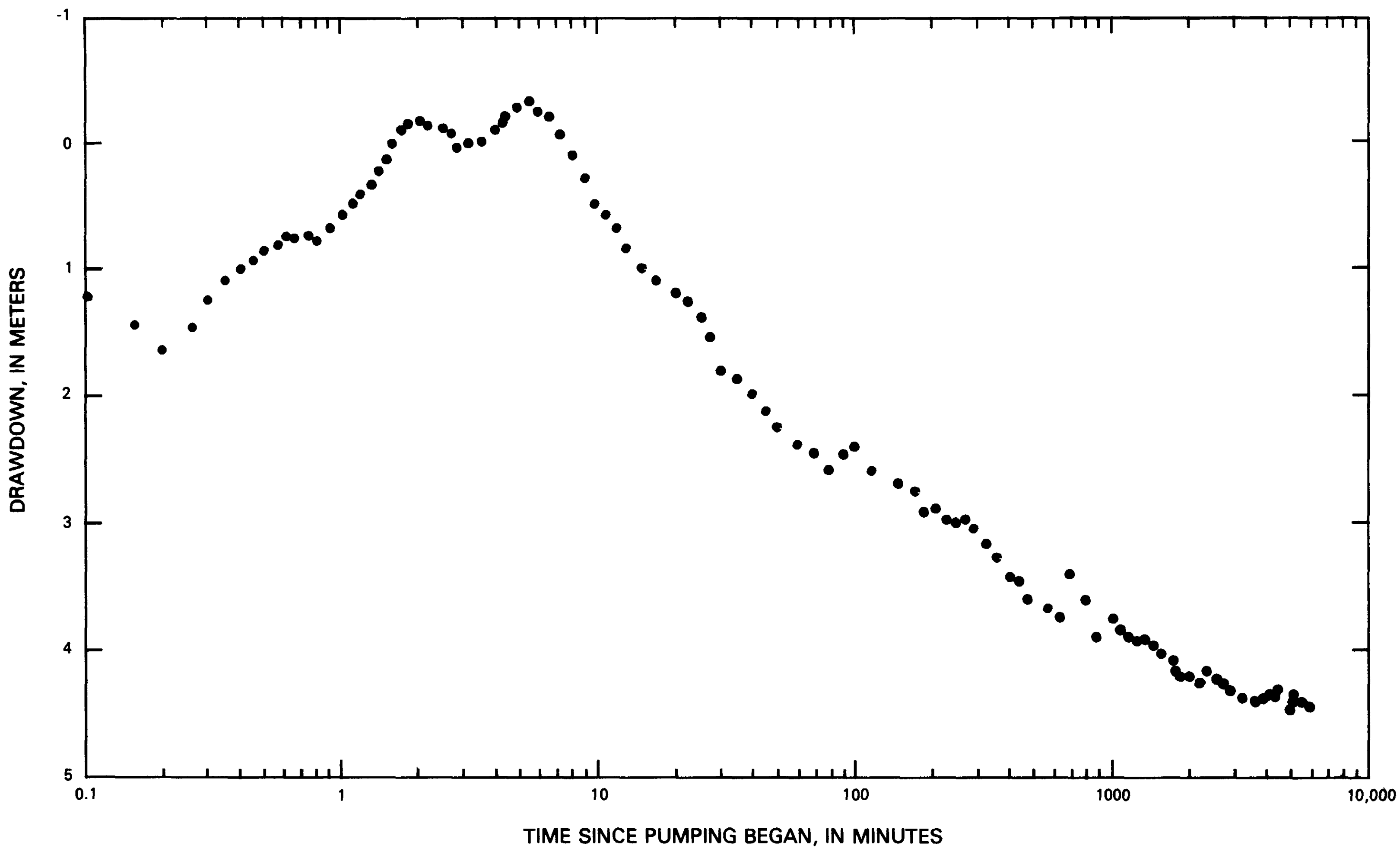

Figure 3.--Drawdown in well USW VH-1 during test 3.

Test 4, the recovery test that followed pumping test 3, had such an abnormal-looking data plot (fig. 4) that the test was terminated after 2,960 minutes and 1.90 m of recovery. The recovery data showed apparent harmonic damping for the first 2 minutes, no significant change in water level for about 200 minutes, a more than 0.7-m decline in water level between 1,800 and 2,700 minutes, and a 0.5-m rise in water level between 2,700 and 2,960 minutes.

Explanations were sought for the unusual water-level fluctuations during test 4. One explanation for the apparent harmonic damping would be failure of the foot valve in the pump column with resultant surging in the well, but this failure had not occurred. No reasonable hydrologic explanation was apparent for the sudden decline and rise in water level after 1,800 minutes of recovery.

Test 5, was made because faulty electronics or instrumentation was suspected during tests 3 and 4. All test equipment used in monitoring water level was checked or replaced, and the well was pumped again during test 5 (fig. 5). Test 5 had a discharge of 15.0 L/s and had a maximum drawdown of 2.01 m after 1,140 minutes of pumping. A possible malfunction in the transducer is suggested because the drawdown data plots of tests 3 and 5 are different, although the discharge rates were similar (15.4 L/s during test 3, and 15.0 L/s during test 5).

Test 6, the recovery test that followed pumping test 5, had an abnormal looking data plot similar to the data plot for the recovery in test 4. The recovery data in test 6 showed apparent harmonic damping for the first 2 minutes, a nearly constant water level for about 10 minutes, and an 0.2-m rise in water level followed by an 0.5-m decline in water level between 10 and 1,140 minutes (fig. 6).

None of the tests was wholly satisfactory because of problems caused by (1) caving and sloughing of the hole; (2) turbulent flow losses in the well and possibly the aquifer; (3) an increase in water temperature during pumping which caused the density of water to decrease; and (4) possibly other unknown factors in the well-aquifer system.

Analysis and Results

Various methods were used to analyze the hydraulic tests, including methods described by Ahrens and others (1981), van der Kamp (1976), Jacob (1947), and Brown (1963). These methods produced results of varying quality, as described below.

The pumping tests were analyzed using a method for estimating transmissivity from specific capacity (Ahrens and others, 1981, p. 161). Because the drawdown and recovery curves were not well defined, standard methods such as the straight-line method (Ferris and others, 1962) were considered not to be applicable. Using the data from test 3, the transmissivity was estimated to be 450 m^2/d (meters squared per day); using the data from test 5, the transmissivity was estimated to be 1,000 m^2/d.

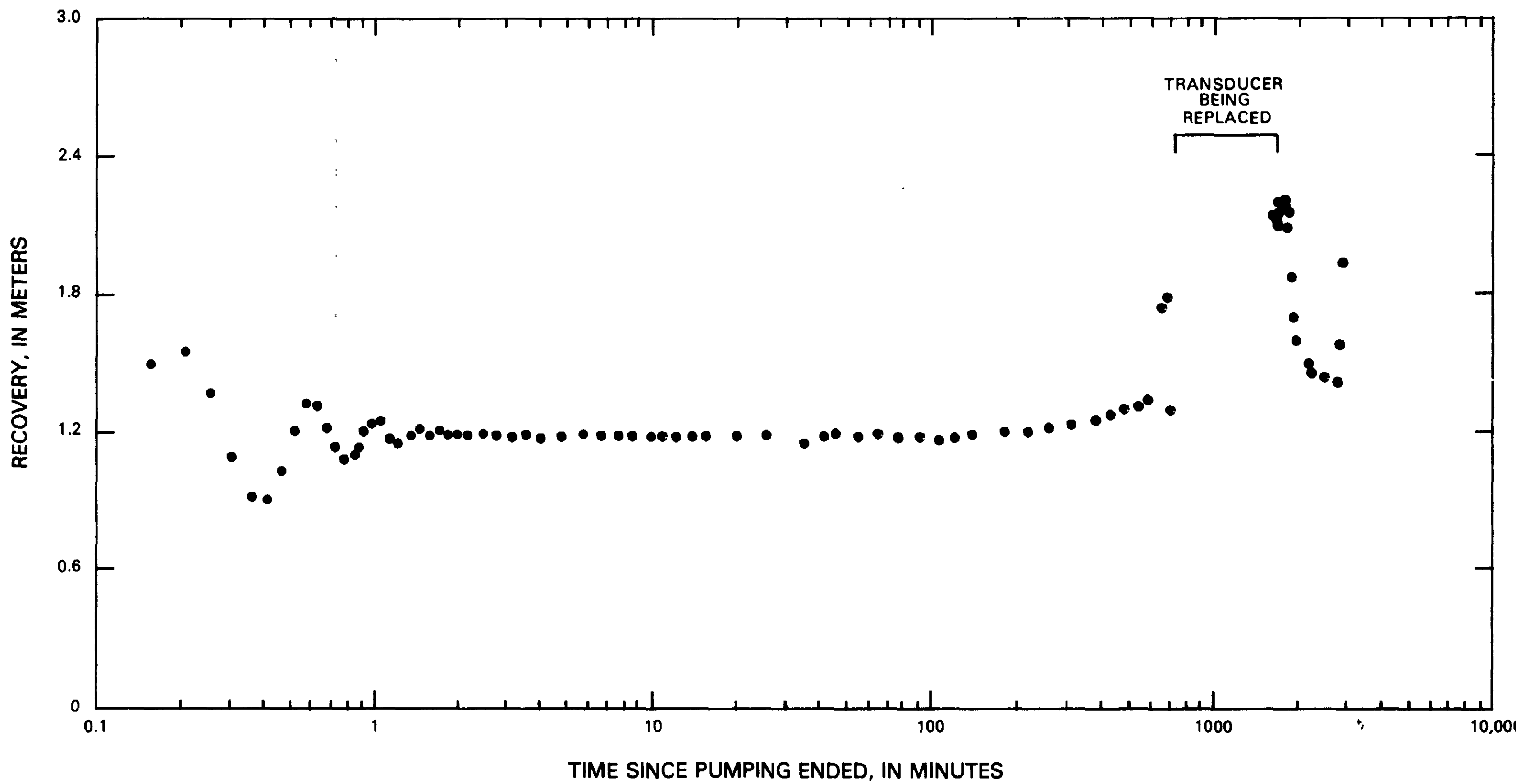

Figure 4.--Recovery in well USW VH-1 during test 4.

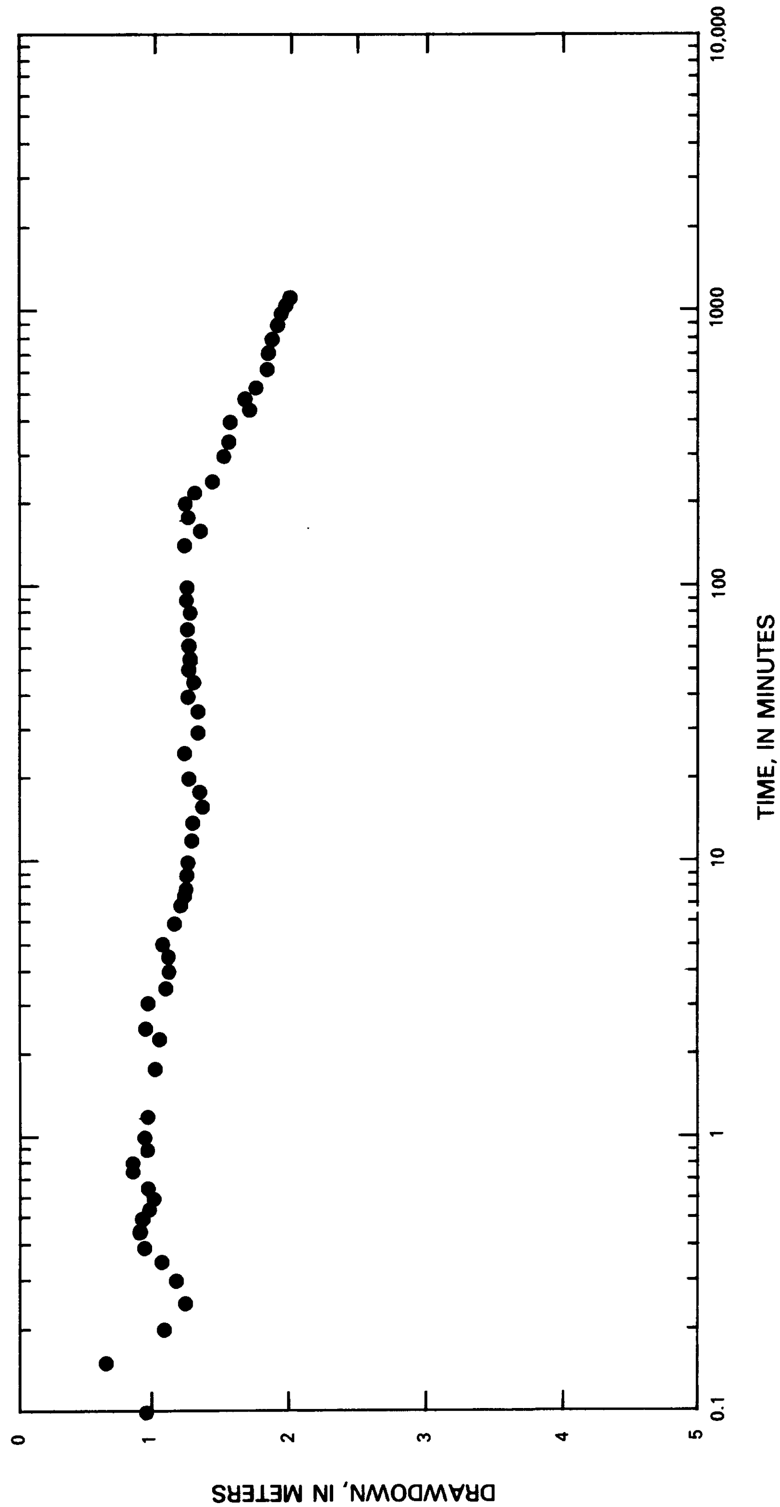

Figure 5.--Drawdown in well USW VH-1 during test 5.

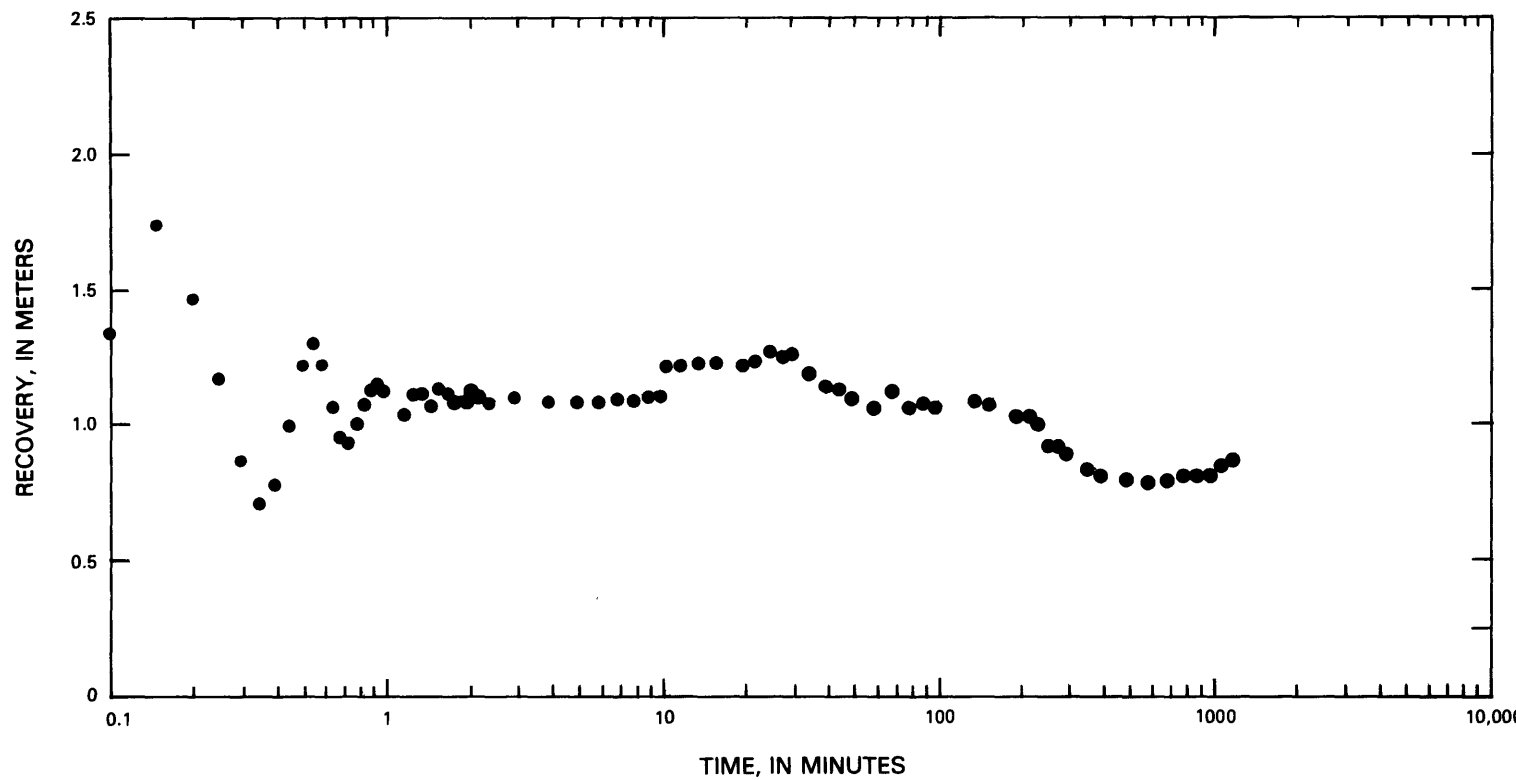

Figure 6.--Recovery in well USW VH-1 during test 6.

Van der Kamp (1976) developed a method for analyzing slug tests for transmissivity. The method employs analysis of harmonic water-level fluctuations that can occur in the early part of a test, when conditions are underdamped. This method should be used with caution for drawdown and recovery tests, because the method was developed principally for slug tests. Van der Kamp's approach was attempted on test 4; and a value for transmissivity of 2,200 m^2/d was obtained from analysis of test 4 (fig. 4).

Tests 1 and 3 were made at very different pumping rates; these tests were analyzed to determine the magnitude of head losses in the well that could have resulted from turbulent flow at the wellbore and in the aquifer. The analytical techniques included both Jacob's method (1974) and the Jacob-Rorabaugh equation (Rorabaugh, 1953; Blankennagel and others, 1981). The analysis yielded values for laminar flow loss in the aquifer (41 percent of total hydraulic head loss measured) and for turbulent flow loss in the aquifer and the well (59 percent); the latter value probably is unreasonably large for wellbore losses, because the well is not cased and the discharge is only moderate (Jacob, 1947). Therefore, the results of this analysis using Jacob's method and the Jacob-Rorabaugh equation are not presented.

Brown's method for estimating transmissivity from specific capacity was used to analyze test 1 (Brown, 1963). Transmissivity estimated by this method is 2,000 m^2/d, with an assumed storage coefficient of 1×10^{-4}, and 2,400 m^2/d, with an assumed storage coefficient of 1×10^{-6}. For this method, the specific capacity was calculated using drawdown that was corrected for turbulent flow loss in the aquifer and the well. Because this calculated value of head loss (59 percent) probably is greater than the actual, the calculated transmissivity probably is also too large.

CHEMICAL QUALITY OF GROUND WATER

A water sample from well USW VH-1 that contained little or no detergent and polymer gel was collected on February 11, 1981, just prior to the end of test 5; the chemical analysis is shown in table 5. The water is of the sodium bicarbonate type and is typical of water from saturated tuff (Blankennagel and Weir, 1973) beneath eastern Pahute Mesa, north and northeast of Crater Flat, and beneath Fortymile Wash, Yucca Flat, and Frenchman Flat (Winograd and Thordarson, 1975). The uncorrected carbon-14 age of water is 17,000±170 years before present.

SUMMARY

At the site of well USW VH-1, the aquifer consists of the Topopah Spring Member of the Paintbrush Tuff and the Bullfrog Member of the Crater Flat Tuff, both of Miocene age. Results of six hydraulic tests using various methods of analysis provided transmissivity values that range from 450 to 2,200 m^2/d. The aquifer probably consists of interconnected fractures in otherwise relatively impermeable rock. The water is of the sodium bicarbonate type and is typical of ground water from tuff in this area.

Table 5.--*Chemical analysis of water from well USW VH-1*

[mg/L, milligrams per liter; ‰, parts per thousand; µg/L, micrograms per liter; pCi/L, picocuries per liter; °C, degrees Celsius; meq/L, milliequivalents per liter; µS/cm, microsiemens per centimeter at 25°C]

Constituent or property	Value	Constituent or property	Value
Alkalinity, total, laboratory as $CaCO_3$, in mg/L	130	Lithium, dissolved (Li), in µg/L	90
Calcium, dissolved (Ca), in mg/L	9.9	Magnesium, dissolved (Mg), in mg/L	1.5
$\delta\,^{13}C$, ‰ PDB[1]	-8.5	$\delta\,^{18}O$, SIRA per mil[3]	-14.2
Carbon-14 (H_2O) age, in years before present	17,000±170	pH (laboratory), in standard units	8.0
Chloride, dissolved (Cl), in mg/L	10	pH (onsite), in standard units	7.5
$\delta\,^{2}H$, ‰ Vienna SMOW[2]	-108	Potassium-40, dissolved, in pCi/L	1.3
Fluoride, dissolved (F), in mg/L	2.7	Potassium, dissolved (K), in mg/L	1.8
Gross alpha, dissolved uranium natural in pCi/L	13	Residue, dissolved, calculated sum, in mg/L	275
Gross alpha, suspended uranium natural, in pCi/L	0.3	Residue, dissolved, on evaporation at 180°C, in mg/L	277
Gross alpha, dissolved uranium natural, in µg/L	19	Silica, dissolved, (Si), in mg/L	49
Gross alpha suspended uranium natural, in µg/L	<0.4	Sodium-absorption ratio (SAR)	6.1
Gross beta, dissolved cesium-137, in pCi/L	3.2	Sodium, dissolved (Na), in mg/L	78
Gross beta, dissolved strontium-90, in pCi/L	3.1	Sodium, percent	84
Gross beta, suspended cesium-137, in pCi/L	<0.4	Specific conductance (onsite) in µS/cm	388
Hardness, total as $CaCO_3$, in mg/L	31	Specific conductance (laboratory) in µS/cm	402
Hardness, onsite, noncarbonate as $CaCO_3$, in mg/L	0	Strontium, dissolved (Sr), in µg/L	60
		Sulfate, dissolved (SO_4), in mg/L	44
		Tritium, total (H^3) in pCi/L	<20
		Water temperature, in °C	35.5

CATIONS	(meq)	ANIONS	(meq)
Calcium (Ca)	0.494	Chloride (Cl)	0.282
Magnesium (Mg)	0.123	Fluoride (F)	0.142
Potassium (K)	0.046	Sulfate (SO_4)	0.916
Sodium (Na)	3.393	Alkalinity, total, laboratory	2.597
Total:	4.056	Total:	3.938

Percent difference, 1.49

[1]Reported as deviation in parts per thousand from the value of the Peedee belemnite standard.

[2]Reported as deviation in parts per thousand from the reference value of the Vienna standard mean ocean water.

[3]Reported as deviation in parts per thousand of the stable isotope ratio from the reference value of the Vienna standard mean ocean water.

Results of hydraulic testing of USW VH-1 were difficult to interpret because they could not be evaluated in the context of the regional hydrogeologic framework, and well-construction and hole conditions precluded thorough and proper testing of the well. Definition of the regional hydrogeologic framework could be improved if two more test wells were drilled in Crater Flat, one north of well USW VH-1, and the other southeast of the well, near the margin of Yucca Mountain. The hydrologic objectives of these wells would be to determine the areal distribution of the zone of moderate fracture permeability that occurs at well USW VH-1. These holes should penetrate deeper stratigraphic units than did well USW VH-1, because permeable fractured rock also probably is present in units deeper than the Bullfrog Member of the Crater Flat Tuff.

If additional holes were drilled in Crater Flat, each would need to have a larger-diameter surface casing than that of well USW VH-1, so that the open hole could be enlarged sufficiently to accept at least 244-mm casing. If caving and sloughing of the hole prevented hydrologic testing in the open hole, a casing could then be installed that would be large enough to accommodate both a pump and access tubing for the tracejector tool and other instruments.

REFERENCES

Ahrens, T.P., Ham, H.H., and Tapp, W.N., 1981, Ground water manual: U.S. Department of the Interior, Water and Power Resources Service, Denver, U.S. Government Printing Office, 480 p.

Blankennagel, R.K., Howells, Lewis, and Miller, W.R., 1981, Completion and testing of Madison Limestone test well 3: U.S. Geological Survey Open-File Report 81-528, 91 p.

Blankennagel, R.K., and Weir, J.E., Jr., 1973, Geohydrology of the eastern part of Pahute Mesa, Nevada Test Site, Nye County, Nevada: U.S. Geological Survey Professional Paper 712-B, 35 p.

Brown, R.H., 1963, Estimating the transmissivity of an artesian aquifer from the specific capacity of a well: U.S. Geological Survey Water-Supply Paper 1536-I, p. 336-338.

Ferris, J.G., Knowles, D.B., Brown, R.H., and Stallman, R.W., 1962, Ground-water hydraulics: U.S. Geological Survey Water-Supply Paper 1536-E, 174 p.

Jacob, C.E., 1947, Drawdown test to determine effective radius of artesian well: American Society of Civil Engineers Transactions, v. 112, paper no. 2321, p. 1047-1064.

Rorabaugh, M.I., 1953, Graphical and theoretical analysis of step-drawdown test of artesian well: Proceedings of the American Society of Civil Engineers, v. 79, Separate no. 362, p. 1-23.

van der Kamp, Garth, 1976, Determining aquifer transmissivity by means of well response tests--The underdamped case: Water Resources Research, v. 12, no. 1, p. 71-77.

Winograd, I.J., and Thordarson, William, 1975, Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

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