HYDROGEOLOGY OF ROCKS PENETRATED BY TEST WELL JF–3, JACKASS FLATS, NYE COUNTY, NEVADA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95-4245

Prepared in cooperation with the
NEVADA OPERATIONS OFFICE,
U.S. DEPARTMENT OF ENERGY, under
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Carson City, Nevada
1996

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter
cubic yard (yd^3)	0.7646	cubic meter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3408	meter per day
foot per mile (ft/mi)	0.1894	meter per kilometer
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon (gal)	3.785	liter
gallon per minute (gal/min)	3.785	liter per minute
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

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

Hydrogeology of Rocks Penetrated by Test Well JF-3, Jackass Flats, Nye County, Nevada

By Russell W. Plume and Richard J. La Camera

ABSTRACT

The U.S. Department of Energy and U.S. Geological Survey are monitoring water levels in southern Nevada and adjacent parts of California in response to concern about the potential effects of pumping ground water to support the Yucca Mountain Site-Characterization Program. Well JF-3 was drilled in the western part of Jackass Flats for monitoring water levels, for determining the likelihood of a hydraulic connection between well JF-3 and production wells J-12 and J-13, and for measuring the hydraulic properties of the Topopah Spring Tuff.

The borehole for JF-3 penetrated about 480 feet of alluvium and 818 feet of underlying volcanic rock. The well was finished at a depth of 1,138 feet below land surface near the base of the Topopah Spring Tuff, which is the principal volcanic-rock aquifer in the area. The Topopah Spring Tuff at well JF-3 extends from depths of 580 feet to 1,140 feet and consists of about 10 feet of partly to moderately welded ash-flow tuff; 10 feet of vitrophyre; 440 feet of devitrified, moderately to densely welded ash-flow tuff; 80 feet of densely welded ash-flow tuff; 10 feet of vitric, nonwelded to partly welded ash-flow tuff; and 10 feet of ash-fall tuff. Fractures and lithophysae are most common in the devitrified tuff, especially between depths of 600 feet and 1,040 feet. Much of the water produced in well JF-3 probably comes from the sequence of these devitrified tuffs that is below the water table. The transmissivity of the aquifer is an estimated 140,000-160,000 feet squared per day and hydraulic conductivity is 330-370 feet per day. These values exceed estimates made at well J-13 by two orders of magnitude. Such large differences may be accounted for by differences in the development of fractures and lithophysae in the Topopah Spring Tuff at the two wells.

Water levels, corrected for the effects of atmospheric pressure, fluctuated 0.1-0.4 foot during periods of a few days to 2 weeks from late January to early March 1992 at well J-12. Corrected water levels at JF-3 fluctuated similarly from February 26 to March 2, 1992, and they fluctuated 0.2-0.7 foot during periods of a few hours to a few days from June 1992 through December 1993. Some short-term fluctuations at JF-3, especially those of only a few hours duration, correspond with nearby earthquakes. Gradual rises and declines of several months duration seem to be related to pumping at production wells J-12 and J-13, which suggests that the Topopah Spring Tuff is hydraulically connected between the three wells. The chemical similarity of water from the three wells further supports the possibility that the wells are hydraulically connected. Long-term monitoring of water levels at JF-3 and more detailed pumping records for J-12 and J-13 would be useful for determining causes of short-term fluctuations and for determining the extent of the hydraulic connection.

INTRODUCTION

Background

The Yucca Mountain area in southern Nevada is being evaluated by the U.S. Department of Energy for suitability as a potential high-level radioactive-waste repository. As part of the site-characterization process, the U.S. Geological Survey is involved in geologic

and hydrologic investigations of the mountain and surrounding area. These investigations are being done cooperatively under Interagency Agreement DE-AI08-92NV10874.

In Jackass Flats, ground water is used to supply water needs for the Yucca Mountain Site-Characterization Program and other activities related to operation of the Nevada Test Site. The only water-supply wells in Jackass Flats are wells J-12 and J-13 (fig. 1). Combined pumpage at the two wells was about 160 acre-ft in both 1990 and 1991, 120 acre-ft in 1992, and 200 acre-ft in 1993 (La Camera and Westenburg, 1994, p. 119; Hale and Westenburg, 1995, p. 66). Ground water beneath Jackass Flats flows toward major discharge areas at Alkali Flat and at Death Valley National Park 25-30 mi south and southwest of the town of Amargosa Valley (fig. 1).

The National Park Service and other groups are concerned that ground-water withdrawals in Jackass Flats eventually could affect the water resources in Ash Meadows (10-20 mi south of Amargosa Valley) and Death Valley National Park. As a result, the U.S. Department of Energy has developed a plan for monitoring ground-water levels and springflow between Yucca Mountain and Death Valley (U.S. Department of Energy, 1991). Construction of well JF-3 in Jackass Flats is a part of that plan.

Well JF-3 was drilled in the western part of Jackass Flats to monitor water levels in, and quantify the hydraulic properties of, the volcanic-rock aquifer that yields water to wells J-12 and J-13. If rocks penetrated by the three wells are hydraulically connected, then water levels measured at JF-3 could provide an early indication of water-level declines that might eventually affect springflow farther south at Ash Meadows and Death Valley National Park. The intent was to complete well JF-3 at the base of the Topopah Spring Tuff, which is part of the uppermost volcanic-flow system in the area (Ervin and others, 1994, p. 5).

Purpose and Scope

The purpose of this report is to describe (1) the construction of well JF-3, (2) the lithologic and hydraulic properties of the Topopah Spring Tuff, (3) indicators of a hydraulic connection between well JF-3 and production wells J-12 and J-13, and (4) any water-level changes at well JF-3 since it was completed in early 1992. Interpretations of a cuttings log and geophysical logs are used to characterize the lithology of the Topopah Spring Tuff and the potential for different zones in the formation to produce water. Water levels measured in 1992-93 are used to evaluate the potential for a hydraulic connection between the three wells and to evaluate water-level changes at JF-3 since it was constructed. Results of an aquifer test at JF-3 are used to estimate the transmissivity and hydraulic conductivity of the aquifer. The general chemical quality of ground water at the three wells also is used to evaluate the potential for a hydraulic connection.

Acknowledgments

Several people provided advice and assistance to the authors during the preparation of this report. The lithologic logs for wells J-12 and JF-3 (tables 1 and 2) were compiled by R.W. Spengler (U.S. Geological Survey, Denver, Colo.). G.L. Dixon (U.S. Geological Survey, Las Vegas, Nev.) reviewed a draft of the report and assisted the authors in the interpretation of the lithologic and geophysical logs for well JF-3. L.E. Thompson and D.C. Olson (TRW Environmental Safety Systems Inc., Geophysics Dept., Las Vegas, Nev.) provided geophysical logs for well JF-3 (fig. 4) and also assisted the authors in the interpretation of the logs. The report was prepared in cooperation with the U.S. Department of Energy.

Physical Setting

Location

Jackass Flats is a basin of about 280 mi^2 in southern Nevada (Scott and others, 1971, p. 39) that is bounded by Yucca Mountain to the west and northwest, Calico Hills to the north, Little Skull Mountain to the southeast, and the Striped Hills to the south (fig. 1). Land-surface altitudes are about 2,800 ft in southern parts of Jackass Flats and 3,000 ft to 4,000 ft in central and northern parts. Altitudes in adjacent mountains are about 4,000 ft to 6,000 ft.

The western part of Jackass Flats is drained by Fortymile Wash and the eastern part by Topopah Wash (fig. 1), both of which are tributaries of the Amargosa River. The washes are ephemeral and flow only during periods of intense precipitation.

Geology

The Nevada Test Site area is underlain by about 38,000 ft of clastic and carbonate rocks of Precambrian through Permian age (Frizzell and Shulters, 1990).

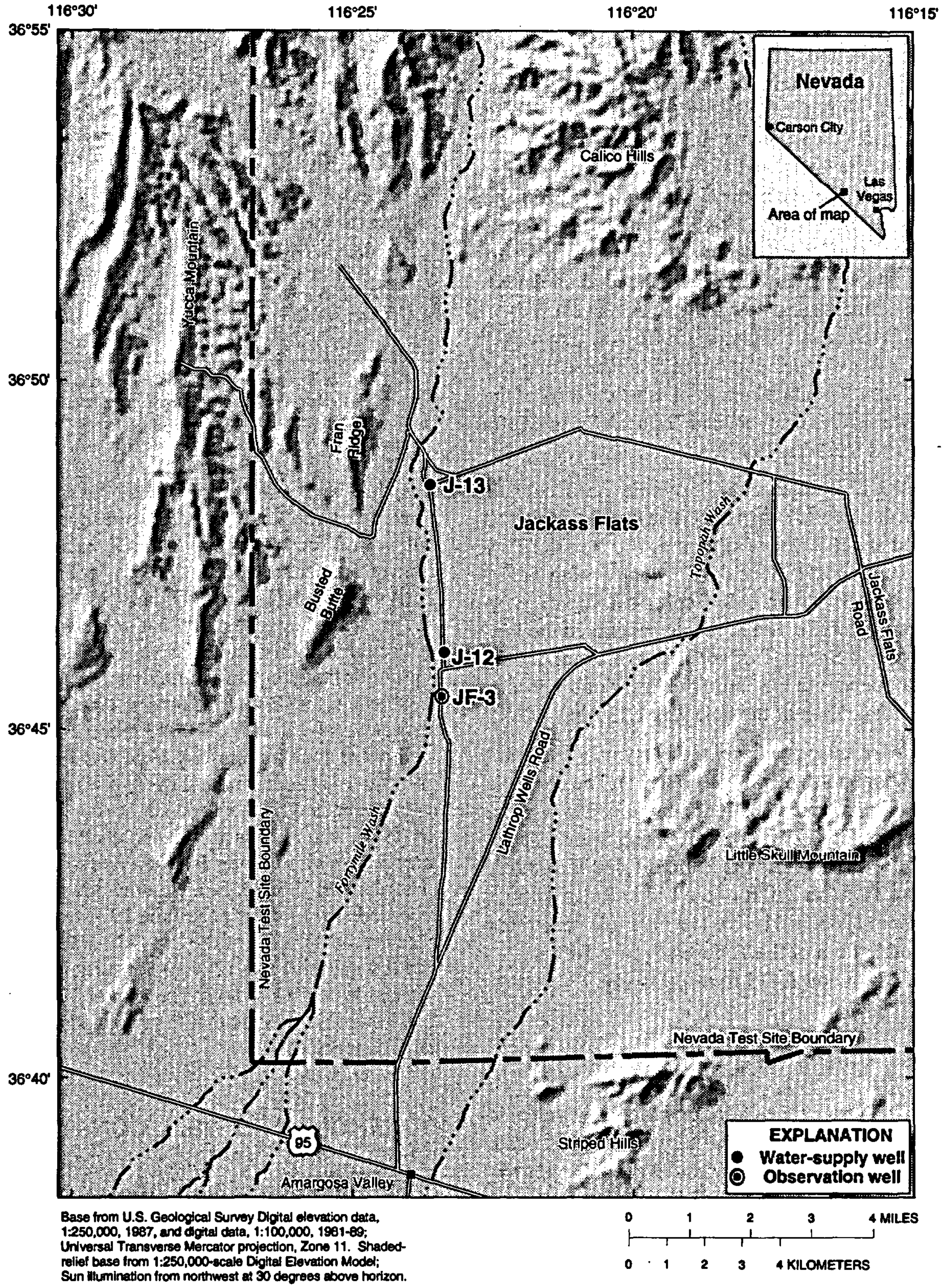

Figure 1. Location of wells JF-3, J-12, and J-13, Jackass Flats, Nevada

Except for the Calico Hills and Striped Hills, exposures of these rocks are rare near Jackass Flats because of the overlying volcanic rocks.

Thick sections of Tertiary volcanic rocks are exposed in the mountains around Jackass Flats and also underlie the central structural basin. About 2,000 ft of ash-flow tuffs (Tiva Canyon and Topopah Spring Tuffs), rhyolitic lavas, and tuffaceous beds overlie rocks of Paleozoic age in the Calico Hills (Frizzell and Shulters, 1990). At Little Skull Mountain, volcanic rocks include tuffaceous sediments, ash-flow tuff, bedded tuff, flows, and flow breccias. The total thickness of these sediments and volcanic rocks may exceed 5,000 ft (Frizzell and Shulters, 1990). Volcanic rocks exposed in the western part of Jackass Flats along the base of Yucca Mountain consist of ash-flow tuffs of the Rainier Mesa, Tiva Canyon, and Topopah Spring Tuffs (Frizzell and Shulters, 1990).

Well J-12 is adjacent to Fortymile Wash and half a mile north of well JF-3 (fig. 1). The borehole for J-12 penetrated about 520 ft of alluvium, 100 ft of the Tiva Canyon Tuff, and 519 ft of the Topopah Spring Tuff (table 1; R.W. Spengler, U.S. Geological Survey, written commun., 1995). The borehole penetrated the top of the Topopah Spring Tuff at a depth of about 620 ft, but did not penetrate the entire thickness of the formation. The total depth of the hole was 1,139 ft.

Well J-13 also is adjacent to Fortymile Wash and is about 3.5 mi north of well JF-3 (fig. 1). The borehole for this well penetrated 435 ft of alluvium, 245 ft of the Tiva Canyon tuff, 795 ft of the Topopah Spring Tuff, 265 ft of the Calico Hills Formation, 1,480 ft of the Crater Flat Tuff and 270 ft of the Lithic Ridge Tuff (Thordarson, 1983, p. 11-12). The borehole penetrated the top and bottom of the Topopah Spring Tuff at depths of 680 ft and 1,475 ft, respectively.

Table 1. Lithologic log of borehole for well J-12

[Modified from compilation by R.W. Spengler, U.S. Geological Survey, Denver, Colo., January 5, 1989]

Stratigraphic and lithologic description	Depth (feet below land surface)	
	Top of interval	Bottom of interval
Alluvium (volcanic clasts)	0	520
Paintbrush Group		
Tiva Canyon Tuff	520	620
Topopah Spring Tuff		
Undifferentiated	620	1,080
Basal vitrophyre	1,080	1,135
Nonwelded vitric basal unit [1]	1,135	1,139
	1,139 feet total depth	

[1] Base of Topopah Spring Tuff is estimated to be about 20 feet deeper than total depth of drill hole; depth intervals based on examination of archived cuttings and interpretation of field-copy density log (R.W. Spengler, U.S. Geological Survey, written commun., 1989).

Hydrology

Ground water beneath Jackass Flats is in volcanic rocks and in underlying sedimentary rocks of Paleozoic age. Alluvium is above the saturated zone. Depths to water are about 710 ft at well JF-3, 740 ft at J-12, and 930 ft at J-13. The regional direction of ground-water flow at Jackass Flats and Yucca Mountain is southward to discharge areas at Death Valley and Alkali Flat (Winograd and Thordarson, 1975, pl. 1).

In the western part of Jackass Flats, ground-water flow is eastward and southeastward from adjacent uplands of Yucca Mountain. Gradients are low (2-4 ft/mi) from near the crest of Yucca Mountain to near Fortymile Wash (Ervin and others, 1994, pl. 1). These flat gradients suggest either that ground-water flow is through a highly transmissive and well-connected aquifer or that the flow is minimal through a less permeable aquifer (Ervin and others, 1994, p. 9). Aquifer tests at well J-12, with well J-13 used as an observation well, were done in February 1964 and June 1970. The purpose was to determine if the two wells are hydraulically connected by the Topopah Spring Tuff. In February 1964, water levels at J-13 had declined about 1.2 ft after 3 days of pumping J-12 at a rate of 367 gal/min (Thordarson, 1983, p. 50). No drawdowns were recorded at J-13 during the June 1970 test, probably because the duration of the test (7 hours) and pumping rate (94 gal/min) at J-12 were not sufficient to cause a detectable decline at J-13. The results from the first test, however, indicate that the two wells are hydraulically connected.

BOREHOLE AND WELL CONSTRUCTION

Drilling and Completion Procedures

Drilling of well JF-3 began on December 10, 1991, and was completed on January 22, 1992. Drilling methods consisted of an auger from 0 to 15 ft, hydraulic rotary from 15 to 90 ft, and a combination of

hydraulic rotary and air hammer from 90 ft to 1,298 ft. A combination of compressed air, water, and detergent (air foam) was used to remove cuttings from the borehole. Casing was installed and the well was completed on February 7, 1992.

The borehole and well-completion diagrams are shown in figure 2. All hole diameters refer to the diameter of the drill bit that was used. Casing and access-pipe diameters are inside for diameters less than 14 in. and outside for diameters of 14 in. or more. The following sequence of holes was drilled:

1. A 36-in. auger hole was drilled to a depth of 15 ft below land surface and cased with 26-in. steel pipe. The annulus was filled to land surface with 5 yd^3 of cement grout.
2. A 24-in. hole was drilled to a depth of 90 ft and cased from land surface to 87 ft with 16-in. steel pipe. The lower part of the annulus was filled with 20 sacks of sand and the upper part with 17 yd^3 of cement grout.
3. A 15-in. hole was drilled to a depth of 524 ft and cased from land surface to 492 ft with 13.375-in. steel pipe. The annulus was filled and pipe cemented into place with cement grout from 426 to 524 ft.
4. A 12.25-in. hole was drilled to the total depth of 1,298 ft and cased with 8.62-in. steel pipe to a depth of 1,153 ft. This casing was perforated with thirty-two, 0.125-in. by 2-in., machine-cut slots per foot from 735 ft to 1,115 ft and with four, 0.25-in. by 6-in., torch-cut slots per foot from 1,115 to 1,140 ft. The open hole below the casing was subsequently filled with washed gravel from total depth to 1,174 ft and with about 1 yd^3 of concrete from 1,174 ft to the finished depth of the well at 1,138 ft.

After the total depth of 1,298 ft was reached, a mixture of compressed air, water, and detergent was used for 15 minutes to remove any residual cuttings from the borehole. This was followed by air-lifting water from the borehole for 20 minutes. The volume of water removed from the borehole was not recorded.

The borehole for well JF-3 deviated only slightly from vertical as drilling progressed. The horizontal deviation was measured using a single-shot survey. Assuming all deviation is in one direction, the maximum horizontal deviation is about 5.6 ft at a depth of 700 ft (near the water table) and about 11.9 ft at total depth. As a result of these deviations, measured depths in the well exceed true-vertical depths by a maximum of 0.02 ft at a depth of 700 ft and 0.06 ft at total depth. However, no corrections are applied to measured depths because actual deviation is not known and because maximum deviations indicate that the actual deviation is minimal.

On February 20, 1992, a submersible pump was installed in the well. During the following week, the well was pumped at rates ranging from 230 to 330 gal/min during periods ranging from 15 to 50 minutes. The total volume of water pumped during the period was about 32,000 gal, which is equivalent to 12 volumes of water contained in the borehole (calculated on the basis of a 12.25-in. diameter hole between the static water level at 710 ft and the finished well depth at 1,138 ft).

Monitoring Configuration

Two steps were required to begin monitoring water levels at well JF-3. The first involved setting the pump and installing an access tube for monitoring water levels during an aquifer test in March 1992 (fig. 2A). The pump intake was set at 925 ft and a 3.5-in. steel discharge pipe was used. A 1.25-in. steel pipe, installed to a depth of 760 ft, provided access for making water-level measurements. In addition, a pressure transducer for continual recording of water levels during the test was attached to the exterior of the access tube at a depth of 740 ft.

The second step of water-level monitoring began after the aquifer test was finished. The pump, discharge pipe, and access tube were removed from the well, and two 2.375-in. steel pipes were installed to provide access for long-term monitoring of water levels. Each of the access pipes is open at the lower end at a depth of 818 ft below land surface and is perforated from 741 to 818 ft (fig. 2B). A pressure transducer, installed in one of the pipes, is used to record water levels at 15-minute intervals. The other pipe provides access for manual water-level measurements, which are made whenever the recorder attached to the transducer is serviced. In addition, atmospheric pressure is recorded at the top of the casing at 15-minute intervals. This is the configuration that will be used for long-term monitoring of water levels at well JF-3.

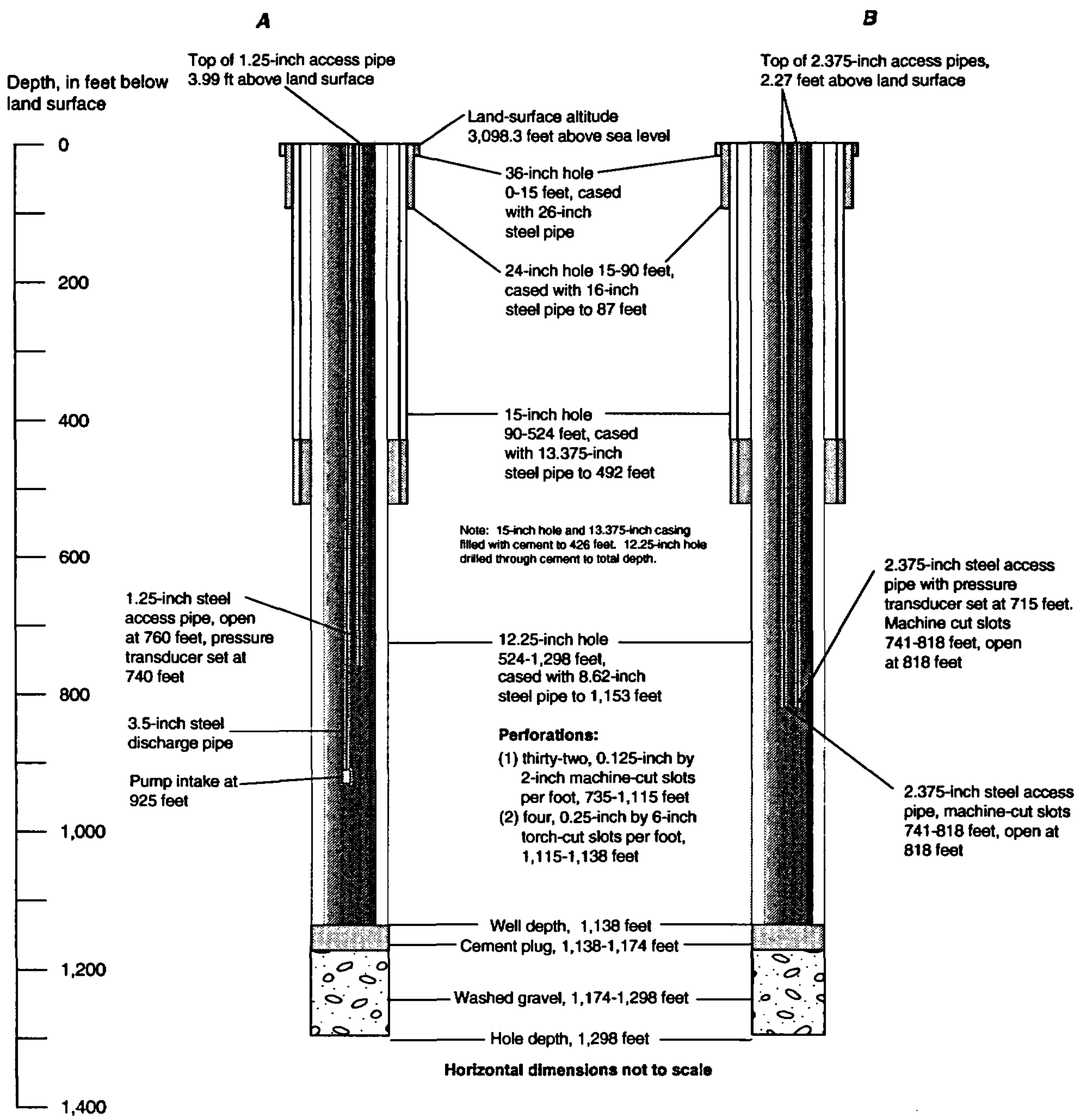

Figure 2. Borehole and completion diagrams for well JF-3, Jackass Flats, Nevada. *(A)* Configuration for aquifer test, *(B)* configuration for long-term monitoring. Hole diameters refer to diameter of the drill bits. Casing and access-pipe diameters are inside for diameters less than 14 inches and outside for diameters of 14 inches or more.

LITHOLOGIC AND GEOPHYSICAL LOGS

Cuttings collected during drilling and geophysical logs measured after the borehole was drilled were used to develop a hydrogeologic log showing lithology and physical and water-bearing properties of the rocks penetrated (fig. 3). A cuttings log, describing lithology in the borehole and indicating depth intervals based on correlations with geophysical logs, is presented in table 2. Geophysical logs obtained for well JF-3 are described in Olson (1995), and are listed in the tabulation below:

Log type	Properties indicated
Focused resistivity (saturated zone) [1]	Resistivity
Induction (unsaturated zone)[1]	Conductivity
Gamma-gamma density	Bulk density
Sidewall (epithermal) neutron	Water-filled porosity
Natural gamma radiation	Total gamma radiation/stratigraphy
Four-arm caliper	Borehole rugosity
Compensated (thermal) neutron [2]	Water-filled porosity
Sonic [2]	Porosity
Borehole televiewer [2]	Borehole image/fracturing

[1] Resistivity log in figure 4 is combination of these two logs.
[2] Log not shown in figure 4. Sonic and borehole televiewer logs are of poor quality and compensated neutron log is similar to sidewall neutron log.

Five of the geophysical logs, used in conjunction with the cuttings log, are shown in figure 4. Tops of units shown in figure 3 were picked on the basis of cuttings descriptions and abrupt changes in the curves for each of the geophysical logs. For consistency, the top of a unit was picked at the lower point of an abrupt change and the transitional depths preceding the abrupt change were assumed to be part of the overlying unit.

The borehole for well JF-3 penetrated 480 ft of alluvium and 818 ft of underlying volcanic rock (fig. 3). The alluvium consists of volcanic clasts that were eroded from volcanic rocks in the mountains adjacent to Jackass Flats. Volcanic rocks consist of ash-flow and ash-fall tuffs of the Tiva Canyon Tuff, bedded tuff, Topopah Spring Tuff, and rocks tentatively identified as the Wahmonie Formation (table 2).

The Tiva Canyon Tuff extends from 480 to 540 ft below land surface (fig. 3). The upper 50 ft consists of densely welded, devitrified, ash-flow tuff, and the lower 10 ft consists of partly welded, vitric ash-flow tuff. The contact between alluvium and Tiva Canyon Tuff is indicated by abrupt increases in the density and gamma radiation logs (fig. 4).

Bedded ash-fall tuffs extend from 540 ft to 580 ft below land surface (fig. 3). The top of these bedded tuffs is indicated by abrupt decreases in resistivity, density, and gamma radiation at a depth of 540 ft (fig. 4).

The Topopah Spring Tuff extends from 580 ft to 1,140 ft below land surface (fig. 3). The top is indicated by abrupt increases in resistivity, density, and gamma radiation (fig. 4). The upper part of the Topopah Spring Tuff consists of partly to moderately welded ash-flow tuff from 580 to 590 ft below land surface and densely welded, vitrophyric ash-flow tuff from 590 to 600 ft below land surface (fig. 3).

Moderately to densely welded, devitrified ash-flow tuffs of the Topopah Spring Tuff extend from 600 to 1,040 ft below land surface. The top of the zone is indicated by a slight decrease in density and abrupt increases in porosity and natural gamma radiation (fig. 4). The sequence of devitrified ash-flow tuffs consists of rocks in which lithophysae or fractures are common, as indicated by abrupt decreases in density, abrupt increases in porosity, and abrupt departures of the borehole from its nominal diameter of 12.25 in. (fig. 4). Owing to the lithophysae and fracturing, the interval between the water table at 710 ft below land surface and the bottom of the sequence at 1,040 ft probably yields most of the water produced by the well. That interval accounts for about 77 percent of the total saturated thickness of the Topopah Spring Tuff in the finished well. Additional analysis of the geophysical logs further indicates that, below the water table, the interval from 710 ft to 795 ft has the greatest potential for producing water in the borehole (Olson, 1995, p. 23).

The lower part of the Topopah Spring Tuff consists of the following units: 80 ft of densely welded, lithophysal ash-flow tuff from 1,040 to 1,120 ft below land surface; 10 ft of nonwelded to partly welded, vitric ash-flow tuff from 1,120 to 1,130 ft; and 10 ft of vitric ash-fall tuff from 1,130 to 1,140 ft (fig. 3). The top of this sequence of units is indicated by an abrupt increase in resistivity and slight decrease in porosity (fig. 4).

The Wahmonie Formation (?) extends from 1,140 ft to the total depth of well JF-3 at 1,298 ft below land surface (fig. 3); the borehole did not fully penetrate the formation. This part of the Wahmonie Formation (?) consists of poorly to moderately consolidated, partly zeolitic ash-fall tuff (fig. 3). The top of the Wahmonie Formation (?) is indicated by decreases in gamma radiation and resistivity, a slight decrease in density, and a slight increase in porosity (fig. 4).

Table 2. Lithologic log of borehole for well JF-3

[Modified from compilation by R.W. Spengler, U.S. Geological Survey, Denver, Colo., March 5, 1992]

Stratigraphic and lithologic description	Depth (feet below land surface) Top of interval	Bottom of interval
Alluvium (volcanic clasts)	0	480
Paintbrush Group		
Tiva Canyon Tuff		
Tuff, ash-flow, pale yellowish brown, densely welded, devitrified; pumice, some altered to moderate orange-pink, clay(?); 1-2 percent phenocrysts (sanidine)	480	530
Tuff, ash-flow, pale yellowish orange, partly welded, vitric; pumice, very pale orange, slightly altered(?); 1 percent phenocrysts (sanidine); abundant black and grayish-orange glass shards	530	540
Bedded tuff		
Tuff, ash-fall (?), moderate brown, poorly consolidated, crystal-rich, contains black glass fragments	540	550
Tuff, ash-fall (?), grayish orange-pink, poorly consolidated, composed of very pale orange vitric to altered pumice fragments; abundant moderate reddish brown lithic fragments	550	580
Topopah Spring Tuff		
Tuff, ash-flow, light brownish gray, partly to moderately welded; pumice, grayish orange-pink, altered (?); 5-6 percent phenocrysts (quartz, sanidine, and biotite)	580	590
Tuff, ash-flow, black to light brown, densely welded, vitrophyric, 6-8 percent phenocrysts (dominantly sanidine and biotite); base may be altered in part to clay	590	600
Tuff, ash-flow, pale red, moderately to densely welded, devitrified; pumice, pale red to grayish orange-pink; vapor phase crystallization, less than 8 percent phenocrysts (sanidine and biotite); upper lithophysal zone (?)	600	800
Tuff, ash-flow, pale red, light brown (mottled), densely welded, devitrified; pumice, very pale orange; 1 percent phenocrysts (sanidine); (1) middle nonlithophysal zone may be from 800-850 feet; (2) lower lithophysal zone from 850-950 feet; (3) lower nonlithophysal zone from 950-1,040 feet	800	1,040
Tuff, ash-flow, dark yellowish brown, densely welded; lithophysal; less than 1 percent phenocrysts (sanidine and biotite)	1,040	1,120
Tuff, ash-flow, light brown, partly to nonwelded, slightly altered (?), vitric; pumice, light-brown, slightly altered, light brown glass shards; less than 1 percent phenocrysts (sanidine); alteration increases below 1,125 feet	1,120	1,130
Tuff, ash-fall (?), light brown, moderately consolidated, vitric; pumice, very pale orange; some pale yellowish-orange glass shards; some moderate brown lithic fragments	1,130	1,140
Wahmonie Formation (?)		
Tuff, ash-fall (?), very pale orange, moderately consolidated, altered (?); pumice, very pale orange, altered (?); abundant light brown lithic fragments less than 2 mm; 3-4 percent phenocrysts (quartz, sanidine, and biotite)	1,140	1,150
Tuff, ash-fall, pinkish gray, yellowish gray, poorly to moderately consolidated, zeolitic (?); 5-15 percent phenocrysts (sanidine, quartz, bronze biotite); abundant grayish red lithic fragments; hornblende and pyroxene; samples almost entirely composed of crystals from 1,180 to 1,210 feet and from 1,240 to 1,250 feet; almost all lithic fragments from 1,260 to 1,298 feet	1,150	1,298
	1,298 feet total depth	

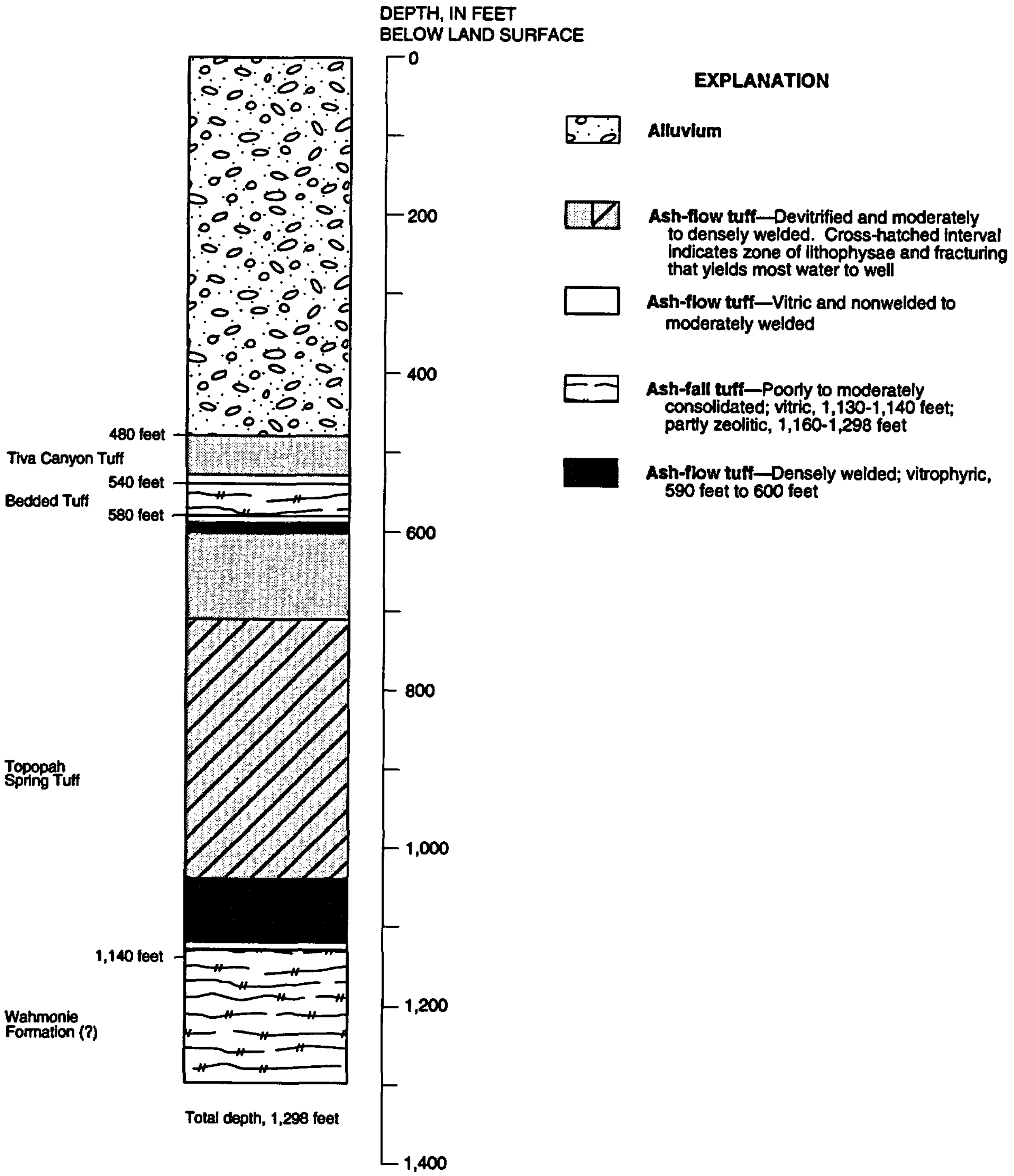

Figure 3. Hydrogeologic log for well JF-3, Jackass Flats, Nevada; based on lithologic log (table 2) and geophysical logs (figure 4).

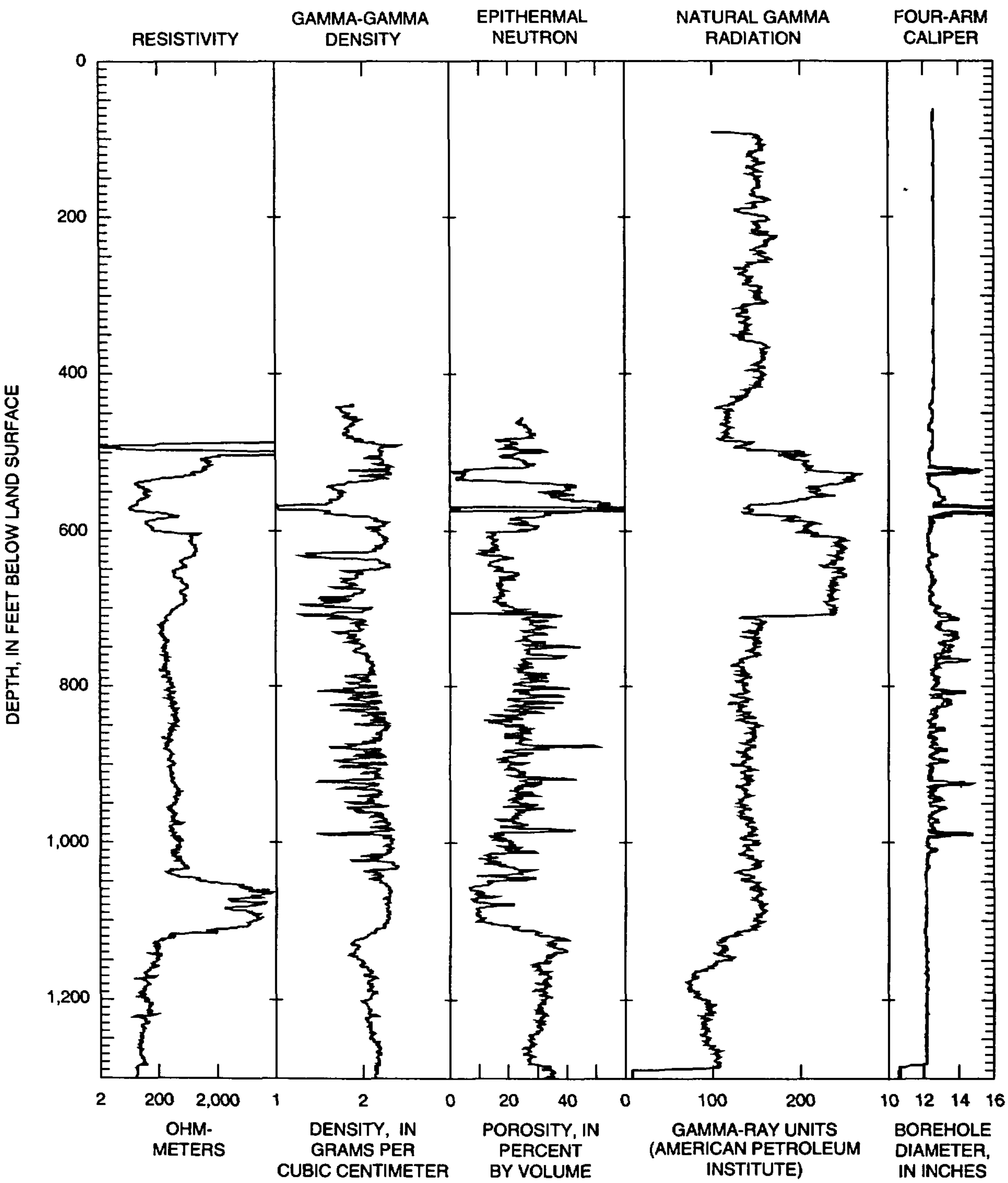

Figure 4. Selected geophysical logs for well JF-3, Jackass Flats, Nevada. Data from L.E. Thompson and D.C. Olson (TRW Environmental Safety Systems Inc., written commun., 1995).

GEOLOGIC AND HYDRAULIC PROPERTIES AT BOREHOLES FOR JF-3, J-12, AND J-13

Wells JF-3, J-12, and J-13 penetrate similar sequences of alluvium and volcanic rocks to about 2,000 ft above sea level (fig. 5). The contact between alluvium and Tiva Canyon Tuff is at an altitude of about 2,620 ft at JF-3, 2,610 ft at J-12, and 2,880 ft at J-13 (fig. 5). The top of the Topopah Spring Tuff is at an altitude of about 2,520 ft at JF-3, 2,510 ft at J-12, and 2,640 ft at J-13 (fig. 5). The bottom of the Topopah Spring Tuff is at an altitude of about 1,960 ft at JF-3, 1,970 ft at J-12, and 1,840 ft at J-13 (Thordarson, 1983, p. 11). Total thicknesses of the Topopah Spring Tuff are 560 ft at JF-3, at least 519 ft at J-12, and 795 ft at J-13 (fig. 5).

The altitude of the water table is about 2,388 ft at wells JF-3 and J-12 and 2,390 ft at J-13. Lithophysae and fractures are most common at JF-3 between altitudes of about 2,390 ft and 1,958 ft; as a result, that zone has a high water-production potential (fig. 3). The zone also includes an interval between altitudes of 2,390 and 2,300 ft (fig. 5) that has been identified as having the greatest potential for production of water in well JF-3 (Olson, 1995, p. 23).

On the basis of a tracer-injection survey done at well J-12 in August 1968, the interval of greatest water production was between altitudes of 2,340 ft and 2,280 ft (fig. 5) in that well (Olson, 1995, p. 57). The upper limit of the interval however, reflects the absence of perforated casing between the water surface and 2,340 ft rather than potential water production from the Topopah Spring Tuff.

Although little direct information on principal water-producing intervals is available for well J-13, the Topopah Spring Tuff was identified as the predominant aquifer at that location and lithophysae or fractures were identified between altitudes of about 2,390 and 2,010 ft (Thordarson, 1983, p. 11).

Comparison of the altitudes and thicknesses listed above indicates that potential zones of high-volume water production are in the upper to middle part of the Topopah Spring Tuff at all three wells. Additionally, intervals with the greatest potential for water production identified in wells JF-3 and J-12 generally correspond in altitude.

WATER LEVELS

Water levels have been monitored since August 1989 at well J-12 and since late May 1992 at JF-3. Water levels also were monitored from February 26 to March 11, 1992, at JF-3 during an aquifer test. Barometric pressure had been recorded at J-12 from January through May 1992, and thereafter was recorded at JF-3. Evidence presented in the following sections of this report indicates that water levels at JF-3 and J-12 are affected by changes in atmospheric pressure and possibly by pumping at J-13. Water levels measured at the two wells had to be corrected for these effects before water-level fluctuations and the aquifer test could be evaluated.

Corrections for Effects of Atmospheric Pressure

Water levels at wells JF-3 and J-12 respond almost instantaneously to changes in atmospheric pressure. Depth to water at the two wells and barometric pressure recorded at well J-12[1] from February 26 to March 11, 1992, are shown in figure 6. Comparison of the pairs of curves indicates that water levels at both wells respond to both daily fluctuations in barometric pressure and to long-term barometric fluctuations of several days or more.

For any particular period, the pairs of curves in figure 6 have nearly the same slope, and for some periods, they have identical slopes. For example, the measured water-level rise at well J-12 exactly corresponds with the measured decrease in atmospheric pressure from February 27-29, 1992. For the same period, the measured water-level rise at well JF-3 was slightly less than the measured decrease in atmospheric pressure. Thus, for periods ranging from a few hours to several days, any change in atmospheric pressure, in feet of water, results in an equal, but opposite, change in water

[1]Depth to water at wells J-12 and JF-3 and barometric pressure at well J-12 were measured with pressure transducers (gaged) and a barometer and recorded at 15-minute intervals during February 26-March 3 and March 9-11, 1992, and at 1-minute intervals during March 3-9, 1992.

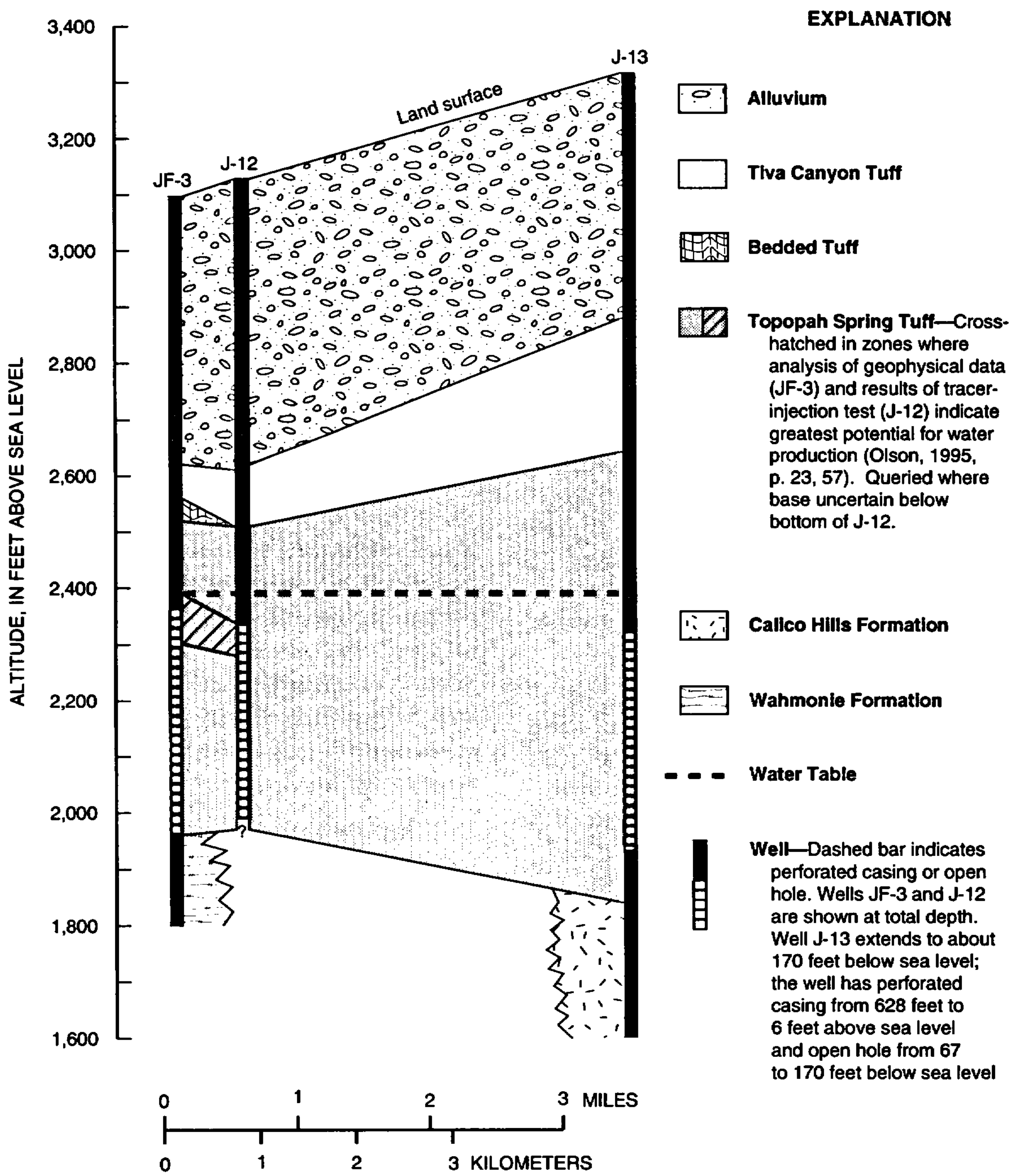

Figure 5. Hydrogeologic correlation diagram showing relation between rock units, water levels, and potential water-producing zones at wells JF-3, J-12, and J-13, Jackass Flats, Nevada. Tops of lithologic units calculated, respectively, from land-surface altitudes of 3,098, 3,128, and 3,317 feet above sea level and lithologic data contained in table 2, table 1, and Thordarson (1983).

level in the wells (fig. 6). This indicates that the barometric efficiency[1] of the aquifer in the Topopah Spring Tuff is about 1. This value for barometric efficiency was used to correct water levels measured at wells JF-3 and J-12 for fluctuations due to changes in atmospheric pressure.

Corrected Water Levels

Wells J-12 and JF-3, January-March 1992

Water levels measured from late January through mid-March at wells J-12 and JF-3, corrected for effects of atmospheric pressure, are shown in figure 7. Water levels at well J-12 fluctuated less than 0.1 ft during periods of a few days and fluctuated as much as 0.3-0.4 ft during periods of 10-15 days. Water levels at the well declined about 0.2 ft from late January through mid-February, rose about 0.3 ft during the last half of February, and then declined 0.4 ft during the first 9 days of March. During nonpumping periods, water levels at well JF-3 also declined about 0.3 ft from late February to early March (fig. 7).

Fluctuations in corrected water levels were similar at wells JF-3 and J-12 from February 26 to March 11, 1992 (fig. 7). This period includes the aquifer test at well JF-3, which was done March 4-5. The sharp decline of about 1.5 ft at JF-3 on March 4 and the approximately equal rise on March 5 mark the start and end of pumping. Water-level fluctuations at well JF-3 were minimal during the 12 hours prior to the test and for about 2 days after the test (fig. 7). These minimal water-level changes coincide with a decrease in the rate of water-level decline at well J-12 during the same period.

The similarity of water-level fluctuations at wells J-12 and JF-3 from February 26 to March 11, 1992 (fig. 7) indicates that water levels at both wells were responding to the same source of stress to the aquifer. This source of stress probably was pumping at J-13 because (1) well J-12 had not been pumped since December 28, 1991, (2) water levels at J-12 and JF-3 had been corrected for effects of atmospheric pressure, and (3) effects of Earth tides (although undoubtedly accounting for some of the fluctuations in corrected water levels) would not account for the magnitude of fluctuations measured during the period.

In 1964, pumping at well J-12 resulted in water-level declines at well J-13 (Thordarson, 1983, p. 50). Thus, pumping of well J-13 during January, February, and March 1992 conversely could have affected water levels at wells J-12 and JF-3 (although water-level changes at these two wells were much less than the decline measured at J-13 during pumping of J-12 in 1964). The reasons for differences between pumping effects in 1964 and January-March 1992 could be due to differences in pumping rates. During tests in 1964, the pumping rate at J-12 was 367 gal/min for 3 days (Thordarson, 1983, p. 50). Although the instantaneous pumping rate at well J-13 was about 600 gal/min in 1992, the well was not pumped continuously; average monthly pumping rates at well J-13 during January, February, and March 1992 were 60 gal/min, 70 gal/min, and 80 gal/min, respectively (D.B. Wood, U.S. Geological Survey, oral commun., 1995). These lesser pumping rates in 1992 could have been sufficient to have caused the small declines shown on figure 7, but were not sufficient to cause a decline similar to that measured at J-13 in 1964.

Well JF-3, June 1992-December 1993

Long-term monitoring of water levels at well JF-3 began in late May 1992. Since then, pumping from wells J-12 and J-13 has been the only source of water in Jackass Flats for the Yucca Mountain Site-Characterization Program and other activities in the immediate vicinity. Depths to water at JF-3, corrected for effects of atmospheric pressure, and combined monthly pumpage at wells J-12 and J-13 are shown in figure 8 for June 1992 through December 1993. All pumpage in Jackass Flats from January to mid-May 1992 was from well J-13 and pumpage from mid-May 1992 through December 1993 was from wells J-12 and J-13.

Water levels at JF-3 generally fluctuated as much as 0.4 ft during periods of a few days to a few weeks between June 1992 and December 1993 (fig. 8A). Fluctuations of as much as 0.5 ft during periods of no more than a few hours on August 13 and October 17 and 22, 1993, corresponded with earthquakes recorded within 100 mi of JF-3. Fluctuations on these days could have resulted from deformation of the aquifer caused by the

[1] The barometric efficiency of an aquifer is the ratio of the net change in water level measured in a well tapping the aquifer to the corresponding net change in atmospheric pressure (Ferris and others, 1962, p. 85). Barometric efficiency commonly is discussed with regard to confined aquifers. However, water levels in wells tapping unconfined aquifers that are separated from the atmosphere by a thick unsaturated zone also can respond to changes in atmospheric pressure (Weeks, 1979, p. 1167).

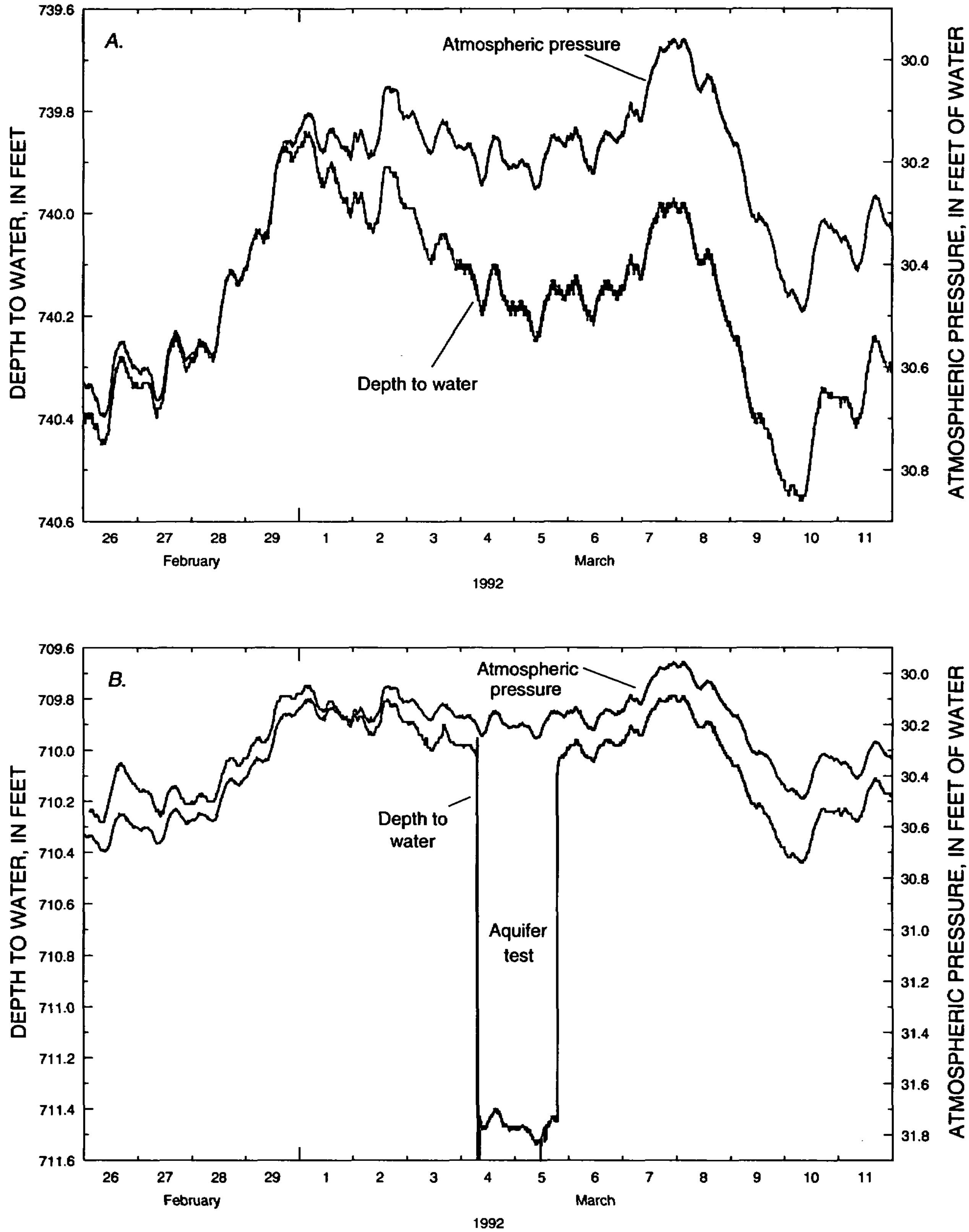

Figure 6. Depth to water and atmospheric pressure at *(A)* well J-12 and *(B)* well JF-3, Jackass Flats, Nevada, February 26-March 11, 1992

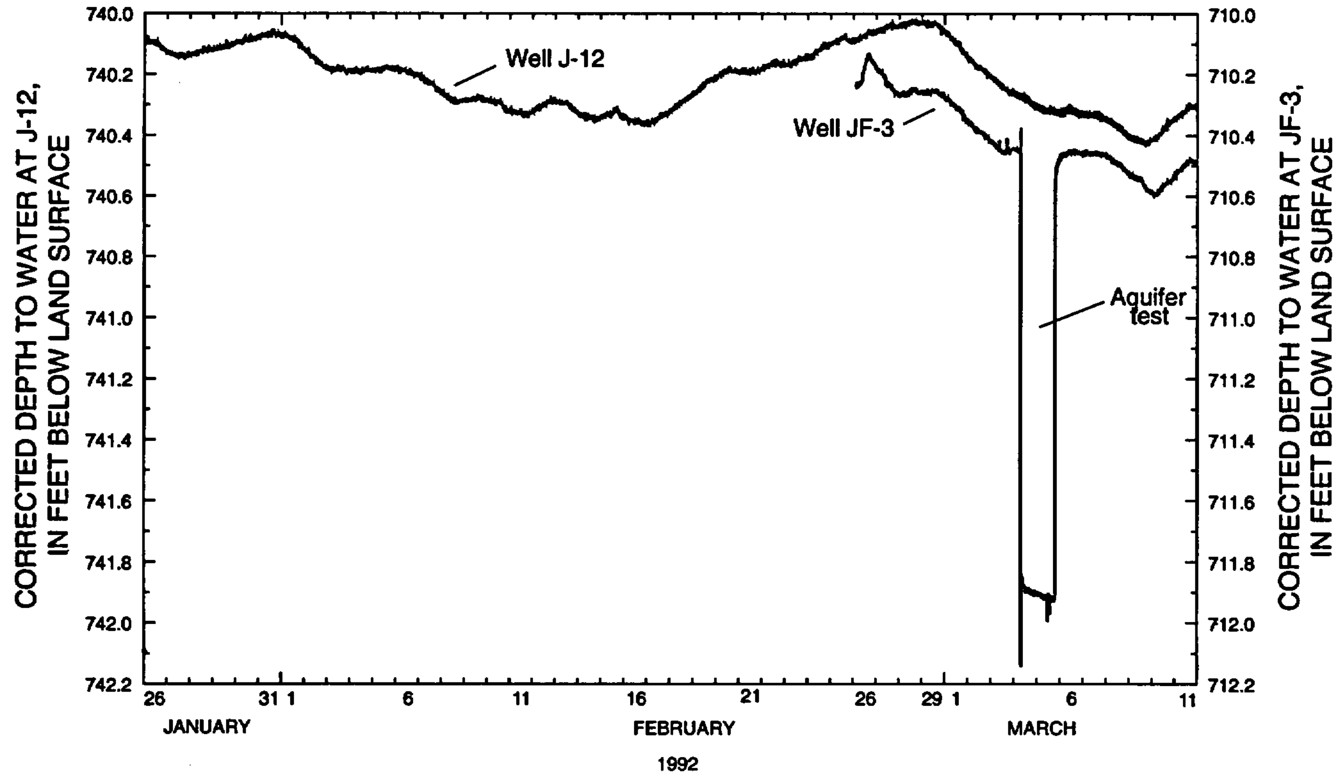

Figure 7. Depth to water at wells J-12 and JF-3, Jackass Flats, Nevada, corrected for effects of atmospheric pressure, January 26-March 11, 1992.

earthquakes. Water-level fluctuations of about 0.7 ft on October 26 and 28, 1993, do not appear to be related to earthquakes, although similar changes of lesser magnitude were recorded at another monitoring well about 15 mi to the southwest. Water-level fluctuations measured at well JF-3 from June 1992 to December 1993 also could have resulted from pumping at wells J-12 and J-13; the short-term effects of pumping on water levels at JF-3, however, cannot be evaluated because pumping records at J-12 and J-13 are not detailed.

Water levels at JF-3 also fluctuated about 0.2 to 0.3 ft during periods of several months between June 1992 and December 1993. These long-term fluctuations are difficult to evaluate because of the effects of short-term fluctuations discussed above. Water levels at JF-3 generally rose from June 1992 through early 1993 (fig. 8*A*). This water-level rise coincides with a period of decreased pumpage at wells J-12 and J-13 (fig. 8*B*). Water-level declines between March and September 1993 coincide with a corresponding increase in monthly pumpage. Although monthly pumpage decreased from October through December 1993 (fig. 8*B*), some of the largest short-term fluctuations in water levels at JF-3 also occurred during this period and make difficult the identification of any long-term declines. Water-level fluctuations at well JF-3 cannot be more fully evaluated until detailed pumping records for wells J-12 and J-13 are available for comparison with water levels.

AQUIFER TEST AT WELL JF-3

During an aquifer test, well JF-3 was pumped at an average rate of 235 gal/min from 7:03 a.m. on March 4, 1992, to 7:00 p.m. the following day. The generator providing power to the pump failed 8 minutes into the test, but was restarted 9 minutes later. The beginning of pumping, for purposes of analyzing water levels recorded during and after pumping, is 7:20 a.m. on March 4. Water from the well was discharged into Fortymile Wash about a quarter mile southwest of (downgradient from) JF-3.

Well J-12 was used as the observation well for the aquifer test and had not been pumped since December 28, 1991. However, pumping at JF-3 does not appear to have affected water levels at J-12. Water levels at J-12 were declining for several days before the test, but the rate of decline decreased during and after the test (fig. 7). A change in the daily pumping rate at well J-13 may have been the cause for the decrease in rate of water-level decline at J-12, but detailed records for pumping at J-13 are not available

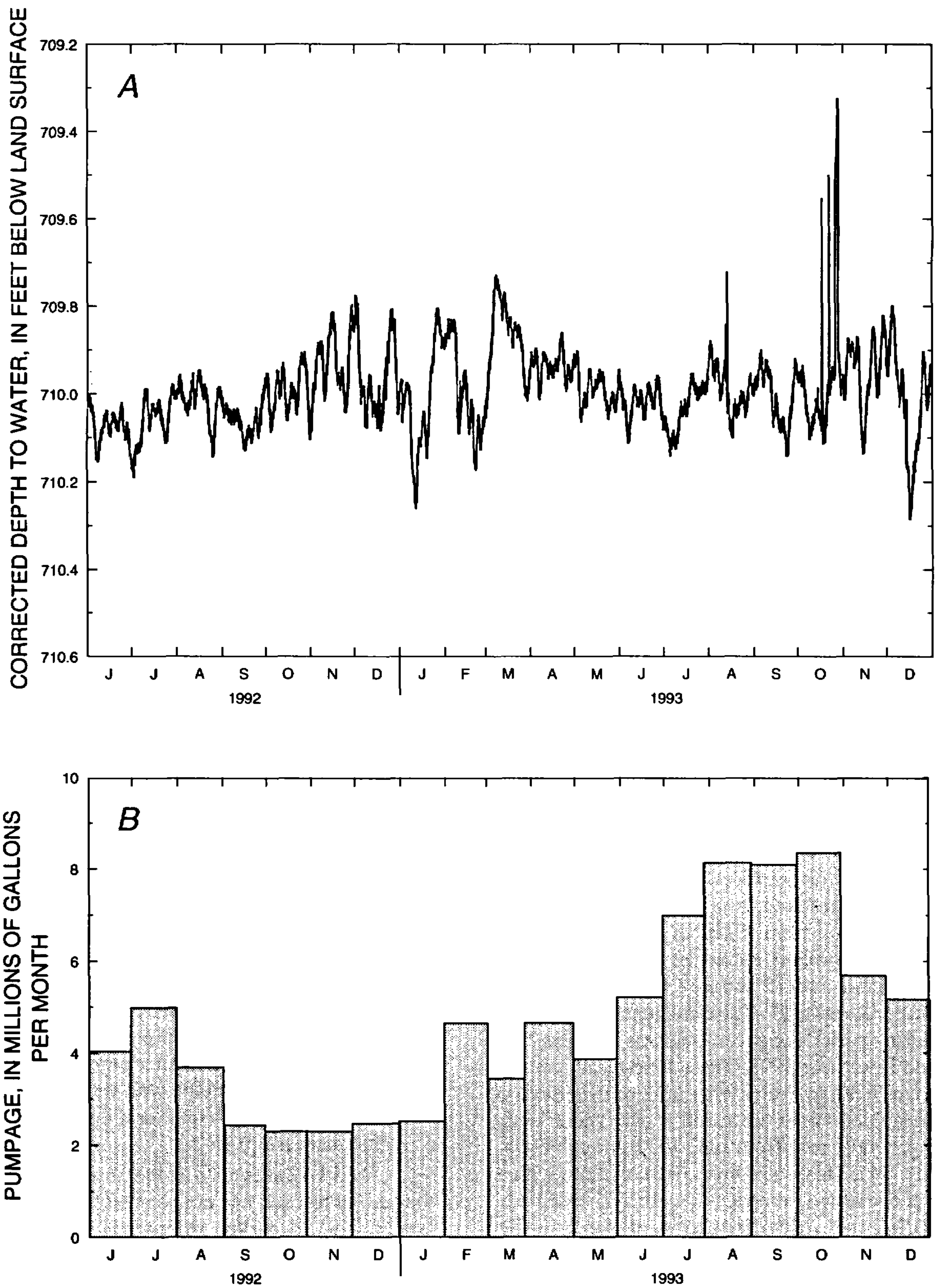

Figure 8. *(A)* Depth to water at well JF-3 corrected for effects of atmospheric pressure, and *(B)* combined monthly pumpage at wells J-12 and J-13, Jackass Flats, Nevada, June 1992-December 1993.

to evaluate this possibility. As a result, only the drawdown and recovery of water levels at well JF-3 were analyzed to determine transmissivity and hydraulic conductivity of the aquifer in the Topopah Spring Tuff.

Water levels also were declining at well JF-3 several days before the aquifer test began (fig. 7). However, water-level fluctuations were minimal during the 12 hours before the test and immediately following the test. For this reason, water levels measured during the test were corrected only for the effects of atmospheric pressure.

Water levels at JF-3 changed nearly instantaneously when the pump was turned on or off or when the pumping rate changed (fig. 9). The water level declined about 1.6 ft approximately 2 minutes after the test began and rose about 0.3 ft nearly 40 minutes later in response to a decrease in the pumping rate from about 270 gal/min to 235 gal/min. The water level rose about 1.2 ft approximately 1 minute after pumping stopped. These nearly instantaneous water-level declines and rises likely were caused by well losses, which are a result of turbulent flow into the casing from the aquifer and in the casing near the pump intake, and do not represent water-level changes in the aquifer next to the well.

Water-level changes in the Topopah Spring Tuff are represented by the gradual declines from about 2 to 37 minutes and 38 to 2,140 minutes after pumping started and the gradual recovery from about 2 to 1,739 minutes after pumping stopped (fig. 9). The nearly identical slopes of the three curve segments suggest that the cone of depression met no boundaries during pumping.

On the basis of the modified nonequilibrium formula and the Theis recovery formula (equations 12 and 17, Ferris and others, 1962, p. 100 and 101), the analytical method used to compute values of transmissivity from the curves in figure 9 is

$$T = 35.3Q/\Delta s, \qquad (2)$$

where T is transmissivity, in feet squared per day,

Q is pumping rate, in gallons per minute, and

Δs is the water-level change, in feet, over one logarithmic cycle of time.

The factor 35.3 in the above equation produces values of transmissivity that are in units of feet squared per day.

Values of Δs are 0.060 ft for both drawdown periods and 0.056 ft for the recovery period. Pumping rates (Q) were 270 gal/min for the earliest period of the drawdown curve and 235 gal/min for the later period of the drawdown curve. An average pumping rate of 235 gal/min was used for computing T from the recovery curve. Values of transmissivity computed from the test results are 160,000 ft^2/d and 140,000 ft^2/d for the drawdown curves and 150,000 ft^2/d for the recovery curve. Corresponding values of hydraulic conductivity, computed on the basis of a saturated interval 428 ft thick, are 330 ft/d, 370 ft/d, and 350 ft/d, respectively. These values exceed, by about two orders of magnitude, estimates for the Topopah Spring Tuff made as part of an aquifer test at well J-13 (Thordarson, 1983, p. 27). However, the transmissivity and hydraulic conductivity of the Topopah Spring Tuff may differ areally by orders of magnitude depending on the intensity of fracturing and resulting interconnections between lithophysae.

Several simplifying assumptions must be made whenever a method is selected for analyzing an aquifer test. These assumptions are listed by Lohman (1972, p. 15). One assumption, that the aquifer is homogeneous and isotropic, probably is not valid for the Topopah Spring Tuff because fractures and lithophysae are not uniformly distributed. A dual-porosity model to account for water yielded by fractures interconnected by lithophysae and water yielded by the rock matrix has been proposed for volcanic rock at Yucca Mountain (Craig and Robison, 1984, p. 10-15). However, the aquifer test at well JF-3 was not of long enough duration to indicate the possible effects of dual porosity in the aquifer.

WATER QUALITY AT WELLS JF-3, J-12, AND J-13

Samples of ground water from well JF-3 were collected four times on March 4-5, 1992, during the aquifer test. Samples of ground water from wells J-12 and J-13 were collected on December 17-18, 1991. All the samples were analyzed for a broad range of inorganic and organic constituents. The analytical results are presented by La Camera and Westenburg (1994, p. 121-156). Comparison of the analyses indicates that, after nearly 36 hours of pumping, the quality of ground water at JF-3 generally was similar to that at J-12 and J-13.

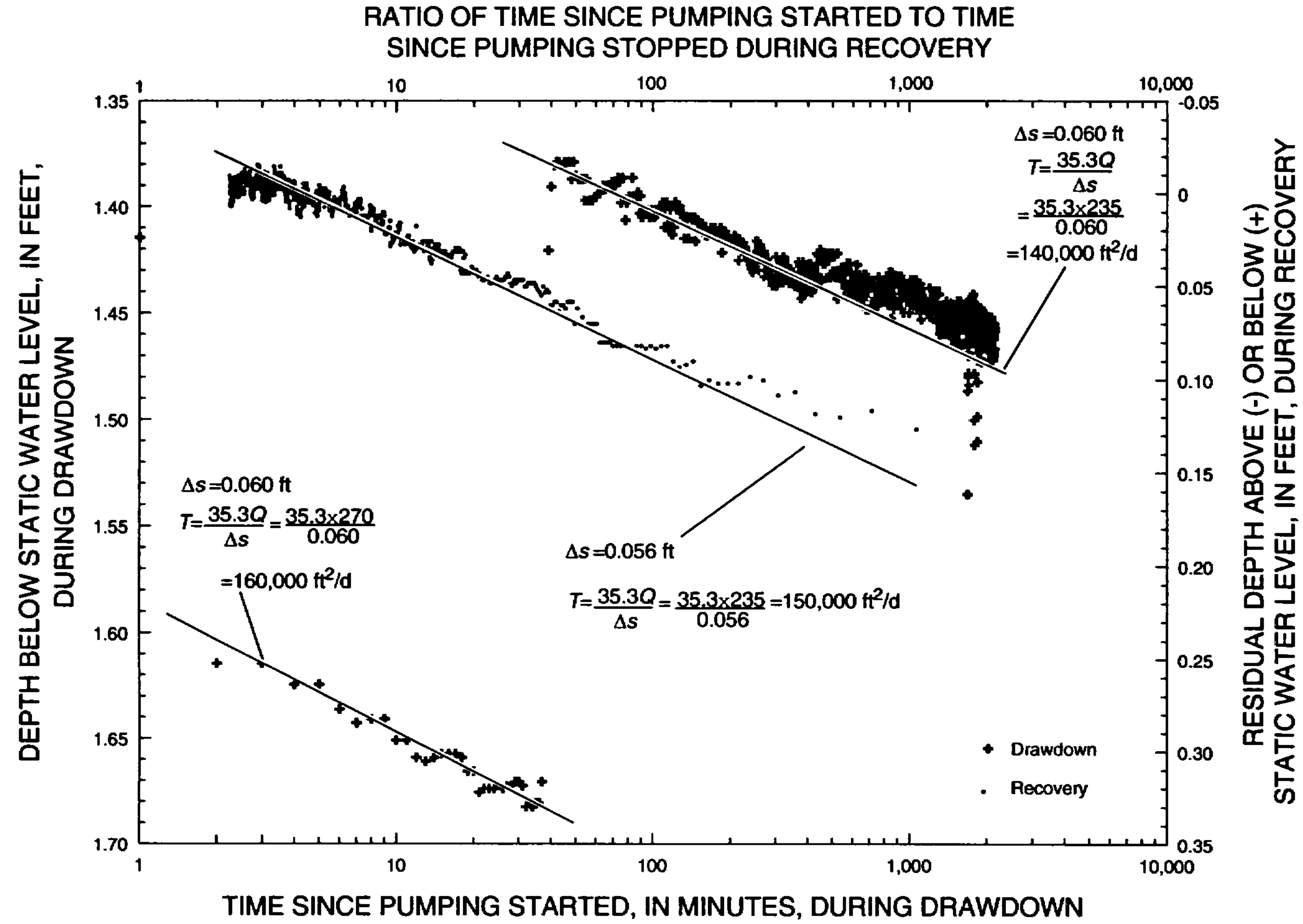

Figure 9. Analysis of water-level drawdown and recovery during aquifer test at well JF-3, Jackass Flats, Nevada, March 4-5, 1992. Water levels are corrected for effects of atmospheric pressure.

The general chemical character of ground water at wells JF-3, J-12, and J-13 is summarized in figure 10. The graph consists of five fields—two triangular and three rectangular. Each chemical analysis is plotted as five points on the diagram. The relative proportions, in percent of total milliequivalents, of major cations and anions are shown on the left and upper triangles, respectively. The pH and dissolved-solids concentrations for each sample are shown on the bottom and right rectangles, respectively. The lines show how values for the analysis of the sample for well JF-3 are plotted in the triangular fields and are projected, by way of the central rectangle, to the rectangular fields for pH and dissolved solids.

Analyses used for the graph are those for J-12 and J-13 on December 17-18, 1991, and a sample collected at JF-3 at 5:35 p.m. on March 5, 1992 (La Camera and Westenburg, 1994, table 7). Ground water at all three wells is a sodium bicarbonate water; pH is 7.6 to 7.7; and dissolved-solids concentrations (as sum of constituents) are 230 mg/L at J-13, 224 mg/L at J-12, and 235 mg/L at JF-3 (fig. 10). Proportions of sodium plus potassium (as percent of total cation milliequivalents per liter) and bicarbonate (as percent of total anion milliequivalents per liter) decrease 7 percent and 5 percent, respectively, in the general direction of ground-water flow from well J-13 to JF-3 (fig. 10). These decreases are compensated for by corresponding increases mostly in the proportions of calcium and sulfate. These compositions are typical of ground water in volcanic rocks and are consistent with the chemical composition of water in the welded-tuff aquifer at Jackass Flats (Winograd and Thordarson, 1975, p. 98-101).

Water quality at the three wells also was similar with respect to minor chemical constituents. Concentrations of most trace elements ranged from below to slightly above analytical detection limits (La Camera

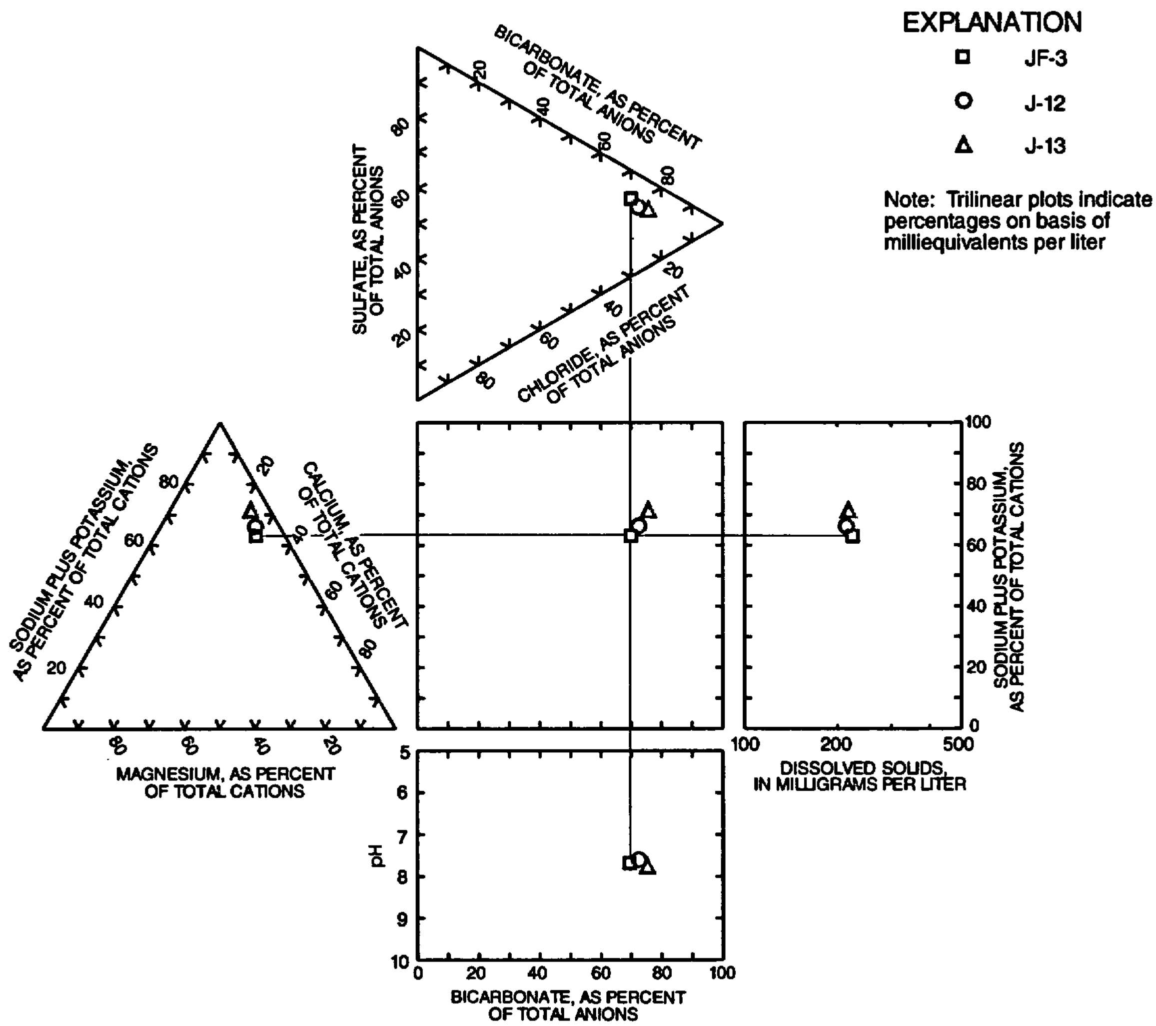

Figure 10. General chemical quality of ground water at wells JF-3, J-12, and J-13, Jackass Flats, Nevada. Data from La Camera and Westenburg (1994, p. 121-123).

and Westenburg, 1994, p. 125). Concentrations of nutrients (several forms of nitrogen and phosphorous) ranged from less than analytical detection limits to about 2.5 mg/L (La Camera and Westenburg, 1994, p. 127). Concentrations of all volatile and semi-volatile organic compounds and pesticides that were sampled for at the three wells were below analytical detection limits (La Camera and Westenburg, 1994, p. 131-155).

Concentrations of total coliform bacteria, iron, and zinc differed substantially in water from the three wells. Concentrations of total coliform bacteria were about 10-20 times higher at well JF-3 (La Camera and Westenburg, 1994, p. 121). Total iron concentrations were about three times higher at well JF-3 than they were at the other two wells, and zinc concentrations were about five to six times lower (La Camera and Westenburg, 1994, p. 125). These differences may be the result of suppressed bacterial populations at water-supply wells J-12 and J-13 (resulting from occasional chlorination of those wells), contamination of water samples by metallic well casing, pumps, and pipes in the wells, or contamination at well JF-3 from other materials used during drilling and testing operations.

The chemical similarity of ground water at well JF-3 with that at wells J-12 and J-13 supports the possibility that water from the three wells is from the same hydraulically connected aquifer.

SUMMARY

Pumping of ground water at wells J-12 and J-13 in Jackass Flats to support the Yucca Mountain Site-Characterization Program has caused concern that water levels and springflow eventually may be affected in the Ash Meadows and Death Valley National Park areas. As a result, the U.S. Department of Energy and U.S. Geological Survey have begun monitoring ground-water levels and springflow in the Yucca Mountain region. Well JF-3 was drilled in the western part of Jackass Flats to provide a means of (1) monitoring water levels in the Topopah Spring Tuff downgradient from the pumping wells, (2) measuring the hydraulic properties of the Topopah Spring Tuff, and (3) determining the likelihood of a hydraulic connection between well JF-3 and the pumping wells.

The borehole for JF-3 penetrated 480 ft of alluvium and 818 ft of underlying volcanic rock. The total depth was 1,298 ft below land surface. The well was finished at a depth of 1,138 ft, which was estimated from lithologic and geophysical logs to be near the base of the Topopah Spring Tuff.

The principal volcanic-rock aquifer in the western part of Jackass Flats is the Topopah Spring Tuff. At well JF-3, the Topopah Spring Tuff consists mostly of moderately to densely welded, vitric and devitrified ash-flow tuffs with a total thickness of 560 ft. Moderately to densely welded, devitrified ash-flow tuff extends from about 600 ft to 1,040 ft below land surface. Fractures and lithophysae are common in this sequence of devitrified tuff, and much of the water produced in well JF-3 probably comes from the interval between depths of about 710 ft (the static water level at JF-3) and 1,040 ft. An independent analysis of geophysical logs indicates that below the static water level, an interval in the Topopah Spring Tuff with the greatest potential for producing water extends from depths of 710 ft to 795 ft. A tracer-injection test at well J-12 indicates that an interval in about the same part of the Topopah Spring Tuff at that location also was found to have a high potential for producing water.

Water levels at wells J-12 and JF-3 respond to changes in atmospheric pressure, and the barometric efficiency of both wells is estimated to be about 1. Water levels measured at the two wells between January and March 1992 were corrected for the effects of atmospheric pressure. Corrected water levels at well J-12 fluctuated 0.1-0.4 ft during periods of a few days to 2 weeks from late January to early March 1992. Corrected water levels at well JF-3 fluctuated similarly from February 26 to March 2, 1992. These fluctuations may have been the result of pumping at well J-13.

Long-term monitoring of water levels at well JF-3 began in late May 1992. Since then, pumpage from wells J-12 and J-13 has continued to supply water needs in Jackass Flats. From June 1992 to December 1993, corrected water levels at well JF-3 fluctuated 0.2 to 0.7 ft over periods of a few hours to a month. Some of these short-term fluctuations, especially those of a few hours duration, generally correspond with nearby earthquakes. From June 1992 to December 1993, corrected water levels at well JF-3 also gradually rose or declined 0.2 to 0.3 ft over periods of months. These long-term rises and declines generally correspond to combined monthly pumpage at wells J-12 and J-13. The water-level rises and declines and the similar water quality at the three wells suggest that JF-3 is hydraulically connected to wells J-12 and J-13. Long-term monitoring of water levels at JF-3 and more detailed pumping records for J-12 and J-13 would be useful for determining the extent of the connection.

Results of an aquifer test at well JF-3 on March 4-5, 1992, indicate that the Topopah Spring Tuff has a transmissivity of 140,000-160,000 ft^2/d and a hydraulic conductivity of 330-370 ft/d. These values exceed estimates made at well J-13 by two orders of magnitude. The difference between the two wells could be a result of differing degrees and intensity of fracturing and development of lithophysae in the Topopah Spring Tuff at the two wells.

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