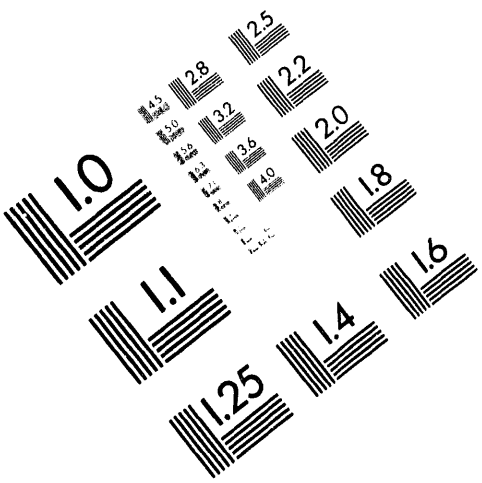

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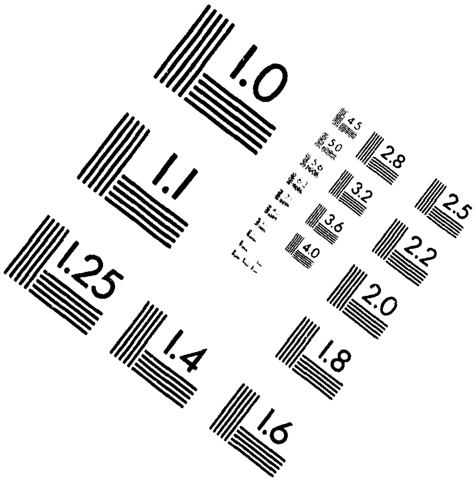

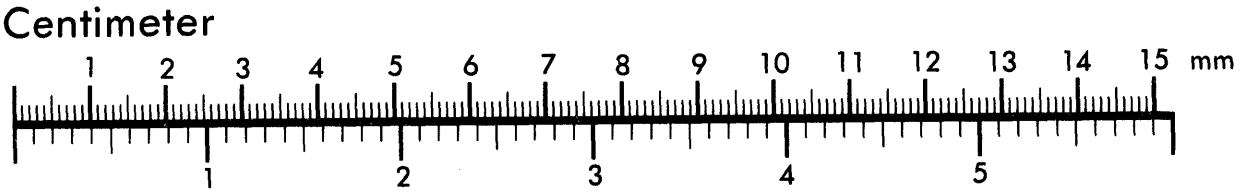

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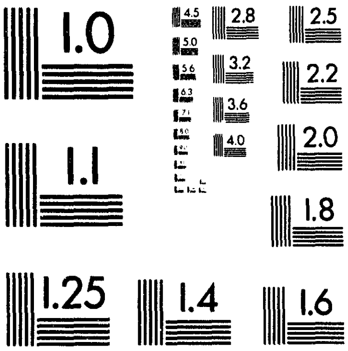

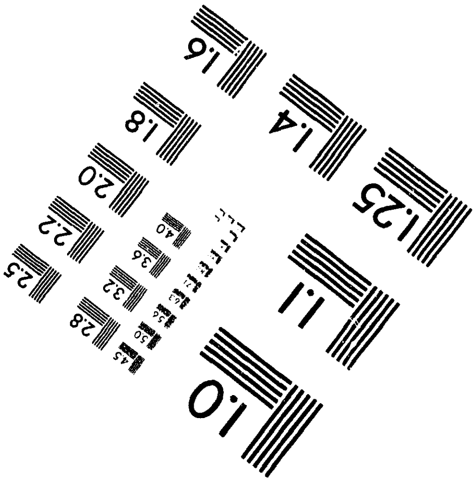

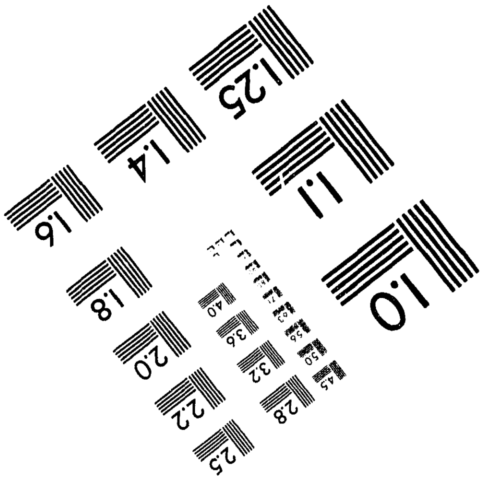

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ORIGIN OF ELEVATED WATER LEVELS ENCOUNTERED IN PAHUTE MESA EMPLACEMENT BOREHOLES: PRELIMINARY INVESTIGATIONS

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Publication #45123

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576–8401.

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Publication No. 45123

prepared for
Nevada Operations Office
U.S. Department of Energy
Las Vegas, Nevada

November 1993

The work upon which this report is based was supported by the U.S. Department of Energy under Contract #DE–AC08–90NV10845.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION AND EXECUTIVE SUMMARY

The presence of standing water well above the predicted water table in emplacement boreholes on Pahute Mesa has been a recurring phenomenon at the Nevada Test Site (NTS). If these levels represent naturally perched aquifers, they may indicate a radionuclide migration hazard. In any case, they can pose engineering problems in the performance of underground nuclear tests. The origin of these elevated waters is uncertain. Large volumes of water are introduced during emplacement drilling, providing ample source for artificially perched water, yet elevated water levels can remain constant for years, suggesting a natural origin instead. In an effort to address the issue of unexpected standing water in emplacement boreholes, three different sites were investigated in Area 19 on Pahute Mesa by Desert Research Institute (DRI) staff from 1990-93. These sites were U-19az, U-19ba, and U-19bh (Figure 1). As of this writing, U-19bh remains available for access; however, nuclear tests were conducted at the former two locations subsequent to our investigations.

The experiments are discussed below in chronological order. Taken together, the experiments indicate that standing water in Pahute Mesa emplacement holes originates from the drainage of small-volume naturally perched zones. The first investigation was made at U-19az, and attempted to identify the origin of standing water in the emplacement borehole from its major-element chemical composition. Compositions differed significantly from those of original drilling fluid and deep saturated zone samples, but whether this change was produced by addition of natural perched water to the drilling fluid, or dissolution of solids from the formation by the drilling fluid, remains uncertain. The second investigation was made at U-19ba, where standing water in the borehole was labeled with a chemical tracer in an effort to observe exchange with water in the surrounding formation. No significant changes in tracer concentration were observed, indicating no movement of water occurred between the borehole and surrounding rock. Both of these studies demonstrated that emplacement drilling fluids should be artificially labeled to be distinguished from formation fluids at Pahute Mesa. In the final study, the fluids used during drilling of the bottom 100 m of emplacement borehole U-19bh were labeled with a chemical tracer. After hole completion, water level rose in the borehole, while tracer concentration decreased. In fact, total mass of tracer in the borehole remained constant, while water levels rose. Unlabeled fluid composed the bulk of fluid entering the borehole after completion; whether this was drilling fluid injected into the formation before labeling began, or naturally perched water, could not be determined. After water levels stabilized in this hole, no change in tracer mass was observed over two years, indicating that no movement of water out of the borehole is taking place (as at U-19ba). Continued labeling tests of standing water are recommended to confirm the conclusions made here, and to establish their validity throughout Pahute Mesa.

BACKGROUND: EMPLACEMENT BOREHOLE DRILLING PROCEDURE

Current techniques for drilling of emplacement boreholes can introduce large quantities of water into the formation. One hundred meters of water are maintained in the borehole above the drill bit during drilling (Figure 2a). For a 1.22-m-diameter borehole the volume of water maintained above the bit is 429,000 liters. On Pahute Mesa, particularly in the Rainier Mesa Formation

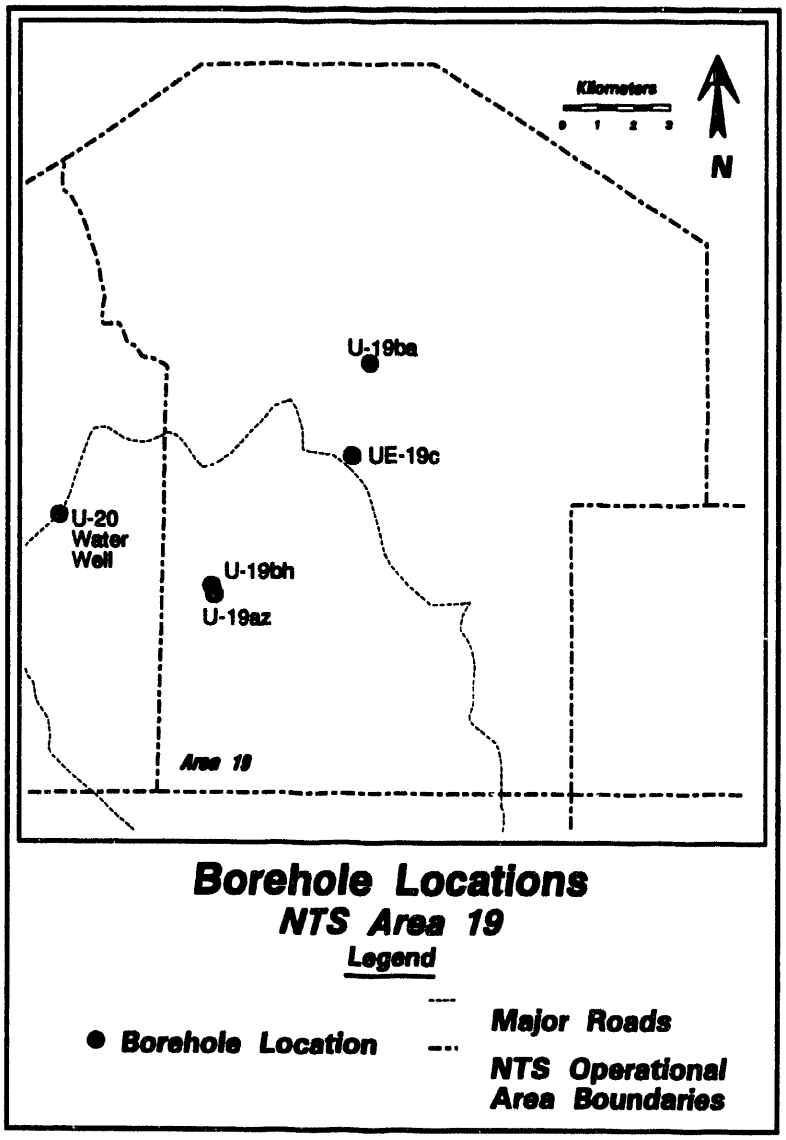

Figure 1. Location map of sites discussed in this study.

(fractured welded tuff), it is often impossible to maintain 100 m of head, even at maximum water supply rates. These observations suggest that several million liters of fresh water (10 times the typical water column volume) may be added to the formation during the course of drilling an emplacement borehole on Pahute Mesa (see Gardner and Brikowski, 1993 for additional infiltration estimates).

The bulk of the water in the borehole is not circulated to the surface. Water and air are pumped downward through the outer portion of the dual pipe to the drill bit (Figure 2b). Here, the fluids entrain drill cuttings and move back upward through the inner portion of the dual pipe. Most of the

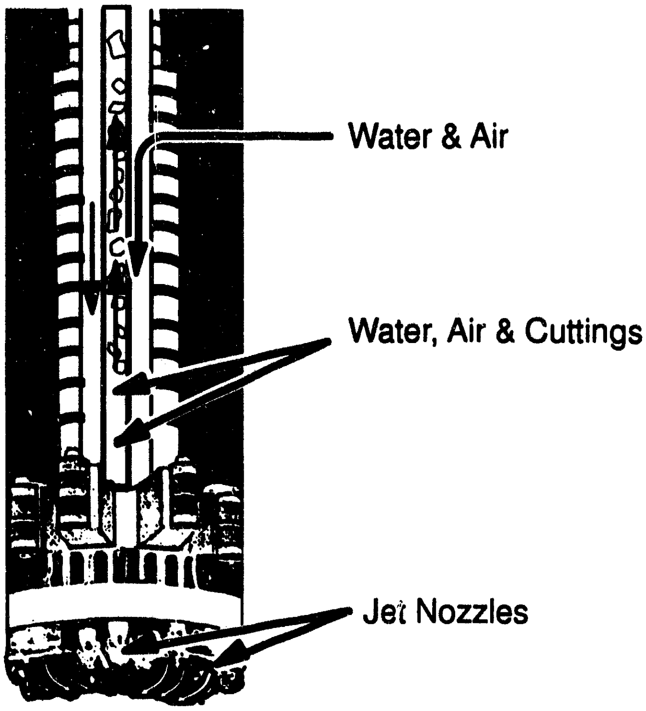

Figure 2a. Schematic illustration of emplacement borehole drilling arrangement showing drill bit and lower portion of drill string. Bit diameter is 1.2 m (after U.S. Department of Energy, 1969).

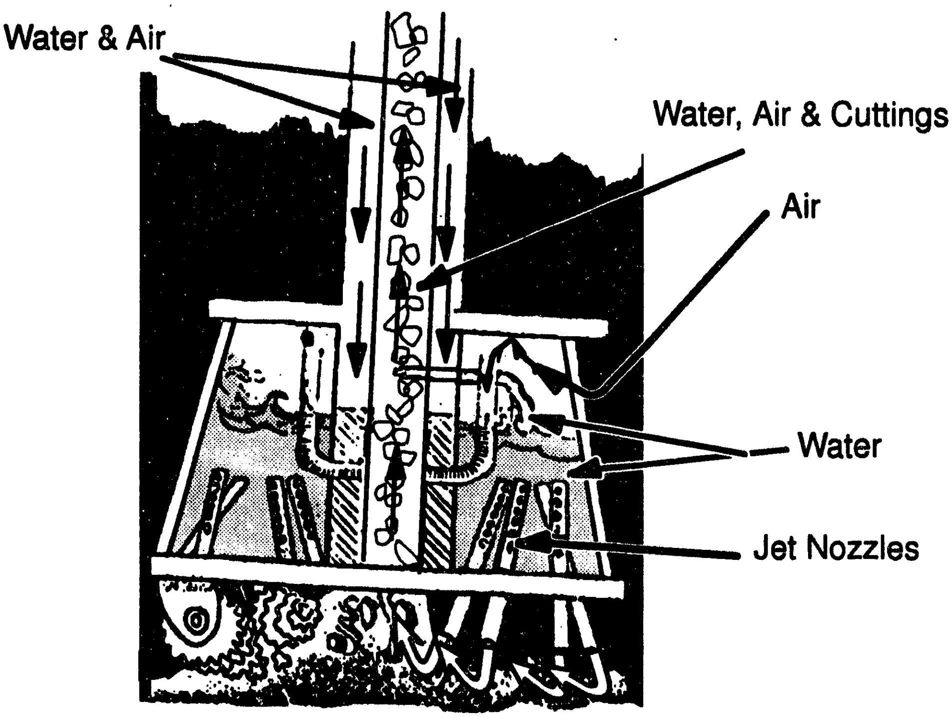

Figure 2b. Detailed schematic of water/air circulation in emplacement hole drill bit (after U.S. Department of Energy, 1969).

air returns to the surface, but some water separates from the fluid at the drill bit and seeps upward into the standing column above the bit. Height of water above the bit is increased by increasing the pumping rate, or increasing the ratio of water to air in the drilling fluid. The water circulated to the surface generally represents less than one-fifth of the total volume of drilling fluid in the borehole. At the completion of drilling, the borehole is blown "dry," with 3 m of water normally remaining in the borehole (this can be reduced to 1 m at great expense).

Drilling fluids are circulated through a controlled loop. For example, at U-19bh three reservoirs of water were present, the borehole (427,705 L), a suction pit (476,910 L) and reserve pit (429,219 L; J. Blevins, pers. commun. 1991). Water circulates up from the borehole carrying cuttings, is pumped into the suction pit where mud settles out, then flows into the reserve pit, then is pumped back into the borehole. The total volume of water in the system at any one time is approximately 1.33 x 10^6 L. Near the end of drilling (approximately the last 100 m), no more fresh water is added to the system; if additional fluid is required in the borehole, the amount of water held in the surface pits is reduced.

OBSERVATIONS

U-19az (Houston)

During the final planning for the Houston event at U-19az, concerns arose regarding potential environmental significance of 11.5 m of water standing in the bottom of the hole. To assess the possible origins of this water, chemical samples of the water were obtained and analyzed for major dissolved species.

Setting

The U-19az emplacement borehole was completed to a depth of 649 m in December 1988, approximately 50 m above the predicted regional water table (Figure 3). The hole intersects 250 m of welded tuffs of the Timber Mountain Group (Ammonia Tanks Member, Tma; Rainier Mesa Tuff, Tmr). Beneath that are about 100 m of Paintbrush Group (Tiva Canyon Tuff, Tpc). Below that the hole intersects 200 m of lavas of the Echo Peak rhyolite (Tpe). The bottom 80 m of the hole penetrates a welded ash-flow tuff within the Tpe unit. Early studies of the dependence of transmissivity on lithology on Pahute Mesa found that transmissivities in rhyolite flows averaged an order of magnitude or more greater than for welded tuffs, and another order of magnitude greater than for bedded and zeolitized tuffs (Blankennagel and Weir, 1973). Sharp contrasts in hydraulic conductivity are generally required to form perched aquifers, and the lithologic contact between lavas and underlying welded portions of the Echo Peak rhyolite may provide such a perching zone at U-19az. Similar conductivity contrasts are suggested by lithology changes at the base of the Tmr unit (its base is nonwelded and the underlying Tpd is bedded) and at the base of the Tma unit (bottom 16 m of Tma is bedded tuff). No direct evidence of perched water is available from the drilling history or the geophysical logs performed in hole U-19az. Conversations with drillers indicated no drilling additives were used in the hole.

NORTH-SOUTH GEOLOGIC CROSS SECTION THROUGH U19-az

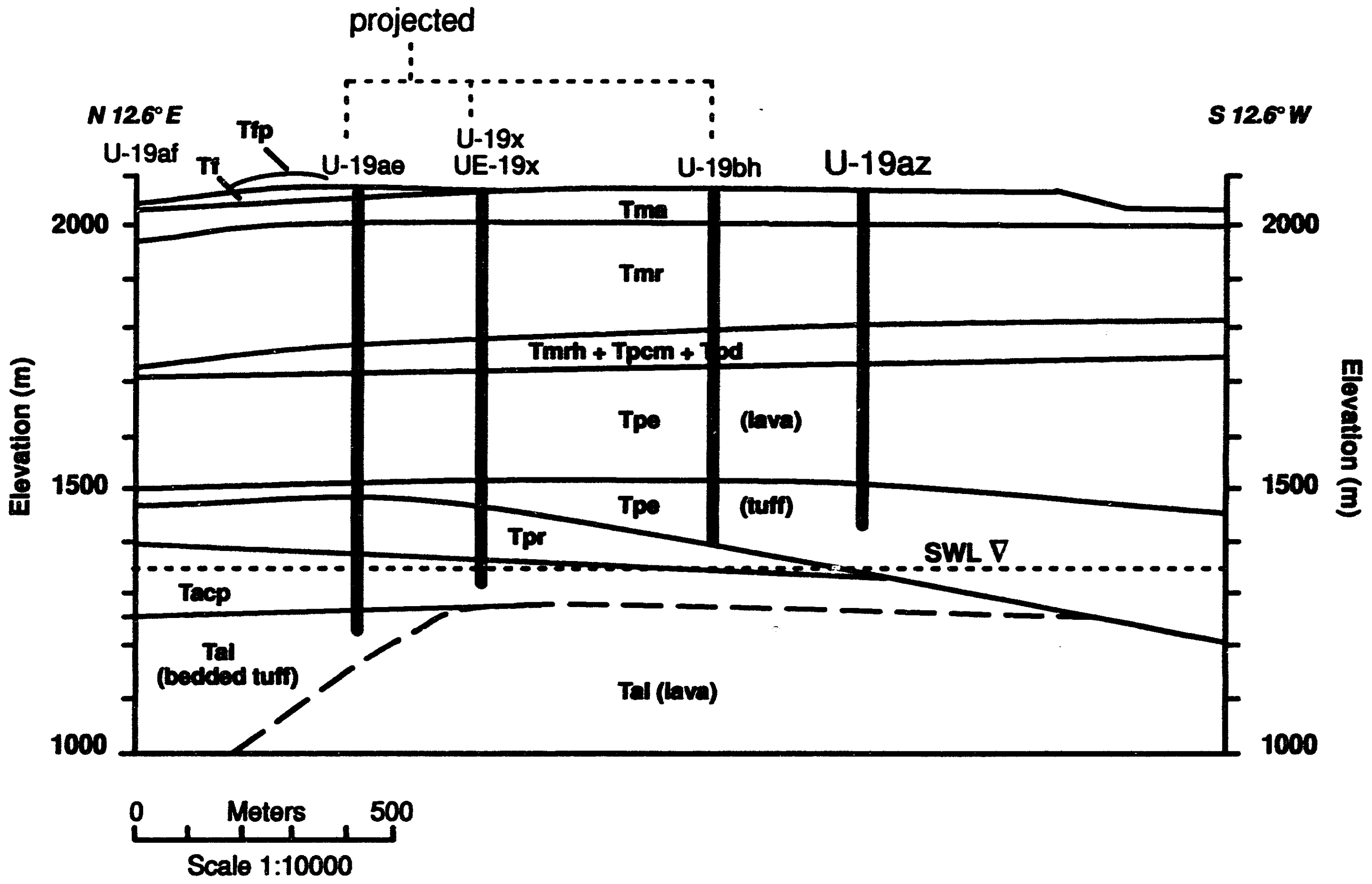

Figure 3. North-south geologic cross section through U-19az. Rock units are Ammonia Tanks Tuff (Tma), Rainier Mesa Tuff (Tmr and Tmrh), Paintbrush Tuff (Tpcm), Delerium Canyon Rhyolite (Tpd), and Echo Peak Rhyolite (Tpe). SWL is predicted static water level.

Water level rose rapidly in the well after blow-down, reaching a relatively steady column height of 15.5 m after two months (Figure 4). There is some indication of a decline in water levels in mid- to late-1990 (last two measurements, Figure 4), although at least 10 m of water remained in the hole at the time it was backfilled in preparation for the Houston event.

Procedure

On October 8, 1990, a water sample was collected with the DRI logging vehicle from U-19az, the emplacement hole for the Houston event. It was hoped that a chemical analysis would help determine if the water was introduced during drilling or produced from an aquifer penetrated by the hole (possibly a perched aquifer). The water level was found to be 634.6 m below land surface (bls) at the time of sampling. The bottom of the hole was reported to be at 646.2 m bls. The sample was collected with a 15-liter discrete bailer while slowly descending to 640 m and slowly ascending back to 635 m with the sample port open. The water sample was analyzed in the field for pH, electrical conductivity, and alkalinity after a tritium measurement with a field scintillation counter indicated no health hazard. Splits of the sample were divided for laboratory measurement of gross chemistry and tritium, with additional splits for carbon-14 and -13, uranium and strontium taken, but not analyzed.

Results

Field and laboratory chemistry results (Figure 5, Table 1) reveal significant differences between the water collected from U-19az and water from the two construction-water supply wells on Pahute Mesa, Water Well 20 and UE-19c (locations given on Figure 1). Any water introduced during the drilling of U-19az would have come from one of the two supply wells. The pH is lower by several tenths of a standard unit in U-19az as compared to the supply wells and the partial pressure of CO_2 is well above atmospheric in the U-19az sample. In contrast, the CO_2 partial pressures in the supply wells are very close to equilibrium with atmospheric values.

The total dissolved solids load of the U-19az water (437 mg/L) is much higher than from Water Well 20 (267 mg/L) or UE-19c (163 mg/L). The bulk of this higher concentration is made up of sodium and chloride ions, though there are also significant increases in bicarbonate, potassium, calcium, and magnesium in the U-19az water. Sulfate is lower in U-19az than in both of the other wells, and silica is generally the same in all three. Tritium concentrations in all three samples were below the detection limit of 10 pCi/L.

Interpretation

The water collected from U-19az is not a simple remnant of water originating from either Water Well 20 or UE-19c. The water sampled could have come from those wells and undergone geochemical changes after injection into U-19az, or the chemical differences may represent the quality of a separate perched aquifer. Differentiating between these two hypotheses is difficult under the given circumstances. In the first scenario, water from one of the supply wells would be introduced into the hole during drilling, resulting in injection of the water into the unsaturated section. This injected water could then have drained out, carrying a higher dissolved solids load due

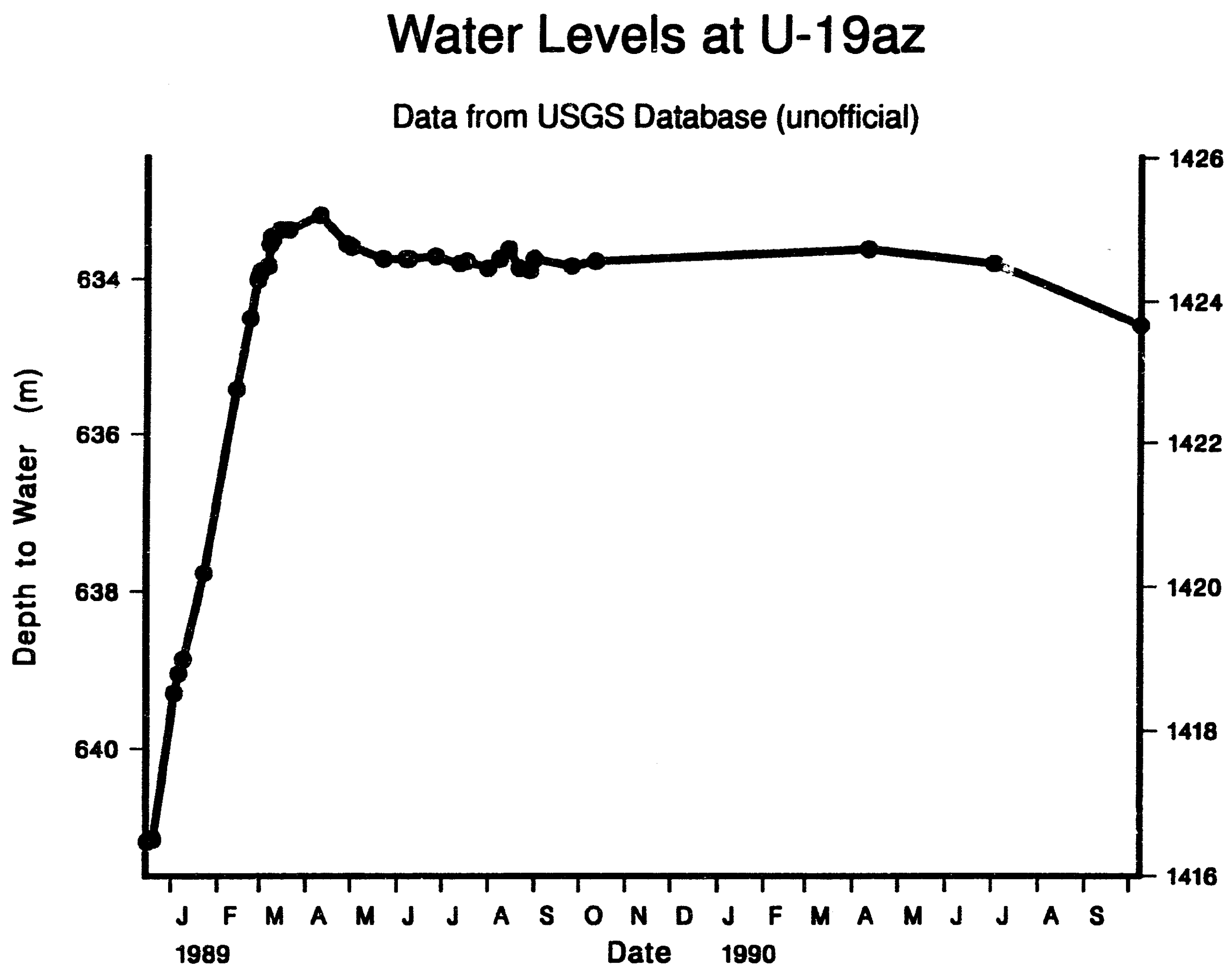

Figure 4. Water levels in U-19az after completion. October 1990 water level obtained by DRI staff, all other data are unofficial from USGS water-level records.

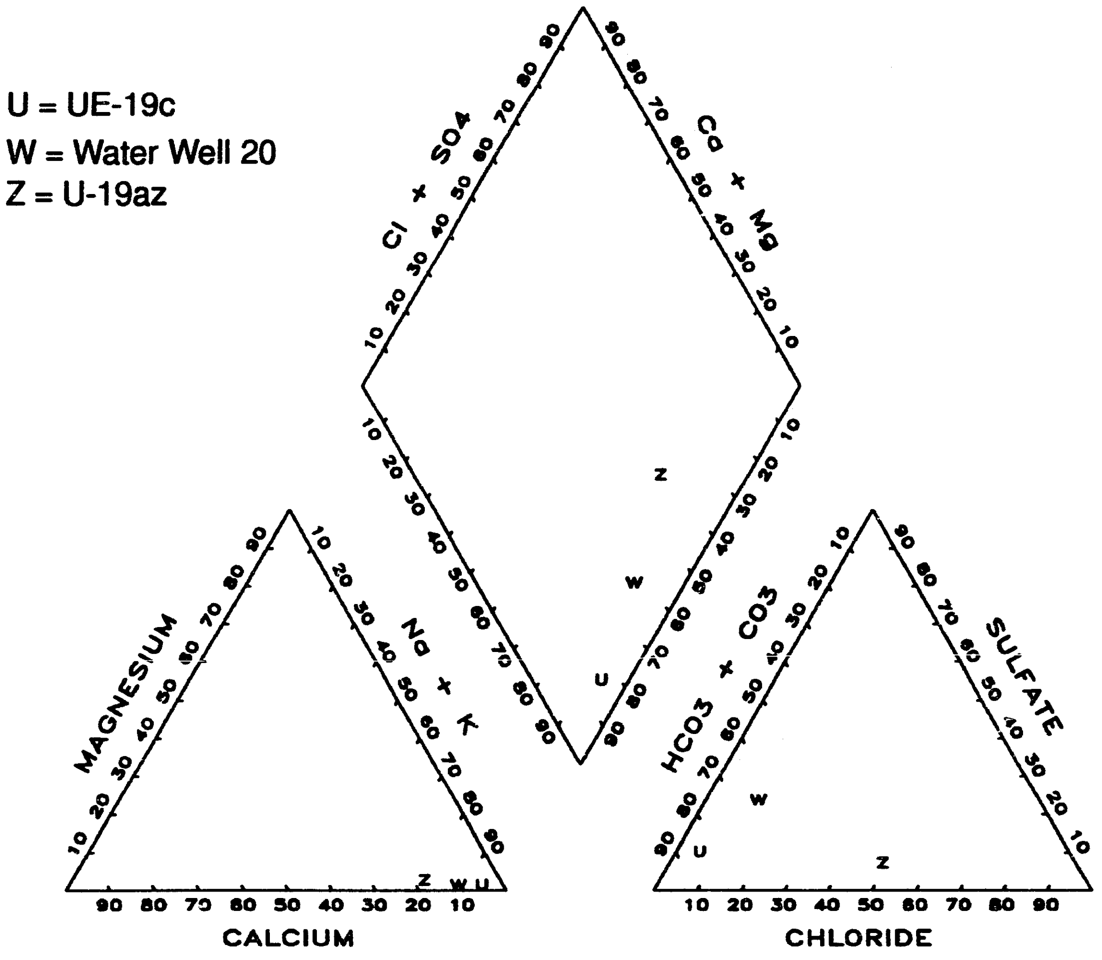

Figure 5. Piper diagram expressing relative ion percentages in Pahute Mesa water-supply wells and U-19az.

to dissolution of soluble material in unsaturated pores and fractures. This scenario is more likely if the drilling water came from UE-19c rather than Water Well 20, since there is no reasonable mechanism to reduce the sulfate concentration of Water Well 20 to that found in U-19az. To more than double the dissolved solids load while only experiencing a small increase in silica concentration requires dissolution of readily soluble minerals such as halides, sulfates and carbonates. It is not known if the mineralogy encountered in the U-19az borehole would support this hypothesis. If present, these minerals would most likely be encountered as primary constituents in sedimentary rocks within the stratigraphic column, rather than as secondary minerals in the volcanic rocks.

TABLE 1. Results of Chemical Analyses of Area 19 and 20 Water-Supply Wells, and Sample from U-19az. Number following "/" for U-19az sample is field-measured value.

Sample #	18883		18355		18356	
Sample Date	8-Oct-90		11-Sep-90		11-Sep-90	
Sample Name	U-19az Pahute Mesa		Water Well 20		UE-19c	
EC	587/596		292		154	
SiO_2	49.4		49.2		45.4	
pH	7.97/8.03		8.33		8.59	
^3H	<10 pCi/L		<10 pCi/L		<10 (4-16-90 sample)	
	mg/L	epm	mg/L	epm	mg/L	epm
HCO_3	145/128	2.377	107		64.9	
CO_3			1.1		5.3	
Cl	94.4	2.662	11.4		2.4	
SO_4	18.7	0.389	30.7		6.19	
NO_3	0.44	0.007	1.99		2.88	
Total Anions		5.435		2.783		1.483
Na	102	4.437	57.0		32.9	
K	5.78	0.148	1.74		0.76	
Ca	19.9	0.993	6.15		1.54	
Mg	1.80	0.148	0.44		0.25	
Total Cations		5.726		2.867		1.548
Anions/Cations		0.949		0.971		0.958
TDS	437		267		163	

For the second scenario, the chemical differences between the water in U-19az and water from the supply wells could be accounted for by different aquifer materials and residence times. The higher salinity of U-19az would suggest a longer residence time, possibly due to very slow groundwater flow rates, consistent with a perched horizon as compared to transmissive aquifers discharging to production wells. Accumulating the concentration of chloride found in U-19az is easier to envision with a larger volume of rock available to supply it during natural infiltration through a thick unsaturated section, relative to the volume of near-borehole rock that would be involved in reactions in the first scenario.

Neither scenario can easily account for the lower pH and supersaturation of CO_2 in the U-19az water. Though water in the unsaturated zone often has CO_2 partial pressures in excess of atmospheric, this is usually due to decay of organic matter and plant-root respiration, neither of which appear to be major processes in the thick unsaturated section beneath Pahute Mesa. Bubbling of air through the drilling fluid and resulting exchange between the air and fluid may account for this supersaturation.

The chemical analysis and tritium count on water from the U-19az borehole do not provide sufficient information to determine the origin of the water. The many chemical differences between the water from U-19az and water from Pahute Mesa supply wells could be explained either by the waters originating in different aquifers, or by supply-well water reacting with unsaturated zone materials after injection during drilling.

U-19ba (Bexar)

The Bexar emplacement hole was completed on September 11, 1989, above the predicted regional water table (Figure 6). Total depth of the hole was reported to be 663.6 m; sloughing of the hole before this experiment began raised the hole bottom to a depth of 661.4 m. After blow-down, water levels rose in the hole at an exponentially decaying rate, stabilizing at about 7 m of water in the hole (Figure 7). During final planning for weapons testing in this borehole, the possibility that a perched aquifer had been intersected was a concern. To identify possible exchange between borehole fluids and perched water in the surrounding formation, a chemical tracer was added to the standing water in the borehole. Any fluid flow or exchange between the borehole and surrounding aquifers should produce an observable decrease in tracer concentration in the borehole vs. time. This procedure is known as a point- or borehole-dilution test.

Setting

Borehole U-19ba was completed to a depth of 663.6 m into zeolitized tuff and breccia of the Crater Flat group (Tct-Tcb, Figure 6). High permeability zones were encountered during drilling; loss of circulation prompted the addition of filler material (cottonseed hulls, cedar bark and walnut shells) in the zone from 42.7 to 165 m depth, in moderately to densely welded tuffs of the Rainier Mesa Tuff (and 30 m of the overlying Ammonia Tanks Tuff) (Drellack 1990). Given the average transmissivities for Pahute Mesa lithologies found by Blankennagel and Weir (1973) natural or artificial perching of pore waters might be expected at the base of the Ammonia Tanks unit (Tmap) and Tmr unit (welded tuff underlain by zeolitized bedded tuff). Hydraulic conductivity in the bottom 60 m of the hole depends on the degree of zeolitization, but is probably low.

Procedure

Given a known concentration of tracer in a constant volume of water in a borehole which is exchanging with its surroundings, the velocity of water flowing past the borehole can be computed using

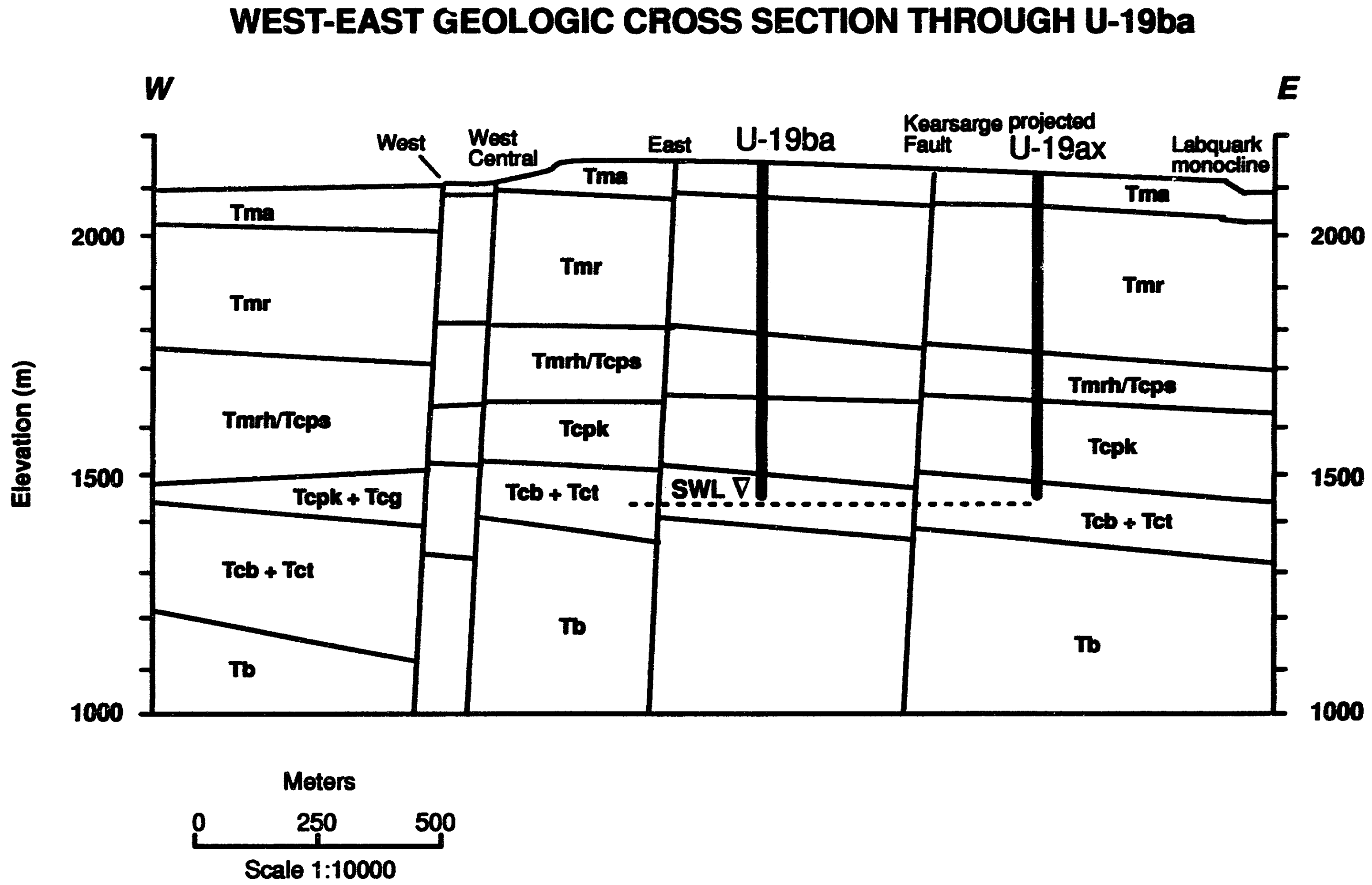

Figure 6. Stratigraphic units encountered in U-19ba. Units are welded Ammonia Tanks Tuff (Tma) underlain by bedded Tma, Rainier Mesa Tuff (Tmr), bedded and zeolitized tuff of the Rhyolite of Sled Formation (Tcps), and partially zeolitized flow breccias of the Rhyolite of Kearsarge (Tcpk), Calico Hills bedded and zeolitized tuff (Tacp), bedded and zeolitized Tuff of Pool (Tcpp), Rhyolite of Holmes Road (Tmrh), Bullfrog Tuff (Tcb), Tram Tuff (Tct), and Belted Range group (Tb) (Drellack, 1990).

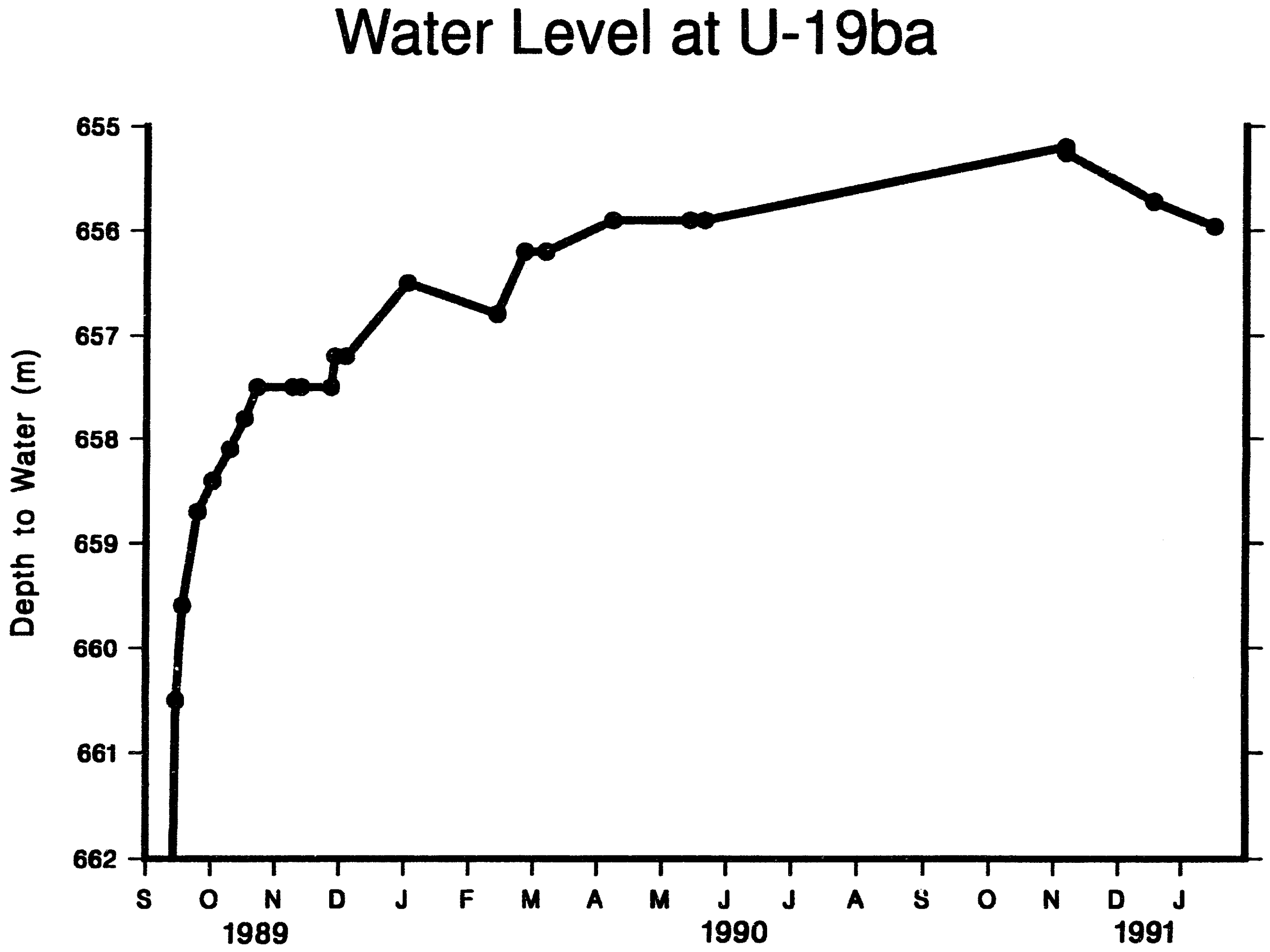

Figure 7. Water levels in U-19ba after completion. Data before November 1990 are from unofficial USGS water-level records. Duplicate measurement by USGS and DRI on November 6, 1990, differed by 0.06 m, levels after this date measured by DRI personnel.

$$V = -\frac{W}{\phi \alpha A t} \ln\left(\frac{C}{C_o}\right) \tag{1}$$

where W is the volume and A is the cross-sectional area of the column of water in the well, ϕ is the effective porosity of the surrounding formation, α is a geometry factor, C/C_o is the ratio of final to initial tracer concentration, and t is the elapsed time (Freeze and Cherry, 1979, p. 428-430).

A tracer was introduced into standing water in U-19ba, and concentrations monitored to carry out such a test. In early November 1990, a sample of standing water in U-19ba was collected and analyzed for electrical conductivity and Li and Br content. The background Br content (0.07 mg/L, Table 2) was typical of Pahute Mesa waters. Dry LiBr (4.5 kg) was mixed in 6.1 m of standing water in the bottom of the 2.44-m-diameter borehole. The salt was packed into a 1.5-m section of 15-cm-diameter PVC well screen, which was lowered into the well on a wireline, then raised and lowered repeatedly between the standing water level and borehole TD. The experiment was designed to increase Br concentrations in the water to at least 100 mg/L. Samples taken immediately after labeling showed concentrations of 127 mg/L. Monthly samples were then collected by bailer until access to the hole was lost.

TABLE 2. Results of Chemical Analyses from U-19ba Point-Dilution Experiment. Li and Br are concentrations in mg/L, EC is electrical conductivity in μS/cm, WL is depth to standing water in the hole in ft. Variation in Br is within analytical error (±5%).

Date	Li	Br	EC	WL	Comment
6 November 1990	0.06	0.07	447	655.26	Before Labeling
6 November 1990	11.7	127	621	655.26	After Labeling
27 November 1990	10.6	129	622	--	
18 December 1990	10.0	129	620	655.72	
16 January 1991	9.85	128	--	655.96	
14 February 1991	9.63	127	623	--	

Results and Interpretation

Analysis of the samples collected for three months following labeling indicated a decrease in Li concentration of approximately 18 percent, while Br remained constant (Table 2 and Figure 8). Li is not a conservative tracer, and should react with rock surfaces, while Br, because of its high solubility, is generally believed to be a conservative tracer. Within the limitations of analytic accuracy, the Br concentrations indicate no exchange or movement of groundwater out of the borehole during the three-month test. Given an approximate maximum analytic error of 5 percent, over this short duration test the minimum detectable velocity would have been 1.14×10^{-6} m/sec (35.6

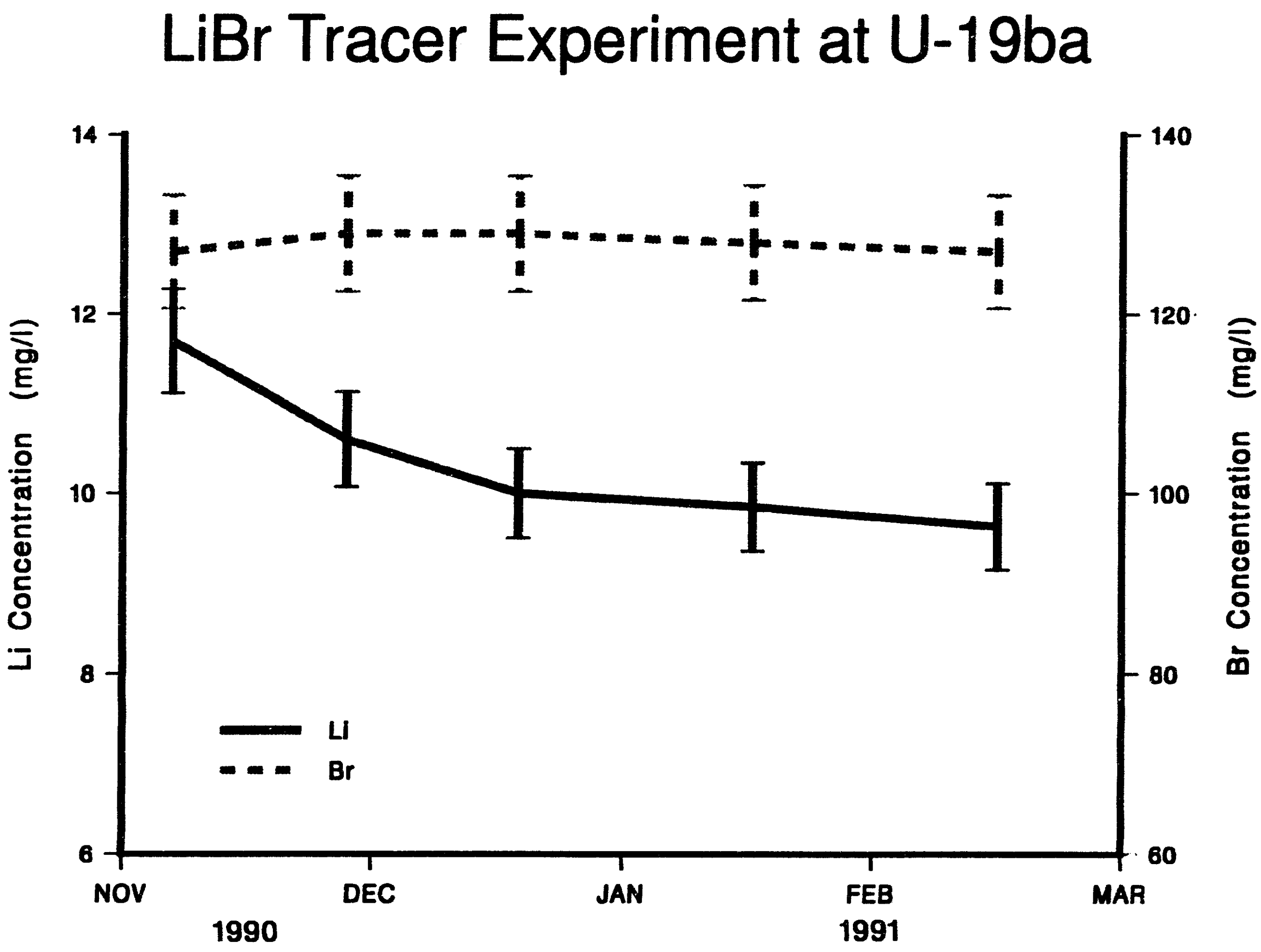

Figure 8. Variation in tracer content, U-19ba point-dilution experiment. Estimated maximum analytical error shown by error bars.

m/yr), where the borehole radius is assumed to be 1.22 m, and $\alpha = 1$, $t = 100$ days, $\phi = 0.01$; then $W = 35.7\ m^3$, $A = 18.6\ m^2$ in equation (1). Reduction in Br content caused by velocities smaller than this would have been indistinguishable from analytical errors. Note that this result is sensitive to the choice for effective porosity, a conservative minimum estimate (maximizing velocity) is used here; see Garber (1971) for estimates of effective porosity in zeolitized tuffs of Yucca Flat.

The results of this point-dilution test (i.e., the lack of detectable changes in Br content) indicate no movement or exchange of water from the borehole; however, the sensitivity of the test is limited by its short duration and uncertainty regarding the effective porosity of the formation. Taken at face value, these results suggest that standing water in U-19ba collected soon after drilling ceased, and remained static for more than a year.

U-19bh

Earlier studies had indicated that emplacement hole drilling fluids should be labeled to determine their contribution to standing water. U-19bh afforded an opportunity to carry out such labeling. Only the bottom of the hole was labeled to avoid difficulties in maintaining constant tracer composition in water added to the hole, and given the assumption that water injected higher in the borehole had already returned to the borehole.

Setting

Emplacement hole U-19bh is located approximately 300 m from borehole U-19az, and the lithologies penetrated by the two holes are essentially identical (Figure 3). Lithologic logs for U-19bh had not been located at the time of this writing, however, the basic suite of diagnostic logging appears to have been performed in the hole (Raytheon, 1992). Since no weapons test has been proposed for this hole, no site prospectus is available summarizing logging results and interpretation. The base of U-19bh was at an elevation of 1408 m at the end of drilling, and the bottom 70 m of the hole penetrates densely welded tuffs of the Echo Peak rhyolite. As at U-19az, the contact between this welded tuff and overlying lavas could serve as a perching zone, but both units would be expected to exhibit high permeabilities.

Procedure

In an effort to determine the hydrologic impact of drilling fluid leakage into the formation during emplacement hole drilling, fluids used in the final 100 m of U-19bh were labeled with LiBr. Emplacement hole U-19bh was spudded on November 20, 1990, and reached a total depth of 655 m on June 14, 1991. To interfere with the drilling as little as possible, pre-mixed solutions of LiBr were poured down the interstring (annulus between inner and outer walls of dual drill string) at an appropriate break in drilling. Ten liters of an approximately 20 molar solution of LiBr (14.5 kg of dry LiBr dissolved in 8 L of water) were introduced in the interstring at 1730 hours on June 3, 1991 (D. Donithan, field notes) at a drilling depth of 568 m (U-19bh hole history). At that time, fluid level in the hole was 83 m. First fluid returns were sampled and blooie line spill was sampled at 12 hours and 24 hours (Table 3). After 24 hours of mixing during drilling, fluids had reached the target concentration of 10 mg/L. Drilling continued with no further addition of water or tracer until the planned TD was reached on June 18, 1991, at which time the hole was dewatered. Samples taken at the beginning, middle, and end of dewatering showed relatively uniform concentrations of Br were present throughout the standing column of water (approximately 4 mg/L). Water levels have risen steadily in the borehole since blowdown, and as of June 1993, 15.6 m of water were standing in the hole (Figure 9). Samples were collected at increasing intervals after the hole was completed (Table 3). A nuclear testing moratorium has allowed access to U-19bh over an extended period, making the latter part of this experiment equivalent to a point-dilution test.

Results and Interpretation

Three intentional reservoirs of fluid are present during emplacement hole drilling, and were sampled throughout the course of this investigation. At the surface is a reserve pit and a suction pit, in the borehole is the column of water, and an unintentional and unsamplable reservoir is any water in the formation. In this experiment approximately 167 moles of Br were added to the drilling fluid; after 24 hours, 48 moles were known to be in the borehole, and 113 moles in the fluids in the surface ponds. During blow-down, 22 moles of Br were removed from the borehole and another 45 moles remained in the surface pits. This implies that some 100 moles, or 60 percent, of the initial Br tracer was injected into the formation during drilling. Since blowdown, Br *concentrations* have declined in the standing fluids in the borehole (Figure 9), but total Br *mass* or inventory remained essentially constant (Figure 10). During that time, water levels rose 13 m, indicating that fluids entering the borehole were not labeled drilling fluid. Lack of significant increase in borehole Br inventory indicates that fluid standing in U-19bh is not returned drilling fluid from the final 100 m of drilling. Possible sources for the standing water are drilling fluid infiltrated above the bottom 100 m, or natural water from a perched or shallower-than-expected saturated zone.

TABLE 3. Results of Chemical Analyses from U-19bh Drilling Fluid Labeling Experiment. Depth to water in meters, concentrations reported in mg/L, maximum analytical error estimated at 5 percent, detection limit for Br is ~0.02 mg/L.

DRI Sample #	Date Taken	Depth to Water	Li	Br	Description
20588	6/3/91	--	0.049	0.02	Background sample, Suction Pit
20590	6/3/91	--	0.061	0.03	Background sample, Return Pit
20589	6/3/91 (1815 hrs)	--	3.07	36.4	1st returns after spike
21298	6/4/91	485.9	0.534	6.0	Blooie sample 12 hrs after spike
21299	6/4/91	485.9	0.883	9.7	Blooie sample 24 hrs after spike
21300	6/18/91	563.9	0.135	4.0	Begin blowdown
21301	6/18/91	608.1	0.132	4.0	Mid blowdown
21302	6/18/91	652.3	0.135	4.2	End blowdown
21303	7/2/91	649.8	0.087	1.7	USGS sample U-19bh-183
21528	7/8/91	648.6	0.083	1.4	USGS sample U-19bh-189
21967	7/26/91	646.8	0.405	1.02	USGS sample U-19bh-207
29223	8/9/93	638.9	0.38	0.70	Collected at depth 2122'

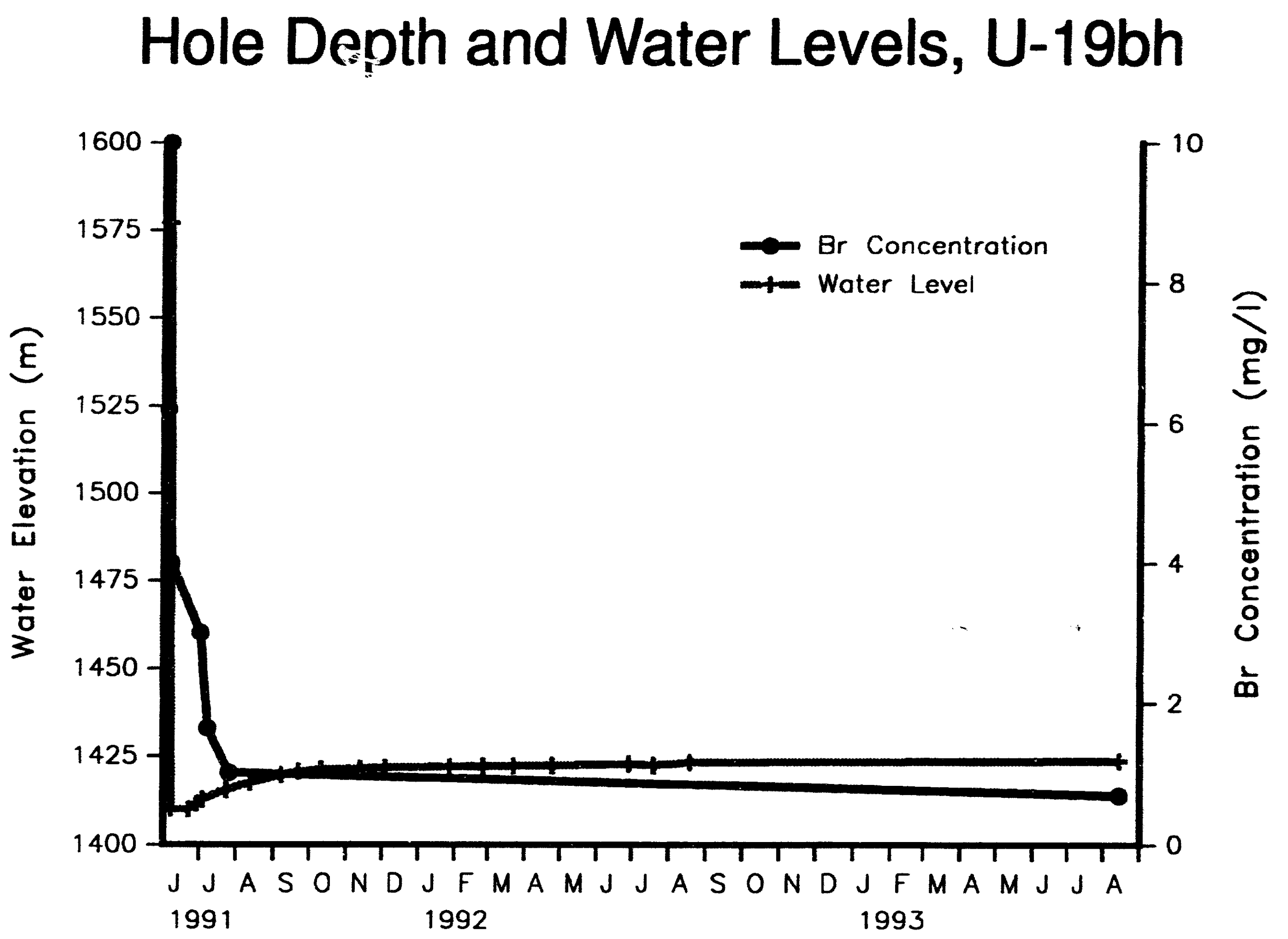

Figure 9. **Variation in water levels and tracer concentration, U-19bh drilling fluid labeling experiment. Initial high water levels reflect top of drilling fluid column before completion of hole. Water level data from USGS database and are unofficial.**

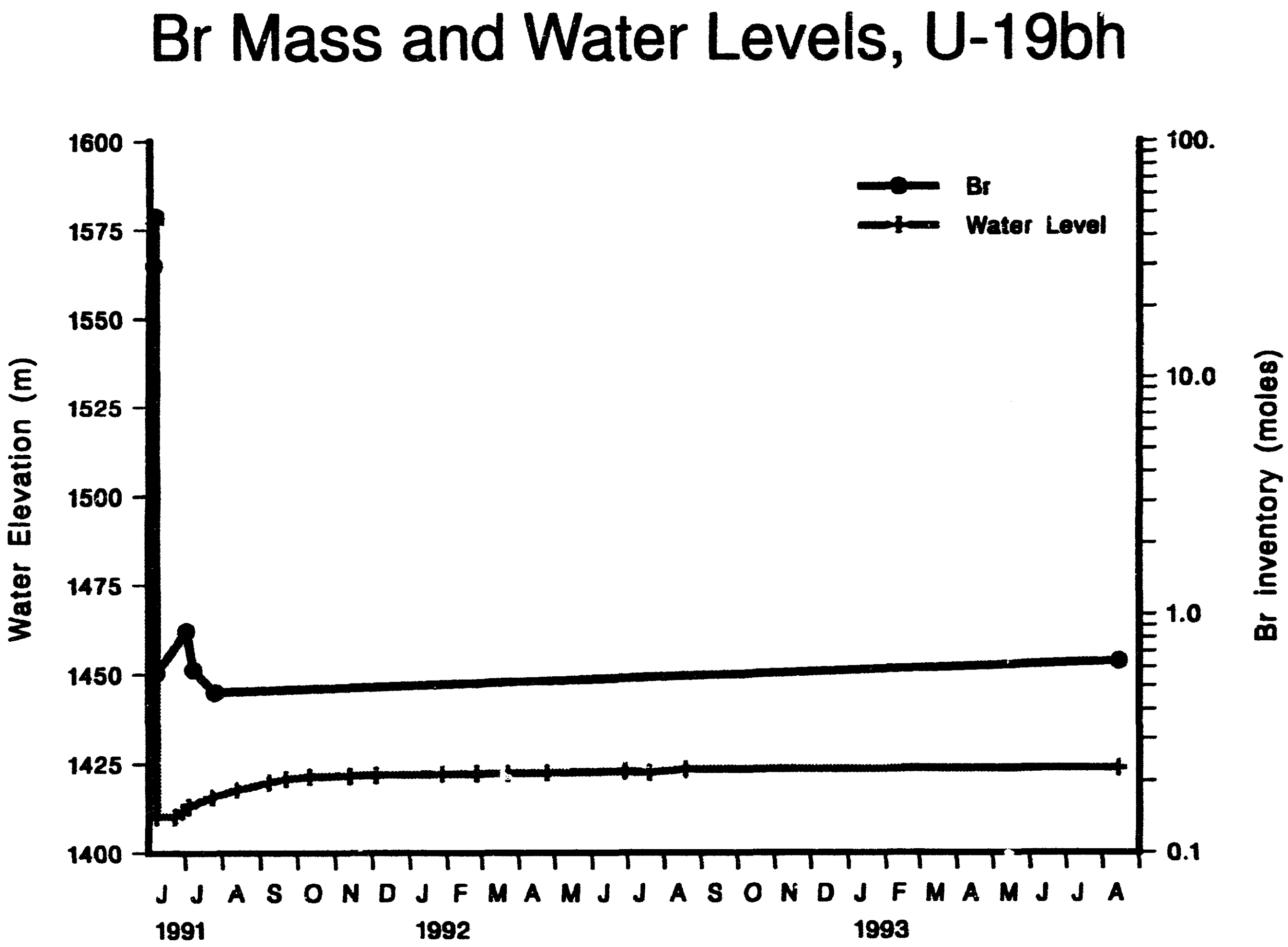

Figure 10. Tracer inventory, U-19bh drilling fluid labeling experiment. Calculation of inventory based on data in Table 3 and is summarized in Table 4.

Long-term access to this borehole has allowed extension of the experiment to a point-dilution type study. Br mass in U-19bh has changed little since fluid levels stabilized in the borehole in late summer 1991. As in the U-19ba study, this indicates little or no movement of water out of the borehole. In this case, using equation (1) with similar inputs as in U-19ba (water column height is now 15.5 m, duration of the test is 751 days) given an analytic error of 5 percent, the smallest recognizable velocity of water passing through U-19bh to date is 1.51×10^{-8} m/sec or 0.48 m/yr. The latter part of the experiment indicates no observable movement or exchange of water out of the borehole, however, very small velocities of water could be masked by analytical errors. The apparent rise in Br mass between August 1991 and August 1993 may reflect sloughing of rock material into the bottom of the borehole, causing water level rise without accompanying increase in water volume and dilution of Br concentrations.

This experiment was designed to trace the contributions of the most recently infiltrated drilling fluids, and determined that their contribution to standing water in U-19bh is minor. Extended access to the borehole has allowed the determination that no dissolved Br (and presumably water) is leaving the borehole, and therefore groundwater flux through the borehole is very close to zero.

DISCUSSION

A variety of origins are possible for unexpected standing water in emplacement boreholes at Pahute Mesa. The standing water may either be natural, in which case Pahute Mesa water tables are significantly higher than predicted from regional data, or the water is introduced, and represents drilling fluids temporarily stored in the formation. Naturally elevated water levels could take the form of perched zones, or represent local variations in the thickness of the saturated zone beneath Pahute Mesa. Since Pahute Mesa is generally believed to be a hydrologic recharge area, perched zones are likely to occur there, caused by water percolating through rock units of differing hydraulic conductivity. Such perching is common at nearby Rainier Mesa (Thordarson, 1965).

Vertical variation in head values within the saturated zone at Pahute Mesa has been invoked as an explanation of water level variation among shallow and deep boreholes on Pahute Mesa (Los Alamos, 1991). Head will decrease downward in a recharge area with or without perching, and therefore standing water levels will depend on well depth, with deeper wells having lower levels of standing water. Potentiometric surface maps prepared using only shallow boreholes predict a considerably higher water table at Pahute Mesa than those predicted using data from all available boreholes. If elevated standing borehole fluids on Pahute Mesa are simply samples of the regional saturated zone, their chemistry should differ little from deep samples. The investigation at U-19az indicated important differences from Pahute Mesa deep saturated-zone compositions, requiring a contribution of higher TDS water or dissolved solids from the surrounding formation to the boreholes. This compositional difference is not consistent with the assertion that unexpected standing water in emplacement boreholes is a part of the regional water table. The impact of drilling on these compositions is uncertain, however, and therefore the assertion is not disproved by the results discussed above. This study indicates only that the elevated waters are certainly not pure drilling fluids and are unlike regional groundwater.

TABLE 4. Calculation of Br Inventory, U-19bh. Intermediate parameters and final results given. Height (h) and volume (V) are for the standing water column in the hole, TD on 6/4/91 is approximately 568.1 m. Column height is water elevation (Table 3) minus TD, volume is $\pi r^2 h$, where r is taken to be 1.22 m. The inventory is given by the product of V and Br concentration, and is given in grams and moles (grams Br/79.904).

Date	Column Height (m)	Column Volume (l)	Br (mg/L)	Inventory	
				Br (gm)	Br (moles)
6/4/91	82.30	3.848×10^5	6.2	2.386×10^3	29.86
6/4/91	82.30 (?)	3.848×10^5	10.0	3.848×10^3	48.16
6/18/91	2.44	1.141×10^4	4.0	45.64	0.5712
7/2/91	4.88	2.282×10^4	3.0	68.46	0.8568
7/8/91	6.10	2.852×10^4	1.65	47.06	0.5889
7/26/91	7.92	3.703×10^4	1.02	37.77	0.4727
8/9/93	15.55	7.271×10^4	0.7	50.90	0.6370

Labeling of drilling fluids can allow their contribution to the final standing water to be determined. Results at U-19bh indicated that water entering the borehole after the completion of drilling was not drilling fluid temporarily infiltrated into the formation (at least not in the bottom 100 m of drilling). The implication is that substantial contribution of natural fluid from the formation, or long-delayed release of infiltrated drilling fluid from high in the unsaturated zone, is taking place (an unlikely scenario, Gardner and Brikowski, 1993).

Accepting the indications from the U-19az and U-19bh studies that formation contribution is required to yield elevated standing water in Pahute Mesa emplacement holes, the form and amount of contribution remains uncertain. The point-dilution studies at U-19ba and U-19bh offer some constraint on the magnitude of possible exchange between borehole and formation fluids. No indication of such exchange was observed in either study, suggesting that standing water at these boreholes was essentially stagnant.

While the three investigations summarized here do not lead to firm conclusions, they do provide important constraints on the probable origin of "elevated" water levels in recent Pahute Mesa emplacement holes. This analysis assumes that hydrologic conditions were similar at all three boreholes. Ideally, a single hypothesis can be found that will explain observations at all sites of unexpected standing water on Pahute Mesa, requiring only minor adjustments for site-specific conditions. Two types of investigation can further clarify the origin of the waters. If additional emplacement hole drilling should take place on Pahute Mesa, all of the drilling fluids should be labeled with a chemical tracer, allowing them to be distinguished from any natural contribution to the borehole. Standing water in unexpended emplacement holes can also be labeled, and can help determine if the results from U-19az and U-19bh are representative of conditions throughout Pahute Mesa.

CONCLUSIONS

These studies taken together indicate substantial movement of dissolvable species and/or natural water from the formation into the emplacement holes to produce the observed elevated waters. Chemical differences (U-19az) suggest that the waters originate from aquifers distinct from the regional saturated zone, while lack of exchange between borehole standing water and possible surrounding groundwater (U-19ba, U-19bh) suggests that the contributing aquifer lies somewhere above the base of the borehole. The long-term lack of decline in tracer content in the U-19bh borehole indicates that only a relatively small reservoir of perched water is drained into the borehole, and that the water remains stagnant in the bottom of the borehole for very long periods of time. Quite similar phenomena are encountered during mining of tunnels in the perched zone at Rainier Mesa (Russell et al., 1987). When a saturated fracture is encountered voluminous discharge begins, rapidly declining until the fracture is essentially drained.

The standing water in the boreholes described above may represent perched water formerly residing in relatively small-volume discrete fracture networks. These drain quickly to form a standing pool at the bottom of the borehole that appears to be essentially stagnant. The implication is that these boreholes are indeed tapping perched groundwater systems, but that the long-term groundwater flux through the borehole is quite small. If so, the environmental consequences of observed standing water are minor, since it does not indicate large groundwater fluxes through the shot point.

Post-testing implications of the standing water are less certain. Nuclear testing induces fracturing and permeability increase in competent rocks, and may tap additional perched reservoirs on Pahute Mesa settings. If so, the potential exists for small to moderate groundwater fluxes through the contaminated zones created by nuclear tests in the unsaturated zone, implying greater than anticipated environmental hazard. Evaluation of this scenario will require drilling and sampling in the unsaturated zone, if it exists, beneath such weapons tests, or some determination of the frequency of these small perched reservoirs. Additional point dilution tests in unused emplacement holes can help constrain this frequency.

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Gylan Allen
Test Operations Division
Nevada Operations Office
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Doug Duncan
Hydrology Program Manager
Office of Environmental Restoration & Waste Management
Nevada Operations Office
U.S. Department of Energy
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Don Elle, Director
Environment Protection Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
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Joseph N. Fiore, Acting Asst. Mgr.
Office of Environmental Restoration & Waste Management
Nevada Operations Office
U.S. Department of Energy
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Joseph H. Kitchen
Technology and Program Management Division
Nevada Operations Office
U.S. Department of Energy
P.O. Box 98518
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Steve Leedom
Test Operations Division
Nevada Operations Office
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Las Vegas, NV 89193-8518

Steve Mellington, Director
Environmental Restoration Division
Nevada Operations Office
U.S. Department of Energy
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Defense Nuclear Agency
U.S. Department of Defense
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Las Vegas, NV 89193-8539

Lawrence Livermore National Laboratory

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Lawrence Livermore National Laboratory
P.O. Box 808, MS L233
Livermore, CA 94550

Los Alamos National Laboratory

Joe Thompson
Los Alamos National Laboratory
INC-11, MS J514
P.O. Box 1663
Los Alamos, NM 87545

U.S. Geological Survey

Virginia Glanzman
U.S. Geological Survey
Box 2506, MS 913
Denver Federal Center
Denver, CO 80225

Randy Laczniak
U.S. Geological Survey
Water Resources Division
6770 S. Paradise Rd.
Las Vegas, NV 89119

Paul Orkild
U.S. Geological Survey
Box 2506, MS 913
Denver Federal Center
Denver, CO 80225

Doug Trudeau
U.S. Geological Survey
Water Resources Division
6770 S. Paradise Rd.
Las Vegas, NV 89119

Desert Research Institute

Roger Jacobson
Desert Research Institute
Water Resources Center
P.O. Box 19040
Las Vegas, NV 89132-0040

Marjory Jones
Desert Research Institute
Water Resources Center
P.O. Box 60220
Reno, NV 89506-0220

Paul Seaber
Desert Research Institute
Water Resources Center
P.O. Box 19040
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International Technology Corp.

Rick Waddell
Geotrans
c/o IT
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Suite 112
MS-439
Las Vegas, NV 89103

Joe Yeasted
International Technology Corp.
4330 Valley View
Suite 112
MS-439
Las Vegas, NV 89103

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