50119

19

LA-12934-MS

UC-903
Issued: June 1995

Earth Science Investigations for Environmental Restoration— Los Alamos National Laboratory Technical Area 21

Edited by
D.E. Broxton
P.G. Eller

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

Received by ER-RPF
OCT 26 1995
Dic

10441

Contents

Abstract 1

Introduction 1
D.E. Broxton and P.G. Eller

Geologic Map of Technical Area 21 7
F. Goff

Measurement and Analysis of Rock Fractures in the Tshirege Member of the Bandelier Tuff along Los Alamos Canyon Adjacent to Technical Area-21 19
K. H. Wohletz

Stratigraphy, Petrography, and Mineralogy of Bandelier Tuff and Cerro Toledo Deposits 33
D.E. Broxton, G.H. Heiken, S.J. Chipera, and F.M. Byers, Jr.

Geomorphic Studies at DP Mesa and Vicinity 65
S.L. Reneau

Preliminary Drilling Results for Boreholes LADP-3 and LADP-4 93
D.E. Broxton, P.A. Longmire, P.G. Eller, D. Flores

Fluorescein Dye Experiment at DP Spring and Sewage Outfall 111
A. Adams, J. DeMuth, D. Counce, and F. Goff

PRELIMINARY DRILLING RESULTS FOR BOREHOLES LADP-3 AND LADP-4

by

D. E. Broxton, P. A. Longmire, P. G. Eller, and D. Flores

This report presents preliminary geologic and hydrologic findings for two geologic characterization boreholes drilled in autumn 1993 as part of TA-21 RFI investigations. LADP-3 was drilled to determine if perched groundwater occurs at depths greater than that of alluvial groundwater in Los Alamos Canyon. LADP-4 was drilled to determine if perched groundwater occurs beneath DP Canyon and to investigate whether subsurface contaminants from the industrialized areas of TA-21 have migrated northward towards DP Canyon.

LADP-3 penetrated a thick sequence of slope-derived colluvium and stream-derived alluvium on the canyon floor before entering bedrock. Bedrock units penetrated by the borehole include the Otowi Member of the Bandelier Tuff (including the Guaje Pumice Bed) and gravels of the Puye Formation. This borehole encountered two perched groundwater zones. The upper zone is part of the canyon's alluvial groundwater and is divided into two distinct zones of saturation. An intermediate-depth perched groundwater zone was encountered at a depth of 325 ft in the Guaje Pumice Bed. Water from this deeper perched zone contains 6.0 ± 0.16 nCi/ℓ of tritium—which is above regional background for surface water but well below the drinking water standard of 20 nCi/ℓ. Preliminary analyses for low-level ^{137}Cs and Pu isotopes failed to detect these constituents. Mixing calculations suggest that ~70% of the groundwater in the Guaje Pumice Bed is recharge from alluvial groundwater.

LADP-4 penetrated alluvium on the canyon floor and entered the following bedrock units: the Tshirege Member of the Bandelier Tuff (including the Tsankawi Pumice Bed), fluvial sediments of the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff (including the Guaje Pumice Bed), and fluvial sands, gravels, and cobbles of the Puye Formation. Low-level tritium was found in this borehole. Preliminary laboratory analysis yielded 2.15 ± 0.18 pCi/g tritium in a tuff sample collected from a moist zone associated with the Tshirege unit 1v/1g boundary at a depth of 158.6 to 160.1 ft. This value is above background but well below the screening action level of 820 piC/g. The origin of the tritium is not yet known, but moisture transport from several industrial sites at TA-21 is a possibility.

Additional chemical and radiochemical analyses are being conducted to more fully characterize potential contamination in these two boreholes. Also, hydrologic testing of core samples is underway to characterize the geohydrologic properties of subsurface units at TA-21.

INTRODUCTION

During autumn 1993, two geologic characterization boreholes were drilled at TA-21. Borehole LADP-3 is located in Los Alamos Canyon south of TA-21, and borehole LADP-4 is located in DP Canyon to the north (Fig. 1). These boreholes, described in section 12.5.1.2 of the RFI work plan, were drilled to identify potential transport pathways in the vadose zone and to characterize vertical and lateral variations in the geohydrologic properties of the site. All work was done according to the RFI work plan.

LADP-3 was drilled to determine if perched groundwater occurs at depths greater than that of the alluvial groundwater in Los Alamos Canyon. In addition, geologic and hydrologic data from LADP-3 are being collected in conjunction with data from other nearby boreholes to identify the presence and properties of major hydrogeologic units at TA-21. These data are used to improve conceptual models for the site, identify potential transport pathways, and provide useful planning information for subsequent drilling operations at TA-21.

LADP-4 was drilled to determine if perched groundwater occurs beneath DP Canyon and to investigate whether subsurface contaminants from the industrialized areas of TA-21 have migrated northward towards DP Canyon. In addition, geologic and hydrologic data from LADP-4 is being collected to characterize the major hydrogeologic units at TA-21.

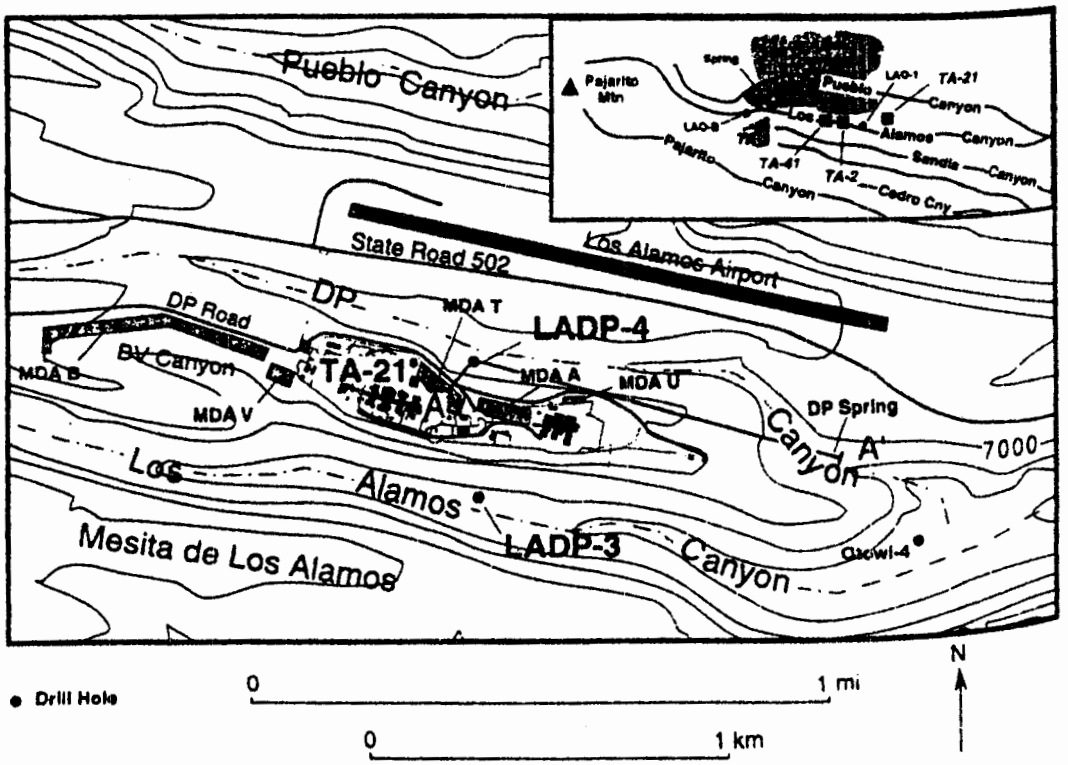

Fig. 1. Map showing locations of boreholes LADP-3 and LADP-4 at TA-21. A-A' is the line of cross section shown in Fig. 15. Inset shows locations of the monitoring wells and DP Spring.

METHODS

LADP-3

Drilling of LADP-3 began November 2, 1993, and was completed on December 17, 1993. Originally, the target depth for LADP-3 was determined by the elevation of the uppermost basalt penetrated by borehole Otowi 4, located ~0.75 miles to the east (Fig. 1), or 490 ft—whichever was encountered first. However, because groundwater was encountered at 325 ft, drilling was terminated at 350 ft after the extent of the perched zone was determined.

LADP-3 was drilled from the surface to 232 ft using an 8.5-in. hollow-stem auger. The borehole was completed to the final depth of 350 ft using air-rotary drilling methods (Fig. 2). Rock coring, using a 4.5-in.-diam rock barrel, alternated with advancement of 5.625-in.-i.d. ODEX casing from 232 to 350 ft. Alluvial and surface groundwater were cased out of the borehole by installing and grouting permanent 8.625-in.-o.d. surface casing to a depth of 90 ft.

Samples for gravimetric moisture and tritium analyses were collected every 5 ft in LADP-3. Four background geochemical and radiochemical samples were also collected. The analytical suite for chemical and radionuclide characterization are described in Table 12.5-III of the RFI work plan. In addition, 36 intact core samples were collected for analysis of hydrogeologic properties. The core was sealed in airtight containers to prevent changes in moisture content and other properties. Water samples were collected from the alluvial groundwater and from the perched zone at 325 ft. Except as noted below, laboratory analyses of cores and water samples are not yet available.

LADP-4

Drilling of LADP-4 began August 30, 1993, and was completed November 7, 1993. Well LADP-4 was drilled to a depth of 800 ft using air-rotary methods (Fig. 3). Surface and near-surface groundwater were cased out of the hole with a 10.75-in.-o.d. surface conductor pipe cemented around the well to a depth of 28 ft. ODEX casing (8.625-in.-o.d.) inside the first pipe lines the hole to a depth of 579 ft. From 579 to 800 ft the ODEX casing telescopes to 6.626-in.-o.d. Continuous core 4.5 in. diameter was collected from the surface to 573-ft depth. Cuttings were collected from 573- to 800-ft depth because the unconsolidated nature of the Puye Formation prevented intact core recovery.

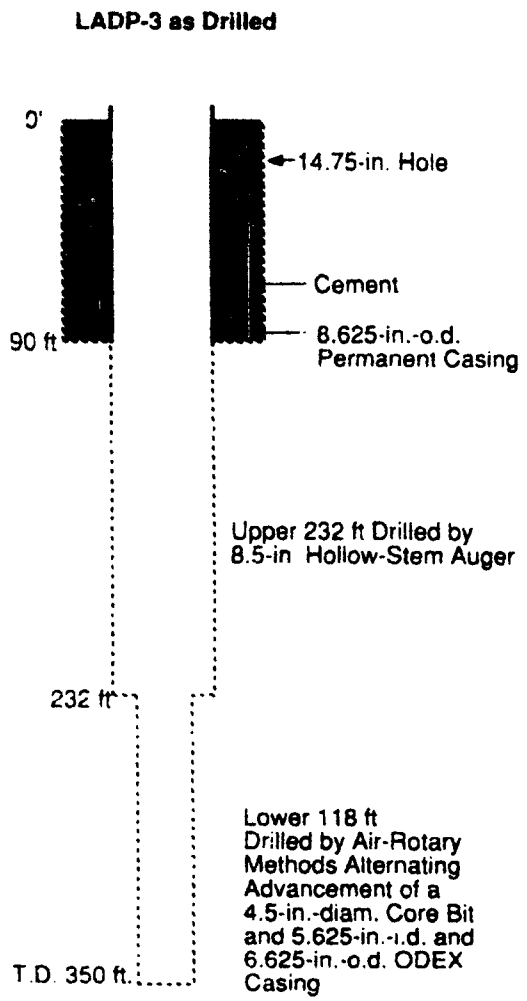

Fig. 2. Construction of LADP-3. (Prepared from data provided by J.C. Newsom and E.D. Davidson, Jr.)

Samples for moisture and tritium analyses were collected every 5 ft for the total depth of LADP-4. Six background geochemical and radiochemical samples also were collected. The analytical suite for chemical and radionuclide characterization is presented in Table 12.5-III of the RFI operable unit work plan. Except as noted below, laboratory analytical results are not yet available. In addition, 25 intact core samples were collected for characterization of hydrogeologic parameters. The core samples were sealed in airtight containers to prevent changes in moisture content and other properties before analysis.

RESULTS

LADP-3

LADP-3 penetrated a thick sequence of slope-derived colluvium and stream-derived alluvium on the canyon floor before entering bedrock. Bedrock units penetrated by the borehole include the Otowi Member of the Bandelier Tuff (including the Guaje Pumice Bed) and gravels of the Puye Formation. Preliminary geologic information for LADP-3 is summarized in Figs. 4 and 5.

Thin sheets of groundwater were encountered at depths of 27 and ~35 ft. These sheets of groundwater occur in stream-deposited alluvium and are at or slightly below the elevation of the main stream channel in Los Alamos

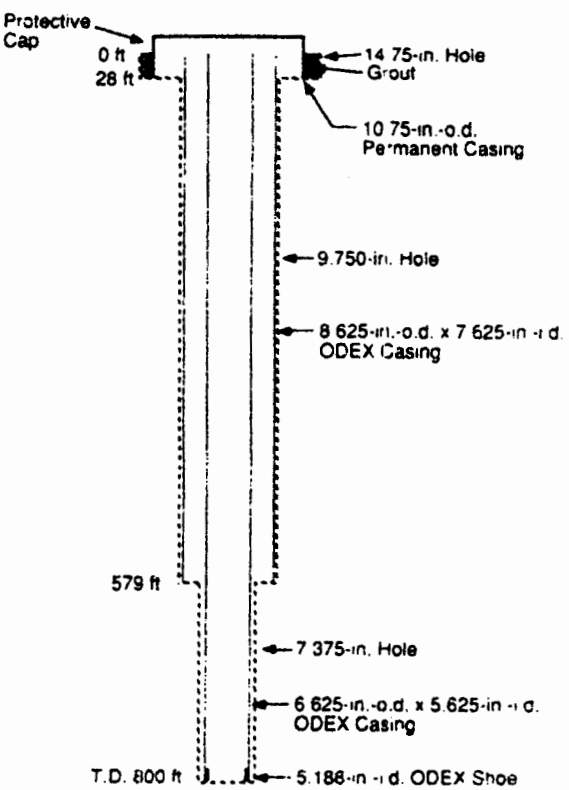

Fig. 3. Construction of LADP-4. (Prepared from data provided by J.C. Newsom and E.D. Davidson, Jr.)

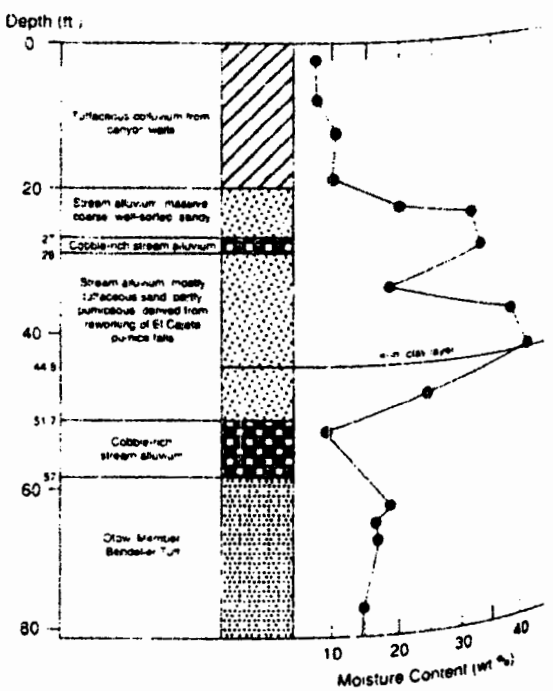

Fig. 4. Preliminary geologic information and variations in moisture content in the alluvial groundwater penetrated by the upper part of LADP-3 in Los Alamos Canyon.

canyon. Because of their position relative to the canyon floor and the nature of their host deposits, these sheet flows are interpreted as being part of the alluvial groundwater in Los Alamos Canyon. Laboratory analyses of water collected from the alluvial groundwater are not yet available.

Another perched groundwater was encountered at a depth of 325 ft in the lower part of the Guaje Pumice Bed. Borehole operations were temporarily suspended at the base of the Guaje Pumice Bed to evaluate this perched zone. Initially, there was 15 ft standing water in the borehole, but after several days the standing water level dropped to ~5 ft. Drilling operations resumed to determine the nature and extent of the groundwater. A clay layer a few inches thick was found at the top of the Puye Formation. This clay layer might be a paleosoil and may act as a permeability barrier that causes the groundwater to perch in the overlying pumice bed. Drilling stopped at the 350-ft depth within Puye Formation after it was determined that the groundwater is confined to the Guaje Pumice Bed.

Water from the perched groundwater at 325 ft was analyzed for major constituents and tritium (see Table I for a summary of results

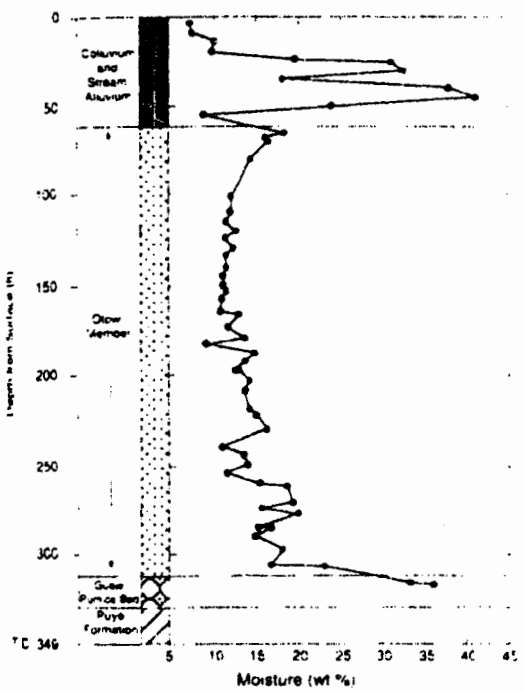

Fig. 5. Preliminary geologic information and variation in moisture content as a function of depth in borehole LADP-3, Los Alamos Canyon.

TABLE I.
CHEMISTRY OF GROUNDWATER SAMPLE PP93-36 AT 325-FT DEPTH IN BOREHOLE LADP-3, LOS ALAMOS CANYON[a]

Ag	<0.0005	Sb	<0.001
Al	0.21 ± 0.03	Se	<0.001
As	<0.001	Si	20.0 ± 0.1
B	0.04 ± 0.01	Sr	0.13 ± 0.01
Ba	0.02 ± 0.01	Zn	0.16 ± 0.01
Br	0.07		
Ca	11.7 ± 0.1	ClO_3	<0.02
Cd	<0.001	CO_3	0
Cl	46.8	HCO_3	65
Co	0.004 ± 0.002	NH_4	0.32
Cr	0.003 ± 0.002	NO_2	0.37
Cs	0.002 ± 0.002	NO_3	1.21
Cu	0.006 ± 0.002	OH	0
F	0.38	PO_4	<0.02
Fe	0.13 ± 0.01	SO_4	12.8
Hg	<0.002	S_2O_3	<0.01
I	<0.01		
K	8.7 ± 0.3	Cation Sum	2.688
Li	0.02 ± 0.01	Anion Sum	2.702
Mg	4.08 ± 0.01		
Mn	0.44 ± 0.01	Total Dissolved Sol	229.3
Mo	0.022 ± 0.002	Cond (µmho/cm)	302
Na	33.8 ± 0.9		
Ni	0.026 ± 0.002	pH	6.62
Pb	<0.002	^3H (nCi/l)[b]	6.0 ± 0.16
Rb	0.046 ± 0.004	^3H (nCi/l)[c]	5.5 ± 0.7

[a] *Values reported in ppm unless otherwise noted. Analyses (except for tritium) performed by D. Counce of the Geology/Geochemistry Group, Los Alamos National Laboratory.*
[b] *Tritium analyzed at University of Florida*
[c] *Tritium analyzed at Group CST-9, Los Alamos National Laboratory*

from these preliminary analyses). This groundwater contains 6.0 ± 0.16 nCi/ℓ of tritium, which is an order of magnitude above background for surface water in Los Alamos Canyon (P. Longmire, unpublished data) but well below the drinking water standard of 20 nCi/ℓ. Preliminary analyses for low-level ^{137}Cs and Pu isotopes failed to detect these constituents. Additional analyses are being conducted to determine if other contaminants are present and to further investigate the possibility of a hydrologic connection between the alluvial groundwater and groundwater in the Guaje Pumice Bed.

Moisture content was determined for 59 core samples in LADP-3. Moisture contents range from 7 to 41%, and the average moisture content is 16%. Moisture distribution as a function of depth is shown in Figs. 4 and 5.

Gravimetric moisture contents up to 40% are associated with the alluvial groundwater near the top of the borehole (Fig. 4). The moisture data reflect the sheet-like occurrence of the groundwater, which occurs in two water-producing zones. The upper zone is associated with a cobble layer at a depth of 27 ft. The lower water-producing zone occurs in a porous, pumice-rich stream alluvium and may be perched above a 4-in. clay layer at a depth of 45 ft.

Moisture contents decrease to 12 to 15% in the bedrock tuffs immediately below the canyon floor. However, moisture contents systematically increase with depth, starting at 170 ft in the middle of the Otowi Member and peak in the upper part of the Guaje Pumice Bed just above the perched groundwater (Fig. 5).

LADP-4

LADP-4 penetrated alluvium on the canyon floor and then entered the following bedrock units: the Tshirege Member of the Bandelier Tuff (including the Tsankawi Pumice Bed), fluvial sediments of the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff (including the Guaje Pumice Bed), and fluvial sands, gravels, and cobbles of the Puye Formation. Figure 6 presents a preliminary geologic log for LADP-4.

The original target depth for LADP-4, 675 ft, was selected in order to penetrate potential perched groundwater zones such as those that occur in the midreach of Pueblo Canyon and near the confluence of Pueblo and Los Alamos Canyons. The borehole also was designed to intersect a basalt flow penetrated by drillhole Otowi 4 in Los Alamos Canyon (Fig. 1). Where present, massive, little-fractured basalt could act as a barrier to the downward migration of groundwater in the vadose zone—causing water to perch. Alternatively, rubble zones at the base of basalt flows are permeable and may divert flow laterally.

Neither basalt nor perched groundwater were encountered in the borehole at its original target depth. The drill hole was deepened to 800 ft to ensure that no basalt flow occurs deeper than originally projected. Drilling was terminated in gravels of the Puye Formation at a depth of 800 ft.

Moisture contents were determined for 139 samples in LADP-4. Moisture in core and cuttings range from 0 to 23%, and the average moisture content is 7%. Figure 7 shows moisture distribution as a function of depth.

Moisture contents are somewhat elevated (~10%) in surface soils and in the upper part of bedrock tuffs in LADP-4. Moisture in the tuff decreases to <5% at a depth of ~136 ft, where a noticeable increase in moisture occurs at the abrupt transition between devitrified tuffs of Tshirege unit 1v and vitric tuffs of Tshirege unit 1g; peak moisture contents reach 23%. Moisture contents also are elevated (~20%) in the lowermost part of Tshirege unit 1g and in the underlying Tsankawi Pumice Bed. Although somewhat variable, moisture in LADP-4 generally decreases with depth below the Tsankawi Pumice Bed.

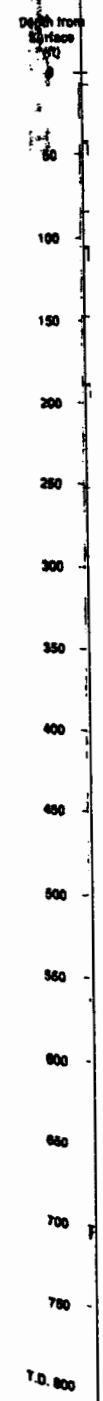

Fig. 6.
DP C6

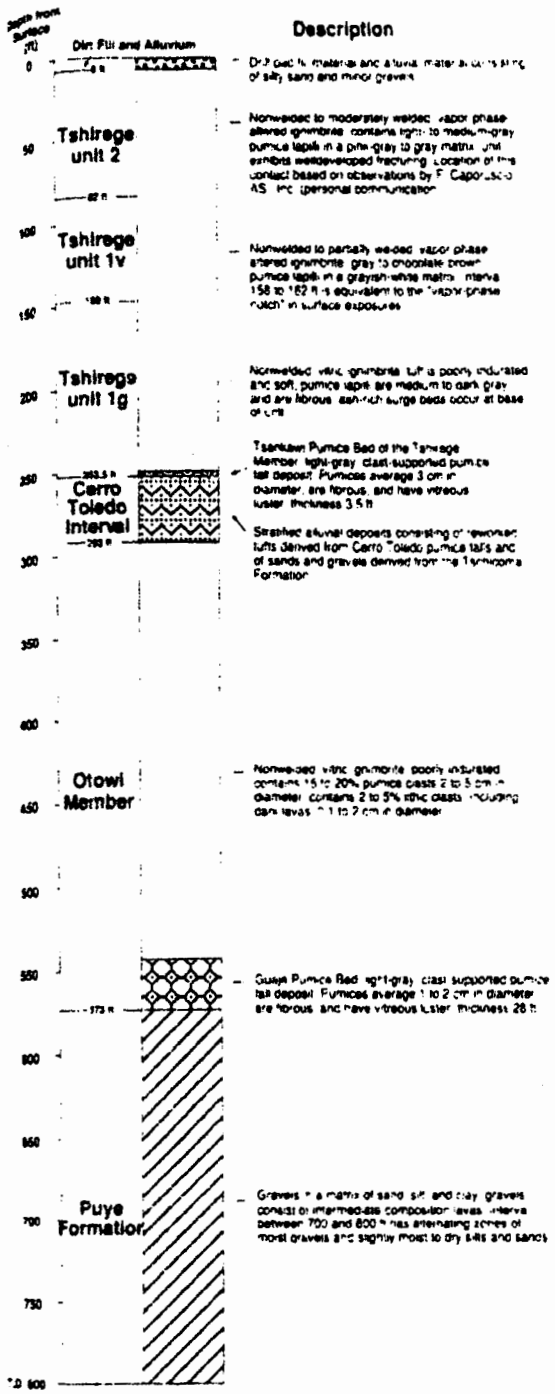

Fig. 6. Preliminary lithologic log for borehole LADP-4, DP Canyon.

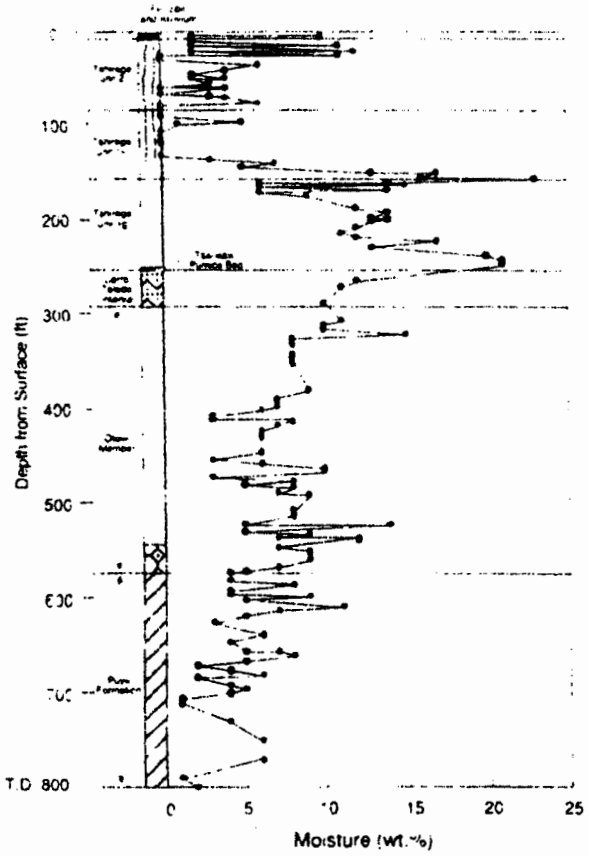

Fig. 7. Variation in moisture content as a function of depth in borehole LADP-4, DP Canyon.

Laboratory tritium results are not yet available for most samples taken from LADP-4. However, initial screening of samples in the field laboratory indicates that low-level tritium is present in some samples. A high-priority laboratory analysis yielded 2.15 ± 0.18 pCi/g tritium in a tuff sample collected from the moist zone associated with the unit 1v/1g boundary at a depth of 158.6 to 160.1 ft. This value is significantly above background but well below the screening-action level of 820 pCi/g for tritium in soils. In general, the tritium concentrations determined by the field laboratory do not correlate well with the moisture content in other parts of the borehole.

DISCUSSION

The alluvial groundwater in LADP-3 was encountered despite attempts to avoid shallow groundwater by siting the hole as far as possible from the stream channel. Evidently, canyon-bottom alluvial groundwaters in the Los Alamos area can extend at least as far laterally as their host alluvial deposits do. Most likely, the alluvial groundwater is confined on its sides and bottom by tuff bedrock, but this not yet confirmed in Los Alamos Canyon.

The chemistry of the Guaje Pumice Bed groundwater is similar in major constituents to that of the alluvial groundwater. This similarity, in addition to the presence of low-level tritium contamination, strongly suggests a hydrologic connection between the two perched groundwaters. Major-ion chemistries and tritium activities of water samples collected from monitor wells LAO-B (background) and LAO-1 as well as a spring in Los Alamos Canyon are compared to analytical results for LADP-3 to evaluate mixing relationships between alluvial and Guaje Pumice Bed groundwaters. Monitor wells LAO-B and LAO-1 are completed in alluvium upstream and upgradient of LADP-3 (Fig. 1). Results of chemical analyses of groundwater samples collected from LAO-B (Fig. 8) show that native alluvial groundwater in Los Alamos Canyon is a Ca^{2+}-Na^{+}-HCO_3^--type solution. This groundwater has a total dissolved solids (TDS) content of 110 ppm. A spring sampled in Los Alamos Canyon north of the skating rink (Fig. 1) contains Na^+, Ca^{2+}, and HCO_3^- as the dominant species (Fig. 8). This spring has a TDS content of 186 ppm. Groundwater collected from LAO-1 is a Na^+-Cl^--HCO_3^--type solution (Fig. 8) and is characterized by a TDS content of 170 ppm. Concentrations of Na^+ and Cl^- increase along the groundwater flow path in the alluvium in Los Alamos Canyon (Fig. 8). These increases result primarily from dissolution of road salt and discharges from Laboratory facilities and secondarily from cation exchange and weathering of the Bandelier Tuff and Tschicoma Formation, which make up the alluvial material (Longmire, unpublished data). Groundwater samples collected from LADP-3 are characterized by a mixed-ion composition in which Na^+, Ca^{2+}, HCO_3^-, and Cl^- are the dominant species. The TDS content of this groundwater is 229 ppm (Table 1). LADP-3 groundwater is enriched in Cl^- and Na^+ relative to water from LAO-B and the spring (Fig. 8). Groundwater within the Guaje Pumice Bed is chemically similar to alluvial groundwater collected from monitor well LAO-1 (Fig. 8). This similarity in major-ion chemistries suggests that alluvial groundwater is recharging the Guaje Pumice Bed.

Figure 9 is a volumetric-mixing curve for the Guaje Pumice Bed and alluvial groundwaters that is based on the conservative species Cl^-. End members for this mixing curve include an estimated Cl^- concentration for noncontaminated groundwater in the Guaje Pumice Bed (3.2 ppm, $10^{-4.06}$ molal) and an average Cl^- concentration (64.51 ppm, $10^{-2.74}$ molal) in groundwater samples collected from LAO-1 over 25 years (1966 to 1991). Monitor well LAO-1 is located hydrologically upgradient of LADP-3. Figure 9 suggests that ~70% of the groundwater in the Guaje Pumice Bed is derived from alluvial groundwater.

Figure 10 shows tritium activities observed in alluvial groundwater (LAO-1). Tritium fluctuations observed in LAO-1 probably are the result of the sampling time, variations in source concentration, radioactive decay, and dispersion. Tritium occurs as tritiated water ($^1H^3HO$), and its retardation factor is equal to unity, which makes this species an excellent radioactive groundwater tracer. A calculated radioactive-decay curve for tritium activities observed in LADP-3 (6.0 ± 0.16 nCi/ℓ) is also shown in Fig. 10. An estimate of groundwater flow velocity in the vertical direction can be calculated from Fig. 10; overlap of the two curves places a plausible time of groundwater recharge from the alluvium to Guaje Pumice Bed (325-ft depth). This

Fig. 9
Pumi
Grour

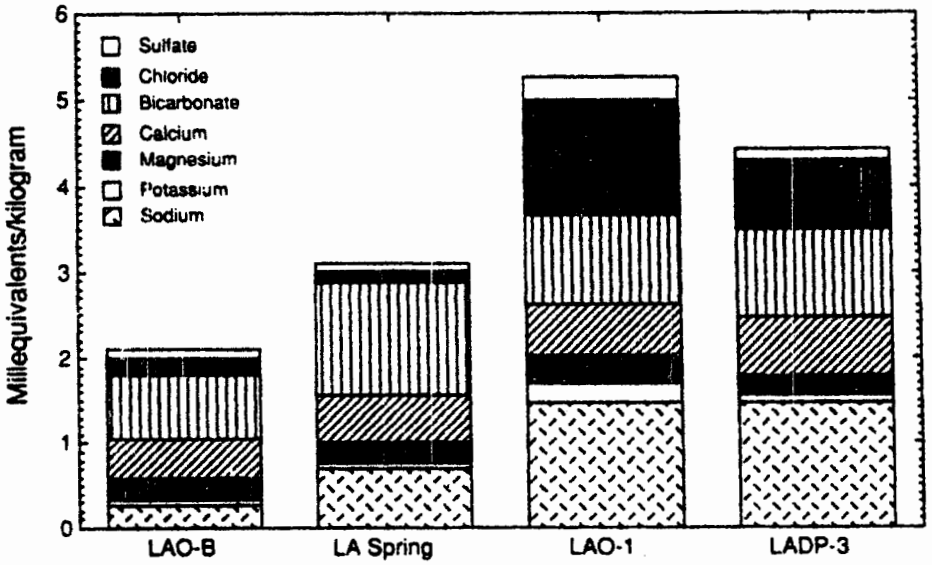

Fig. 8. Major-ion chemistry for selected waters in Los Alamos Canyon.

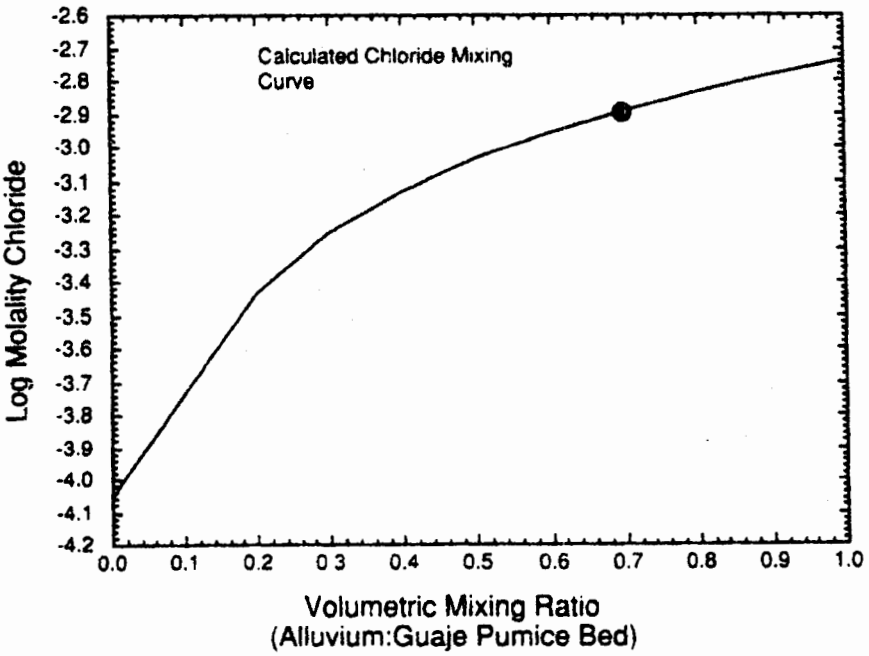

Fig. 9. Calculated volumetric chloride mixing curve for alluvial groundwater (monitor well LAO-1) and Guaje Pumice Bed groundwater (LADP-3), Los Alamos Canyon. The filled circle represents the mixing ratio for groundwater collected from LADP-3.

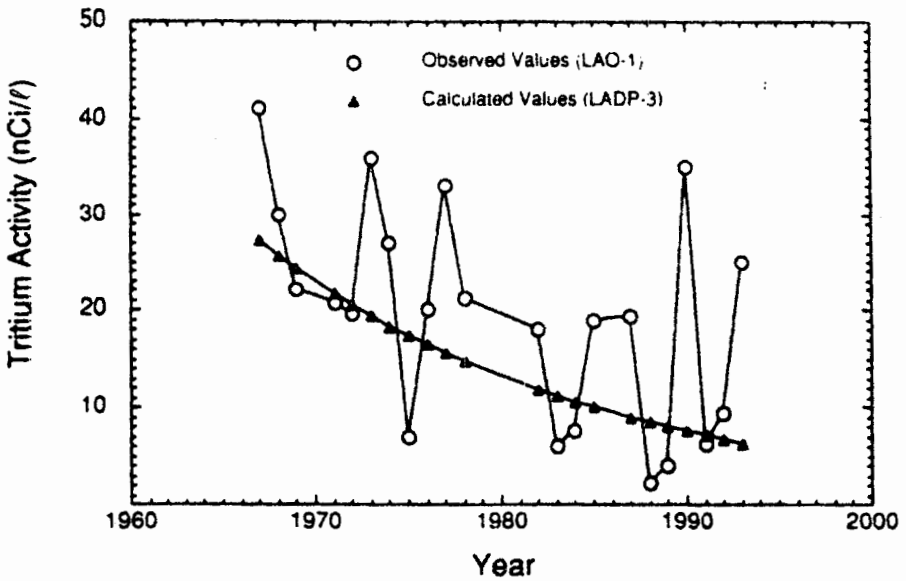

Fig. 10. Observed tritium activities in alluvial groundwater (monitor well LAO-1) and calculated tritium decay in Guaje Pumice Bed groundwater (LADP-3), Los Alamos Canyon.

assumes that (1) tritium concentrations observed at LAO-1 are representative of alluvial groundwater recharging the Guaje Pumice Bed, (2) decreases of tritium activities are mainly due to radioactive decay ($T^{1/2}$ for tritium is 12.33 years), and (3) dispersion and evapotranspiration are insignificant. Based on the data shown in Fig. 10, a realistic recharge event possibly occurred in 1972, which suggests that a minimum vertical groundwater flow velocity, calculated for 1994, is 15 ft/year (325 ft/22 years). This calculation applies to fracture and matrix flow, where the vertical groundwater flow velocity is controlled by the degree of saturation, the unsaturated hydraulic conductivity, and the hydraulic gradient.

One hypothesis for the origin of Guaje Pumice Bed groundwater is that infiltration occurs at several points of recharge or along a line source of recharge on the canyon bottom. Surface water and alluvial groundwater, the likely sources of recharge, may reach the Guaje Pumice Bed as porous media flow through local zones of saturation (Fig. 11). Given the relatively low moisture content (10 to 15%) in the upper part of the Otowi Member (Fig. 5), it is unlikely that LADP-3 penetrated a zone of recharge. These moisture contents represent ~25% saturation in tuffs containing 40 to 50% porosity. Groundwater movement at these low saturation levels could occur only if the smallest pores in the tuff are interconnected. It is possible that recharge occurs upstream of LADP-3 or that the recharge pathways are tortuous and poorly characterized by individual boreholes.

Alternatively, faults, fractures, and joints crossing the canyon floor may act as preferential pathways for recharge that reaches the Guaje Pumice Bed (Fig. 11). Where present, these structural features may act as conduits that allow groundwater to bypass unsaturated rocks before spreading laterally in permeable stratigraphic units. The Guaje Mountain fault, which is projected to cross Los Alamos Canyon in the vicinity of TA-2, is an example of a structural feature that may act as a conduit for recharge of perched systems beneath the canyon floor.

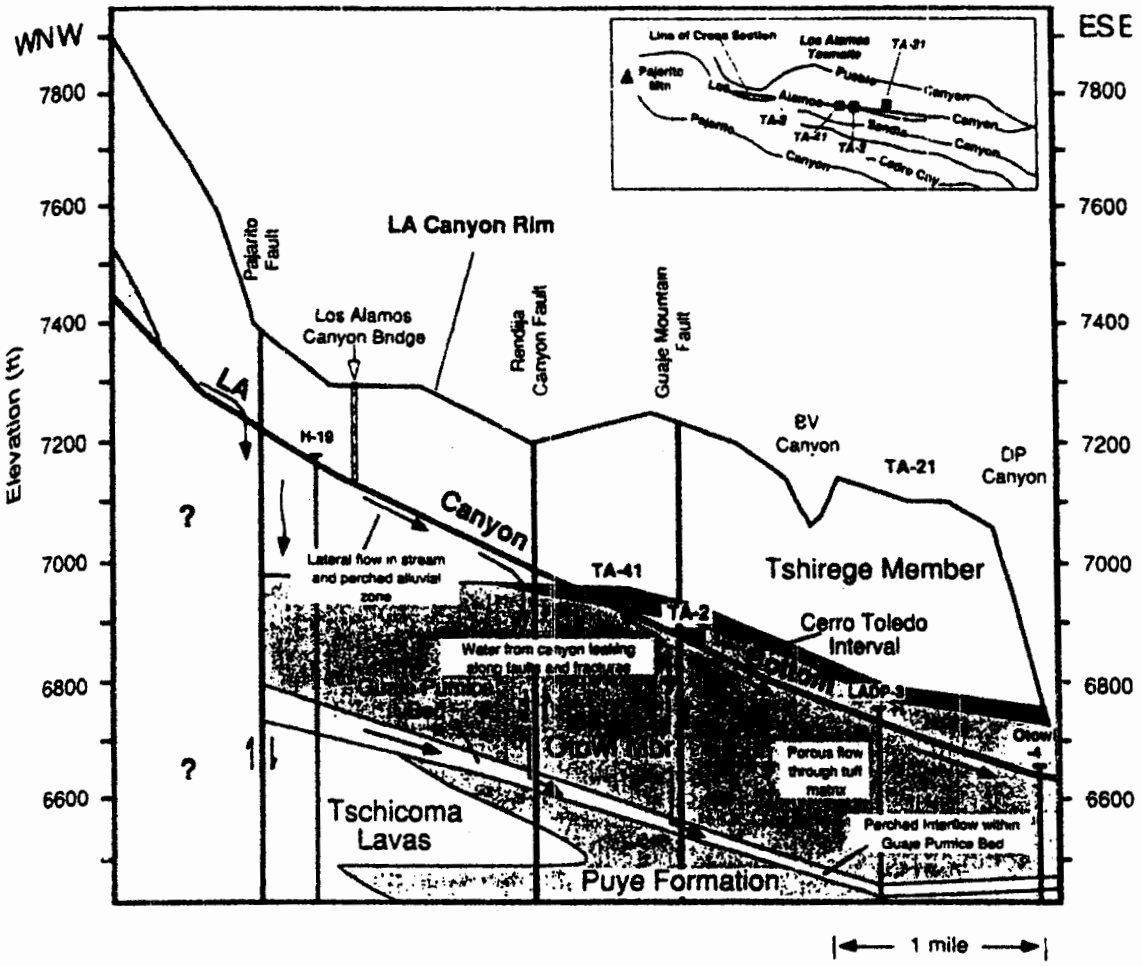

Fig. 11. Schematic cross section showing possible groundwater pathways (black arrows) below the floor of Los Alamos Canyon. Stream-fed shallow groundwater moves downcanyon within alluvial deposits in the canyon bottom. Infiltration of this shallow groundwater feeds at least one intermediate-depth perched zone in the Guaje Pumice Bed. Infiltration may occur either as porous media flow through partially saturated tuffs or as fracture flow along faults, fractures, and joints. Displacements along the Rendija Canyon and Guaje Mountain faults may be significant in pre-Bandelier units but are not shown in this figure because there are insufficient subsurface data. This cross section is based on borehole data from H-19, LADP-3, and Otowi-4 as well as surface geologic studies of Los Alamos Canyon by D.E. Broxton.

Lack of perched conditions in the Guaje Pumice Bed in LADP-4 to the north indicates that the Guaje Pumice Bed groundwater is not a laterally extensive, sheet-like body that extends under DP Mesa. However, present data are insufficient to determine how far northward this groundwater extends under TA-21 (Fig. 12). This perched groundwater may be localized under Los Alamos Canyon because the surface stream and its associated alluvial groundwater provide the likely source of recharge. Perhaps, the perched groundwater is a ribbon-like zone of saturation that follows the canyon course. Because the Guaje Pumice Bed is a pumice fall that mantles paleotopography, the elevation of this deposit may vary significantly from place to place (see Fig. 12). Thus, groundwater in the Guaje

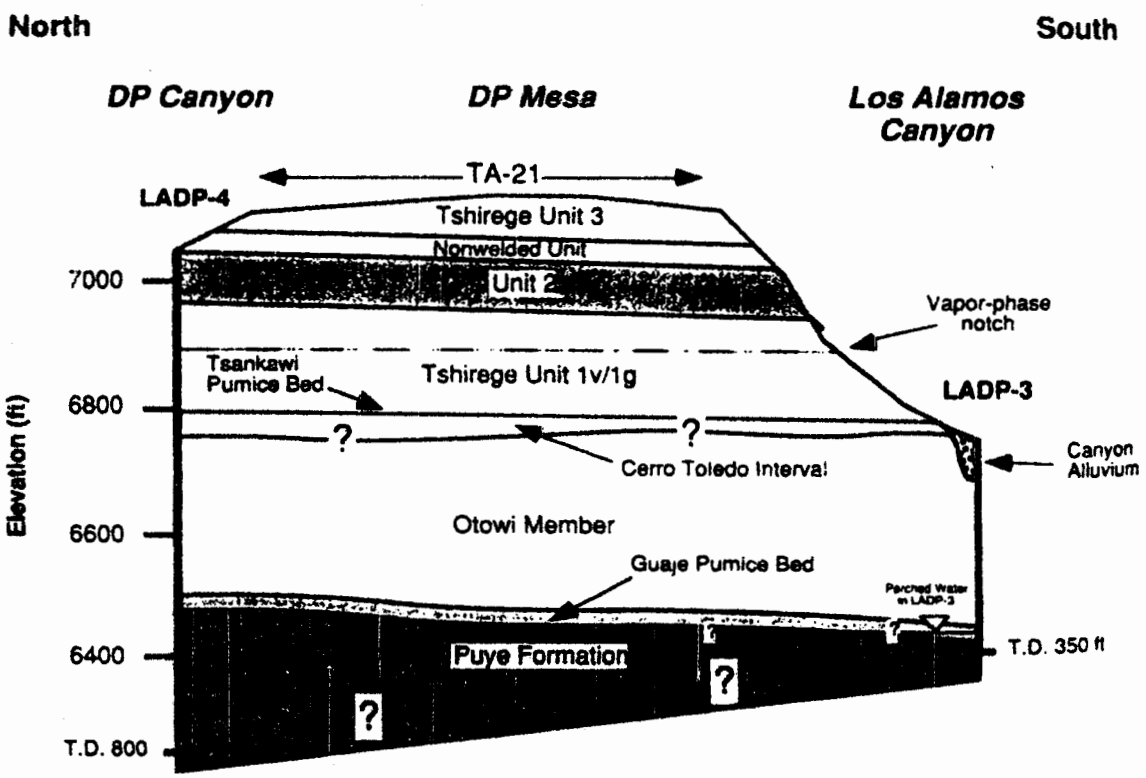

Fig. 12. N-S geologic cross section of TA-21 showing the distribution of principal stratigraphic units. Perched groundwater occurs in the Guaje Pumice Bed under Los Alamos Canyon, but its extent northward under the industrialized areas of DP Mesa is not known.

Pumice Bed at LADP-3 may flow downgradient into the Puye Formation in other parts of Los Alamos Canyon. In the geologic log for well Otowi-4, Stoker *et al.* (1992) observed, "*Some perched water was visible in a video log of the 48-in. hole at about 253 ft where the water cascaded in from large gravel.*" The perched groundwater in Otowi-4 occurs in the Puye Formation 0.75 miles downcanyon and 64 ft lower in elevation than the Guaje Pumice Bed groundwater in LADP-3 (Fig. 13). Although these occurrences of perched groundwater may be related, this hypothesis cannot be demonstrated with certainty using the data currently available.

At this point in the investigation, the source of tritium in the Guaje Pumice Bed groundwater in Los Alamos Canyon has not been determined. The Laboratory's TA-2 and TA-41 are located on the floor of Los Alamos Canyon upgradient of the tritium contamination detected at LADP-3. TA-2 is a possible contamination source because it was the source of tritium releases in the past. In January 1992, it was determined that tritium-laden primary coolant water from the Omega West Reactor at TA-2 was leaking into the alluvial groundwater. Surface water and alluvial groundwater from the canyon bottom are possible sources of recharge to the Guaje Pumice Bed groundwater. TA-21 is a less likely source for the tritiated groundwater because thick, unsaturated tuffs, lack of available surface and groundwater, and low recharge rates could serve as effective barriers to contaminant transport from the mesa top.

The discovery of Guaje Pumice Bed groundwater shows that surface water can infiltrate to substantial depths in the unsaturated zone beneath the large canyons of the Pajarito Plateau. Although the presence of the Guaje Pumice Bed perched groundwater raises questions about potential transport through the unsaturated zone, it is important to note that 600 ft of unsaturated Puye Formation separate the Guaje Pumice Bed groundwater from the main aquifer (Fig. 13). In addition, tritium levels in LADP-3 are below EPA drinking-water standards and likely would be diluted further if these groundwaters

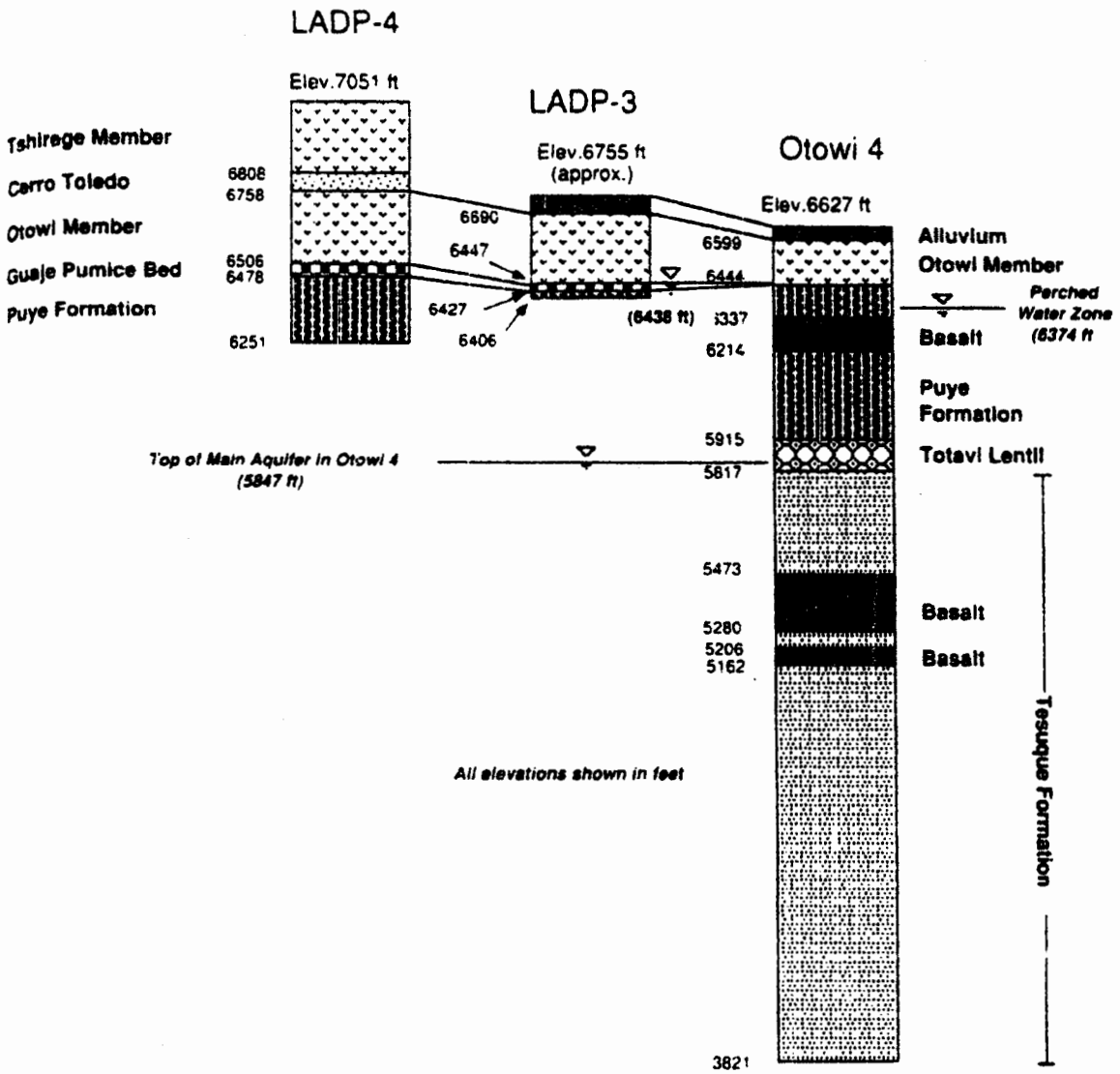

Fig. 13. Summary of subsurface geology in the vicinity of TA-21. Otowi 4 geology is summarized from Stoker et al. (1992). Intermediate-depth perched groundwater in LADP-3 and Otowi 4 are ~600 ft above the main aquifer. Guaje Pumice Bed groundwater in Los Alamos Canyon does not extend as far north as LADP-4 in DP Canyon.

entered the main aquifer. Additional boreholes planned for the area around TA-2 and TA-41 should penetrate to the depth of the Guaje Pumice Bed groundwater. These boreholes will provide important information about the lateral extent of the Guaje Pumice Bed perched groundwater and will help identify the source of tritium and groundwaters.

As specified in RFI work plan, LADP-3 was completed as a monitoring well when groundwater was encountered in the Guaje Pumice Bed. The monitoring well was completed with 2-in. PVC inside a temporary ODEX casing, which was subsequently removed. Estimated thickness of the perched zone is 5 to 7 ft, and the well is screened from 326 to 316 ft. Figure 14 shows details of the completed monitoring well. Future plans for the monitoring well include installation of a continuous groundwater-level monitoring transducer and groundwater sampling on a quarterly basis.

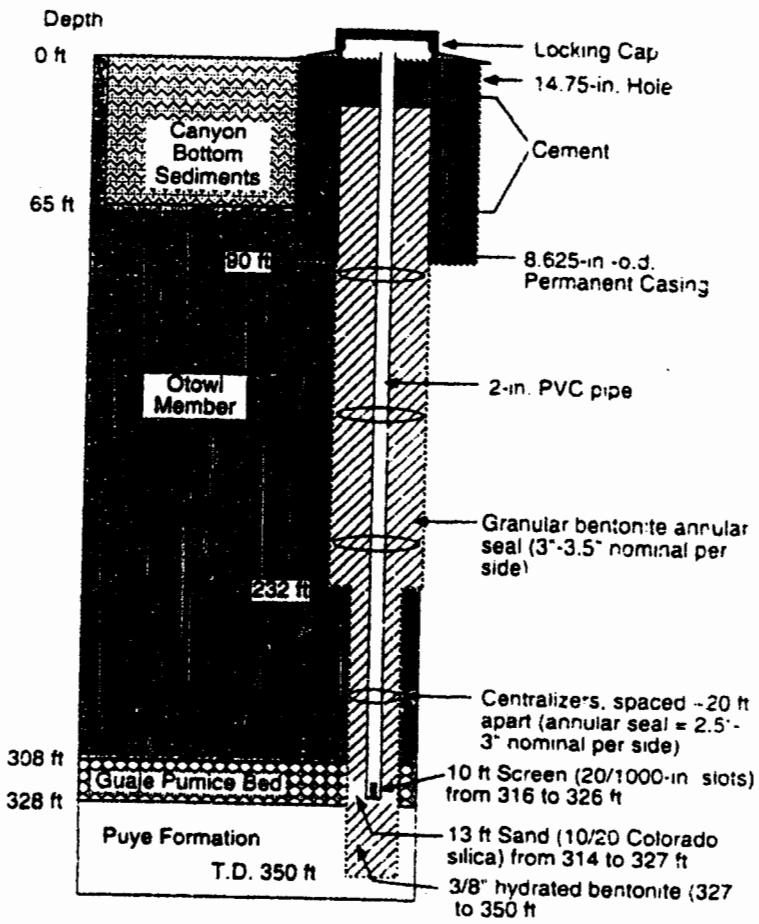

Fig. 14. Completion of LAPD-3 as a monitoring well (prepared from data provided by J.C. Newsom and E.D. Davidson, Jr.).

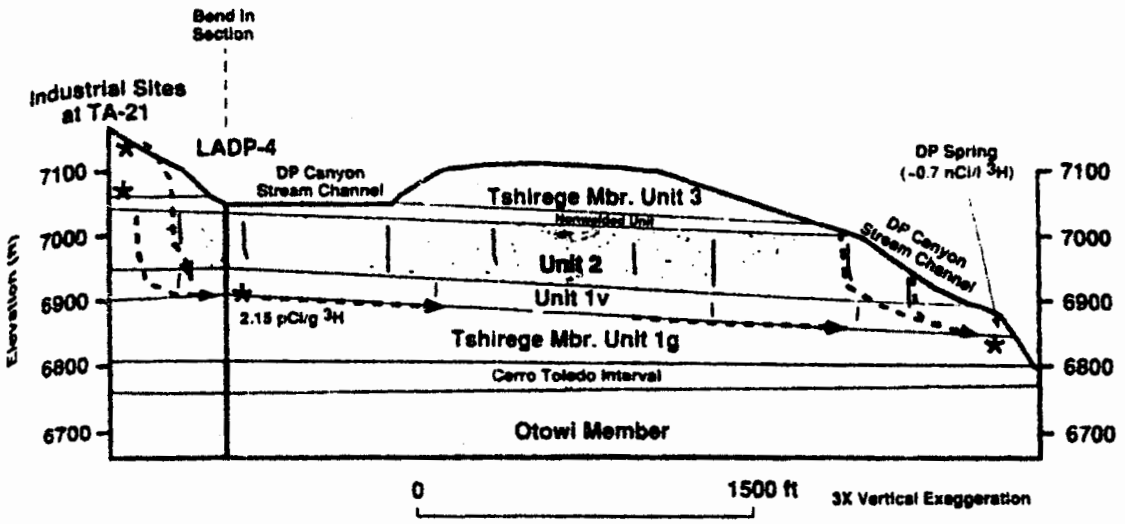

Fig. 15. Schematic geologic cross section showing setting of tritium contamination in the vicinity of DP Canyon (See Fig. 1 for location of cross section). Areas of known tritium contamination are indicated by (*). Tritiated groundwater at DP Spring may be derived from alluvial groundwater in DP Canyon. An alternative hypothesis is that perched groundwater travels laterally along the unit 1v/1g boundary before emerging at DP Spring. In both scenarios, industrialized areas at TA-21 are likely sources of the tritium.

Tritium in LADP-4 in DP Canyon is associated with high moisture content at the Tshirege unit 1g/1v boundary. The origin of the tritium is not yet known, but several industrial sites at TA-21 are potential sources. For example, tritium from TA-21 was released into DP Canyon from outfalls, especially from Building 257. In addition, subsurface tritium contamination has been documented at MDA T, just south of the borehole. Both treated and untreated tritium-bearing effluent from processing of plutonium was disposed of in four absorption beds at MDA T from 1945 to 1966 (Rogers, 1977). In 1974, seven boreholes were drilled to a depth of 40 ft between absorption beds 1 and 3 at MDA T to gather subsurface data for a proposed retrievable-waste storage facility. Samples from these boreholes contained 0.6 to 28 nCi/ℓ in soil moisture.

The localized nature of tritium in LADP-4 suggests that the unit 1v/1g boundary acts as a preferential pathway for the lateral movement of moisture and tritium (Fig. 15). The tritium may have reached its present position in LADP-4 as part of a vapor plume that traveled laterally along a horizon of greater permeability. When ongoing testing of samples is completed, it will be possible to compare the hydrologic properties of the tuffs above, below, and at the unit 1v/1g boundary. Alternatively, the moisture content at the 1v/1g boundary may be high enough for porous-media flow to occur where smaller, interconnected pores in the tuff are water-filled. The highest moisture content at this boundary is 23%—or about two-thirds saturation—assuming 40% porosity.

Tritium is found not only in LADP-4, but also in DP Spring, which is located on the north side of lower DP Canyon (Figs. 1 and 15). The tritium levels in DP Spring vary seasonally with the discharge rate, but they typically average about 0.7 nCi/ℓ (see Adams *et al.*, Sec. VII, this report). The spring occurs at a cascade that marks an abrupt change in streambase level between middle and lower

DP Canyon. Data are not yet available for determining if tuffs in LADP-4 and DP Spring are hydrologically connected, but the occurrence of tritium at both locations suggests that such a connection might exist.

One hypothesis for the origin of tritiated groundwater at DP Spring is that it is derived from alluvial groundwater in DP Canyon, which becomes slightly contaminated as it flows past a source or sources associated with industrialized areas of TA-21 (Fig. 15). Shallow groundwater is unusual in a canyon of this size whose headwaters are on the Pajarito Plateau. Runoff into DP Canyon is probably augmented by diversion of surface water into the canyon from extensive paved areas in the canyon's headwaters. Alluvial groundwater commonly emerges in the stream channel as isolated small pools and short stretches of intermittent surface-water flow in the middle reaches of the canyon. Eastward, DP Canyon becomes steeper, narrower, and deeper as the stream cuts downward through welded-tuff bedrock. Stream alluvium is thinner and more discontinous in this part of the canyon because short, intense summer thunderstorms tend to scour sediments from areas where the stream gradient is high. Surface flow is intermittent in this portion of the canyon. Because DP Spring is perennial and the stream channel is dry for much of the year, water storage probably occurs within stream alluvium—particularly in the middle reaches of the canyon where alluvial deposits are thickest. Downcanyon, where alluvium is thin and discontinuous, some water storage may occur in fractures.

An alternative hypothesis for the origin of the tritiated groundwater at DP Spring is that it derives from a perched groundwater body located beneath DP Canyon (Fig. 15). No perched water was encountered in borehole LADP-4 in the middle reach of the canyon, but relatively high moisture contents and low-level tritium contamination occur along the Tshirege unit 1v/1g boundary. This boundary is ~30 ft above the point where DP Spring emerges in DP Canyon. As noted above, this body may be a preferential pathway for the lateral movement of groundwater or water vapor. Perhaps borehole LADP-4 missed a perched groundwater body in the middle reach of the canyon or perched groundwater occurs beneath one of the mesas adjacent to the canyon.

Two boreholes will be drilled in DP Canyon as part of future ER studies. These boreholes will provide additional information about the source of tritium at DP Spring and possible hydrologic connections between DP Spring and tritium source areas at TA-21.

CONCLUSIONS

Two geologic characterization boreholes were drilled at TA-21 between August 30 and December 17, 1993. These boreholes were drilled to determine if perched groundwater occurs beneath Los Alamos and DP Canyons and to characterize the major hydrogeologic units at TA-21. This report has presented preliminary geologic and hydrologic data collected from these boreholes.

Borehole LADP-3 in Los Alamos Canyon encountered two perched groundwater zones. The upper zone is likely part of the canyon's alluvial groundwater and its occurrence in this borehole shows that these shallow groundwaters can extend at least as far laterally as their host alluvial deposits do. Moisture data for the borehole shows that this upper groundwater is divided into two distinct zones of saturation. Guaje Pumice Bed groundwater occurs at a depth of 325 ft. A water sample of this deeper perched zone contained 6.0 ± 0.16 nCi/ℓ of tritium, which is above regional background for surface water but well below the drinking water standard of 20 nCi/ℓ. Preliminary analyses for low-level ^{137}Cs and Pu isotopes failed to detect these constituents. Mixing calculations suggest that ~70% of the groundwater in the Guaje Pumice Bed is recharge from alluvial groundwater. Additional analyses are being conducted to

determine if other contaminants are present in this perched groundwater and to further investigate the possibility of a hydrologic connection between the alluvial groundwater and the Guaje Pumice Bed groundwater.

The source of tritium in the Guaje Pumice Bed groundwater in Los Alamos Canyon cannot be determined with certainty yet. TA-21 is a less likely source for the tritium contamination because thick, unsaturated tuffs, little or no available water sources, and low recharge rates may serve as effective barriers to contaminant transport from the mesa top. TA-2 is considered a much more likely source of tritium contamination in Los Alamos Canyon because it was the source of tritium releases in the past and because surface water and alluvial groundwater are available to promote recharge through the canyon floor.

Tritium also was found in borehole LADP-4 in DP Canyon. Preliminary laboratory analysis yielded 2.15 ± 0.18 pCi/g tritium for a tuff sample collected from the moist zone associated with the unit 1v/1g boundary at a depth of 158.6 to 160.1 ft. This value is above background but well below the screening action level of 820 pCi/g for tritium in soil moisture. The origin of the tritium is not yet known, but several industrial sites at TA-21 are potential source areas.

Additional characterization of the perched groundwater in Los Alamos Canyon will take place when additional boreholes are drilled as part of both OU-1098 RFI studies at TA-2 and the Canyons RFI investigations. In addition, two boreholes will be drilled in DP Canyon as part of future TA-21 RFI studies to provide additional information about the occurrence of tritium in LADP-4 and at DP Spring.

ACKNOWLEDGEMENTS

We thank J. Gardner, J. Wolff, and E. Springer, who provided critical reviews of this report.

REFERENCES

Adams, A., DeMuth, J., Counce, D., and Goff, F., 1995, Fluorescein dye experiment at DP Spring and sewage outfall, Technical Area 21, Los Alamos, New Mexico, Sec. VII, this report.

Rogers, M.A., 1977, History and environmental setting of LASL near-surface land disposal facilities for radioactive wastes (Areas A, B, C, D, E, F, G, and T), Los Alamos National Laboratory report LA-6848-MS Vol. 1, 55 pp.

Stoker, A.K., McLin, S.G., Purtymun, W.D., Maes, M.N., and Hammock, B.G., 1992, Water supply at Los Alamos during 1989, Los Alamos National Laboratory Report LA-12276-PR, 51 pp.