Water Supply for the Nuclear Rocket Development Station at the U.S. Atomic Energy Commission's Nevada Test Site

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1938

Prepared in cooperation with the U.S. Atomic Energy Commission

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By R. A. YOUNG

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By R. A. Young

ABSTRACT

The Nuclear Rocket Development Station, in Jackass Flats, occupies about 123 square miles in the southwestern part of the U.S. Atomic Energy Commission's Nevada Test Site. Jackass Flats, an intermontane valley bordered by highlands on all sides except for a drainage outlet in the southwestern corner, has an average annual rainfall of 4 inches.

Jackass Flats is underlain by alluvium, colluvium, and volcanic rocks of Cenozoic age and, at greater depth, by sedimentary rocks of Paleozoic age. The alluvium and the colluvium lie above the saturated zone throughout nearly all of Jackass Flats. The Paleozoic sedimentary rocks contain limestone and dolomite units that are excellent water producers elsewhere; however, these units are too deep in Jackass Flats to be economic sources of water.

The only important water-producing unit known in the vicinity of the Nuclear Rocket Development Station is a welded-tuff aquifer, the Topopah Spring Member of the Paintbrush Tuff, which receives no significant recharge. This member contains about 500 feet of highly fractured rock underlying an area 11 miles long and 3 miles wide in western Jackass Flats. Permeability of the aquifer is derived mostly from joints and fractures; however, some permeability may be derived from gas bubbles in the upper part of the unit. Transmissivity, obtained from pumping tests, ranges from 68,000 to 488,000 gallons per day per foot. Volume of the saturated part of the aquifer is about 3.5 cubic miles, and the average specific yield probably ranges from 1 to 5 percent. The volume of ground water in storage is probably within the range of 37–187 billion gallons. This large amount of water should be sufficient to supply the needs of the Nuclear Rocket Development Station for many years.

Water at the Nuclear Rocket Development Station is used for public supply, construction, test-cell coolant, exhaust cooling, and thermal shielding during nuclear reactor and engine testing, and washdown. Present (1967) average consumption of water is 520,000 gallons per day—all supplied by one well. This supply well and a standby well have a production capability of 1.6 million gallons per day—adequate for present needs.

Water in the welded-tuff aquifer is of the sodium bicarbonate type. Dissolved-solids content of the water in Jackass Flats is in the general range 230 milligrams per liter in the western part to 890 milligrams per liter in the eastern part.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The U.S. Geological Survey in cooperation with the U.S. Atomic Energy Commission began an investigation of ground-water supply in the vicinity of the Nuclear Rocket Development Station in Jackass Flats in April 1963. The principal objectives of the investigation were (1) to delineate the welded-tuff aquifer, (2) to identify the chemical quality of water in the aquifer, (3) to estimate the quantity of water in storage and how long the supply would last under the expected rate of use by the Nuclear Rocket Development Station, and (4) to recommend sites for future well development.

LOCATION AND EXTENT OF AREA

The Nuclear Rocket Development Station occupies about 123 square miles of the southwestern part of the U.S. Atomic Energy Commission's Nevada Test Site (fig. 1). The working area of the station extends from the watershed north of Skull Mountain on the east to Fortymile Wash on the west and from Little Skull Mountain on the south to the Calico Hills on the north (pl. 1). The productive area of the welded-tuff aquifer lies along Fortymile Wash in the western part of Jackass Flats. This area is about 3.5 miles wide and 11 miles long.

PREVIOUS WORK

The study area is covered by five 7.5-minute topographic quadrangle maps at a scale of 1:24,000: Topopah Spring SW, Jackass Flats, Skull Mountain, Lathrop Wells, and Striped Hills. The areal geology has been mapped by the U.S. Geological Survey (Burchfiel, 1966; Ekren and Sargent, 1965; Lipman and McKay, 1965; McKay and Burchfiel, 1966a, b; McKay and Williams, 1964).

METHODS OF INVESTIGATION

A geologic map of the southwestern part of the Nevada Test Site was compiled from the previously mentioned geologic quadrangle maps. This map was designed to show major geologic features and the outcrop area of the Topopah Spring Member of the Paintbrush Tuff, a welded-tuff unit of Tertiary age, which is the principal aquifer in the area. The map also shows the approximate area underlain by that part of the aquifer which serves as the ground-water reservoir for the station. Pumping tests to determine the transmissivity of the welded-tuff aquifer were made on the two supply wells (J–12, J–13). Data from the pumping tests and estimates of the volume of the aquifer were used to calculate the long-term supply of water available for use by the Nuclear Rocket Development Station.

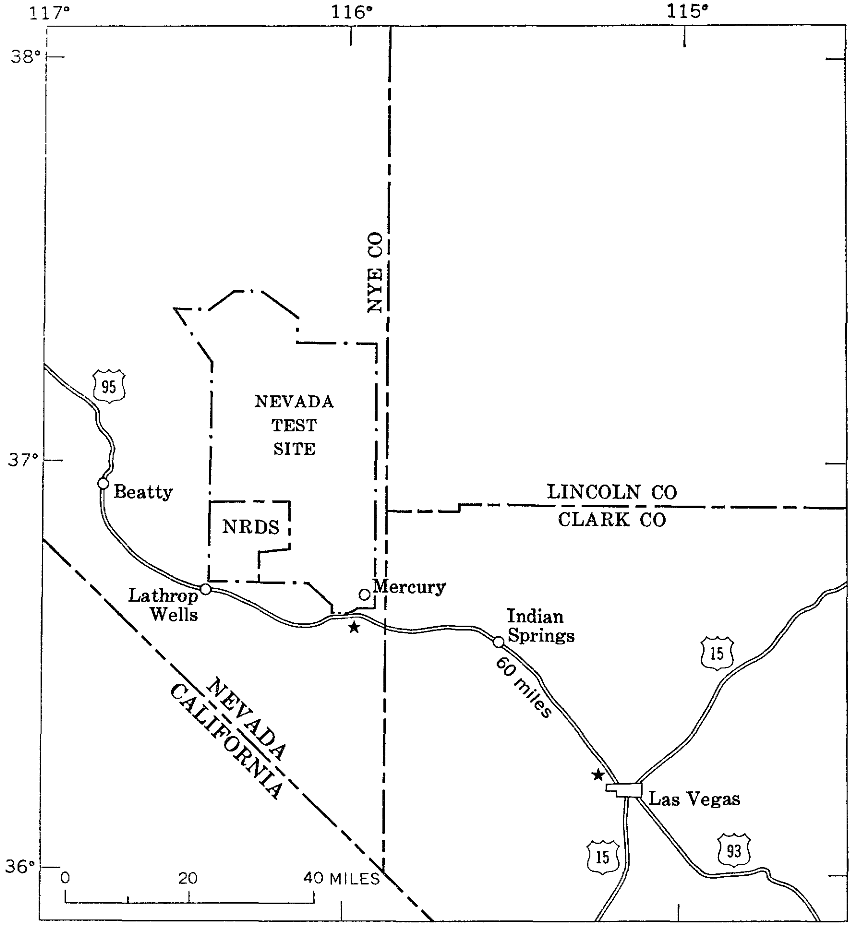

FIGURE 1.—Location of Nuclear Rocket Development Station (NRDS) and Nevada Test Site.

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SURFACE FEATURES, DRAINAGE, AND CLIMATE

Jackass Flats is an intermontane valley bordered by highlands on all sides, except for a drainage outlet in the southwestern corner. The surrounding highlands include Calico Hills, Kiwi Mesa, Skull Mountain, Little Skull Mountain, and Yucca Mountain (pl. 1). Except for several small hills of volcanic rock in the west-central part of Jackass Flats, the valley floor is composed of coalescing alluvial fans and slopewash from the highlands.

Runoff at Jackass Flats drains through a topographic low near the southwest corner of the valley. Ephemeral streams have cut two dry washes, Fortymile Wash and Topopah Wash, that carry water from infrequent thunderstorms. These washes were probably cut during the late Pleistocene when southern Nevada received more precipitation than in Holocene time.

Jackass Flats receives an average annual rainfall of only 4 inches, because most of the area lies within the rain shadow of the Sierra Nevada. Thunderstorms from the south provide summer precipitation. Compared with the eastern part of the Nevada Test Site, Jackass Flats is deficient in rainfall (Ralph F. Quiring, U.S. Weather Bureau, written commun., 1965).

Extreme temperatures at weather station 4JA in the central part of Jackass Flats range from 7° to 110°F. From 1958 to 1965, average daily maximum temperature for January was 54°F, and for July, 97°F; daily minimums were 32° and 68°F, respectively.

Vegetation in Jackass Flats is dominated by a community of Larrea-Franseria (creosotebush-bursage). Higher parts of the fans support shadscale and desertholly (*Atriplex sp*). Many perennials blossom in years when soil moisture and temperature are in optimum combination.

GEOLOGY AND OCCURRENCE OF GROUND WATER

Jackass Flats is underlain by alluvium, colluvium, and volcanic rocks of Cenozoic age and, at greater depth, by sedimentary rocks of Paleozoic age. The distribution of these units is shown on the geologic map (pl. 1). The geologic structure is characterized by folds and thrust faults involving formations of Paleozoic age and by extensive normal faults involving both the Paleozoic rocks and Cenozoic volcanic rocks.

Alluvium and colluvium, derived from slopewash and coalescing alluvial fans, form the uppermost geologic units throughout most of Jackass Flats. There are also patches of dune sand stacked against rock outcrops in the surrounding highlands. The alluvial-colluvial material is composed principally of sand and gravel of Quaternary and late Tertiary ages. The gravel consists largely of cobbles and contains boulders of welded and nonwelded tuff and vesicular basalt; the sand is generally medium coarse, clayey, and tuffaceous. Alluvium and colluvium range in thickness from 425 feet at well J–13 (pl. 1) to 1,025 feet at well J–11. Both units lie above the saturated zone throughout nearly all of Jackass Flats.

Cenozoic volcanic rocks in the area around Jackass Flats have been divided into 13 units (pl. 1). These volcanic flows and tuffs range in composition from rhyolite to basalt. Most of the individual tuff units grade from a vitrophyre at the base through a welded-tuff sequence to ash-fall tuff at the top. Many of the vitrophyres, welded tuffs, basalt flows, and rhyolite flows are sufficiently fractured to be potential aquifers if located below the water table. However, the only important water-producing unit known is the Topopah Spring Member of the Paintbrush Tuff. The ash-fall tuffs generally do not yield significant quantities of water to wells.

The Topopah Spring Member is an ashflow tuff that averages 700 feet in thickness. The upper 35–50 feet is partly welded and somewhat silicified and therefore forms a cap over the permeable section of the member. Three welded units underlie the cap and aggregate 500–600 feet of highly fractured rock that forms the aquifer. Outcrops of the member are broken by at least four systems of joint planes and are highly fractured; if the productivity of the wells is an indication, fractures are as numerous in the subsurface. The botton unit of the Topopah Spring Member, a nonwelded tuff about 30 feet thick, has low permeability. The tuffs of Crater Flat, which crop out in the south scarp of Little Skull Mountain and in the central part of Yucca Mountain (pl. 1), contain about 45 feet of welded tuff that should underlie the southern part of Jackass Flats. This unit may be 1,500 feet below the Topopah Spring Member and thus may be beyond the economic reach of wells.

Sedimentary rocks of Paleozoic age underlying Jackass Flats and the surrounding hills are predominantly carbonate rocks and quartzite. Although the carbonate rocks are excellent water producers elsewhere, in Jackass Flats these units are considered to be too deep to be economic sources of water. Because no wells have been drilled into the Paleozoic rocks in Jackass Flats, their depth can only be inferred from gravity measurements, which indicate depths of 3,500–7,600 feet. Well J–13, drilled to a depth of 3,488 feet, did not penetrate any Paleozoic rocks.

The water table lies near the top of the principal aquifer (Topopah Spring Member) in two of the three production wells (J–12, J–13) at Jackass Flats. In the third well (J–11) the water table lies within the basalt of Kiwi Mesa about 100 feet above the top of the Topopah Spring Member.

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HYDROLOGY OF THE WELDED-TUFF AQUIFER

Water for the Nuclear Rocket Development Station is obtained from the units of welded tuff of the Topopah Spring Member; hereafter, this aquifer is referred to as the welded-tuff aquifer. This unit is the only aquifer of economic importance in Jackass Flats.

AREAL EXTENT AND SATURATED THICKNESS

The saturated part of the welded-tuff aquifer underlies a strip about 11 miles long and 3.5 miles wide in the Fortymile Wash area of western Jackass Flats (pl. 1). This 38-square-mile strip is elongate in a north-south direction and is roughly parallel to Fortymile Wash. The limits of the aquifer were estimated from surface geology and drilling and (or) were inferred from hydraulic boundaries identified from aquifer tests.

Plate 1 shows a cross section through the welded-tuff aquifer—the longer north-south dimension of the aquifer. The western boundary of the aquifer is interpreted as a north-south-trending normal fault, or a series of step faults, east of Busted Butte and Long Ridge (pl. 1) because the top of the Topopah Spring Member at well J–13 lies about 900 feet lower than at outcrops on Long Ridge, a lateral distance of 1 mile. Alluvium, however, obscures any faults that may exist. The outcrops of the unit well above the water table certainly limit the westward extent of the aquifer. The eastern boundary is also interpreted to be a north-south-trending normal fault concealed by alluvium. Again, the outcrops of the unit above the water table certainly limit the eastward extent of the aquifer in the Fortymile Wash area. The northern boundary of the aquifer is apparently an upwarp that causes the welded tuff to occur above the water table between well J–13 and the Calico Hills (pl. 1, section *A–A′*). The location and nature of the southern boundary of the welded-tuff aquifer are uncertain. The aquifer may simply dip to the south below saturated alluvium and wedge out (pl. 1, section *A–A′*), or there may be a normal fault with the aquifer downfaulted to the south.

In summary, the welded-tuff aquifer in the vicinity of Fortymile Wash appears to occupy a graben with fault boundaries on the east and west sides, which is a typical structural feature in the Basin and Range province. The welded tuff crops out above the water table in the northern, eastern, and western sides of the area, and it probably wedges out in the subsurface to the south. The aquifer, therefore, is a tabular body of finite dimensions. Average saturated thickness of the productive interval is estimated to be 500 feet, and the volume of the saturated part of the aquifer is therefore estimated to be 3.5 cubic miles.

Ground water has also been obtained from the welded tuff at well J–11, which is east of the Fortymile Wash graben (pl. 1).

RECHARGE, MOVEMENT, AND DISCHARGE

Recharge to the welded-tuff aquifer probably is negligible, owing to the low annual rainfall and the high evaporation rate in southern Nevada. Jackass Flats has an average annual rainfall of 4 inches; in the highlands surrounding Jackass Flats, rainfall may be as much as 8 inches. Evaporation rates are very high. No figures for evaporation in the Nuclear Rocket Development Station area are available, but pan evaporation at Boulder City, Nev., 100 miles to the southeast, is 113 inches annually (U.S. Weather Bureau). Evaporation rates in Jackass Flats and in the surrounding area, where the welded-tuff aquifer crops out, probably are similar. A small amount of water from thunderstorms penetrates fractures in outcrops of the welded-tuff aquifer to a sufficient depth to escape immediate evaporation. Recharge to the welded-tuff aquifer is sufficient to maintain a gentle hydraulic gradient to the south. The apparent water-table gradient shown on section A–A′ (pl. 1) suggests some ground-water inflow from the north, but the quantity may be small. A small amount of recharge may be possible from Timber and Yucca Mountains to the west, but the presence of numerous faults makes the hydraulic connection with the main part of the aquifer tenuous at best. Thus, water pumped from wells tapping the welded-tuff aquifer is derived primarily from storage within the aquifer.

Ground water in the welded-tuff aquifer apparently moves southward toward Lathrop Wells (pl. 1) and ultimately to discharge points in the Amargosa River valley in California (I. J. Winograd and others, written commun., 1968). This southward direction of movement is suggested by the hydraulic gradient and the water-quality data.

A hydraulic gradient appears to exist between wells J–13 and J–12, which tap the welded-tuff aquifer in Fortymile Wash, and wells tapping the alluvium in the Lathrop Wells area. Elevations of the water table are 2,390 feet at well J–13; 2,387 feet at well J–12; and 2,313 feet at well 15S/50–18c5 (pl. 1). The apparent hydraulic gradient between wells J–13 and J–12 is about 1 foot per mile, whereas that between J–12 and well 15S/50–18c5, which taps alluvium, is about 8 feet per mile. The apparent steepening of the hydraulic gradient could be caused by a lower permeability in the alluvium than in the tuff, which would result in a change in gradient where the tuff was in lateral contact with the alluvial aquifers. The similarity in chemical quality between water from the tuff and water from the alluvium (table 4) suggests a hydraulic connection between the tuff and the alluvium.

The amount of water actually moving from the tuff aquifer into the alluvium probably is small.

Upward movement of water from deep Paleozoic carbonate aquifers into the welded-tuff aquifer is a possibility. Such movement could occur if hydrostatic heads in the carbonate aquifers are higher than those in the welded-tuff aquifer. However, such upward movement is extremely unlikely because (a) the head difference, if it exists, is probably very small (I. J. Winograd and others, written commun., 1968); (b) the thick tuff section of low permeability underlying the welded-tuff aquifer would impede such movement; and (c) the chemical quality of water from the welded tuff shows no evidence of being a mixture of water from carbonate and tuff aquifers.

HYDRAULIC CONDUCTIVITY, TRANSMISSIVITY, AND SPECIFIC CAPACITY

The hydraulic conductivity of the welded-tuff aquifer is largely due to joints and fractures, that is, from secondary openings. However, some permeability may be due to primary interstitial openings, particularly those formed by gas bubbles in the upper part of the welded tuff. The transmissivity depends on number, position, and interconnection of joints, fractures, and gas bubbles and also on the degree to which these openings have been filled with mineral matter. Outcrops of the welded tuff show that some of the openings are partly filled by deposition of silica and silicates.

As in most fractured formations, the hydraulic conductivity of the welded-tuff aquifer varies both vertically and horizontally. Thus, it is unrealistic to convert values for the transmissivity, quoted in this report, to average values for hydraulic conductivity.

The values for the transmissivity of the welded-tuff aquifer, obtained from pumping tests at wells J–12 and J–13, are 68,000, 170,000, and 488,000 gpd per ft (gallons per day per foot). The wide range in values of transmissivity is primarily due to variations of hydraulic conductivity within the aquifer. I. J. Winograd and others (written commun., 1968) postulate extensive compartmentalization of fractured aquifers in southern Nevada. The effect of this compartmentalization is to divide an aquifer into a mosaic of blocks; generally within each block, transmissivity is believed to be relatively constant. However, adjacent blocks and intervening fault zones may have very different transmissivities. Such compartmentalization generally makes the analysis of pumping test data (drawdown and recovery curves) difficult, owing to the presence of many hydraulic boundaries. However, the data from long-term pumping tests can be used to interpret the limits of an aquifer—the limits showing up as discharge (negative) hydraulic boundaries on drawdown and recovery curves. When the cone of depression from a pumping well intercepts a discharge (negative) boundary, the drawdown rate is increased. This increase is shown by a steepening of slope on a semilogarithmic plot of drawdown versus time.

A pumping test on well J–13 (Feb. 18–22, 1964) illustrates the hydraulic effect of discharge boundaries in the welded-tuff aquifer. A plot of drawdown versus time for this test is shown in figure 2. A transmissivity value of 68,000 gpd per ft for the welded-tuff aquifer in the vicinity of the pumping well was determined by applying the modified nonequilibrium formula of Jacob (1950) to the initial limb of the curve (1–250 min). The break in slope observed at 250 minutes could represent the effect of the cone of depression intercepting a fault, possibly the western boundary fault of the aquifer. Likewise, the break

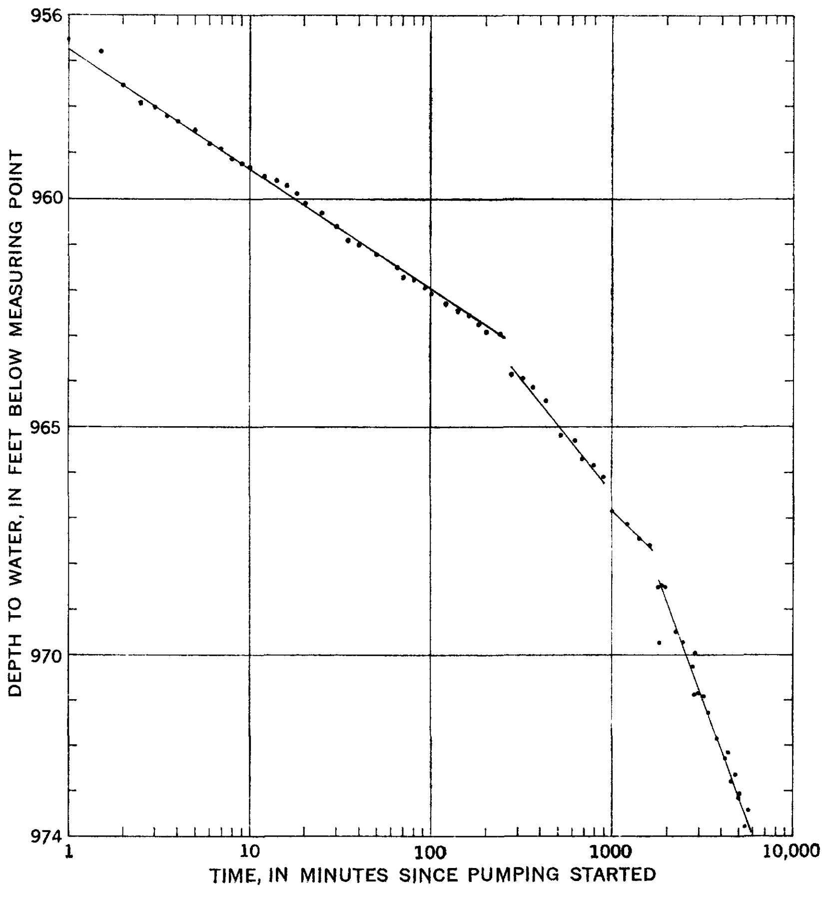

FIGURE 2.—Drawdown versus time during pumping test in well J–13, February 18–22, 1964. Average discharge rate, 697 gpm.

in slope at about 1,800 minutes could represent the effect of some more distant boundary of the aquifer, possibly to the north.

Specific capacity of a well (yield in gallons per minute divided by drawdown in feet or gallons per minute per foot) is influenced primarily by aquifer transmissivity. However, specific capacity may also be greatly influenced by well construction, well development, and aquifer boundaries.

The specific capacity of well J-12 (see table 1 for well data) is 148 gpm per ft (gallons per minute per foot) (computed from a pumping test in which the pumping rate was 370 gpm and the drawdown was 2.5 ft after 5,000 min July 1965). Because of the length of the test, the computed values include the effects of the aquifer boundaries.

TABLE 1.—*Summary of data on production wells J-11, J-12, and J-13, Nuclear Rocket Development Station, Jackass Flats, Nev.*

	J-11	J-12	J-13
Location (Nevada coordinates, central zone, in feet).	N. 740, 969. 26 E. 611, 766. 08	N. 733, 508. 63 E. 581, 011. 06	N. 749, 209 E. 579, 651
Elevation of land surface (in feet above mean sea level).	3, 442. 8	3, 128. 4	3, 318
Total depth (in feet)	1, 330	887	3, 488
Date spudded Date completed	June 4, 1957 July 19, 1957	Aug. 4, 1957 Oct. 9, 1957	September 1962 January 1963
Drilling contractor	Perry Bros. Drilling Co., Flagstaff, Ariz.	Perry Bros. Drilling Co., Flagstaff, Ariz.	Western-Republic Drilling Co., Lubbock, Tex.
Drilling method	Cable tool	Cable tool	Rotary-air
Casing record (cased interval, in feet; outside diameter of casing in inches).	*Casing* *O.D.* 0-1, 330 12¾	*Casing* *O.D.* 0-887 12¾	*Casing* *O.D.* 0-2. 5 30 0-435 18 0-1, 301 13⅜ 1, 301-1, 546 11¾ 1, 484-3, 385 5½
Perforated interval (in feet)	1, 076-1, 096 1, 244-1, 300	793-868	996-1, 301 (jet perforated) 1, 090-1, 301 (gun perforated) 1, 301-1, 390 (gun perforated) 2, 690-3, 312 (machine cut openings)
Aquifer	Basalt of Kiwi Mesa and welded tuff (Topopah Spring Member of Paintbrush Tuff)	Welded tuff (Topopah Spring Member of Paintbrush Tuff)	Welded tuff (Topopah Spring Member of Paintbrush Tuff)
Static water level (in feet below land surface). Date of measurement	1, 040. 6 Aug. 16, 1962	741. 4 Jan. 27, 1960	926. 7 Dec. 30, 1962

Specific capacities calculated from well J-13 (see table 1 for well data) from several pumping tests are as follows:

Date	Duration of test (minutes)	Discharge (gallons per minute)	Drawdown (feet)	Specific capacity (gallons per minute per foot)
December 1960	180	300	9.3	32.3
Do	180	350	12.4	28.3
Do	180	430	19.0	22.6
Do	2,795	430	25.9	16.6
February 1964	5,765	697	43.3	16.0

Differences in values of specific capacities result from the effects of both aquifer boundaries and well construction. The three short tests gave the highest values because the tests were discontinued before the effects of aquifer boundaries and resulting increased rate of drawdown could be felt. The differences in values of specific capacities obtained from the three short tests were interpreted as being attributable predominantly to the effect of well construction. The casing in well J–13 was perforated twice—first with 0.5-inch bullets, many of which did not penetrate the casing, and second with 2-inch jet perforations (1 per 10 ft). The percentage of the casing wall area containing perforations is not known. Increasing the pumping rate of the well, however, causes a disproportionate increase in drawdown. This increase indicates that head losses at the perforations are high and that the effective area of perforations is probably small.

GROUND-WATER STORAGE AND LONG-TERM YIELD OF THE AQUIFER

Water supplied to wells tapping the welded-tuff aquifer is derived from storage in the aquifer. Recharge to the aquifer is probably insignificant. Thus, any water pumped from the aquifer is being "mined," and the long-term yield of the aquifer is dependent on the amount of water available from storage.

Theoretically, the amount of usable ground water in storage is simply the volume of the aquifer multiplied by the average specific yield of the aquifer. The **specific yield** is the ratio of the volume of water an aquifer will yield by gravity to the total volume of the aquifer, expressed as a percentage (Meinzer, 1923, p. 28). The specific yield, which has been used interchangeably with the term **effective porosity**, is thus the percentage of aquifer volume occupied by openings that actually transmit water. **Total porosity** is the percentage of aquifer occupied by all openings—both water-transmitting openings and isolated voids.

Volume of the aquifer has been estimated to be about 3.5 cubic miles, or 526.9 billion cubic feet.

It was not possible to determine the average specific yield of the welded-tuff aquifer during the investigation; however, accumulated pumping of the aquifer and changes in water level suggest that specific yield is probably in the range of 1–5 percent. Although the interstitial porosity of the welded-tuff aquifer, determined from laboratory analysis of cores taken in well J–13, ranges from 2.7 to 8.7 percent, laboratory values of porosity may bear little relationship to the effective porosity (or specific yield) of a fractured formation. The reason for this discrepancy is that porosity values of cores are based on the volume of tiny interstitial openings, which are not effective transmitters of water, rather than on the joints and fractures, which are the principal water-transmitting openings.

Table 2 shows estimates of the amount of theoretically usable ground water in storage in the welded-tuff aquifer. It is assumed that a system of wells could be installed to dewater a large volume of the aquifer. Specific yields of 1 and 5 percent were used in the calculations. The table also shows the amount of water in storage per foot of aquifer and the estimated extent of dewatering (in feet) after 5 years of pumping at rates of 500, 1,000, and 1,500 gpm. From the data in table 2, the length of time required to dewater the 500-foot saturated thickness of the aquifer can be estimated. For example, assuming a specific yield of 5 percent, an average pumping rate of 1,000 gpm would dewater the aquifer in about 380 years. If the specific yield were 1 percent, pumping at the same rate (1,000 gpm) would dewater the aquifer in about 76 years.

The amount of dewatering (water-level decline) to 1967 indicates that the specific yield is probably closer to 5 percent than 1 percent. Table 3 shows water levels in wells J–11, J–12, and J–13 in Jackass Flats. The measurements in wells J–12 and J–13 are of special interest

TABLE 2.—*Ground-water storage in the welded-tuff aquifer (Topopah Spring Member) beneath western Jackass Flats*

Specific yield (percent)	Amount of ground water in storage (cubic feet) [1]	Amount of water in storage per foot of aquifer		Extent of dewatering in feet after 5 years' pumping at an average rate of —[2]		
		Gallons	Cubic feet	500 gpm	1,000 gpm	1,500 gpm
1	5, 270, 000, 000	78, 800, 000	10, 500, 000	16. 6	33. 2	49. 8
5	26, 350, 000, 000	394, 100, 000	52, 700, 000	3. 3	6. 6	9. 9

[1] Aquifer volume estimated at 526.9 billion cubic feet (assuming length of 10.8 miles, width of 3.5 miles and saturated thickness of 500 ft).

[2] Assumes mining of water and no recharge across boundaries.

because these wells tap the welded-tuff aquifer in the Fortymile Wash area. Well J–13 shows a water-level decline of about 2 feet during the period 1962–67. The average pumping rate from wells J–12 and J–13 during this same 5-year period is not precisely known, but it is estimated to be 500,000 gpd, or 350 gpm. Thus, about 900 million gallons of water was probably removed from storage from 1962 to 1967. The removal of this amount of water and the estimated extent of dewatering (water-level decline of 2 ft) during this 5-year period indicate a specific yield of more than 5 percent. This value of the specific yield is probably conservative because it is based on the assumption that the observed water-level decline in well J–13 occurred throughout the aquifer.

TABLE 3.—*Water levels in wells J–11, J–12, and J–13 at Jackass Flats*

Well	Date	Time of day	Depth to water level below land surface (feet)
J–11	1–27–58		1,039.1
	3–15–61	1135	1,042.1
	3–15–61	1155	1,042.3
	3–22–61	1543	1,041.9
	4–10–61	1130	1,041.5
	8–16–62	1000	1,040.6
	11–27–63	1205	1,041.7
	2–19–64	1415	1,040.0
	2–19–64	1435	1,040.3
J–12	1–27–60		741.4
J–13	12–30–62	0505	926.7
	1– 1–63	1050	926.8
	1– 1–63	1715	926.8
	2– 4–63	1510	926.3
	2– 4–63	1520	927.8
	2– 4–63	1535	927.7
	11–27–63	1515	928.0
	12–17–63	1025	927.9
	12–19–63	1310	928.8
	2– 4–64	1600	927.5
	2– 7–64	1121	928.0
	3–31–64	1405	924.7
	3–11–67	0945	928.8

The preceding discussion of the amount of usable ground water in storage assumes no movement of ground water from outside sources into the welded-tuff aquifer. However, the possibility exists that prolonged pumping in the welded-tuff aquifer will induce recharge from alluvial aquifers to the south. As discussed in the section on "Recharge, Movement, and Discharge," ground water probably moves south from the tuff aquifer into alluvial aquifers in the Lathrop Wells area (pl. 1).

The present (1967) apparent hydraulic gradient slopes to the south, and the head decreases about 77 feet between the tuff (well J–13) and the alluvial aquifers (well 15S/50–18c5). However, if prolonged pumping caused water levels in the tuff aquifer to drop below water levels in the alluvium, the gradient would be reversed, and water could move from the alluvium into the welded-tuff aquifer. Because of this possibility of inducing recharge from the alluvium, estimates of the long-term yield of the welded-tuff aquifer (table 2) should be considered conservative. Induced inflow from other directions probably would be small because of the likelihood that low-permeability rocks would be in lateral contact with the welded-tuff aquifer along faults.

If future reappraisals of the long-term yield of the aquifer are to be meaningful, accurate pumpage records must be maintained and periodic water-level measurements must be made.

CHEMICAL QUALITY OF THE GROUND WATER

Although wells J–11, J–12, and J–13 tap the same aquifer, water from Jackass Flats is of two types. Water from well J–11 in the eastern part of Jackass Flats is a sodium sulfate type; water from wells J–12 and J–13 in the Fortymile Wash area is a sodium bicarbonate type (see table 4). In addition, the dissolved-solids content of three water samples from well J–11 ranges from 883 to 893 mg/l (milligrams per

TABLE 4.—*Chemical constituents of ground water*

[Results in milligrams per liter, except as indicated;

Well	Nevada coordinates (feet)	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Selenium (Se)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)
J-11	N. 738,968; E. 611,764.	67	0.1	0.11	0.00	85	14	157	16	-----	102	0	484	20
	do	67	.1	[1].00	.00	84	13	154	16	-----	104	0	479	18
	do	68	.1	.13	.00	82	13	143	15	-----	102	0	449	18
J-12	N. 733,509; E. 581,011.	26	-----	-----	-----	9.6	1.9	46	5.2	-----	121	0	24	7.0
	do	49	-----	-----	-----	14	1.5	42	4.4	-----	118	0	24	8.0
	do	60	.13	.10	.00	14	2.5	39	6.0	-----	119	0	19	8.8
	do	56	[2].00	[2].05	[2].00	17	.9	40	4.6	-----	120	0	21	7.4
J-13	N. 749,209; E. 579,651.	57	.03	.16	.24	14	2.4	46	6.6	0.03	124	0	25	8.4
	do	58	[2].03	[2].04	[2].11	14	1.8	48	5.0	-----	136	0	23	7.4
15S/49-22a1	---------------	52	.1	[1].09	.00	25	2.4	41	5.2	-----	145	0	33	8.0
15S/50-18c5	---------------	45	.0	.67	-----	21	2.9	103	6.0	-----	162	0	122	18

[1] In solution at time of analysis.

liter), whereas the dissolved-solids content of water from wells J–12 and J–13 to the west ranges from 169 to 229 mg/1 and 230 to 242 mg/1, respectively. Water from well J–11 more closely resembles water from the carbonate aquifers elsewhere on the Nevada Test Site than it does the water from the wells in Fortymile Wash (I. J. Winograd and others, written commun., 1968). The water from well J–11 probably had its origin in the Paleozoic rocks that underlie the eastern part of Jackass Flats.

The volcanic rocks of the Calico Hills and the area surrounding Wahmonie Flat show many sings of hydrothermal alteration. Silicification, alunitization, and kaolinization are evident in the rhyolitic lavas and tuffs of the Calico Hills and in the andesitic tuffs of the Wahmonie Formation of Tertiary age. Presumably, the waters responsible for the alterations in these rocks are still to be found at depth under the eastern part of Jackass Flats. Water in the welded-tuff aquifer tapped by wells J–12 and J–13 is a sodium bicarbonate type and is similar chemically to many of the other waters from volcanic tuffs at the Nevada Test Site. Comparison of chemical quality shows that water from well J–13 does not differ greatly from water from J–12 despite the proximity of J–13 to the Calico Hills. This fact would indicate that the altered rhyolites in the Calico Hills are not readily dissolved

from wells in Jackass Flats and surrounding area

NRDS, Nuclear Rocket Development Station]

Fluoride (F)	Nitrate (NO_3)	Orthophosphate (PO_4)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$		Specific conductance at 25°C (micromhos)	pH	Percent sodium	Sodium adsorption ratio	Date sampled	Water-bearing formation	Location	Type of water	Denver lab. No.
				Calcium, magnesium	Noncarbonate									
0.9	7.4	0.00	893	270	186	1,210	7.8	54	4.16	9-18-57	Paintbrush Tuff	NRDS	Na_2SO_4	2,166
1.0	5.8	.00	882	263	178	1,200	8.0	54	4.13	4-24-58	---do-------	NRDS	Na_2SO_4	2,516
1.1	3.0	.00	883	258	174	1,180	7.6	53	3.86	12-16-58	---do-------	NRDS	Na_2SO_4	3,009
1.8	.0	.00	169	32	0	266	8.2	72	3.54	4-25-58	---do-------	NRDS	$NaHCO_3$	2,508
1.8	.7	.00	206	41	0	276	7.4	66	2.85	2-19-59	---do-------	NRDS	$NaHCO_3$	3,122
1.2	7.7	.12	197	45	0	252	8.0	----	2.53	3-31-62	---do-------	NRDS	$NaHCO_3$	4,756
2.2	5.3	.00	229	46	0	287	6.8	----	-----	5-26-64	---do-------	NRDS	$NaHCO_3$	65-9
2.0	5.6	.12	242	45	0	285	7.0	----	2.98	1- 1-63	---do-------	NRDS	$NaHCO_3$	5,027
2.4	4.5	.00	230	43	0	303	6.8	----	-----	5-25-64	---do-------	NRDS	$NaHCO_3$	65-7
1.4	3.5	.00	233	72	0	336	8.0	53	2.25	4-24-58	Quaternary alluvium	Amargosa Desert	$NaHCO_3$	2,515
1.4	6.9	.00	408	64	0	863	7.9	76	-----	6-26-59	---do-------	---do-------	$NaHCO_3$–Na_2SO_4	3,314

[2] In solution at time of collection.

by the ground water or, more likely, that recharge from the Calico Hills is negligible.

Wells in the alluvium down the trace of Fortymile Wash in the Amargosa Desert produce water with chemical constituents in the same general proportions as in water from well J–12 (see table 4, well 15S/49–22a1). This fact suggests that the waters in the welded-tuff aquifer and in the alluvial aquifer in the Fortymile Wash are hydraulically connected. However, the concentration of dissolved constituents in water from wells less than 2 miles east of Fortymile Wash (see table 4, analysis for well 15S/50–18c5) is intermediate between that of the waters in J–11 and J–12 (dissolved-solids content: J–11, about 890 mg/l; J–12, in the range 169 to 229 mg/l; 15S/50–18c5, 408 mg/l). These data suggest that well 15S/50–18c5 could receive some water from the Paleozoic carbonate rocks.

Minor constituents of interest in the water from wells J–12 and J–13 are fluoride and selenium.

Recommended limits for fluoride in public water supplies shown in the following table were set by the U.S. Public Health Service (1962, p. 8) and are dependent on daily average temperatures of the area.

Annual average of maximum daily air temperature, in degrees Fahrenheit	Recommended limits of fluoride concentration, in milligrams per liter		
	Lower	Optimum	Upper
50.0–53.7	0.9	1.2	1.7
53.8–58.3	.8	1.1	1.5
58.4–63.8	.8	1.0	1.3
63.9–70.6	.7	.9	1.2
70.7–79.2	.7	.8	1.0
79.3–90.5	.6	.7	.8

The amount of fluorides in the waters from wells J–12 and J–13 are two to three times higher than the optimum shown for the highest temperature listed in the preceding table.

Selenium is recognized as being toxic to both man and animals. Published recommendations of the U.S. Public Health Service (1962, p. 52) limit the concentration of selenium in all water intended for human consumption to 0.01 mg/l. One sample of water from Jackass Flats had a selenium content of 0.03 mg/l (table 1 well J–13). This one sample does not necessarily imply that selenium in drinking water is a general problem at Jackass Flats. However, it does suggest that water quality should be carefully monitored if water is to be developed further for drinking.

WATER SUPPLY AT NUCLEAR ROCKET DEVELOPMENT STATION

This section of the report describes the well-construction program and the present utilization of the water supply, and, based on the previous evaluation of the long-term yield of the aquifer, makes recommendations for future ground-water development.

WELL UTILIZATION

Well J–11, in eastern Jackass Flats (pl. 1), produced water from the basalt of Kiwi Mesa and from the welded-tuff aquifer. In a 4-day pumping test, the well produced water at a rate of 105 gpm with a drawdown of 40 feet for a specific capacity of 2.6 gpm per ft of drawdown. In 1962 the production of well J–11 declined because of casing corrosion. The casing was reperforated using shaped-propellant jet charges that ruptured the casing. The well was finally abandoned because of this and because of the poor chemical quality of the water (sulfate content of 479 mg/l).

Well J–12, in the Fortymile Wash area of western Jackass Flats (pl. 1), produces water from the welded-tuff aquifer. In a 4-day pumping test, the well produced water at a rate of 370 gpm with a drawdown of 2.5 feet for a specific capacity of 148 gpm per ft. Use of a pump having twice the present capacity (370 gpm) is possible. Well J–12 has been placed on standby status.

Well J–13, also in the Fortymile Wash area of western Jackass Flats (pl. 1), produces water from the welded-tuff aquifer. Most of the water produced by well J–13 enters the well from the interval between 1,070 and 1,310 feet. The tuff units below 1,310 feet, tested by swabbing, had a specific capacity of less than 0.6 gpm per ft (A. C. Doyle and G. L. Meyer, written commun., 1963). In 1967 the production capability of well J–13 was 770 gpm. During a 4-day pumping test in February 1964, the well produced water at a rate of 697 gpm with a drawdown of 43.3 feet for a specific capacity of 16.0 gpm per ft. All the water used at the Nuclear Rocket Development Station is supplied by well J–13.

UTILIZATION OF WATER SUPPLY

Water is used for public supply, construction, test-cell coolant, exhaust cooling and thermal shielding during nuclear reactor and engine testing, and washdown at the Nuclear Rocket Development Station.

The average consumption in 1967 was 522,000 gpd, and peak consumption was 720,000 gpd—all supplied by well J–13 which is capable of producing 770 gpm (1 mgd). Well J–12 can supply an additional 370 gpm (530,000 gpd).

The combined production capabilities of wells J–12 and J–13 are thus about 1,100 gpm (about 1.6 mgd). The installation of a pump with twice the present capacity of the pump in well J–12 would increase the combined production capability of wells J–12 and J–13 to about 1,500 gpm. Although 1,500 gpm will supply sufficient water for the anticipated expansion at the Nuclear Rocket Development Station through 1971, continuous operation of both wells would be required to maintain such a yield.

FUTURE DEVELOPMENT

To supply the estimated requirement for 1,500 gpm of water by 1971 and to provide a standby well for use if either J–12 or J–13 should have to be shut down, a third production well should be constructed in the welded-tuff aquifer. This well should be drilled about 3,000 feet north or 3,000 feet south of well J–12 (pl. 1). A well completely penetrating the welded-tuff aquifer at these locations should produce about 1,000 gpm.

Long-term development of ground water at the Nuclear Rocket Development Station depends on the volume of ground water available from storage in the welded-tuff aquifer. The volume of ground water in storage is estimated to range from 5 to 25 billion cubic feet, or 37 to 187 billion gallons. This large amount of water should be sufficient to supply the needs of the Nuclear Rocket Development Station for many years. With the installation of another well, as suggested above, it is expected that a total draft of 1,500 gpm by 1971 should lower the water level over a wide area, or dewater the aquifer, at an estimated rate of 10–50 feet in 5 years (table 2). Assuming no recharge to the aquifer, the ground-water reservoir would be depleted in 50–250 years. Of course, if future pumping rates exceed 1,500 gpm, the ground-water reservoir would be depleted in proportionally less time.

The possibility exists that extensive dewatering of the welded-tuff aquifer will induce recharge from alluvial aquifers to the south. Such recharge would decrease the rate of dewatering and thus prolong the life of the aquifer.

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