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Los Alamos National Laboratory

Environmental Restoration

A Department of Energy environmental clean-up program

EXTENT OF SATURATION IN MORTANDAD CANYON

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1.0 EXECUTIVE SUMMARY

1.1 Purpose

This study was conducted partly to fulfill a special condition in the RCR- HSWA permit issued to the DOE and LANL in March 1990. A major field data collection effort was conducted in Mortandad Canyon to enlarge the factual basis for the permit-required preliminary evaluation of the extent of saturation and the occurrence of radioactive, inorganic, and organic contaminants in the perched alluvial water in the bottom of the canyon and the unsaturated tuff beneath the saturated alluvium. The conclusions of the study are also based on a large amount of related data collected as part of the ongoing LANL environmental monitoring program and groundwater protection management program.

The canyon receives NPDES-permitted effluents from the LANL Radioactive Liquid Waste Treatment Plant at TA-50 (Fig. 1-1) as well as other permitted discharges and runoff. The effluents, waste water, and storm runoff recharge a shallow aquifer in the alluvium. The residual contaminants in the effluents and discharges have accumulated on stream-channel sediments and in the perched water in the alluvium.

The permit-required data collection included the drilling of three core holes through the alluvium in the bottom of the canyon. Two of the holes (MCM-5.1 and MCM-5.9A in Fig. 1-1) penetrated the saturated portion of the alluvium. One hole (MCM-5.1) reached a depth of about 100 feet, the other (MCM-5.9A) reached about 200 feet. They were constructed using a large diameter hollow stem auger as a casing to isolate the perched water and prevent it from moving down the borehole while collecting cores from the underlying unsaturated tuff. The third hole, reaching a depth of about 100 feet, was constructed just beyond the Laboratory boundary, about 1 mile downstream and downgradient from the furthest extent of the zone of saturation. All three holes were completed with small diameter casing to permit measurement of formation water content with a neutron moisture probe. Cores from all three holes were analyzed for radioactive constituents, cores from the two onsite holes were analyzed for inorganic constituents, and cores from the onsite hole furthest upstream were analyzed for organic constituents.

1.2 Extent of Saturation

The saturated aquifer is of limited extent as the recharge (effluents, waste water, and storm runoff) is sufficient only to maintain a saturated zone in the alluvium extending about 3.5 km (5.8 mi) downstream from the outfall location (about the edge of the conceptual illustration in Fig. 1-1). This eastern extent of saturation is about 1.6 km (1 mi) within the Laboratory boundary as observed in test holes on the Laboratory lands and the core hole constructed on San Ildefonso in cooperation with the BIA and Pueblo. Test holes drilled or cored through the alluvium indicated that the underlying tuff, weathered to silts and clays immediately below the alluvium, is not saturated. The saturated porition of the alluvium is perched on weathered-unweathered tuff and is generally no more than 10 feet thick. Moisture content generally declines to less than 50 percent of saturation conditions both transverse to canyon axis and at depth. Test holes completed in the weathered tuff below the saturated alluvium will not yield free water.

1.3 Extent of Contamination

Most, generally more than 99 percent, of the residuals from the treatment plant effluents are associated with sediments in or immediately adjacent to the stream channel. All of these contaminated sediments are located within the Laboratory property, none have moved offsite. A small fraction of the residuals, on the order of 1 percent or less, are present in the perched water in the alluvium. As the perched water does not extend to the site boundary, there has been no offsite transport of contaminants in perched water.

There has been very little movement of contaminants into the unsaturated tuff beneath the saturated portion of the alluvium. Except for tritium, radioactive constituents have apparently moved less than about 10 feet into the unsaturated zone, based on analysis of cores from the two onsite coreholes. Tritium, as tritiated water, has moved to depths of at least 195 feet in the tuff. Tritium concentrations in the deepest onsite corehole decrease by a factor of about 100 between 150 and 195 feet and suggest that tritium may not have moved much deeper; however, additional samples from greater depths will be needed to confirm this. No tritium contamination has ever been detected in water in the main aquifer based on samples from a deep test well (total depth 1065 ft, water level 968 ft), which is located in Mortandad Canyon.

Water in the perched aquifer contains inorganic constituents listed in the RCRA Regulations Appendix IX are present, as expected from residuals in effluent. No organic chemical constituents listed in Appendix IX are present in perched water based on analyses of samples by two different laboratories.

No cores taken in or beneath alluvium to depths of about 100 feet showed any detectable organic chemical (volatiles, semivolatiles, herbicides, pesticides, or PCBs) contaminants. Analysis of cores by the EP Toxicity method showed no metal constituents exceeding (or even approaching) criteria levels.

1.4 Hydrologic Conditions

Beneath the bottom of the saturated alluvium, moisture content of weathered and unweathered tuff is about 30 to 50 percent of saturation for most of the observed depth (100 to 200 feet) in the two onsite core holes. However, a 15-foot thick zone, at a depth of about 100 feet near the contact of two different members of the tuff, has a higher moisture content, 80 to 90 percent of saturation. The same pattern occurs, but at a lower moisture content, in the offsite corehole.

Saturated hydraulic conductivities determined on core samples taken at depths beneath the perched aquifer in the two onsite coreholes generally range from about 5×10^{-5} cm/sec to about 2×10^{-3} cm/sec, comparable to those of silty sand. Unsaturated hydraulic conductivities at the in-situ moisture contents range from about 10^{-6} to 10^{-11} cm/sec in most cores, but are as large as 10^{-3} to 10^{-2} in the 15-foot thick zone at about 100 foot depth. The unsaturated zone pressure head at the in-situ moisture contents are generally between -10^{2} and -10^{4} cm of water, but do not clearly indicate a gradient with depth, suggesting limited movement in the unsaturated zone.

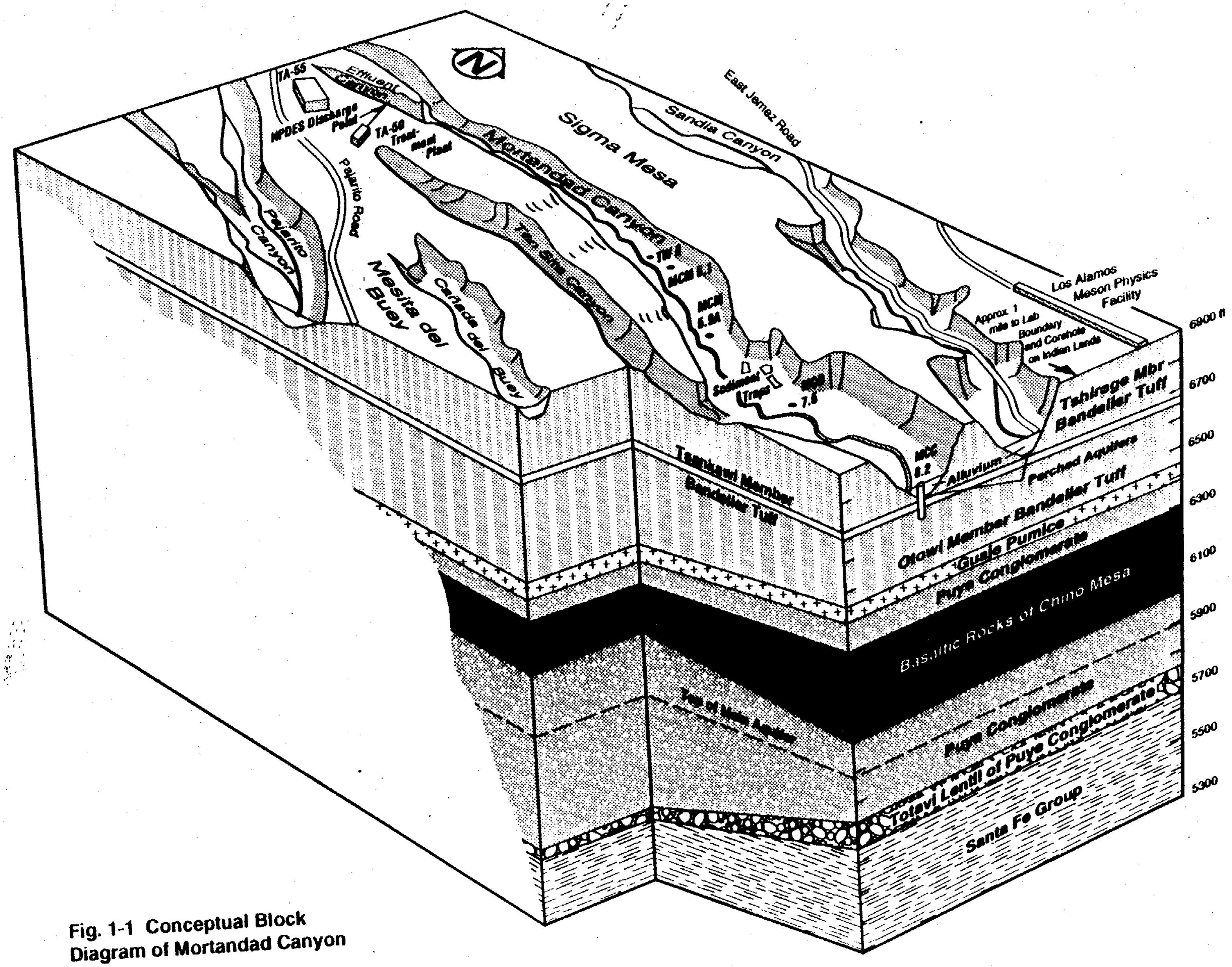


Fig. 1-1 Conceptual Block Diagram of Mortandad Canyon

2.0 INTRODUCTION

2.1 Organization of the Report

This report is primarily intended to present the data and major findings of the study conducted in response to the permit conditions. In order to provide a context for understanding and suitable documentation of methods this report contains information that may have limited interest for different readers. This description of the organization and content of the report should provide a guide to readers with different backgrounds and interests, enabling them to identify those portions of the report useful to their individual perspectives.

The balance of Section 2 contains general background (2.2) and the permit conditions (2.3). Section 3 provides a limited general background on the canyon including identification of previous relevant studies (3.1), a description of the monitoring facilities constructed over the years prior to the present study (3.2), and some information on the ongoing routine monitoring program conducted by LANL (3.3). Section 4 summarizes the methods and results of two recent pre-permit special studies that have not been previously published elsewhere, but that provide information relevant to the issues addressed in the permit special condition.

Section 5 documents the methods of the present, permit-required data collection program. This includes the methods for investigating the occurrence of saturation by core drilling (5.1.1) and seismic refraction (5.1.2), the methods for determining the extent of contamination by analysis of core samples (5.2.1) and the methods for constructing and sampling wells in the perched zone (5.2.2), and the determination of hydrologic properties of the core samples (5.3).

Section 6 presents the basic data of the study in summary tables and figures, as appropriate, for the extent of saturation (6.1), the extent of contamination (6.2), and the hydrologic properties (6.3).

Section 7 presents generalized, largely qualitative, conclusions drawn from the data and directly addressing the permit condition issues regarding the extent of saturation (7.1), the extent of contamination (7.2), and the hydrologic properties (7.3). Related data collected previously or under auspices of the other programs are included where appropriate to provide context and enhance understanding and to provide a compilation of information for use in future interpretive studies. Additional data needs are discussed in Section 7.4 and descriptions of more detailed and quantitative interpretive efforts now underway or planned for the future are included in Section 7.5.

2.2 General Background

Radioactive liquid industrial wastes from operations of the Los Alamos National Laboratory are collected and treated at the Radioactive Liquid Waste Treatment Plant at TA-50 (see conceptual illustration in Fig. 1-1). After treating the water to remove most of the radionuclides, the effluent is released into Mortandad Canyon. This effluent, effluents from other NPDES permitted discharges (which include cooling water and treated sanitary waste water from other operations), and storm runoff combine and create surface water flow in Mortandad Canyon. The surface water recharges a perched shallow aquifer in the canyon alluvium (i.e., the shallow ground water separated from the underlying main body of deep ground water by a unsaturated zone). The silts and clays of the underlying weathered tuff retard movement to the deep aquifer. As the water in the shallow aquifer moves horizontally downgradient along the canyon, losses occur from evapotranspiration and infiltration into the underlying tuff.

Most of the residual radioactive constituents in the effluent (e.g., plutonium, cesium, and americium) are adsorbed on the sediments in the stream channel. This accounts more than 99 percent of the inventory. The remainder moves with the surface water into the alluvial perched aquifer. Tritium, the radioactive isotope of hydrogen, however, is chemically bonded as a hydrogen atom in the water molecules and moves with the surface water into the alluvium or evaporating in the same proportion as the non-radioactive water.

The plant became operational in 1963 and since that time has released low-level radioactive effluents into the canyon. Hydrologic studies were initiated in 1960 as a part of the Laboratory environmental program, and continue to the present. Additional investigations were initiated to determine the water and contaminant movement from the shallow aquifer into the unsaturated zone above the main aquifer. Abstracts from special geohydrologic investigations are included in this report in Appendix 8.2.1.

Previous investigations delineate the geohydrology of the canyon. The initial programs drilled and installed 21 observation wells and 31 moisture access hole in the canyon. Data from these wells helped outline the geology and understand the hydrology of the stream-connected shallow aquifer in the alluvium. Two gaging stations were installed and operated in the canyon to aid in determining a water balance.

A deep test well (TW-8) located near the middle of the canyon was completed into the main aquifer 968 ft below the canyon bottom or 938 ft below the base of the shallow aquifer. analyses of water samples from this deep test well have never shown any detectable contaminants during the last three decades.

Routine environmental monitoring has been conducted in Mortandad Canyon throughout the discharge history from the treatment plant. Since 1971, the results of this monitoring has been documented in a series of annual surveillance reports published by the Laboratory; earlier data was compiled in reports prepared by the U. S. Geological Survey. These reports are listed in Appendix 8.2.2.

2.3 Special Permit Condition

On March 8, 1990, the EPA Region VI issued a Hazardous Waste Permit to the DOE and the University of California, Los Alamos National Laboratory. That permit includes certain requirements stated as:

> "SPECIAL CONDITIONS PURSUANT TO THE 1984 HAZARDOUS AND SOLID WASTE AMENDMENTS TO RCRA FOR LOS ALAMOS NATIONAL LABORATORY
>
> . . .
>
> "C. SPECIAL PERMIT CONDITIONS
>
> . . .
>
> "6. Vertical Extent of Saturation
>
> "The permittee shall conduct a subsurface investigation of saturation by drilling test holes through the shallow alluvial perched aquifer in Mortandad Canyon. Construction of the test holes will hydraulically isolate the perched aquifer from the underlying unsaturated tuff. This perched aquifer is recharged in part from wastewater treatment discharges located upstream. The investigation shall provide an initial evaluation of the maximum extent of the vertical and horizontal water and contaminant movement into the unsaturated tuff beneath the saturated alluvium The study shall attempt to recover cores from the tuff to be used to determine laboratory values for unsaturated hydraulic conductivity conductance (sic), specific retention and specific yield, effective porosity and saturated permeability. The boring shall be analyzed for the applicability of installation of neutron moisture probe access tubes to determine moisture over time. Chemical and radiochemical analyses of the cores shall also be made to assist in the determination of fluid movement from the perched alluvial aquifer into the underlying unsaturated tuff. The chemical analysis shall include Appendix IX constituents, while radiochemical analysis shall include 3H, 137 Cs, Total U,

> 238Pu, 239Pu, 240Pu (sic), 241 Am, Gross Gamma, and Gross Alpha, as appropriate. A report detailing the results of this study shall be submitted within one year of the effective date of this permit."

The study described in this report fulfills that requirement.

3.0 GENERAL HYDROGEOLOGIC SETTING

Los Alamos National Laboratory and the associated residential areas of Los Alamos and White Rock are located in Los Alamos County, north-central New Mexico, approximately 100 km (60 mi) north northeast of Albuquerque and 40 km (25 mi) northwest of Santa Fe (Fig. 3-1). The 111-km^2 (43-mi^2) Laboratory site and adjacent communities are situated on Pajarito Plateau, which consists of a series of fingerlike mesas separated by deep east-to-west oriented canyons cut by intermittent streams. The mesa tops range in elevation from approximately 2 400 m (7 800 ft) on the flank of the Jemez Mountains to about 1 900 m (6 200 ft) at their eastern termination above the Rio Grande Valley.

Ash flows, ash falls, and pumice of the Bandelier Tuff form the fingerlike mesas of the Pajarito Plateau (Fig. 3-2). The tuff, ranging from nonwelded to welded, is more than 300 m (1 000 ft) thick in the western part of the plateau and thin eastward to about 80 m (260 ft) above the Rio Grande. The tuff was deposited by a series of eruptions of a volcano in the Jemez Mountains about 1.1 to 1.4 million years ago.

The tuffs overlap onto the Tschicoma Formation, which consists of older volcanic rocks that form the Jemez Mountains. The tuff is underlain by the Puye Conglomerate (Fig. 3-2) under the central and eastern edge of the Plateau along the Rio Grande. Chino Mesa basalts (Fig. 3-2) interfinger with the conglomerate along the Rio Grande. These formations overlay the sediments of the Santa Fe Group (Fig. 3-2), which extends across the Rio Grande Valley and is in excess of 1 000 m (3 300 ft) thick.

Los Alamos area surface water occurs primarily as intermittent streams. Springs on the flanks of the Jemez Mountains supply base flow into upper reaches of some canyons, but the amount is insufficient to maintain surface water flows across the Laboratory site. Flow loss occurs by evaporation, transpiration, and infiltration. Runoff from heavy thunderstorms or heavy snowmelt reaches the Rio Grande several times a year in some drainages. Effluents from sanitary sewage and industrial waste treatment plants, and cooling-tower blowdown

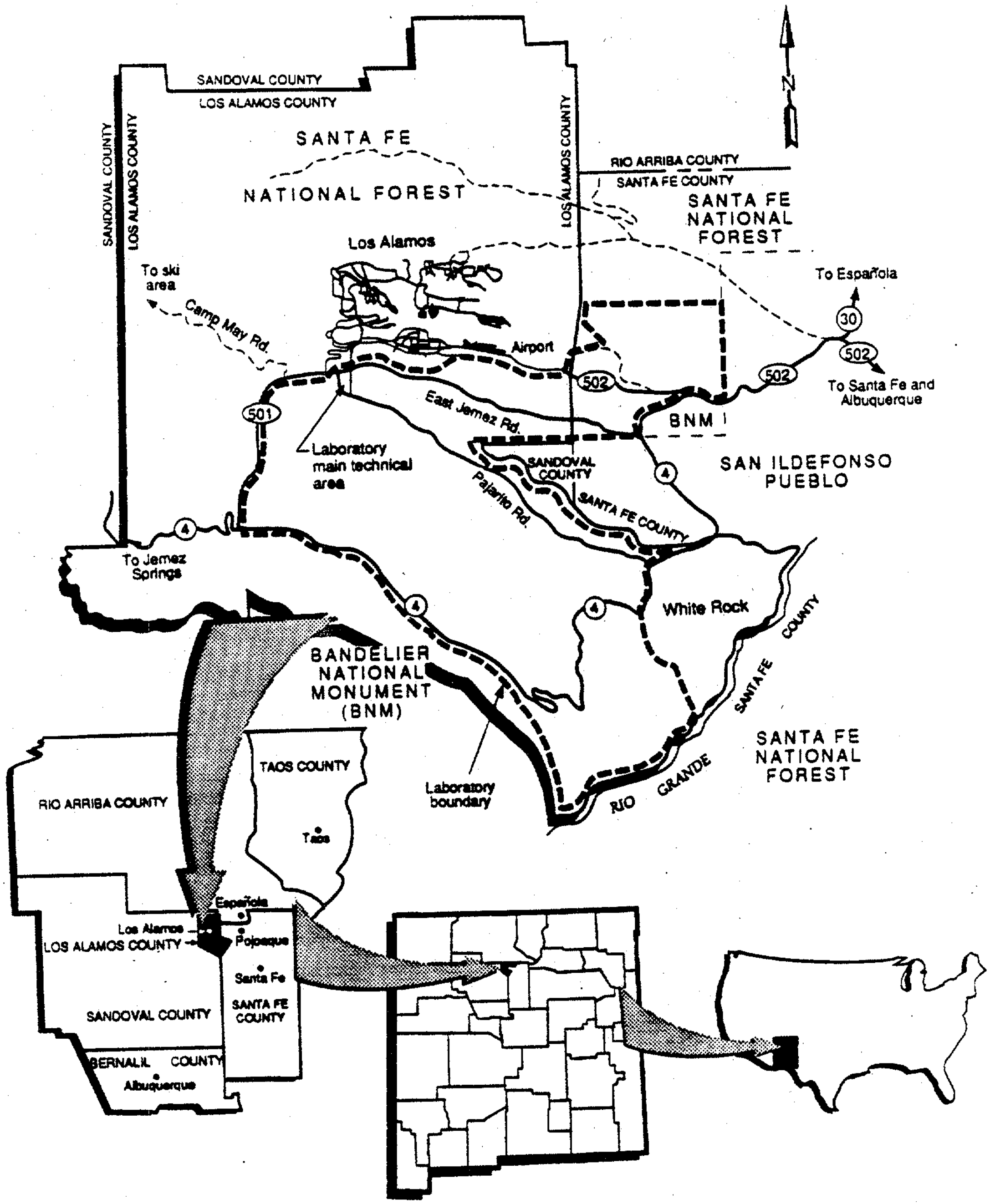


Fig. 3-1 Regional Location of Los Alamos

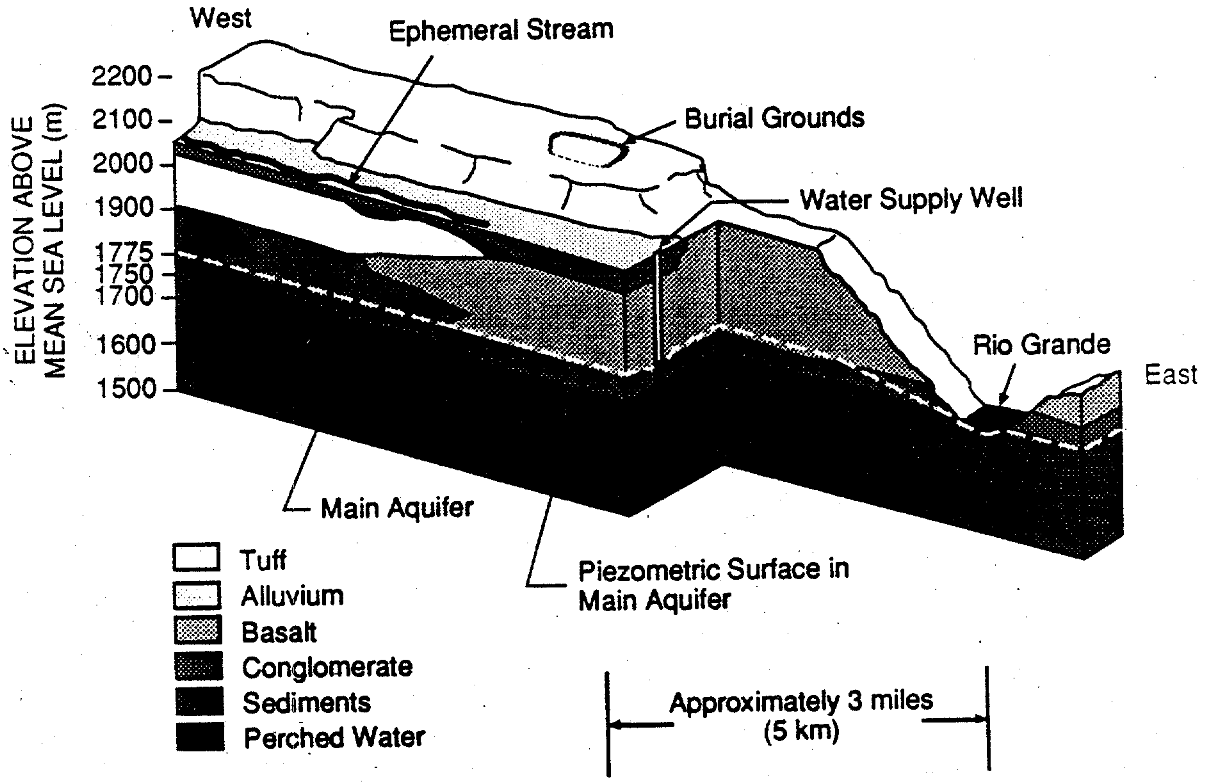


Fig. 3-2 Conceptual Illustration of Geologic-Hydrologic Relationships in Los Alamos

are released into some canyons at rates sufficient to maintain surface water flows for varying distances. None of these flows normally reach the Rio Grande

Ground water occurs in three modes in the Los Alamos area: (1) water in shallow alluvium in canyons, (2) perched water (a groundwater body above a less permeable layer that separates it from the underlying main body of groundwater by an unsaturated zone), and (3) the main aquifer of the Los Alamos area (Fig.3-2).

Intermittent streamflow in canyons of the plateau have deposited alluvium that ranges in thickness from less than 1 m (3 ft) to as much as 30 m (100 ft). The alluvium is permeable, in contrast to the underlying volcanic tuff and sediments. Intermittent run-off in canyons infiltrates and percolates through the alluvium until its downward movement is impeded by the less permeable tuff and volcanic sediment. This results in a shallow alluvial groundwater body that moves down laterally down-gradient within the alluvium. As water in the alluvium moves down gradient, it is depleted by evapotranspiration and movement into underlying volcanics (Purtymun 1977). This is the type of shallow alluvial water that occurs in Mortandad Canyon.

Perched water occurs in the conglomerates and basalts beneath the alluvium in two limited areas: 1) about 37 m (120 ft) deep in the midreach of Pueblo Canyon; and 2)about 45 to 60 m (150 to 200 ft) beneath the surface in lower Pueblo and Los Alamos canyons near their confluence. The second area is located mainly in the basalts (Fig. 3-2) and has one discharge point at Basalt Spring in Los Alamos Canyon. This type of perched water does not occur in the vicinity of Mortandad Canyon

The main aquifer of the Los Alamos area is the only aquifer in the area capable of serving as a municipal water supply. The surface of the aquifer rises westward from the Rio Grande within the Santa Fe Group into the lower part of the Puye Formation beneath the central and western part of the plateau. Depth to the aquifer decreases from 360 m (1 200 ft) along the western margin of the plateau to about 180 m (600 ft) at the eastern margin. The main aquifer is isolated from alluvial and perched waters by about 110 to 190 m (350 to 620 ft) of unsaturated tuff and volcanic sediments. Thus, there is little hydrologic connection or potential for recharge to the main aquifer from alluvial or perched water.

Water in the main aquifer is under water table conditions in the western and central part of the plateau and under artesian conditions in the eastern part and along the Rio Grande (Purtymun 1974b). Major recharge to the main aquifer is from the west, probably from the intermountane basin of the Valles Caldera in the Jemez Mountains west of Los Alamos. The water table in the caldera is near the land surface. The underlying lake sediment and

EXTENT OF SATURATION IN MORTANDAD CANYON

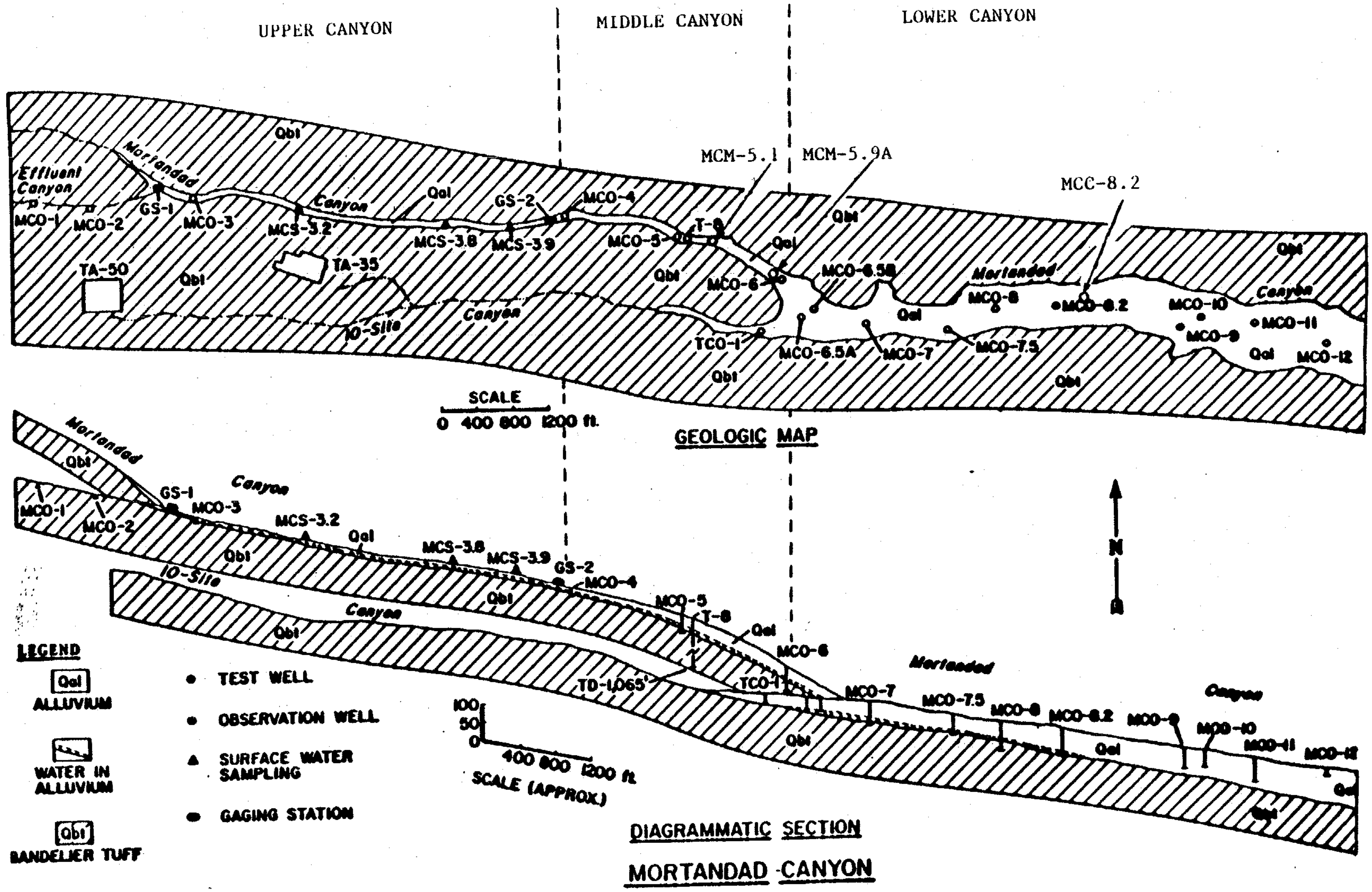


Fig. 3-3

volcanics are highly permeable and presumably contribute to the recharge of the aquifer through the Tschicoma Formation interflow breccias (rock consisting of sharp fragments embedded in a fine-grained matrix) and the Tesuque Formation. The Rio Grande receives groundwater discharge from the main aquifer through springs. The 18.5-km (11.5-mi) reach of the river in White Rock Canyon between Otowi Bridge and the mouth of Rito de Frijoles receives an estimated 5.3 to 6.8 ± 10^6 m^3 (4 300 to 5 500 acre-ft) annually from the aquifer.

Mortandad Canyon is an east to southeast-trending canyon that heads on the western part of the plateau and is tributary to the Rio Grande to the east. The canyon is cut into the Bandelier Tuff. The canyon floor is narrow near the plant outfall and widens eastward. The canyon walls are steep, and in places are near vertical. The canyon contains a shallow aquifer recharged by industrial effluent and runoff. The spatial extewnt of this aquifer is within the Laboratory boundaries, extending from near the plant outfall on the west to near observation well MCO-8, Fig. 3-3 (see also Fig. 1-1, which is a conceptual illustration, and Appendix 8.1, which contains a detailed map of Mortandad Canyon). Transverse to the canyon axis, the aquifer does not extent to the canyon walls

The alluvium thickens eastward from less than 5 ft in the upper reach of the canyon to as much as 75 ft east of MCO-8. The shallow aquifer in the alluvium occupies less than 10% of the volume of alluvium. The greatest potential for the surface transport of contaminants from the area is with storm runoff in solution, suspended sediments, and bed sediments. Due to the small drainage area and the large volume of unsaturated alluvium there has been no continuous surface runoff through the canyon extending off the Laboratory since the hydrologic investigations began in 1960. The largest runoff events have extended no further than a hundred or so meters past the sediment traps (see Appendices 8.1 and 8.2.3).

A brief description of members and lithology of the Bandelier Tuff in the bottom of the canyon is presented in descending order:

Bandelier Tuff

  Tshirege Member

    Unit 1A Tuff, nonwelded to moderately welded, light gray, consisting of quartz and sanidine crystal and crystal fragments, rock fragments of pumice, latite, and rhyolite in a matrix of gray ash. Weathered gray, buff, light to dark brown in color, pumice and ash matrix weathered to clay.

Tsankawi Member

Thin lenses of silt, sand, and gravels consisting of pumice, quartz and sanidine crystals and rock fragments of latite and rhyolite ranging in color from gray to dark brown, ash and some pumice weathered to clay. Member represents erosion and deposition at the top of a massive ash flow.

Otowi Member

Tuff, nonwelded to moderately welded, gray to dark brown when weathered, consisting of quartz and sanidine crystal and crystal fragments, numerous pumice fragments up to 2-inches in length, rock fragments of latite and rhyolite in a ash matrix. Ash matrix and some of the pumice weather to silts and clays.

The alluvium in the canyon is derived from weathering of the tuff, and thus consists of clay, silt, sands, and gravels of quartz and sanidine crystals and crystal fragments, small (generally less than 1-inch dia.) rock fragments of tuff, pumice, latite, and rhyolite.

The canyon has been conceptually divided into three sections: Upper Canyon, Middle Canyon, and Lower Canyon, Fig. 3-3. The hydrologic characteristics of each are slightly different:

The **upper canyon** is narrow, and filled with underbrush, shrubs, pine, fir, box elder, and oak trees. The alluvium thickens eastward from less than 1 ft at plant outfall to about 18 ft thick at MCO-4. The stream flow in this section is perennial from waste water and periodic releases of industrial effluents. The stream channel is entrenched. Major recharge to the shallow aquifer occurs in the upper canyon. Large losses by evapotranspiration occur in this section of the canyon due to the large amount of vegetation and to the surface of the aquifer being near the ground surface.

The **middle canyon** widens and alluvium thickens from 18 ft at MCO-4 to 36 ft at MCO-6. The stream channel is well defined, but surface flow is intermittent. The underbrush thins and the canyon floor is covered with pines.

The **lower canyon** becomes progressively wider and the alluvium continues to thicken to about 60 ft near MCO-8. The stream channel is discontinuous, braiding out on the canyon floor. The number of pines decrease eastward from the middle canyon with a transition to scattered pinon-juniper community. To prevent the transport of contaminants by storm runoff out of the lower canyon, three sediment traps have been constructed between MCO-7 and MCO-7.5. These traps have a capacity of about 1.2 million gallons (see large-scale map in Appendix 8.1).

3.1 Previous Studies

A variety of studies have been conducted in Mortandad Canyon beginning with those of the USGS in 1960. Abstracts of studies selected to represent the information of greatest importance to addressing the Special Permit Condition issues are reproduced in Appendix 8.2.1. The following major conclusions represent the highlights of the previous investigations:

1. Recharge by industrial effluents and waste water to the shallow aquifer occur in the upper canyon. Storm runoff recharges the upper canyon and dependent of volume may extend in to the lower canyon. Long periods of snow-melt runoff or wastewater discharge will over ride the saturated section in the upper canyon and infiltrate along the saturated front. When discharge ends the stream flow will retreat up the canyon and the front will break off and move as a ground water mound down the canyon.

2. The volume of recharge since 1960 has not been sufficient to significantly change the volume of the shallow aquifer, and it does not extend beyond the lower canyon or to the Laboratory boundary.

3. The alluvium in the canyon becomes thicker and widens down gradient from the plant outfall.

4. The saturated thickness of the aquifer varies dependent on the amount of recharge.

5. The alluvium in the canyon consists of two distinguishable units that affect the hydrologic characteristics of the aquifer. Water in the aquifer west of MCO-5 is in a sand unit and is transitional into a silty clay unit near MCO-6. East of MCO-6 the aquifer is in a silty clay unit. Tracer tests indicate that the velocity of the water in the aquifer in the sand unit is 50 ft/day,

the transition from sand to silty clay unit is 20 ft/day, and in the silty clay unit 6 to 7 ft/day. Based on velocity, the transit time from the plant out fall to eastern end of the aquifer is about one year.

6. Quality of water data indicate that there is a complete turn over of water in the aquifer in a year.

7. Test holes and moisture probe access holes indicate that the saturated section of the alluvium does not extend beneath the mesas to the north and south. The saturated section of alluvium exist as a narrow ribbon down the canyon. In cross- section shaped as a saucer, thick near the middle and thinning outward to the edges of the canyon.

8. The largest volume of water in storage in the aquifer in the period 1967 to 1978 was 30000 m^3 in 1967 and the smallest volume of water was 15000 m^3 in 1977. Surface water recharge in 1967 was 139000 m^3 while loss from storage were 129000 m^3. Surface water recharge in 1977 was 54000 m^3 with losses from storage during the year of 56000 m^3.

9. The distribution of storage during 1967-78 was 18% upper canyon, 23% middle canyon, and 59% lower canyon.

10. Water balance 1965-67 indicated that the largest loss from storage occurred in the upper canyon probably due to the near surface of the shallow aquifer that the large amount of vegetation in the canyon (high evapotranspiration).

11. Logging of moisture probe access hole in the canyon indicate that the soil moisture and capillary zone above the aquifer merge west of MCO-6 while to the east as the shallow aquifer becomes deeper there is a distinct soil moisture zone and capillary zone. Soil moisture extends down to about 10 ft while the capillary rise is up to about 8 ft.

    There is little or no recharge to the aquifer from precipitation on the canyon bottom in the lower canyon. Recharge occurs from storm runoff in the stream channel and by movement of water downgradient in the shallow aquifer.

12. Injection of water in to the tuff through and experimental injection wells on a mesa adjacent to Mortandad Canyon indicate that the major movement of water is downward beneath the injection well while minor movement occurred outward from the well, Fig. 3.1-1. The movement of water in the high moisture content beneath the injection zone was by gravity. After injection stopped the moisture content decreased until there was little or no movement when the moisture content reached the specific retention values of the tuff. Downward and outward movement of moisture from beneath the injection zone continued by capillary movement. Outward movement of water from the injection zone occurred due to distribution by capillary size pores in the tuff. In addition there was some increase in moisture in the tuff above the injection zone due to capillary size pores.

13. As industrial effluents are released into the canyon and move down gradient, radionuclides (except tritium) and some inorganic chemical are adsorbed or bound to the bed sediments, reducing the amount of radionuclides or chemicals in the water or effluents. A high build up of radiochemicals or chemicals do not occur in the alluvium at the effluent outfall sinceperiodic storm runoff transports and disperses sediments and contaminants down the channel in the canyon. Adsorption of contaminants reduces the concentrations in the perched aquifer.

14. Monitoring the quality of water in the alluvium through the observation wells indicates a general decrease of radiochemical and chemical concentrations downgradient through adsorption and dilution of the effluent with waste water and storm runoff.

15. A test hole was drilled into the top of the main aquifer to determine the geology and hydrology of the rocks underlying the canyon. The well was drilled near the center of the canyon (Fig. 3.1-2a and -2b). The test hole penetrated about 40 ft of alluvium (cased out of completed well), about 450 ft of ash flows and ash falls of the Bandelier Tuff, about 90 ft of volcanic sediment of the Puye Conglomerate, 145 ft of basalts and interflow breccias, and 340 ft of additional volcanic sediments of the Puye Conglomerate. The total depth of the test hole was 1,065 ft with the top of the main aquifer at about 968 ft. The test hole encountered no water between the water in the alluvium and top of the main aquifer.

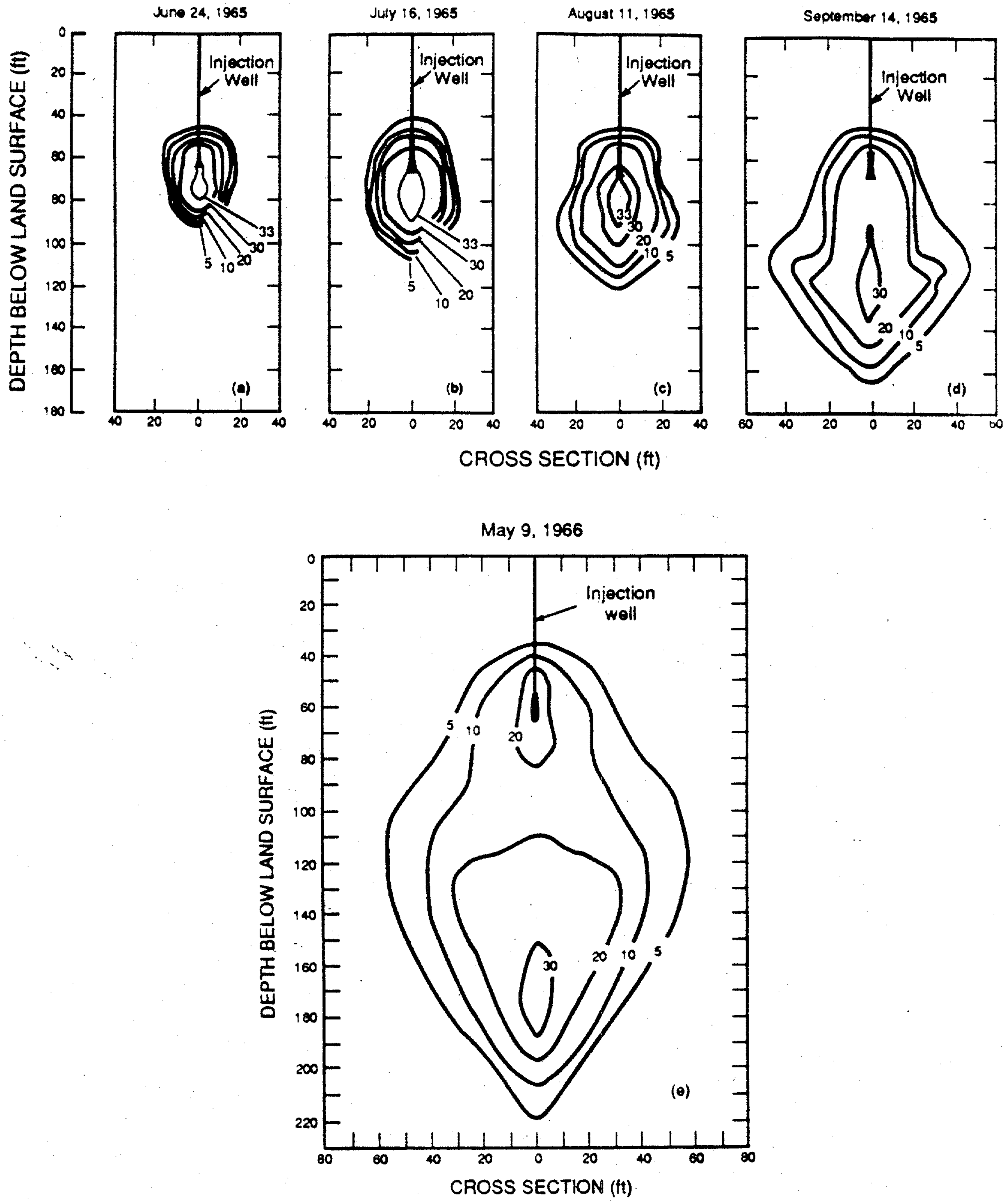
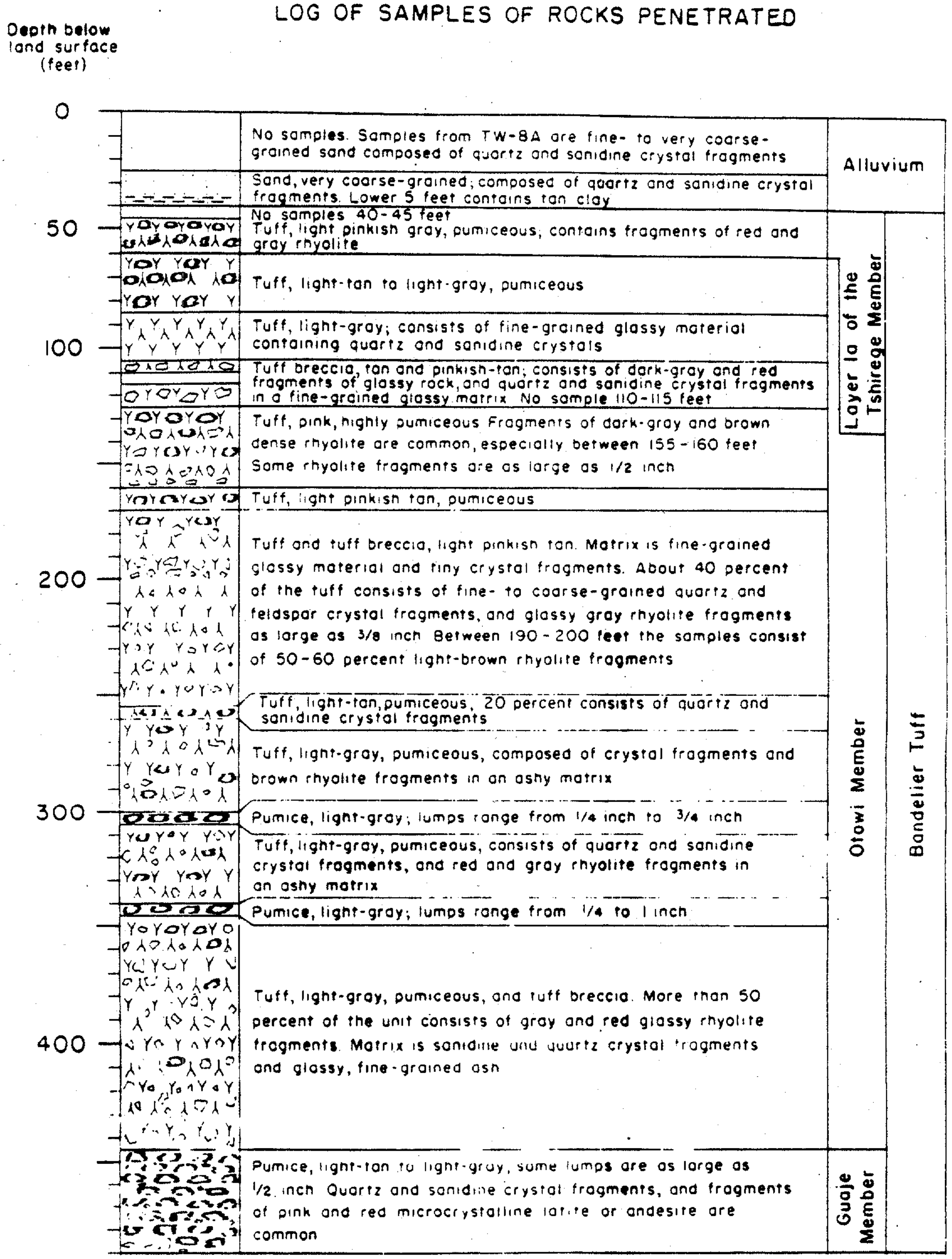


Fig. 3.1-1 Nephol as constructed from moisture measurements in observation holes, with contoured lines indicating moisture (in percent by volume). Measurements were taken (a) 7, (b) 29, (c) 55, (d) 89, and (e) 327 days after the test began (June 17, 1965).



LOG OF SAMPLES OF ROCKS PENETRATED

No samples. Samples from TW-8A are fine- to very coarse-grained sand composed of quartz and sanidine crystal fragments

Sand, very coarse-grained; composed of quartz and sanidine crystal fragments. Lower 5 feet contains tan clay

No samples 40-45 feet

Tuff, light pinkish gray, pumiceous; contains fragments of red and gray rhyolite

Tuff, light-tan to light-gray, pumiceous

Tuff, light-gray; consists of fine-grained glassy material containing quartz and sanidine crystals

Tuff breccia, tan and pinkish-tan; consists of dark-gray and red fragments of glassy rock, and quartz and sanidine crystal fragments in a fine-grained glassy matrix. No sample 110-115 feet

Tuff, pink, highly pumiceous. Fragments of dark-gray and brown dense rhyolite are common, especially between 155-160 feet. Some rhyolite fragments are as large as 1/2 inch

Tuff, light pinkish tan, pumiceous

Tuff and tuff breccia, light pinkish tan. Matrix is fine-grained glassy material and tiny crystal fragments. About 40 percent of the tuff consists of fine- to coarse-grained quartz and feldspar crystal fragments, and glassy gray rhyolite fragments as large as 3/8 inch. Between 190-200 feet the samples consist of 50-60 percent light-brown rhyolite fragments

Tuff, light-tan, pumiceous, 20 percent consists of quartz and sanidine crystal fragments

Tuff, light-gray, pumiceous, composed of crystal fragments and brown rhyolite fragments in an ashy matrix

Pumice, light-gray; lumps range from 1/4 inch to 3/4 inch

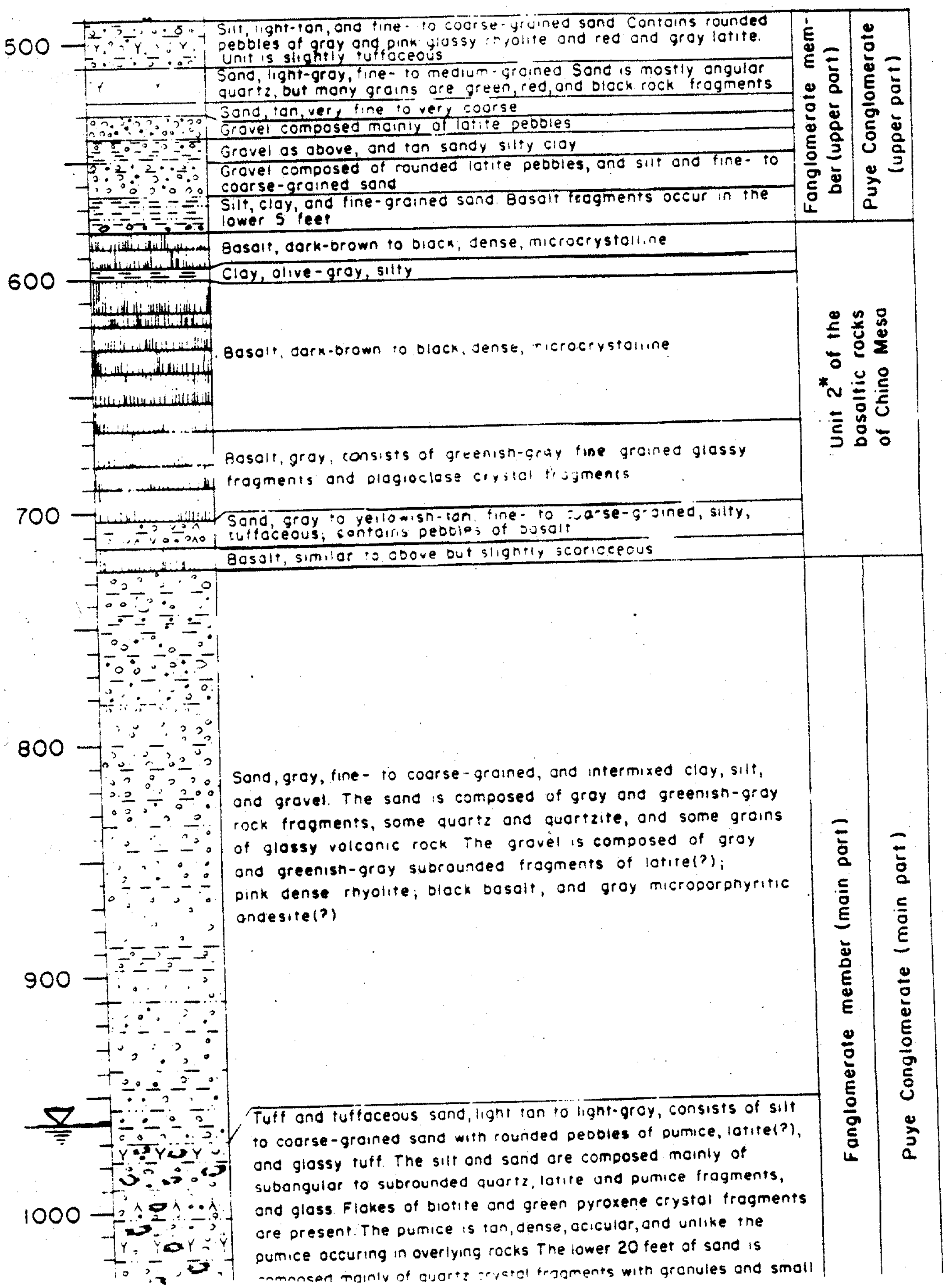
Tuff, light-gray, pumiceous, consists of quartz and sanidine crystal fragments, and red and gray rhyolite fragments in an ashy matrix

Pumice, light-gray; lumps range from 1/4 to 1 inch

Tuff, light-gray, pumiceous, and tuff breccia. More than 50 percent of the unit consists of gray and red glassy rhyolite fragments. Matrix is sanidine and quartz crystal fragments and glassy, fine-grained ash

Pumice, light-tan to light-gray, some lumps are as large as 1/2 inch. Quartz and sanidine crystal fragments, and fragments of pink and red microcrystalline latite or andesite are common

Fig. 3.1-2a Lithologic Log Test Well 8



Silt, light-tan, and fine- to coarse-grained sand. Contains rounded pebbles of gray and pink glassy rhyolite and red and gray latite. Unit is slightly tuffaceous

Sand, light-gray, fine- to medium-grained. Sand is mostly angular quartz, but many grains are green, red, and black rock fragments

Sand, tan, very fine to very coarse

Gravel composed mainly of latite pebbles

Gravel as above, and tan sandy silty clay

Gravel composed of rounded latite pebbles, and silt and fine- to coarse-grained sand

Silt, clay, and fine-grained sand. Basalt fragments occur in the lower 5 feet

Basalt, dark-brown to black, dense, microcrystalline

Clay, olive-gray, silty

Basalt, dark-brown to black, dense, microcrystalline

Basalt, gray, consists of greenish-gray fine grained glassy fragments and plagioclase crystal fragments

Sand, gray to yellowish-tan, fine- to coarse-grained, silty, tuffaceous; contains pebbles of basalt

Basalt, similar to above but slightly scoriceeous

Sand, gray, fine- to coarse-grained, and intermixed clay, silt, and gravel. The sand is composed of gray and greenish-gray rock fragments, some quartz and quartzite, and some grains of glassy volcanic rock. The gravel is composed of gray and greenish-gray subrounded fragments of latite(?); pink dense rhyolite; black basalt, and gray microporphyritic andesite(?)

Tuff and tuffaceous sand, light tan to light-gray, consists of silt to coarse-grained sand with rounded pebbles of pumice, latite(?), and glassy tuff. The silt and sand are composed mainly of subangular to subrounded quartz, latite and pumice fragments, and glass. Flakes of biotite and green pyroxene crystal fragments are present. The pumice is tan, dense, acicular, and unlike the pumice occuring in overlying rocks. The lower 20 feet of sand is composed mainly of quartz crystal fragments with granules and small

The test hole was cased and completed in December 1960 as a test well TW-8 and later was equipped with a pump. Samples bailed from the well prior to installation of the pump and samples collected from pumping have detected no change in chemical quality of the water in the main aquifer. The quality of water in the main aquifer shows no recharge from the shallow aquifer in the alluvium.

3.2 Monitoring Facilities

The geology and hydrology of the canyon has been partly defined through the construction of 23 observation wells, 14 test holes, and 33 moisture probe access holes. These studies began in 1960 when the USGS initiated their studies and continued through 1990 when the holes for this study were completed.

3.2.1 Observation Wells

Data on the 23 Observation Wells installed between 1960 and 1974 including date completed, depth, water levels and elevation are summarized in Table 3.2.1-I and Appendix 8.3. Two of the wells have been abandoned, two are no longer usable, and two could not be located in early 1991. Some of these wells contained water, the others were dry but were completed as observation wells to provide a means for observing any change in the extent of the perched aquifer and for collecting samples should saturated conditions occur. Seven of the wells (MCO-3, MCO-4, MCO-5, MCO-6, MCO-7, MCO-7.5, and MCO-8) are used for the ongoing routine environmental monitoring program. Five additional monitoring wells were installed in 1990 to fulfill another special permit condition; these are described in Sec. 5.2.2 of this report.

The earlier holes were drilledwith the 4 1/2-inch diameter hollow-stem augers, and cased with 2-inch or 3-inch diameter plastic pipe. Later wells were constructed using a 7 1/4-inch auger and set with 4-inch plastic pipe, perforated through the screened section. At the surface, the casings were grouted in with cement and a pad constructed. Geologic logs and construction data are shown in Figures contained in Appendix 8.4.

3.2.2 Test Holes

To monitor the special conditions of the occurrence and movement of water in the alluvium and the underlying tuff, 14 special test holes were drilled. Samples of cuttings or cores of the perched aquifer sediments and tuff underlying the aquifer. A number of different construction methods for completion were used, including completion as monitoring wells or moisture probe access tubes, or plugging and abandonment. Basic data for each hole is presented in Table 3.2.2-I and Appendix 8.3; and the geologic and completion logs are shown on figures in Appendix 8.4. The casings were grouted in at the surface with cement and pads constructed.

3.2.3 Moisture Probe Access Holes

During the initial USGS studies to characterize the hydrology of Mortandad Canyon 30 holes were drilled and completed with blank casing to serve as access holes for neutron moisture probes. Although they have not been used for measurements since about 1965, many are still useable and some moisture measurements have been made in 1990 and 1991. Basic data for each hole is presented in Table 3.2.3-I and Appendix 8.3; and the geologic and completion logs are in Appendix 8.4.

Most of the moisture probe access tubes are completed in the alluvium or extend only a few feet into the tuff beneath the alluvium. Five of the early holes were completed a greater distance into the tuff. Two were drilled into the tuff on an angle beneath the stream channel (MCM-2.2 and MCM-2.8). Three other moisture probe access holes were completed into the unsaturated zone beneath the aquifer (MCM-4.5, MCM-6.5, and MCM-7.5). In these three holes, water in the alluvium was sealed out of the lower part of the hole by setting a casing into the unsaturated tuff and then deepening the hole by drilling through the casing and setting a plastic access pipe for the neutron moisture probe.

3.3 Routine Monitoring Program

Routine environmental monitoring has been conducted at Los Alamos since the mid-1940s. The USGS. conducted monitoring for the Atomic Energy Commission through the late 1960s. Monitoring carried out by the laboratory is documented in a continuous series of reports starting in 1970. A listing of all the USGS and Los Alamos surveillance reports is included in Appendix 8.2.2. This program continues at present in conformance with DOE Order 5400.1 ("General Environmental Protection Program," November 1988). The routine monitoring program includes regular collection and analysis of water and sediment samples from Mortandad Canyon. Appendix 8.2.4 includes tables excerpted from Appendix G of the 1989 environmental surveillance report that contain data on samples collected in Mortandad Canyon.

A number of special monitoring studies have been conducted in Mortandad Canyon over the years under the auspices of the routine monitoring program, often in response to specific natural events such as major runoff

TABLE 3.2.1-I

Hydrologic Data for Observation Wells (Mortandad Canyon)

					Water Levels					
Observation Wells	Date Completed	Depth Drilled (ft)	Depth Completed (ft)	Depth 1991	At Completion (ft)	Date	(ft)	Elevation Land-Surface Datum (LSD) (ft)	Top of Casing (MP) to Land-Surface Datum	Remark
MCO-1	11/60	8	8	–	2.8	–	–	7153	–	Unable to locate in 1991
MCO-2	11/60	10	9	7.5	0.3	4/91	5.06	7133	2.00	
MCO-3	11/60	18	12	10.1	4.4	4/91	3.36	7052.72	1.54	
MCO-4	10/63	24	19	16.3	3.3	4/91	7.19	6900.36	1.02	
MCO-4.9	7/73	42	30	23.4	–	4/91	22.10	6879.31	1.25	
MCO-5	10/60	47	46	44.9	24.6	2/91	20.75	6875.80	1.95	
MCO-6	10/60	82	71	–	38.1	–	–	6849	–	Plugged and abandoned (relocated).
MCO-6	3/74	47	47	41.5	28.9	2/91	33.75	6848.96	2.34	
MCO-6.5A	11/61	47	45	33.3	41.0	2/91	Dry	6840	2.15	
MCO-6.5B	11/61	42	42	36.0	36.3	2/91	Dry	6839	0.70	
MCO-7	10/60	77	69	54.7	39.7	2/91	37.47	6827.40	1.24	
MCO-7.5A	11/61	63	60	–	41.2	–	–	6809	–	Well damaged (relocated).
MCO-7.5B	7/74	62	60	56.0	42.1	2/91	43.71	6808.80	1.28	
MCO-8	10/60	92	84	22.7	61.6		–	6796.45	0.25	Obstruction in well.
MCO-8A	11/61	52	50	48.5	Dry	2/91	Dry	6800	0.61	
MCO-8.2	11/61	72	70	60.3	59.2	2/91	Dry	6782	2.00	
MCO-9	11/60	57	55	54.6	Dry	2/91	Dry	6747.77	1.44	
MCO-9.5	11/61	57	46	40.3	Dry	2/91	Dry	6740	2.00	
MCO-11	11/61	23	20	–	Dry	–	–	–	–	Unable to locate in 1991.
MCO-12	11/61	64	60	–	Dry	–	–	6700	–	Casing pulled; hole plugged (relocated).
MCO 12	6/71	112	108	96.2	Dry	2/91	Dry	6702	0.62	
MCO-13	7/70	112	107	106.2	Dry	2/91	Dry	6674	0.67	
TSCO-1	11/61	37	35	23.1	Dry	2/91	8.93	6857	0.97	

TABLE 3.2.2-I

Hydrologic Data for Test Holes (Mortandad Canyon)

					Water Levels					
Observation Wells	Date Completed	Depth Drilled (ft)	Depth Completed (ft)	Depth 1991	At Completion (ft)	Date	(ft)	Elevation Land-Surface Datum (LSD) (ft)	Top of Casing (MP) to Land-Surface Datum	Remark
MCM-2.2	11/61	90	87	87	Dry	4/91	Dry	7109	2.20	Angle hole beneath channel. (45°)
MCM-2.8	11/61	68	58	58	Dry	4/91	Dry	7086	5.00	Angle hole beneath channel. (30°)
MCM-4.5	11/61	48	48	35	–	–		6891	1.70	Double cased moisture hole
MCM-6.5	11/61	95	95	95	–	–		6840	0.20	Double cased moisture hole
MCM-7.5	11/61	94	94	94	–	–		6809	1.00	Double cased moisture hole
MT-1	11/88	69	69	68	43.0	2/91	42.92	6811.79	1.79	
MT-2	11/88	64	64	64	62.0	2/91	Dry	6796.88	1.60	
MT-3	11/88	74	74	73	45.0	2/91	54.72	6796.88	1.30	
MT-4	11/88	74	74	74	58.0	2/91	59.84	6785.22	1.34	
MCM-5.1	9/90	112	112	112	–	–	–	6870	0.22	
MCM-5.9	7/90	94	–	–	–	–	–	6852	–	Plugged and abandoned.
MCM-5.9A	7/90	194	194	194	–			6859.29	0.94	
MCC-8.2	4/89	184	–		73	–	–	6780	–	Plugged and abandoned.
SIMO	9/90	104	104	–	Dry	–	–	6658	–	On sacred land (San Ildefonso Pueblo).

TABLE 3.2.3-I

Construction Data for Moisture Access Holes (Mortandad Canyon)

Moisture Access Hole	Construction Date	Elevation LSD (ft)	Plastic Casing Diameter (in.)	Length of Casing LSD (ft)	Alluvium (ft)	Bandelier Tuff (ft)	Remark
MCM-1A	11/60	7156	2	12	0	12	
MCM-1B	11/60	7155	2	11	0	11	
MCM-2A	11/60	7139	2	11	0	11	
MCM-2B	11/60	7134	2	1	0	1	
MCM-3A	11/60	7049	2	13	11	3	
MCM-3B	11/60	7048	2	10	10	0	
MCM-4A	11/60	6901	2	9	9	0	
MCM-4B	11/60	6900	2	24	18	6	
MCM-4.8	11/61	6887	2	33	30	3	
MCM-5A	10/60	6881	2	25	23	3	
MCM-5B	10/60	6879	2	30	25	5	
MCM-5C	10/60	6878	2	37	30	7	
MCM-6A	10/60	6852	2	18	10	8	
MCM-6B	10/60	6851	2	52	37	15	
MCM-6C	10/60	6851	2	57	47	10	
MCM-6D	10/60	6850	2	35	35	0	
MCM-6E	10/60	6851	2	21	12	9	
MCM-6.5A	8/89	6839	2	23	23	–	Al casing
MCM-8A	10/60	6807	2	20	3	17	
MCM-8B	10/60	6797	2	30	30	0	
MCM-8C	10/60	6797	2	66	57	9	
MCM-8D	10/60	6796	2	86	59	27	
MCM-8E	10/60	6797	2	53	32	21	
MCM-8F	10/60	6799	2	23	4	19	
MCM-10	10/60	6731	2	67	62	5	
MCM-12A	6/71	6718	2	98	98	5	
MCM-12B	6/71	6705	2	79	79	0	
TSCM-1	11/61	6859	2	22	22	0	

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ENVIRONMENTAL SURVEILLANCE AT LOS ALAMOS DURING 1983

Environmental Surveillance Group

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

E. Distribution of Moisture, Tritium, and Plutonium in the Alluvium, Aquifer, and Underlying Tuff in Mortandad Canyon [W. D. Purtymun, M. N. Maes (HSE-8) and R. Peters (HSE-9)]

1. Introduction. Mortandad Canyon received industrial effluents containing trace amounts of radionuclides from the treatment plant at TA-50 (Fig. 13). The effluents and surface runoff recharge a shallow aquifer in the canyon. The shallow aquifer in the alluvium is perched (separated by about 290 m of unsaturated volcanics and sediments from the main aquifer) on the underlying tuff (Purtymun 1983A). The aquifer is of limited extent, as water in the aquifer is depleted by evapotranspiration and infiltration into the underlying tuff. This investigation was made to determine the distribution of infiltration (moisture) and radionuclides in the alluvium and underlying tuff in a section of Mortandad Canyon.

Concentrations of radionuclides in water of the shallow aquifer decrease downgradient in the canyon from the effluent outfall. This reduction is caused by adsorption or ion exchange of the radionuclides with silt or clay minerals in the alluvium or dilution of the effluent by storm runoff. The distribution of the radionuclides in the aquifer is monitored by seven observation wells (Purtymun 1977).

At observation Well MCO-6, three core holes were drilled at right angles to the stream channel. Two other holes were cored to obtain background information. Cores taken from five holes were analyzed to determine moisture content and concentrations of tritium and plutonium (Table E-XLI).

The alluvium in the canyon is derived from the weathering of the Bandelier Tuff. At Well MCO-6, the alluvium is thickest beneath the stream channel and thins away from channel (Fig. 30). The alluvium is a silty sand that includes a thin layer of silty clay of weathered tuff at the base. The tuff is a light pinkish gray moderately welded tuff composed of quartz and sanidine crystals and crystal fragments, small rock fragments of rhyolite, latite, and pumice in an ash matrix. The tuff beneath the aquifer is weathered; the ash matrix contains some light brown silts and clays. The amount of silt and clays (degree of weathering) decrease at depth and with distance from the aquifer.

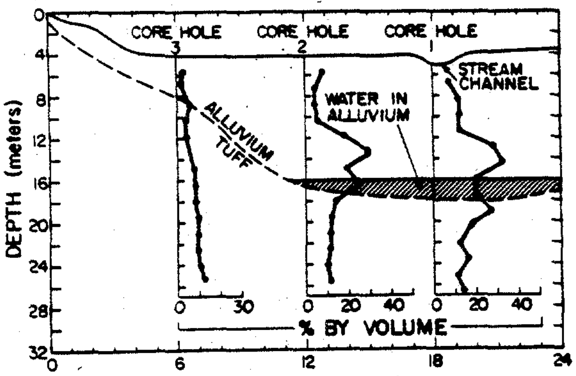


Fig. 30. Distribution of moisture in alluvium and tuff in Mortandad Canyon.

2. Moisture Distribution. The distribution of moisture in the alluvium and tuff is shown in Fig. 30. In core holes 1 and 2 the moisture content approaches 30% by volume from 1 to 3 m above the top of the aquifer. This anomaly above the aquifer is in a silty clay unit within the alluvium. The water table fluctuates twice a year because of seasonal runoff from snowmelt and summer precipitation. At the time the holes were cored, the water table was declining.

The moisture content of the aquifer material ranged from 20 to 25% by volume. There is some infiltration of water into the tuff beneath the aquifer. At core hole 1 the moisture content ranges from about 10 to 27% to a depth of 8 m below the base of the aquifer. At core hole 2 the moisture content is lower, ranging from 10 to 18% to a depth of 8 m below the aquifer. Core hole 3 indicates some horizontal component of movement of moisture from the aquifer only in the low moisture range, greater than 5% by volume below a depth of 13 m (Fig. 30). Natural moisture content of the tuff is about 5% by volume (Table E-XLI).

3. Tritium Distribution. Water distilled from the cores was analyzed for tritium (^{3}H). Tritium, a part of the water molecule, moves with the water and is not affected by adsorption or ion exchange with clay minerals. The average ^{3}H concentration in water in the aquifer (1978 when core was taken) at Well MCO-6 was 303×10^{-6} μCi/mℓ, having declined from a high of 1760×10^{-6} μCi/mℓ in 1976. The core from hole 1 contained a high of 400×10^{-6} μCi/mℓ about 1 m below the aquifer, and was about 550×10^{-6} μCi/mℓ at the same depth below the aquifer in core hole 2 (Fig. 31). The ^{3}H concentrations generally decline with depth below aquifer. The high concentrations in the tuff below the aquifer probably reflect the movement of tritium beneath the aquifer in the tuff, possibly from the high concentration that occurred in 1976. At core hole 2 a high concentration of ^{3}H (290×10^{-6} μCi/mℓ) occurred in the silt and clay base alluvium at a depth of about 10 m. This is above the aquifer. The ^{3}H in core hole 3 increases slightly with depth and is above background (Table E-XLI). The concentrations are low, less than 50×10^{-6} μCi/mℓ, but the ^{3}H concentrations reflect the same pattern of the movement of moisture from the aquifer (Figs. 30 and 31).

4. Plutonium Distribution. Samples of water taken from observation wells were filtered through a 45-μm pore membrane filter to remove fine sediments. The

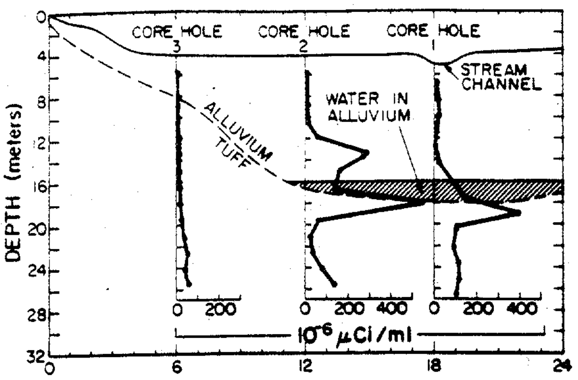


Fig. 31. Distribution of tritium in alluvium and tuff in Mortandad Canyon.

Table XXII

Average Plutonium Concentrations in Soil Cores from Mortandad Canyon

	$\bar{x} \pm 2s$	
Location	^{238}Pu (pCi/g)	^{239,240}Pu (pCi/g)
Core Hole 1	0.001 ± 0.005	0.004 ± 0.009
Core Hole 2	0.000 ± 0.003	0.011 ± 0.025
Core Hole 3	−0.001 ± 0.003	0.006 ± 0.015
Core Hole 4 (control)	−0.001 ± 0.002	0.000 ± 0.006
Core Hole 5 (control)	−0.001 ± 0.002	−0.002 ± 0.003

filtrate and the filter were analyzed for ^{238}Pu and ^{239,240}Pu. The data indicated little, if any, plutonium was retained on the filter and most, if not all, of the plutonium was in solution. This is in direct contrast with what occurs in the channel when the effluent is released from the treatment plant. The plutonium in the effluent is readily adsorbed or attached to silt and clays in the alluvium in the channel (Section VI.F). Concentrations in solution and on sediments decrease downgradient in the canyon.

Cores taken through the alluvium, aquifer, and into the underlying tuff were analyzed for plutonium to determine if there was any transport or buildup of plutonium in silts and clays beneath the channel in the alluvium, aquifer, or tuff. When the cores were taken in 1978, the alluvium in the channel contained about 2.7 pCi/g of ^{238}Pu and 4.0 pCi/g of ^{239,240}Pu. Water in the aquifer contained an average of 2.2×10^{-6} µCi/mℓ of ^{238}Pu and 0.28×10^{-6} µCi/mℓ of ^{239,240}Pu at Well MCO-6. Results of the analyses of cores indicate no significant concentrations of ^{238}Pu in silts and clay of the alluvium, aquifer, or underlying tuff (Table XXII). A comparison of the ^{239,240}Pu concentrations in cores with the control core concentrations indicate some high concentrations from core holes 1 and 2 and perhaps from core hole 3. However, the ^{239,240}Pu concentrations are low, being much lower than those found in solution in the aquifer or attached to sediments in the stream channel.

*5. **Summary.*** In summary, a study of the distribution of moisture, tritium, and plutonium in the Mortandad Canyon aquifer indicates some infiltration of water into the underlying tuff. This infiltration was accompanied by similar movement of tritium. The concentrations of plutonium on the sediments in the aquifer were low when compared to the high concentrations in solution in the aquifer or on sediments in the stream channel. It appears that most of the plutonium in the aquifer is in solution, in an ionic complex that does not readily exchange or is adsorbed by clay minerals in the alluvium.

Table E XLI

Distribution of Moisture, Tritium, and Plutonium from Core Holes in Mortandad Canyon

	Depth (m)	Per Cent Moisture by Volume	^3H (10^{-6} µCi/mℓ)	^{238}Pu (pCi/g)	$^{239,240}Pu$ (pCi/g)
Core Hole 1 **(In channel)**	1.8	7	10 ± 0.8	0.001 ± 0.002	0.000 ± 0.003
	3.4	12	29 ± 1.4	-0.003 ± 0.004	0.016 ± 0.008
	4.9	12	21 ± 1.2	0.001 ± 0.002	0.004 ± 0.003
	6.4	12	14 ± 1.0	-0.001 ± 0.002	0.008 ± 0.006
	7.9	28	8.5 ± 0.8	0.006 ± 0.003	0.010 ± 0.004
	9.4	32	23 ± 1.2	0.000 ± 0.003	0.003 ± 0.004
	11.0	19	...	...	...
	12.5	20	150 ± 4.0	0.003 ± 0.003	0.002 ± 0.002
	14.0	27	391 ± 12	0.003 ± 0.003	0.004 ± 0.003
	15.2	18	106 ± 3.6	0.005 ± 0.003	0.000 ± 0.002
	15.5	17	101 ± 3.4	-0.001 ± 0.002	0.002 ± 0.002
	17.1	12	91 ± 3.0	0.003 ± 0.003	0.002 ± 0.003
	18.6	16	118 ± 3.8	0.001 ± 0.003	0.001 ± 0.002
	20.1	11	115 ± 3.8	-0.001 ± 0.001	0.004 ± 0.003
	21.6	14	107 ± 3.6	0.000 ± 0.002	0.000 ± 0.002
Summary: x ± 2s		17 ± 14	92 ± 198	0.001 ± 0.005	0.004 ± 0.009
Core Hole 2 **(6 m south of channel)**	1.8	8	7.9 ± 0.8	-0.001 ± 0.000	0.010 ± 0.004
	3.4	4	...	0.002 ± 0.002	0.043 ± 0.008
	4.9	4	11 ± 1.0	-0.002 ± 0.004	0.020 ± 0.006
	6.4	6	16 ± 1.0	-0.001 ± 0.003	0.001 ± 0.003
	7.9	18	62 ± 2.2	0.001 ± 0.002	0.008 ± 0.004
	9.3	29	291 ± 10	0.000 ± 0.002	0.010 ± 0.004
	9.4	29	277 ± 8.0	-0.001 ± 0.002	0.035 ± 0.008
	11.0	19	169 ± 6.0	0.002 ± 0.004	0.006 ± 0.004
	12.5	25	138 ± 4.0	0.003 ± 0.003	0.010 ± 0.004
	14.0	14	541 ± 18	-0.001 ± 0.002	0.005 ± 0.003
	15.5	12	60 ± 2.2	-0.001 ± 0.002	0.004 ± 0.004
	17.1	11	34 ± 14	-0.001 ± 0.003	0.000 ± 0.002
	18.6	11	65 ± 2.4	-0.001 ± 0.002	0.002 ± 0.002
	20.1	10	80 ± 2.8	-0.001 ± 0.002	0.002 ± 0.003
	21.6	11	139 ± 4.0	-0.001 ± 0.003	0.002 ± 0.002
Summary: x ± 2s		14 ± 17	135 ± 296	0.000 ± 0.003	0.011 ± 0.025
Core Hole 3 **(12 m south) of channel)**	1.8	3	18 ± 1.0	0.004 ± 0.004	0.000 ± 0.004
	2.9	2	...	-0.002 ± 0.002	0.003 ± 0.003
	4.9	6	2.4 ± 0.8	-0.003 ± 0.003	-0.002 ± 0.003
	6.4	4	6.0 ± 1.2	-0.001 ± 0.002	-0.001 ± 0.003
	7.9	4	17 ± 1.0	0.000 ± 0.003	0.000 ± 0.003
	9.4	...	14 ± 1.0	0.000 ± 0.001	-0.001 ± 0.002
	11.0	7	13 ± 1.0	0.000 ± 0.004	0.017 ± 0.006
	12.5	8	13 ± 1.0	-0.002 ± 0.003	0.002 ± 0.004
	14.0	8	16 ± 1.0	0.000 ± 0.002	0.003 ± 0.004
	15.5	9	25 ± 1.2	-0.002 ± 0.001	0.015 ± 0.004
	17.1	9	35 ± 1.6	-0.003 ± 0.002	0.003 ± 0.004
	18.6	9	50 ± 2.0	-0.001 ± 0.001	0.010 ± 0.004
	20.1	10	44 ± 1.8	-0.001 ± 0.003	0.010 ± 0.004
	21.6	12	53 ± 2.0	-0.001 ± 0.001	0.022 ± 0.006
Summary: x ± 2s		7 ± 6	28 ± 39	-0.001 ± 0.003	0.006 ± 0.015
Core Hole 4 **(control)**	1.8	5	4.5 ± 0.8	-0.002 ± 0.002	-0.002 ± 0.003
	3.4	5	1.6 ± 0.8	0.000 ± 0.003	-0.001 ± 0.003
	4.9	5	1.3 ± 0.6	...	...
	6.4	3	...	-0.001 ± 0.002	0.004 ± 0.003
Summary: x ± 2s		4 ± 2	2.5 ± 3.5	-0.001 ± 0.002	0.000 ± 0.006
Core Hole 5 **(Control)**	1.8	3	6.0 ± 0.8	-0.002 ± 0.004	-0.004 ± 0.003
	3.4	3	1.7 ± 0.4	-0.002 ± 0.002	-0.001 ± 0.002
	4.9	2	...	0.000 ± 0.002	-0.001 ± 0.004
	6.4	5	3.8 ± 0.8	-0.001 ± 0.002	-0.003 ± 0.002
Summary: x ± 2s		3 ± 2	3.8 ± 4.3	-0.001 ± 0.002	-0.002 ± 0.003
Core Holes 4 and 5 **(Control)** **Summary: x ± 2s**		4 ± 2	3.0 ± 3.5	-0.001 ± 0.002	-0.001 ± 0.005

Notes: 1. One sample taken at each depth.

2. The ± value is twice the uncertainty for that analysis.

events, or to address specific questions such as the movement of contaminants beneath the aquifer. One study regarding the transport of contaminants associated with sediments under storm runoff conditions is reproduced in Appendix 8.2. The rest of this section is a reproduction of a special study conducted in 1983 that collected core samples from three holes to depths of 21.6 m near observation well MCO-6.

4.0 RECENT STUDIES ON OCCURRENCE OF ALLUVIAL WATER

The studies described in this section were carried out prior to issuance of the permit. They produced information relevant to addressing the issues of the special permit condition. The results are presented here as they have not been previously published elsewhere. The relevant results are discussed in contest in Sections 6 and 7.

4.1 MT-Holes

Four test holes were cored in to the aquifer in the Lower Canyon in 1988 to determine the lithology and shape and extent of the aquifer. Samples were collected and analyzed to determine the concentrations of selected radionuclides in the aquifer and aquifer materials. Basic data on the holes is presented in Appendix 8.3 Table "TBLMCT", and geologic logs are included in Appendix 8.4. The cores indicated that there was a distinct transition between the silt and clay interspersed with sand lenses that make up the aquifer, and the silt and clay below the aquifer that serves to perche the water. The section (Fig. 4.1-1) along the canyon axis shows the thinning of the saturated section of the aquifer and a thickening of the unsaturated alluvium. The thickest section of saturated alluvium occurs beneath the sediment traps between MCO-7 and MT-1. A transverse cross section of the aquifer (Fig. 4.1-2) was constructed using data from test holes MT-2 and MT-3 and with data from observation well and moisture probe access holes constructed in 1961. The aquifer thins from the axis parallel to the canyon to the edges of the canyon., Water and suspended solids were collected from MT-1, MT-2, MT-3, and MT-4. The water was bailed and contained a large amount of suspended solids. The solids were separated from the solution by filtering through a 0.45 micron filter and analyzed separately for plutonium. Results of the analyses are presented in Table 4.1-I. It appears in this section of the aquifer there are only small amounts of radioactivity in the water, the aquifer material (suspended solids), or cores taken from the aquifer and below the aquifer.

4.2 Hole MCC-8.2

Test Hole MCC-8.2 was cored through the alluvium, Tshirege Member Unit 1A, Tsankawi Member, and into the top of the Otowi Member in April 1989. The top of the shallow aquifer was encountered at a depth of about 59 to 67 ft. The hole was cored with the 3-1/4 inch hollow stem auger. Drilling was done with minimal cleaning of the hole to keep the cuttings packed around the auger through the aquifer, thus temporarily sealing the water out of the hole. At a depth of 184 ft the seal was lost and water and cuttings cascaded into the hole. The auger was pulled to 164 ft where it became stuck in the hole. In attempting to pull the auger out of the hole, it was broken off at a depth of about 8 ft below surface. Two 4-1/2 inch diameter holes were drilled to a depth of 154 ft along side the hollow stem in an unsuccessful attempt to free the 3-1/4 inch hollow stem. The hole was abandoned and plugged with cement slurred both inside the hollow stem auger and down the 4 1/2 in holes adjacent to the auger.

Samples of the cores from the hole were analyzed for chemical and radiochemical constituents and for water content. Basic data on the hole is included in Table 3.2.2-I and Appendix 8.3, the geologic log is in Figure 4.2-1 and in Appendix 8.4. Data on the radiochemical and inorganic chemical analyses are discussed in Section 6.2 in Tables 6.2.2.3-II and 6.2.2.3-III. Water content and tritium concentrations in the water are presented in Table 6.2.2.3-I.

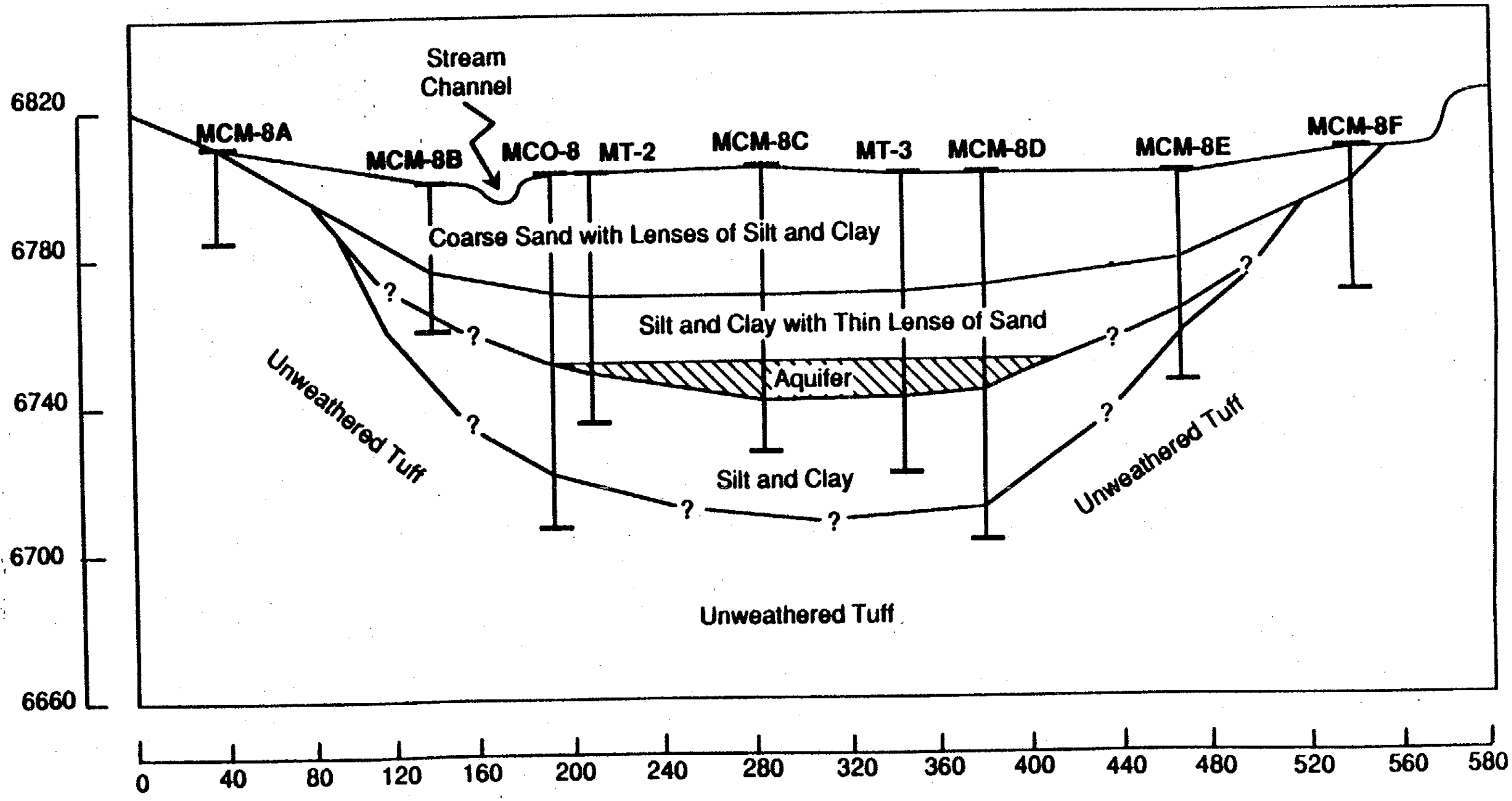

Stream Channel
MCM-8A
MCM-8B
MCO-8
MT-2
MCM-8C
MT-3
MCM-8D
MCM-8E
MCM-8F
Coarse Sand with Lenses of Silt and Clay
Silt and Clay with Thin Lense of Sand
Aquifer
Silt and Clay
Unweathered Tuff
Unweathered Tuff
Unweathered Tuff
?
6820
6780
6740
6700
6660
0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
580

Fig. 4.1-2

EXTENT OF SATURATION IN MORTANDAD CANYON

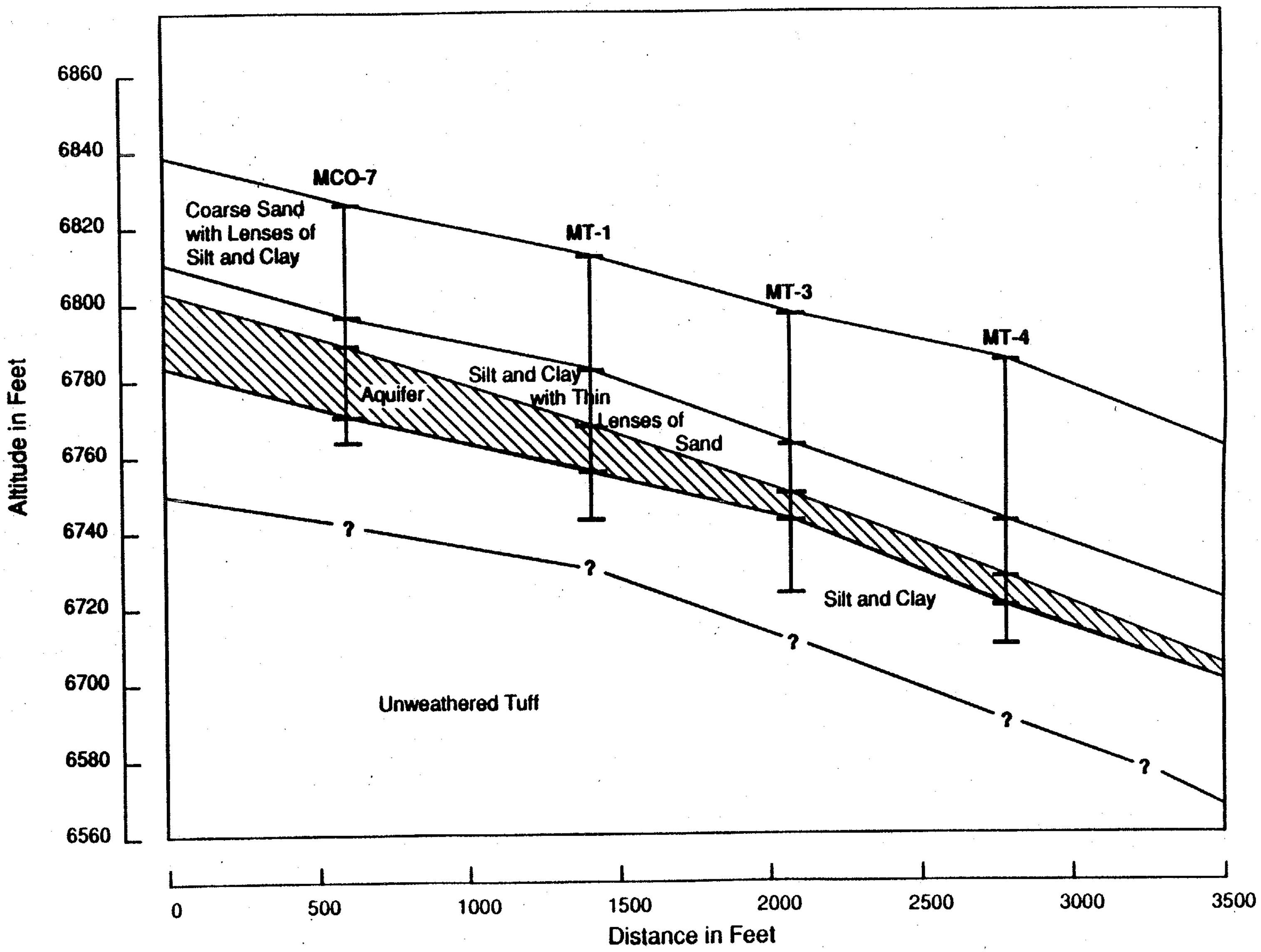


Fig. 4.1-1

TABLE 4.1-I

Radiochemical Analyses of Water Samples and Cores from Mortandad Canyon MT Holes

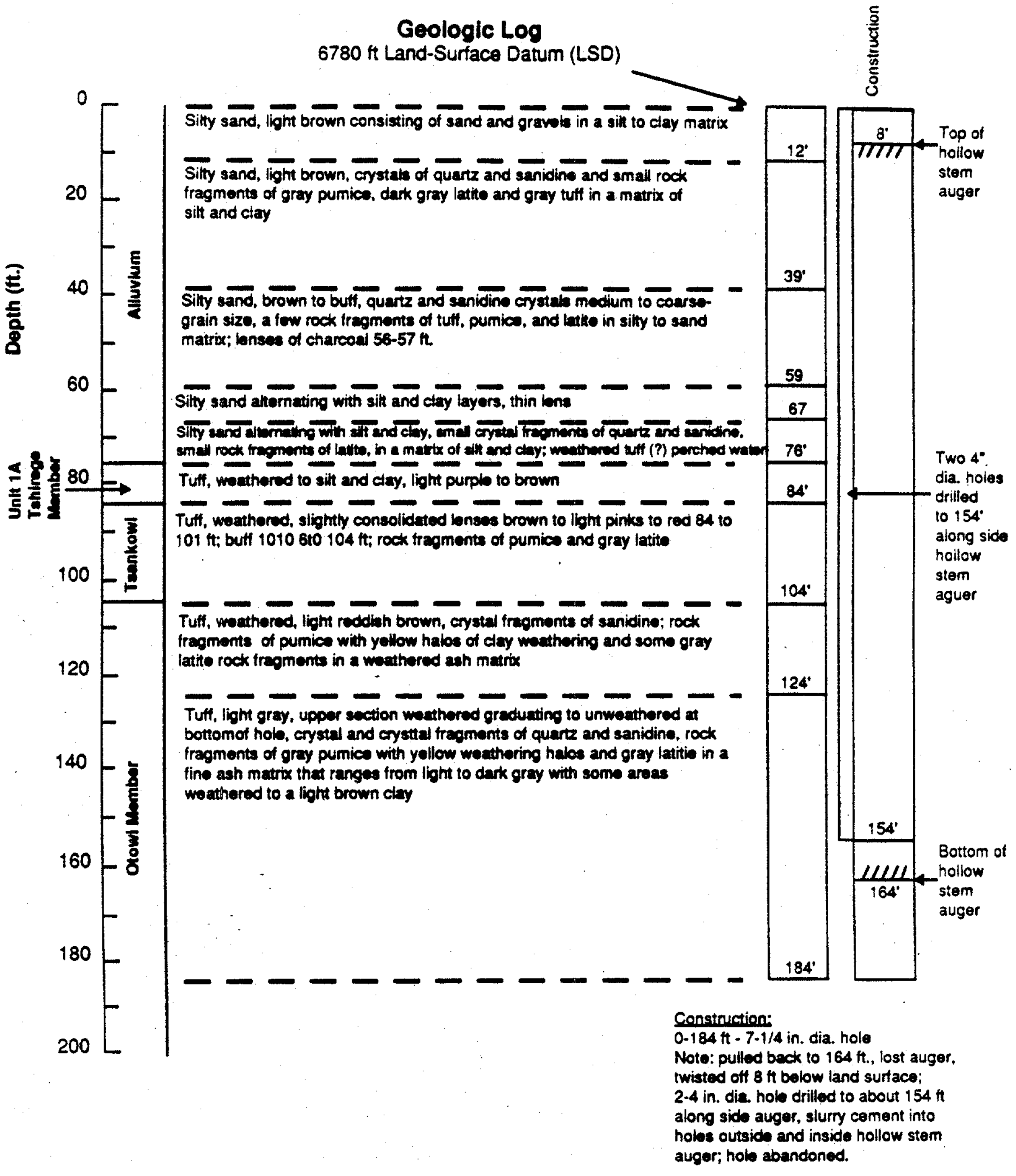
Water Samples (pCi/L solution or pCi/g in suspended solids, except as noted)

Sample	Cs^{137}	Gamma	H^3	Pu^{238}	Pu^{239}
MT-1 solution	104.0(74.6)	-180.(70.)	190.(20.)	0.013(0.006)	0.003(0.004)
MT-1 suspended	—	—	—	0.033(0.004)	0.034(0.004)
MT-2 solution	84.7(68.9)	0.(70.)	190.(20.)	0.028(0.007)	0.015(0.005)
MT-2 suspedned	—	—	—	0.022(0.003)	0.030(0.004)
MT-3 solution	14.1(90.1)	-90.(70.)	71.(7.0	0.003(0.003)	0.003(0.003)
MT-3 suspended	—	—	—	0.002(0.001)	0.003(0.001)
MT-4 solution	139.0(69.4)	-60.(70.)	200.(20.)	0.024(0.008)	0.002(0.003)
MT-4 suspended	—	—	—	0.015(0.003)	0.051(0.005)

Core Samples

Sample	Cs^{137} (pCi/g)	Gamma (cmp/g)	H^3 (nCi/L)	Pu^{238} (pCi/g)	Pu^{239} (pCi/g)	U (µg/g)
MT-1 44 ft.	0.218(0.106)	0.9(0.4)	210.(20.)	0.000(0.001)	0.000(0.001)	2.25(0.2)
MT-1 69 ft	0.243(0.107)	7.5(0.8)	150.(20.)	0.004(0.001)	0.000(0.000)	7.92(0.8)
MT-2 49 ft	0.173(0.097)	2.6(0.5)	370.(40.)	0.001(0.001)	0.000(0.001)	3.51(0.4)
MT-2 74 ft	-0.125(0.109)	5.1(0.6)	300.(30.)	0.000(0.001)	0.000(0.000)	4.65(0.5)
MT-3 54 ft	0.042(0.044)	2.4(0.4)	0.(0.3)	0.012(0.002)	0.003(0.001)	—
MT-3 64 ft	-0.026(0.041)	2.3(0.4)	61.(6.0)	0.005(0.001)	0.002(0.001)	3.75(0.4)
MT-4 59 ft	0.166(0.107)	0.2(0.4)	230.(20.)	0.020(0.002)	0.038(0.003)	2.22(0.2)
MT-4 74 ft	-0.008(0.113)	6.4(0.7)	200.(20.)	0.000(0.001)	0.001(0.001)	6.70(0.7)

Note: Standard deviation of radiochemical counting statistics shown in parentheses



Silty sand, light brown consisting of sand and gravels in a silt to clay matrix

Silty sand, light brown, crystals of quartz and sanidine and small rock fragments of gray pumice, dark gray latite and gray tuff in a matrix of silt and clay

Silty sand, brown to buff, quartz and sanidine crystals medium to coarse-grain size, a few rock fragments of tuff, pumice, and latite in silty to sand matrix; lenses of charcoal 56-57 ft.

Silty sand alternating with silt and clay layers, thin lens

Silty sand alternating with silt and clay, small crystal fragments of quartz and sanidine, small rock fragments of latite, in a matrix of silt and clay; weathered tuff (?) perched water

Tuff, weathered to silt and clay, light purple to brown

Tuff, weathered, slightly consolidated lenses brown to light pinks to red 84 to 101 ft; buff 1010 8t0 104 ft; rock fragments of pumice and gray latite

Tuff, weathered, light reddish brown, crystal fragments of sanidine; rock fragments of pumice with yellow halos of clay weathering and some gray latite rock fragments in a weathered ash matrix

Tuff, light gray, upper section weathered graduating to unweathered at bottomof hole, crystal and crysttal fragments of quartz and sanidine, rock fragments of gray pumice with yellow weathering halos and gray latitie in a fine ash matrix that ranges from light to dark gray with some areas weathered to a light brown clay

Construction:
0-184 ft - 7-1/4 in. dia. hole
Note: pulled back to 164 ft., lost auger, twisted off 8 ft below land surface; 2-4 in. dia. hole drilled to about 154 ft along side auger, slurry cement into holes outside and inside hollow stem auger; hole abandoned.

Fig. 4.2-1 Test Hole MCC-8.2 (core hole test, April 1989, water level about 73 ft)

5.0 METHODS FOR PRESENT STUDY

This section describes or references the methods of sample collection and the analytical or other laboratory procedures applied. Where standard methods were available, they were used and are referenced as such. In many cases, standard methods were not available and more extensive discussion is included to document the methods. Examples of these latter situations are the methods used for constructing the core holes through the alluvial aquifer, and the packaging of the core samples.

5.1 Methods for Investigating Extent of Saturation

5.1.1 Deep Core Hole Construction and Sampling

Based on the data collected from previous studies including that from the core holes near MCO-6 (1983), the MT holes (1988) and core hole MCC-8.2 (1989), it was clear that there were significant variations in hydrologic properties, water contents, and distribution of contaminants with depth beneath the perched aquifer. Some questions were raised about the possibility of cross-contamination of samples (especially for tritium and water content measurements) from hole MCC-8.2.

Accordingly, a new technique was developed to permit better assurance of sealing off the perched aquifer during coring to prevent possible cross-contamination of samples taken at depth below the perched aquifer. The technique involves core drilling through the perched aquifer to a depth of a few feet below the saturated zone with 3 1/2-inch ID hollow stem auger and continuous core tube equipment. Then the hole is then reamed using a larger, 8 1/2-inch ID diameter, hollow stem auger, rotated as little as possible, to a slightly greater depth to act as a casing through the perched aquifer. This casing prevents water in the perched aquifer from flowing down the core hole. Once the 8 1/2 inch auger is emplaced through the perched aquifer, the 3 1/4-inch ID hollow stem auger is run back in the hole through the larger auger, and continuous coring is continued on below the perched aquifer. O-rings were used in the couplings of both sizes of hollow stem auger to further reduce the likelihood of water entering the auger. (One initial attempt to apply the technique was thwarted because a blank steel plate in the cutting auger of the 8 1/2 inch tool could not be pushed aside in the formation once it was pushed out of the end of the tool.) Successful holes were drilled by using the larger diameter auger without a blank plate, and permitting the bottom 5 to 10 feet of the auger plug with formation material. The unsuccessful hole, MCM-5.9 (July 1990), and the two successful holes MCM-5.9A (July 1990) and MCM-5.1 (September

1990) are described in subsequent subsections, in the order of their geographic placement at increasing distance downstream in Mortandad Canyon.

A third deep core hole was drilled just east of the LANL boundary on San Ildefonso Pueblo lands in September 1990. This was completed as a cooperative venture between the Bureau of Indian Affairs and LANL personnel with the approval of San Ildefonso Pueblo under general terms of a three-party Memorandum of Understanding covering environmental monitoring on Pueblo lands. This hole, SIMO-1, was drilled by conventional continuous coring technique, without the larger diameter casing, because there was no expectation of a saturated zone that distance downstream in the canyon based on previously drilled holes (i.e. monitoring wells and moisture probe access holes downstream from MCO-8.2). The hole is described in a subsequent subsection.

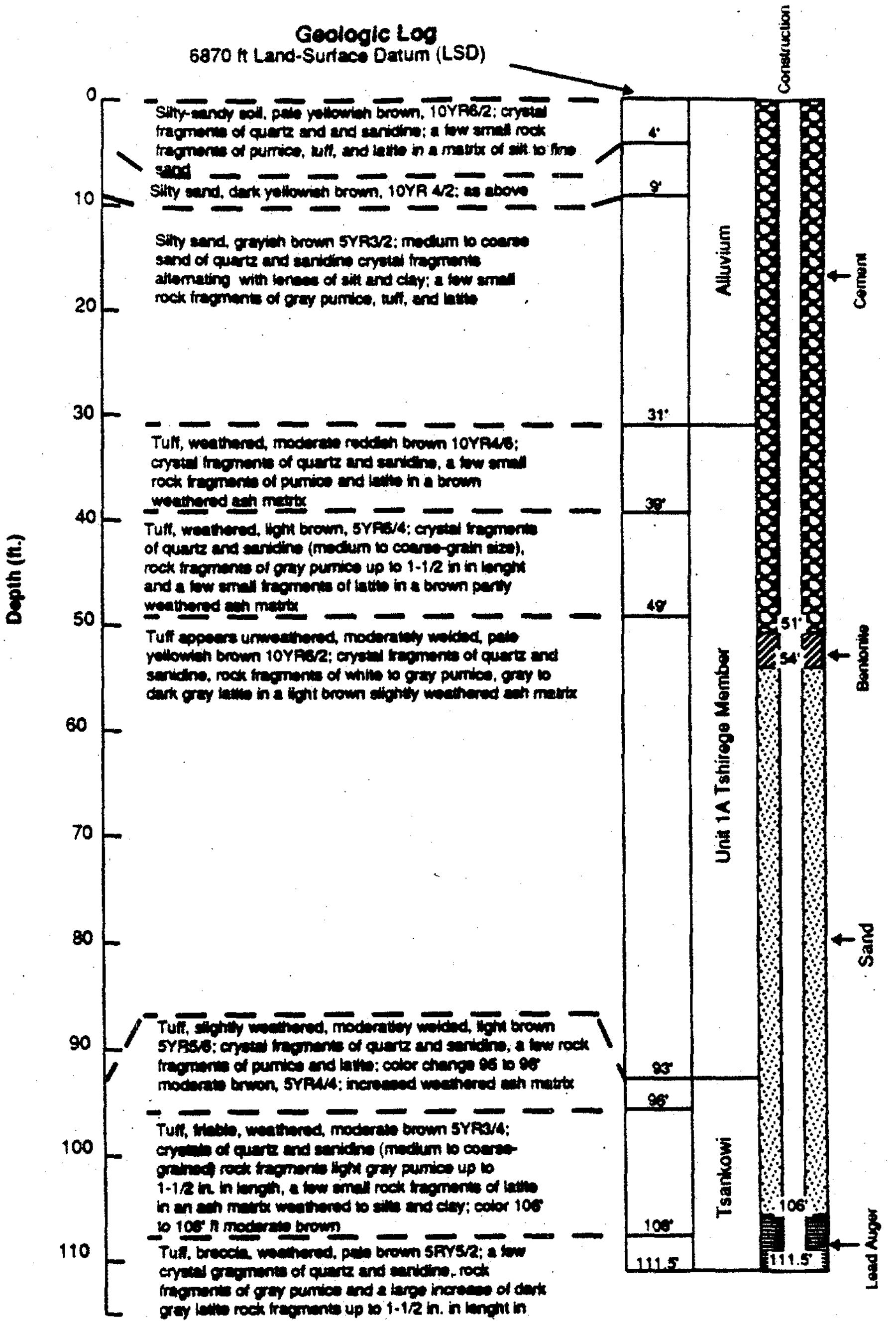
5.1.1.1 Core Hole MCM-5.1

Test hole MCM-5.1 was cored to a depth of 111 ft. The hole penetrated the alluvium, the Tshirege Member Unit 1A, and was completed into the Tsankawi Member Fig. 5.1.1.1-1. The hole was cored with a 3-1/4 ID hollow stem auger through the aquifer. The auger was removed from the hole and the hole was reamed with a 8-1/2 inch ID hollow stem auger. This auger was set into the weathered tuff beneath the aquifer at a depth of 39 ft., sealing the water out of the hole. Coring continued through the 8-1/2 inch dia. auger to about 112 ft. After the coring auger was removed from the hole the hole was completed with a 2-inch ID PVC casing for use as a moisture probe access tube. The perched aquifer was sealed out of the access hole with cement grout as the 8-1/4 inch hollow stem auger was removed from the hole.

Basic data for the hole is included in Appendix 8.3, the geologic and completion log is in Figure 5.1.1.1-1 and in Appendix 8.4

Samples were collected for organic, inorganic, and radiochemical analyses as well as for hydrologic properties. The samples were collected in precleaned 6-inch long by 2 1/2 inch OD stainless steel or brass sleeves inserted inside the 5-foot long core barrel. Upon retrieval of the barrel from a drilling run, the barrel was opened and each sleeve in turn removed and sealed as quickly as possible.

The two bottommost sleeves (stainless steel), destined for organic chemical analysis, were sealed first. The sealing was accomplished by placing a 2 1/2 inch diameter Teflon disk over each end of the sleeve; wrapping each end with two separate layers of 4-inch wide Teflon tape pulled tight to deform and seal tightly against the



Silty-sandy soil, pale yellowish brown, 10YR6/2; crystal fragments of quartz and and sanidine; a few small rock fragments of pumice, tuff, and latite in a matrix of silt to fine sand

Silty sand, dark yellowish brown, 10YR 4/2; as above

Silty sand, grayish brown 5YR3/2; medium to coarse sand of quartz and sanidine crystal fragments alternating with lenses of silt and clay; a few small rock fragments of gray pumice, tuff, and latite

Tuff, weathered, moderate reddish brown 10YR4/6; crystal fragments of quartz and sanidine, a few small rock fragments of pumice and latite in a brown weathered ash matrix

Tuff, weathered, light brown, 5YR6/4; crystal fragments of quartz and sanidine (medium to coarse-grain size), rock fragments of gray pumice up to 1-1/2 in in lenght and a few small fragments of latite in a brown partly weathered ash matrix

Tuff appears unweathered, moderately welded, pale yellowish brown 10YR6/2; crystal fragments of quartz and sanidine, rock fragments of white to gray pumice, gray to dark gray latite in a light brown slightly weathered ash matrix

Tuff, slightly weathered, moderatley welded, light brown 5YR5/6; crystal fragments of quartz and sanidine, a few rock fragments of pumice and latite; color change 95 to 96' moderate brwon, 5YR4/4; increased weathered ash matrix

Tuff, friable, weathered, moderate brown 5YR3/4; crystals of quartz and sanidine (medium to coarse-grained) rock fragments light gray pumice up to 1-1/2 in. in length, a few small rock fragments of latite in an ash matrix weathered to silts and clay; color 106' to 108' ft moderate brown

Tuff, breccia, weathered, pale brown 5RY5/2; a few crystal gragments of quartz and sanidine, rock fragments of gray pumice and a large increase of dark gray latite rock fragments up to 1-1/2 in. in lenght in weathered light brown ash matrix

Construction:
0-39 ft - 11-1/2 in. dia. hole
49-111.5 ft - 7-1/4 in. dia. hole
Cased 2-in. dia. plastic pipe 0-111.5 ft.

Fig. 5.1.1-1 Test Hole MCM-5.1 (completed September, 1990, water in alluvium cased out of hole)

sleeve; and then placing a friction fit plastic cap over the Teflon tape. Each sealed sleeve was placed inside two separately sealed, recloseable plastic bags, and then placed in an ice chest for preservation and transport to the analytical chemistry laboratory.

The next two sleeves (brass), destined for hydrologic property analysis, were sealed with Teflon tape and plastic caps, as described above, and additionally sealed with plastic adhesive tape over the plastic caps as a further precaution against any loss of moisture during transport to the hydrologic laboratory. These were also double-bagged and placed in an ice chest for preservation and transport.

The fifth sleeve, destined for radiochemical analysis, was sealed with the plastic end caps, placed in double plastic bags, and stored and transported in ice chests.

5.1.1.2 Core Hole MCM-5.9

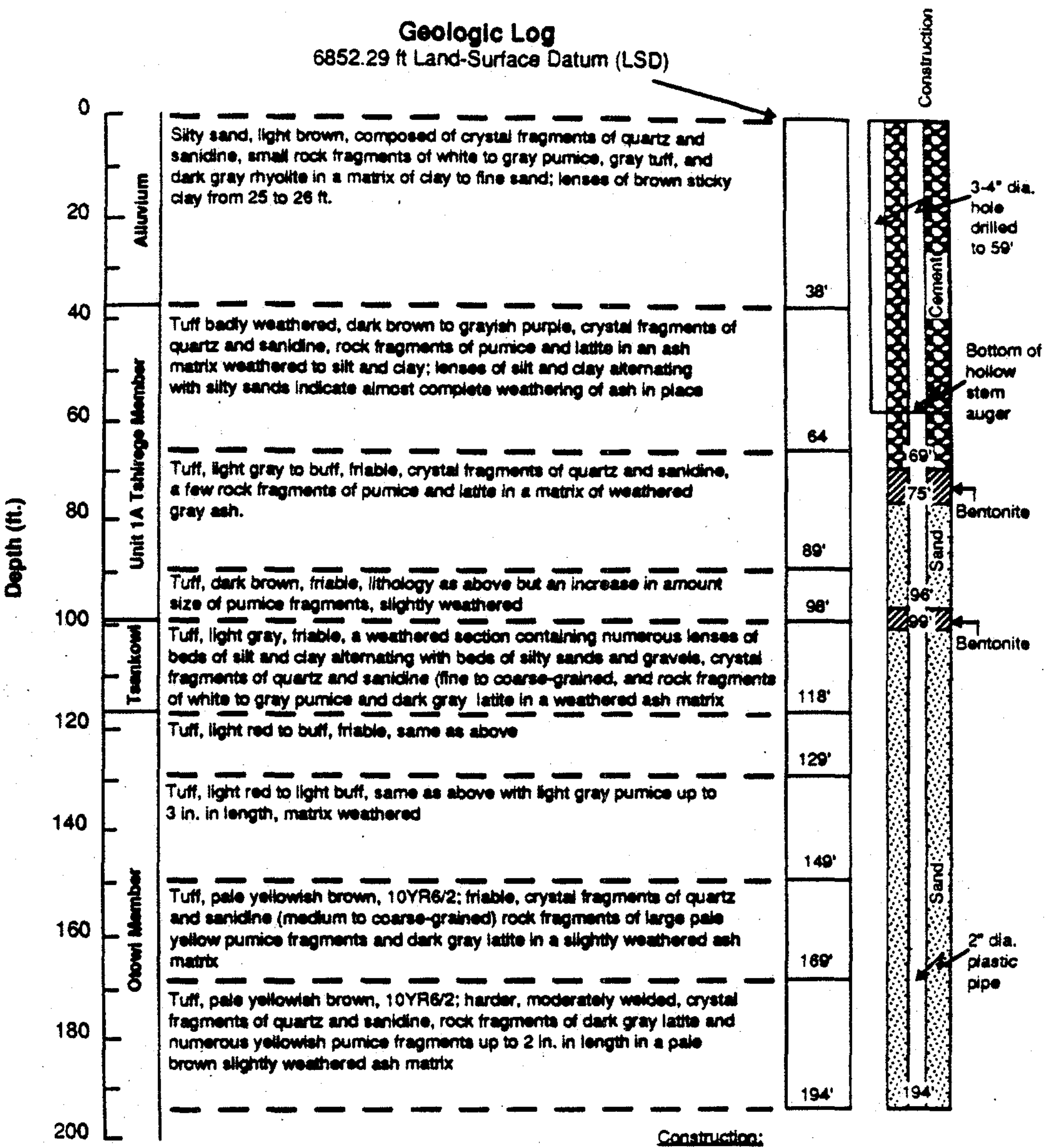
Test hole MCM-5.9 was cored through the alluvium in to the top of the Tshirege Member Unit IA . The hole was abandoned and plugged after the blank plate from the 8-1/4 inch hollow stem auger could not be pushed to the side to permit introduction of the 3 1/4 inch hollow stem auger coring tool.

Basic data for the hole is included in Appendix 8.3 (Table "TBLMCT"), the geologic and completion log is in Appendix 8.4

No samples from the hole were analyzed.

5.1.1.3 Core Hole MCM-5.9A

Test Hole MCM-5.9A was cored through the alluvium, Tshirege Member Unit 1A, Tsankawi Member, and into the top of the Otowi Member, Fig. 5.1.1.3-1. The hole was first cored to a depth of 64 ft. and then reamed with the 8-1/4 inch hollow stem auger to a depth of 59 ft or 21 ft below the bottom of the aquifer. The 8-1/4 inch hollow stem cased out the water in the aquifer. The hole was then cored to a depth of 194 ft. It was completed with 2 inch ID PVC pipe as a moisture probe access tube. The 8-1/4 inch hollow stem was stuck in the hole. A cement plug placed from 69 ft to land surface cased the water out of the lower part of the hole that contained the moisture probe access tube.



Silty sand, light brown, composed of crystal fragments of quartz and sanidine, small rock fragments of white to gray pumice, gray tuff, and dark gray rhyolite in a matrix of clay to fine sand; lenses of brown sticky clay from 25 to 26 ft.

Tuff badly weathered, dark brown to grayish purple, crystal fragments of quartz and sanidine, rock fragments of pumice and latite in an ash matrix weathered to silt and clay; lenses of silt and clay alternating with silty sands indicate almost complete weathering of ash in place

Tuff, light gray to buff, friable, crystal fragments of quartz and sanidine, a few rock fragments of pumice and latite in a matrix of weathered gray ash.

Tuff, dark brown, friable, lithology as above but an increase in amount size of pumice fragments, slightly weathered

Tuff, light gray, friable, a weathered section containing numerous lenses of beds of silt and clay alternating with beds of silty sands and gravels, crystal fragments of quartz and sanidine (fine to coarse-grained, and rock fragments of white to gray pumice and dark gray latite in a weathered ash matrix

Tuff, light red to buff, friable, same as above

Tuff, light red to light buff, same as above with light gray pumice up to 3 in. in length, matrix weathered

Tuff, pale yellowish brown, 10YR6/2; friable, crystal fragments of quartz and sanidine (medium to coarse-grained) rock fragments of large pale yellow pumice fragments and dark gray latite in a slightly weathered ash matrix

Tuff, pale yellowish brown, 10YR6/2; harder, moderately welded, crystal fragments of quartz and sanidine, rock fragments of dark gray latite and numerous yellowish pumice fragments up to 2 in. in length in a pale brown slightly weathered ash matrix

Construction:
0-59 ft - 11-1/2 in. dia. hole
59-194 ft - 7-1/4 in. dia. hole
0-194 ft cased 2-in. plastic pipe
Note hollow stem auger 8-1/4 in. ID, 11-1/2 in. OD left in hole 0-59 ft, 3-4 in. dia. hole drilled around 11-1/2 in auger to a depth of 59 ft, cement slurry into the hole outside and inside 11-1/2 in. OD hollow stem auger

Fig. 5.1.1.3-1 Test Hole MCM-5.9A (completed July 1990, water in alluvium cased out of hole)

Basic data for the hole is included in Appendix 8.3 (Table "TBLMCT"), the geologic and completion log is in Figure 5.1.1.3-1 and in Appendix 8.4

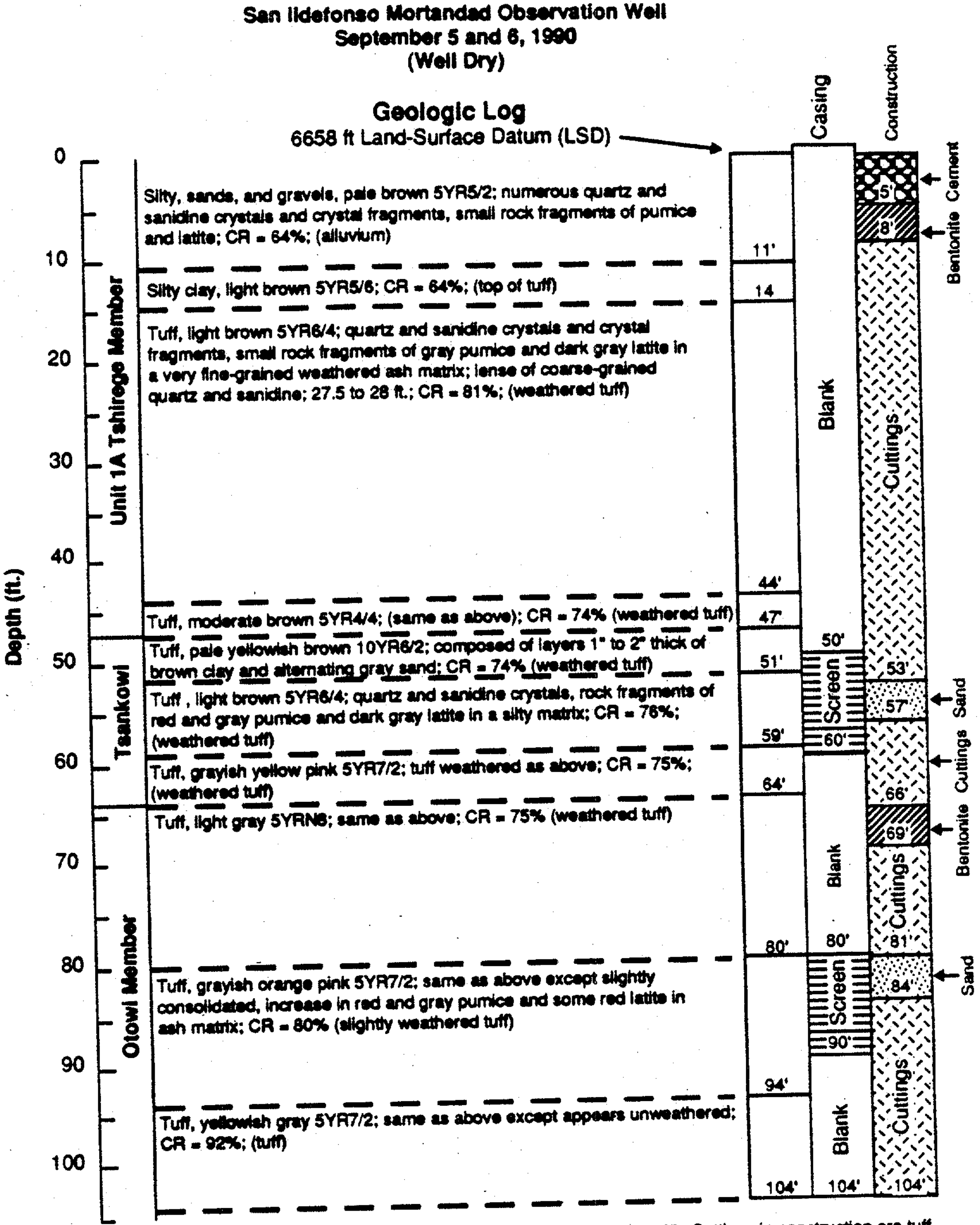
Samples were collected for radiochemical and inorganic analyses as well as for hydrologic properties. The hydrologic samples were collected in 6-inch long by 2 1/2 inch OD brass sleeves inserted inside the 5-foot long core barrel. Upon retrieval of the barrel from a drilling run, the barrel was opened and the brass sleeve removed, covered with a plastic end caps, and sealed with plastic adhesive tape. The radiochemical and inorganic samples were collected as a composite from the remaining material in the 5-foot core interval in recloseable plastic bags. Analytical methodology was as described above in Section 5.1.1.1.

5.1.1.4 Core Hole SIMO-1

Core hole SIMO-1 was drilled (September 1990) on the Pueblo of San Ildefonso a few hundred feet east of the Laboratory boundary. The test hole was drilled to collect samples and confirm the expected absence of any perched aquifer in the alluvium. The hole was cored to a depth of 104 ft through the alluvium, Tshirege Member Unit 1A, Tsankawi Member and top of the Otowi Member, Fig. 5.1.1.4-1. The hole was dry. A 2-inch dia. plastic casing with perforations was run in the hole for continued use as a moisture probe access tube, or the collection of water samples should that part of the canyon ever become saturated in the future. The top was sealed with cement and a BIA steel security cover installed.

Basic data for the hole is included in Appendix 8.3 (Table "TBLMCT"), the geologic and completion log is in Fig. 5.1.1.4-1 and in Appendix 8.4

Samples were collected for radiochemical analyses and moisture content. An extra, brass-sleeved sample was collected and held for possible additional analysis in the future. Upon retrieval of the barrel from a drilling run, the barrel was opened and the brass sleeve removed, covered with a plastic end caps, and sealed with plastic adhesive tape. The radiochemical and inorganic samples were collected as a composite from the remaining material in the 5-foot core interval in recloseable plastic bags. Analytical methodology was as described above in Section 5.1.1.1.



NOTE: Cased with Schedule 40 PVC - 2" ID; screen slotted 0.010". Cuttings in construction are tuff from hole ranging from silts-sands-gravels. CR = Core Recovery for section.

Fig. 5.1.1.4-1 Test Hole SIMO drilled with and in cooperation with San Ildefonso Pueblo and Bureau of Indian Affairs.

5.1.2 Shallow Seismic Refraction Methods

A shallow seismic refraction survey was carried out in September 1990 by a subcontractor, Charles B. Reynolds & Associates. The survey was intended to identify the form and depth of the interface of the alluvium and the tuff, and, where possible, to detect the presence of perched groundwater in the alluvium. There were seven sets of two crossed lines located in Mortandad Canyon. Locations extended from near MCO-5 eastward to near the Los Alamos-Santa Fe County line (Appendix 8.1 and Appendix 8.9). The lines were fully reversed and analyzed by a wavefront reconstruction technique using both low and high frequency components. The full description of the methodology is presented in Appendix 8.9.

5.2 Methods for Investigating Extent of Contamination

5.2.1 Leachates/Extracts from Cores

Analyses for radiochemical, inorganic, and organic constituents were performed by the Health and Environmental Chemistry Group (HSE-9) at Los Alamos National Laboratory. Descriptions of the standard analytical methods are documented in other Los Alamos publications (Williams 1990 and Gautier 1990). In addition to the standard analyses for radiochemicals, general chemical parameters, EP Toxicity analysis for metals extractable from cores, and organic vapors and extracts performed in accord with EPA guidance and regulations where appropriate, selected cores were subject to a metal scan. This procedure involved taking a 1 gram sample of the rock matrix, leaching it in a 1 percent nitric acid solution for 24 hours on a shaker, and then analyzing the extract on an ICP-Mass Spectrometer for 57 measurable metals.

5.2.2 Construction and Sampling of Wells in Perched Zone

Module VIII of the Hazardous and Solid Waste portion of the RCRA permit included a requirement for special Perched Zone Monitoring. In conformance with those requirements, new monitoring wells were installed in several of the canyons, including Mortandad Canyon. The installation and construction of those wells was completed in 1990 (Purtymun, 1990a). The wells were drilled and constructed in accord with EPA recommendations given in the RCRA Ground-Water Monitoring Technical Enforcement Guidance Document (TEGD) to the extent practicable and allowing for some site-specific modifications based on more than 40 years experience with monitoring initiated by the U. S. Geological Survey. Basic data on the new wells are presented in Table 5.2.2-I and geologic and completion logs are included in Appendix 8.4

Table 5.2.2-I

Basic Data for New Monitoring Wells in Mortandad Canyon

Well Characteristics and Water Levels

	Date Drilled	Date Completed	Depth Drilled (ft)	Depth Completed (ft)	Water Levels Below Land Surface Datum (ft) Date	Water Level	Date	Water Level
MCO-4A	11-01-89	11-01-89	24	19.4	11-14-89	5.1	8-15-90	Dry
MCO-4B	8-20-90	8-21-90	34	33.9	—	—	8-21-90	21.7
MCO-6A	11-02-89	11-06-89	33	32.7	11-09-89	30.3	6-02-90	Dry
MCO-6B	8-09-90	8-13-90	48	47.1	—	—	8-13-90	33.2
MCO-7A	11-06-89	11-14-89	47	44.8	11-09-89	35.2	6-21-90	37.2

Observation Well Elevations and Measuring Points

	Top of Steel Casing	Top of PVC Casing, Measuring Point	Land SurfaceMeasuring Datum, orPoint to Land Brass Cap	Surface Datum	New Mexico State Plane Coordinates (Brass Cap) Northing	Easting
MCO-4A	6889.00	6888.24	6887.53	-0.71	1 769 638.132	491 784.644
MCO-4B	6889.13	6888.71	6887.56	-1.15	1 769 634.899	491 792.173
MCO-6A	6851.80	6851.45	6850.18	-1.27	1 768 899.886	493 388.651
MCO-6B	6851.84	6851.08	6850.37	-0.71	1 768 921.493	493 386.276
MCO-7A	6829.27	6828.75	6827.71	-1.04	1 768 447.198	494 259.239

The wells were all constructed with basically the same methods. A pilot hole was drilled with either a standard continuous-flight auger (4-1/2 inch diameter) or cored with hollow stem auger (7-1/4 inch hole diameter). The depth to the base of the aquifer was determined by the cuttings and drilling pressure or by direct inspection of the continuous core retrieved from the hole. The pilot hole provided a guide for reaming the hole using a larger diameter hollow stem auger (6-1/4 inch I.D.).

Two-inch diameter casing was set through the hollow stem auger, with the screened portion resting on the bottom of the hole. The lowest portion of the casing consisted of 1 or 2 ten-foot lengths of 0.010 inch slotted screen with a plug at bottom. (In three wells a five-foot blank section was extended below the screen section in order to provide for bailer descent needed to collect adequate sample volumes.) The annulus between the hollow stem auger and casing screen was filled with the filter pack (sand) in increments of 2 to 3 feet at which time the auger was pulled up a corresponding amount. Keeping the sand in the auger while raising the auger assured a continuous gravel pack between the bore hole wall and the screen by preventing any formation material from caving in around the casing. At this point a seal of bentonite and/or cement was extended to the surface using the same method of emplacement through the auger to assure a continuous seal with no formation material collapsing in around the blank tubing. The upper part of the well was filled with cement and the well head security cap was set about 1 1/2 to 2 feet into the cement.

The wells were developed using a surge block, pumping, bailing, and jetting. At least two methods were used in each well. The choice of methods depended on the depth to water and observations of the saturated thickness. Jetting was the most commonly used method and was applied to all of the Mortandad Canyon wells. However, none of the wells that have water in them have yet been able to meet the turbidity guideline of 5 nephelometric turbidity units. This is as expected based on previous experience with the 25 to 30 year old U.S. Geological Survey wells. Because of this experience with continued turbidity resulting from the fine suspended clays and silts found in the aquifer, the smallest size screen generally available from commercial sources (0.010-inch) with matched size sand (0.010 to-0.020- inch) was used in completing all the new wells. These clays and silts are derived from weathering of the ash matrix of the tuff.

Wells were completed in Mortandad Canyon near existing wells MCO-4, MCO-6, and MCO-7. These are identified as MCO-4A, -6A, and -7A, respectively. Two of the wells, MCO-4A and -6A, became dry during the summer due to lack of surface runoff. Two additional wells, designated MCO-4B and MCO-6B, were drilled because the old USGS. wells indicated the water level had declined beneath the lowest part of the ten-foot screen installed in the first new wells. The replacement wells were equipped with 20-foot screen sections to allow for the considerable fluctuation in the water level during seasonal variations.

Basic data on both the old and new wells are presented in Appendixes 8.3 and 8.4.

The new wells that contained water were sampled for detailed analysis of radiochemical, inorganic, and organic constituents (Environmental Restoration Program 1990). They were first sampled on September 11 and 12, 1990. At the same time, samples were collected from adjacent older wells in Mortandad and Los Alamos canyons to permit comparison of the results from those wells with results from the new wells constructed in accord with the permit conditions. (The older wells include MCO-4, MCO-6, and MCO-7 in Mortandad Canyon. These older wells have long been monitored under the routine Environmental Surveillance program and data from them have been published annually in the Environmental Surveillance Reports (see Sec. 3.3 of this report)

The new wells were sampled a second time by the International Technology Corporation (IT) on November 1 and 2, 1990, for analysis of the entire RCRA Appendix IX list of constituents, including some analyses not presently performed by the Health and Environmental Chemistry Group, HSE-9. The data is presented in Section 6.2.1.

Details of the sampling methodology, analytical methods, and quality assurance programs were documented in the previously submitted reports identified in the two above references.

5.3 Methods for Investigating Hydrologic Properties

Analysis for hydrologic properties including moisture content, were performed by a subcontractor, Daniel B. Stephens, Inc. Their methods and quality assurance program are documented in their final report, included in this document as Appendix 8.8, parts H and I.

6.0 SUMMARY OF RESULTS

This section will present summaries of the data specifically obtained in response to the special permit condition. The detailed data is contained in Appendix 8. Cross-references to subsections of Appendix 8 are included. Where appropriate, reference will be made to other related data contained in the appendixes or in other previous reports.

6.1 Extent of Saturation

As expected from earlier studies and measurements, the saturated thickness of the alluvium in Mortandad Canyon is relatively thin and occurs perched on top of the weathered tuff of Unit 1a of the Tshirege member of the Bandelier Tuff. In the three core holes penetrating saturated conditions, the saturated thickness ranged from about 2 ft in hole MCM-5.9A, to about 8 ft in both MCM-5.1 and MCC-8.2. No zone of saturation was observed in hole SIMO-1.

6.1.1 Cores

The moisture content at less than saturation varied considerably with depth and lithologic strata. A graphic presentation of the gravimetric moisture profiles found in each of the four holes is presented in Fig. 6.1.1-1. and Quantitative data is summarized in Tables 6.2.2.1 -I, 6.2.2.2-I, 6.2.2.3-I, and 6.2.2.4-I in Section 6.2.2, and detailed in Appendix 8.5. Gravimetric moisture content measurements were made for samples from all four holes to permit some comparisons between holes to be made.

Most of the measurements from samples collected in holes MCM-5.1, MCM- 5.9A, and MCC-8.2 tfrom depths below the perched water were in the range of 10 to 30 percent. There is a gradual increase in gravimetric moisture content with depth , peaking at about 100 feet. This occurs in the Tsankawi member of the Bandelier tuff and is just above or at the contact with the Otowi member. There appears to be an initial decrease in gravimetric moisture with depth into the Otowi member (based mainly on data from holes MCM-5.9A and MCC-8.2), which quickly levels off between 12 and 18%.

In hole SIMO-1, where there was no perched zone, the gravimetric moisture content was relatively constant at between 4 and 9 percent through the Tshirege and Tsankawi members, decreases to about 2 to 4 % at the contact with the Otowi member, and then gradually increases to between 10 and 20% in the bottom 20 feet of the hole. It is interesting to note that the gravimetric moisture content in the portion of the hole 20 to 40 feet into the Otowi member is very similar to that observed in the comparable section of the Otowi member in holes MCM-5.9A and MCC-8.2.

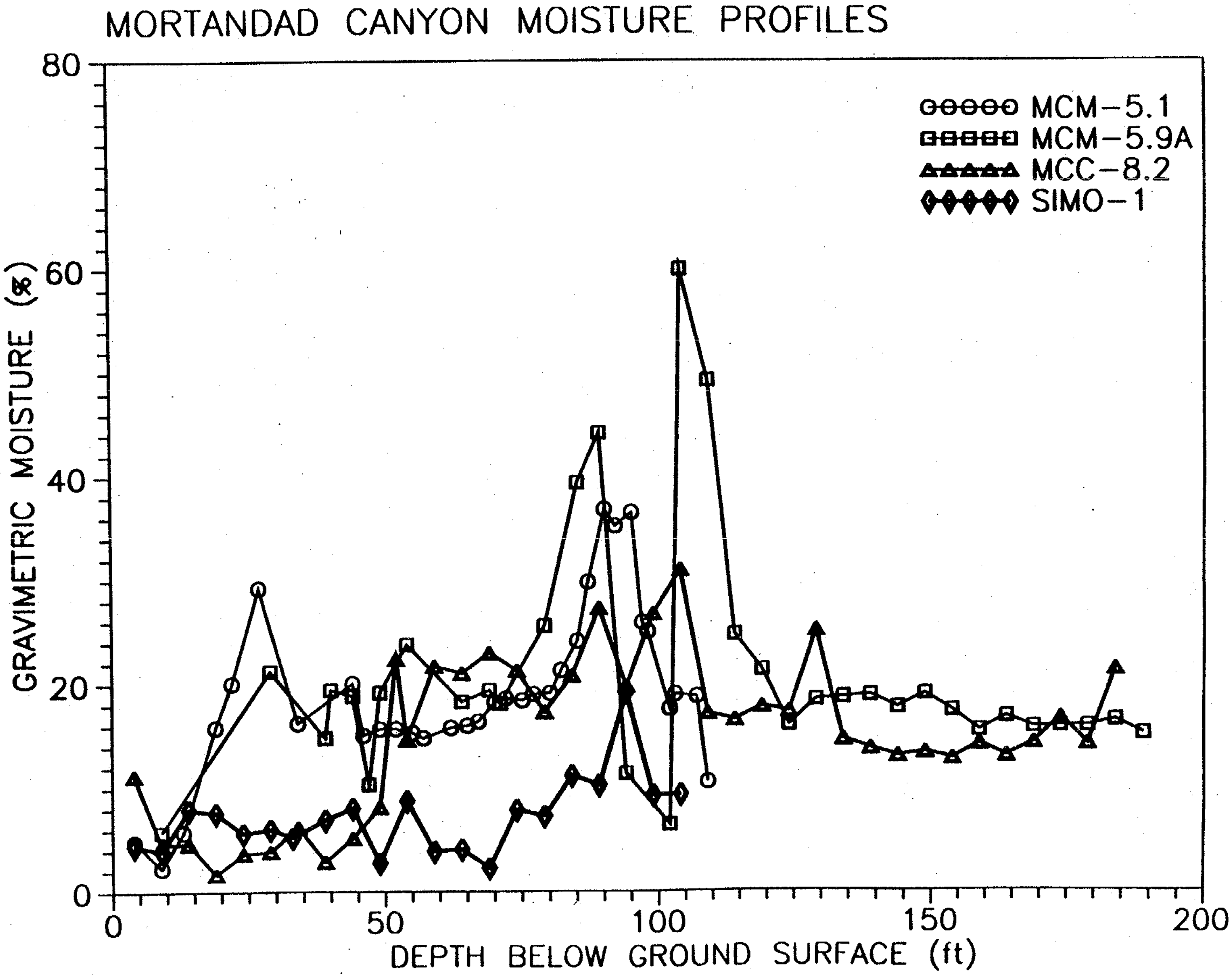

MORTANDAD CANYON MOISTURE PROFILES
MCM-5.1
MCM-5.9A
MCC-8.2
SIMO-1
GRAVIMETRIC MOISTURE (%)
0
20
40
60
80
DEPTH BELOW GROUND SURFACE (ft)
0
50
100
150
200

Fig. 6.1.1-1

Other measures of moisture content, which include percent of saturation and moisture potential are of considerable interest in relation to hydrologic properties. Measurements of these properties were made on selected cores from holes MCM-5.1 and MCM-5.9A by a contract hydrologic laboratory, and are discussed in Section 6.3.

6.1.2. Seismic Refraction

The shallow seismic refraction study results generally confirmed that the zone of saturation is thin throughout the canyon based on the lines surveyed. The complete interpretation is presented in the subcontractor's report, reproduced in Appendix 8.9. The large-scale map in Appendix 8.1 depicts refractions with sufficiently high velocities to suggest the possibility of saturation as shaded areas. In summary, the seismic results suggested the maximum thickness of saturation occurred under or near the existing stream channel in the upper portion of the canyon. In the lower part of the canyon, from about MCO-8 and further east , the thickest sections appear to be located south of the stream channel. The maximum suggested saturated thickness was about 10-15 ft on one of the lines in the vicinity of MCO-8. There was some evidence of near-saturation conditions as far east as the Los Alamos-Santa Fe County line (see map in Appendix 8.1), although holes drilled in previous studies nearer the stream channel have never encountered saturation east of MCO-9). The seismic data also suggested that the highest elevations of saturated conditions occur under or near the stream channel, with some slope downward toward one or both canyon sides (mounding). This possibility of mounding perpendicular to the canyon axis has also been noted by water levels observed in holes drilled in transect across the canyon.

6.2 Extent of Contamination

The contaminants of interest in Mortandad Canyon are predominantly those released as residuals in the treated effluent from the TA-50 Radioactive Liquid Waste treatment plant. The residual radioactive materials have historically been of most interest. Records of releases from the TA-50 plant were summarized to provide a basic indication of the history of releases. Data on tritium in the effluent is presented in Table 6.2-I; data for plutonium and americium is in Table 6.2-II.

Tritium is of great interest in evaluating the hydrologic process because tritium, the radioactive isotope of hydrogen, is chemically part of the water molecules and physically moves with water virtually unaffected by any geochemical processes such as ion exchange, chelation, or adsorption. Accordingly it can be used as a fundamental conservative tracer to follow the movement of water, including identification of dilution or mixing.

TABLE 6.2-I

TA-50 Tritium Effluent

	Effluent Data as Released			Record Decay Corrected Data			
Year	Effluent Volume (10^6 Liters)	^3H Effluent (Curies)	Release Year H Concentration (nCi/L)	Decay to 1991	1991 ^3H Concentration (nCi/L)	1991 ^3H Inventory (Ci)	1991 ^3H Cumulative Summary (Ci)
1963	27.38	0	0.0	0.21	0.0	0.0	0.0
1964	51.39	0	0.0	0.22	0.0	0.0	0.0
1965	48.99	0	0.0	0.23	0.0	0.0	0.0
1966	52.8	0	0.0	0.25	0.0	0.0	0.0
1967	59.67	20 ?	0.0	0.26	0.0	0.0	0.0
1968	60.28	0	0.0	0.27	0.0	0.0	0.0
1969	54.47	20 ?	367.2	0.29	106.6	5.8	5.8
1970	53.17	0	0.0	0.31	0.0	0.0	5.8
1971	45.67	0	0.0	0.32	0.0	0.0	5.8
1972	57.07	5.971	104.6	0.34	36.0	2.1	7.9
1973	53.72	17.47	325.2	0.36	118.2	6.4	14.2
1974	40.6	4.05	99.8	0.38	38.4	1.6	15.8
1975	39.72	26	654.6	0.41	266.3	10.6	26.3
1976	39.89	187	4687.9	0.43	2017.6	80.5	106.8
1977	42.09	36.5	867.2	0.46	394.8	16.6	123.4
1978	40.54	12.3	303.4	0.48	146.1	5.9	129.4
1979	48.58	32.7	673.1	0.51	342.9	16.7	146.0
1980	52.83	44.9	849.9	0.54	458.0	24.2	170.2
1981	55.33	17	307.2	0.57	175.1	9.7	179.9
1982	39.76	14.2	357.1	0.60	215.4	8.6	188.5
1983	34.5	8.7	252.2	0.64	160.9	5.5	194.0
1984	35.05	13	370.9	0.67	250.3	8.8	202.8
1985	28.6	69.4	2426.6	0.71	1732.0	49.5	252.3
1986	30.5	72.5	2377.0	0.76	1794.7	54.7	307.1
1987	26.6	100	3759.4	0.80	3002.5	79.9	386.9
1988	29.3	21	716.7	0.84	605.5	17.7	404.7
1989	22.8	16	701.8	0.89	627.1	14.3	419.0
1990	21.1	12	568.7	0.95	537.6	11.3	430.3

TABLE 6.2-II

TA-50 Effluent, Plutonium and Americium Content

Year	Pu-238			Pu-239			Am-241		
	Release (mCi)	Average Concentration (pCi/L)	Cumulative Sumary (mCi)	Release (mCi)	Average Conc. (pCi/L)	Cumulative Sumary (mCi)	Release (mCi)	Average Concentration (pCi/L)	Cumulative Sumary (mCi)
1963	0.0	0.0	0.0	1.6	58.4	1.6	0.0	0.0	0.0
1964	0.0	0.0	0.0	1.9	37.8	3.5	0.0	0.0	0.0
1965	0.0	0.0	0.0	3.5	71.2	7.0	0.0	0.0	0.0
1966	0.0	0.0	0.0	1.6	30.7	8.7	0.0	0.0	0.0
1967	0.0	0.0	0.0	4.2	70.7	12.9	0.0	0.0	0.0
1968	0.0	0.0	0.0	2.6	43.0	15.5	0.0	0.0	0.0
1969	0.0	0.0	0.0	6.8	124.5	22.2	0.0	0.0	0.0
1970	0.0	0.0	0.0	5.0	93.7	27.2	0.0	0.0	0.0
1971	0.0	0.0	0.0	6.2	135.5	33.4	0.0	0.0	0.0
1972	7.7	134.7	7.7	1.0	17.9	34.4	0.0	0.0	0.0
1973	8.4	156.3	16.1	0.6	10.8	35.0	1.4	25.2	1.4
1974	11.4	280.8	27.5	0.4	9.6	35.4	1.7	40.9	3.0
1975	14.8	372.6	42.3	0.7	16.9	36.1	1.1	28.4	4.1
1976	7.5	187.5	49.8	1.1	26.3	37.1	1.1	28.6	5.3
1977	2.6	61.1	52.3	1.5	34.9	38.6	1.9	45.9	7.2
1978	4.1	99.9	56.4	1.8	45.1	40.4	1.7	42.7	8.9
1979	0.6	11.3	56.9	1.7	35.2	42.1	4.7	96.3	13.6
1980	1.3	24.6	58.2	8.2	155.2	50.3	5.7	107.9	19.3
1981	2.9	52.4	61.1	55.0	994.0	105.3	23.0	415.7	42.3
1982	3.0	75.5	64.1	16.6	417.5	121.9	17.8	447.7	60.1
1983	11.0	318.8	75.1	42.0	1217.4	163.9	38.0	1101.4	98.1
1984	6.1	174.0	81.2	8.1	231.1	172.0	8.2	234.0	106.3
1985	3.9	137.4	85.2	5.8	201.0	177.8	5.4	189.5	111.7
1986	1.5	49.2	86.7	3.6	116.4	181.3	3.2	106.2	115.0
1987	1.4	52.6	88.1	3.2	120.3	184.5	3.6	135.3	118.6
1988	1.1	37.5	89.2	1.1	37.5	185.6	3.7	126.3	122.3
1989	0.6	24.6	89.7	2.0	87.7	187.6	4.1	179.8	126.4
1990	0.2	9.5	89.9	0.6	28.4	188.2	2.7	128.0	129.1

The first four columns in Table 6.2-I include information on the annual amount of tritium released, the annual effluent volume, and the arithmetic average concentration for each year. The last four columns provide information to account for the radioactive decay of tritium (approximately 12.3 year half-life), including the decay factor from the year of release to 1991, the decayed-corrected concentration and total annual release, and a decay-corrected cumulative sum of the releases through 1990.

Table 6.2-II presents the annual total release and annual average concentration in the effluent for Pu-238, Pu-239, and Am-241. A running cumulative sum of total release is provided for each nuclide. Analysis of the effluents through 1971 was made for total plutonium only, reported here as Pu-239, which was the dominant constituent through most of that time.

Monitoring and special studies during the entire history of TA-50 discharges into Mortandad Canyon provide basic data on the fate of the major radioactive residuals. The residuals associated with sediments accounted for 99 to more than 99.9 percent of the total releases for all radioactivity except tritium. One detailed study (Purtymun 1983) summarized the distribution of constituents associated with the channel sediments and those found in the perched aquifer. The proportions found in the perched aquifer ranged from a maximum of about 1 percent for gross alpha, down to about 0.03 percent for Pu-239. Patterns of concentrations have remained relatively constant, and while total inventory has increased from continued releases (Tables 6.2-I and 6.2-II), the overall proportions of distribution must be similar. Additional studies have addressed the details of distribution of radionuclides in the perched aquifer especially as they may reflect the association of specific isotopes with various size particulates and colloids (e. g. Penrose 1990). These studies show that a significant portion of the materials in the perched aquifer may be associated with neutral and therefore mobile colloids.

Tritium exhibits a somewhat different pattern. The concentrations of tritium in the aquifer vary over three orders of magnitude, generally following the average concentrations in the effluent, but lagging by periods of approximately a year. This is graphically represented in Fig. 6.2-1 that shows annual average tritium concentrations in the effluent and in six of the observation wells located through the reach of Mortandad Canyon where the perched aquifer occurs. Detailed studies of the movement of tritium (Purtymun, 1983; and Purtymun, 1974)have found that tritium moves with water through the aquifer about 3 km from the release point to MCO-8 in about 390 days. Based on inventory estimates, it appears that about half of the tritium, and thus half of the effluent, entering the canyon in a given year is lost through evaporation and movement out of the alluvium into the adjacent or underlying tuff.

EXTENT OF SATURATION IN MORTANDAD CANYON

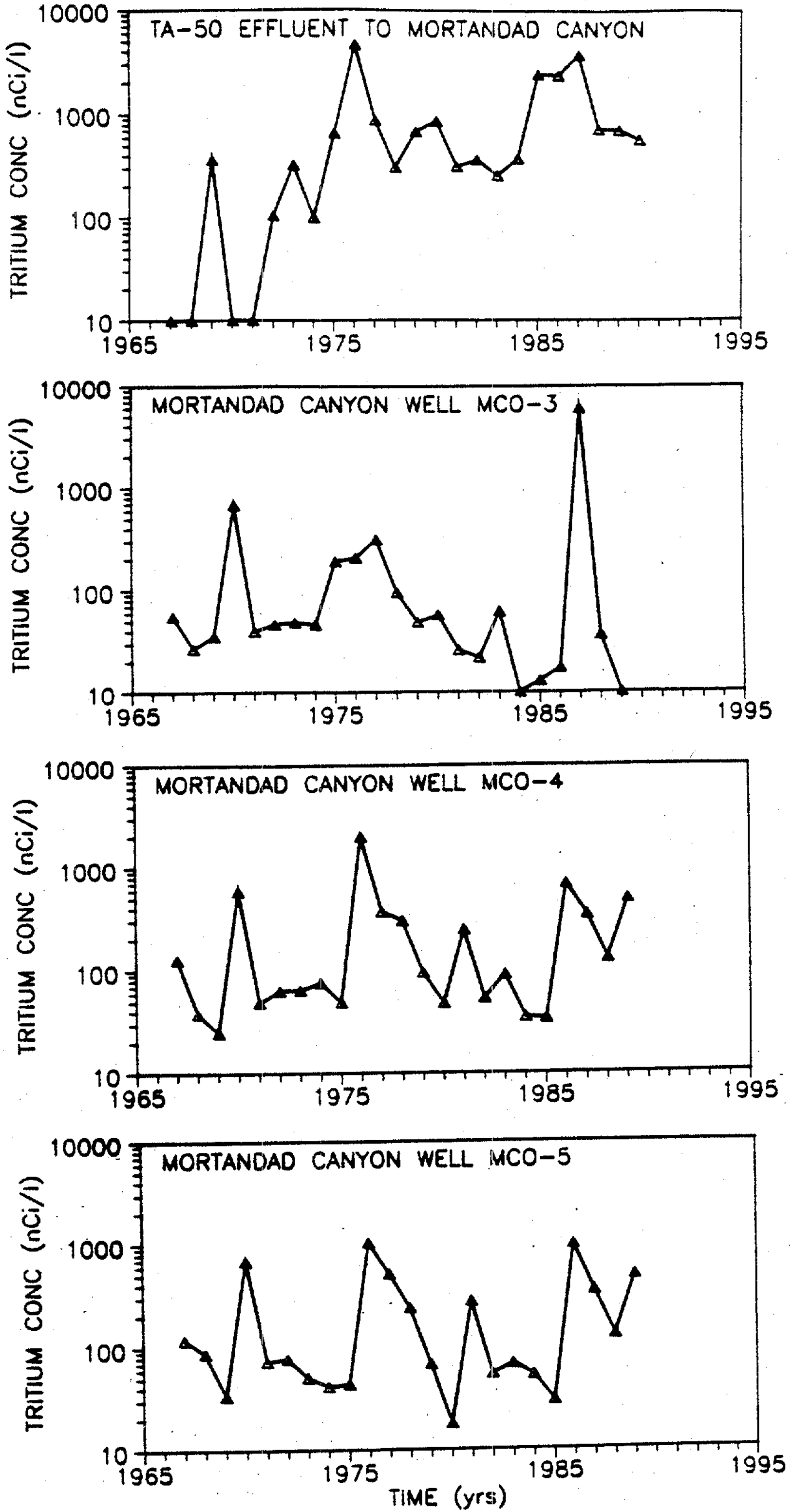


Fig. 6.2-1 Annual Tritium Concentration in Mortandad Canyon

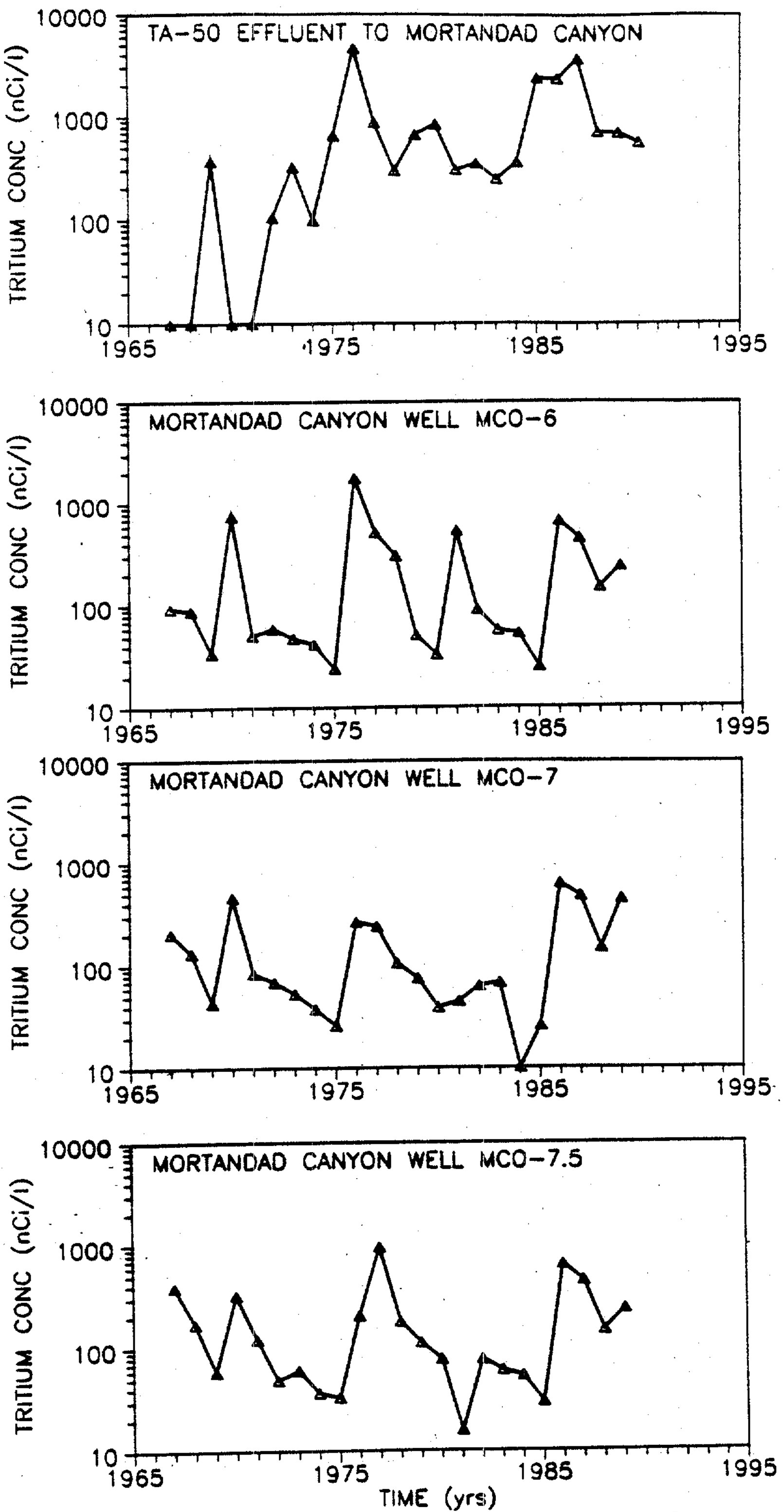


Fig. 6.2-1 Annual Tritium Concentration in Mortandad Canyon (continued)

6.2.1. Alluvial Water

The samples collected in the fall of 1990 in fulfillment of the permit special condition were subject to a full range of analyses for radiochemical constituents and Appendix IX constituents. The samples were collected from both old observation wells and adjacent new wells, and indicate the nature of contaminants found in the perched aquifer. The results of the laboratory analyses are summarized in five tables, as follows:

Table 6.2.1-II summarizes Radiochemical Analyses for Gross Gamma, Gross Alpha, ^{241}Am, Total U, ^{3}H, ^{137}Cs, ^{238}Pu, and ^{239,240}Pu. All of the constituents were present in locations and amounts expected from the results of the long term monitoring program. Tritium concentrations were found to be very comparable between adjacent old and new well pairs, indicating good hydrologic continuity; and is expectable because tritium in the water molecules is not subject to adsorption. Plutonium concentrations in samples from the new wells in Mortandad Canyon (MCO-4B, MCO- 6B, and MCO-7A) were considerably lower than in samples from the old wells (MCO-4, MCO-6, and MCO-7). This is probably expectable because construction of the new wells resulted in significant new disturbed surfaces for adsorption of plutonium.

Table 6.2.1-II summarizes the Appendix IX Inorganic Constituents. Most of the metals were found in concentrations above detection limits in some or all of the samples, and in general, fit expectations of occurrence based on results of the long term monitoring program. Barium and lead levels were higher than previously observed. Sulfides were found in all the new wells at levels from 1 to 2.8 mg/L. Results from the two laboratories were generally comparable considering possible variation because of approximately seven weeks difference in sampling dates.

Table 6.2.1-III summarizes the Appendix IX Organic Compounds Detected. The only Appendix IX organics detected that could not be attributed to minor analytical laboratory contamination included diethylphthalate (18 micrograms/L) in the sample from one of the old wells (MCO-4.5) and the possible presence of N-nitrosomorpholine (3 micrograms/Liter) in two of the new wells (MCO-4B and MCO-6B) but at levels less than one-third of the reporting limit (10 micrograms/L) for the analytical method. There is apparently no organic contamination from effluent discharges or developed-surface runoff in the perched alluvial water.

Table 6.2.1-IV summarizes the general chemical parameters analyzed. These results indicate generally good comparability between the paired old and new wells. The data indicate that there is good hydrologic continuity in the alluvium for materials that would not be significantly affected by adsorption or geochemical interactions such as sodium, nitrate, and total dissolved solids. Some other materials show much more variation between the adjacent wells; these are expectably subject to geochemical interactions with the newly disturbed tuff surfaces created by the drilling, and the emplacement of non-native filter pack material as required by the TEGD.

Table 6.2.1-V summarizes additional data for these samples based on analyses completed since the December 1990 report (ERP 1990). The data indicate the distribution of plutonium associated with the filterable material (i.e., that retained on a 0.45 micron membrane filter) in comparison with that generally considered "dissolved" (i.e., passing through the filter), though it must be remembered that a large portion (e.g., 40 to 50%) of this may be associated with colloids smaller that 0.45 microns. The old wells have a much larger proportion of "dissolved" plutonium, ranging from about 37 to more than 98 percent; while the new wells have a small proportion, ranging from about 2 to 30 percent.

TABLE 6.2.1-I

SUMMARY OF RADIOCHEMICAL ANALYSES OF SAMPLES FROM PERCHED ZONE MONITORING WELLS

		PARAMETER (pCi/L except where noted, ± value is analytical standard deviation)								
WELL	LAB[1]	^{3}H	^{238}Pu	^{239,240}Pu	^{137}Cs	^{241}Am	Gross Alpha	Gross Beta (cm/L)	Gross Gamma	Total U (mg/L)
MCO-4B	HSE-9	67000±7000	0.0529±0.0213	0.112±0.027	28±69	1.47±0.10	9±3	120±10	110±80	6.4±0.1
MCO-4	HSE-9	43000±4000	0.371±0.042	1.42±0.92	101±70	4.14±0.19	8±3	160±20	80±80	1.5±0.1
MCO-6B	HSE-9	130000±10000	0.0187±0.0148	0.0327±0.0169	163±73	2.27±0.13	34±8	59±6	10±80	18.1±0.4
MCO-6	HSE-9	100000±10000	1.12±0.01	3.18±0.20	90±71	2.52±0.13	10±3	100±10	180±80	5.9±0.1
MCO-7A	HSE-9	21000±2000	0.0172±0.0106	0.0344±0.0137	20±70	0.375±0.042	7±2	18±2	20±80	6.5±0.2
MCO-7	HSE-9	13000±1000	0.0178±0.0154	0.0444±0.0155	87±70	0.216±0.034	3±1	12±1	210±80	1.4±0.1

Notes:

[1] Entry indicates particular sampling date and analytical laboratory performing analyses.

HSE-9 samples collected on September 11 (MCO-4B, MCO-4, MCO-6B, MCO-7A, and MCO-7) or September 12, 1990 (MCO-6) and analyzed by Los Alamos National Laboratory, Environmental and Health Chemistry Group, HSE-9.

TABLE 6.2.1-II

SUMMARY OF APPENDIX IX INORGANIC ANALYSES ON SAMPLES FROM PERCHED ZONE MONITORING WELLS

		PARAMETER (micrograms/L)																		
WELL	LAB[1]	Sb	As	Ba	Be	Cd	Cr	Co	Cu	Pb	Hg	Ni	Se	Ag	Tl	Sn	V	Zn	CN (mg/L)	Sulfides (mg/L)
MCO-4B	IT	<30	<40	190	<1	<5	<10	<20	10	<30	<1	<20	<60	<5	<40	<20	<10	81	0.01	2.0
	HSE-9	0.5	15.1	337	2.1	0.9	17.3		16.5	42.3	<0.2	10.9	2.5	0.3	0.4		171	72	0.041	
MCO-4	HSE-9	0.7	19.1	128	<0.1	0.9	15.9		17	2.8	<0.2	14.8	2.4	0.2	0.2		215	20	0.036	
MCO-6B	IT	<30	<40	690	4	<5	30	<20	30	70	<1	<20	<60	<5	<40	<20	30	150	<0.01	1.0
	HSE-9	<0.5	12.7	1670	8.3	0.7	22.5		17	163	<0.2	17.3	2.2	1.3	2.1		155	149	0.046	
MCO-6	HSE-9	<0.5	17.7	231	0.4	0.6	19.8		12.3	16.2	<0.2	16.3	2.6	<0.2	0.2		185	43	0.046	
MCO-7A	IT	<30	<40	420	3	<5	20	<20	30	50	<1	30	<60	<5	<40	<20	40	100	<0.01	1.6
	HSE-9	<0.5	15.8	820	4.7	0.7	28		21.2	94	<0.2	20.3	1	0.4	0.8		147	107	0.026	
MCO-7	HSE-9	<0.5	15.6	254	0.9	<0.5	15.8		49.7	16.8	<0.2	10.3	1	0.6	0.2		126	74	0.026	

Notes:

[1] Entry indicates particular sampling date and analytical laboratory performing analyses.

IT samples collected on November 1 (MCO-6B and MCO-7A) and November 2 (MCO-4B),1990, and analyzed by IT Corporation.

HSE-9 samples collected on September 11 (MCO-4B, MCO-4, MCO-6B, MCO-7A, and MCO-7) or September 12, 1990 (MCO-6) and analyzed by Los Alamos National Laboratory, Environmental and Health Chemistry Group, HSE-9.

TABLE 6.2.1-III

Summary of Appendix IX Organic Analyses (Compouns Detected) On Samples from Perched Zone Monitoring Wells[1]

WELL	LAB[2]	RESULTS
MCO-4B	IT	N-Nitrosomorpholine, estimated at 3 µg/l, noted by laboratory as below reporting limit of10 µg/L for method.
	HSE-9	None detected
MCO-4	HSE-9	Diethyl phthalate, 18 µg/L; also found in blank at 13.7 µg/L, analyst judges to be from laboratory contamination.
MCO-6B	IT	N-Nitrosomorpholine, estimated at 2 µg/L, noted by laboratory as below reporting limit of 10 µg/L for method
	HSE-9	Methylene chloride 6 µg/L, analyst judges to be from sample preparation or storage.
MCO-6	HSE-9	None detected.
MCO-7A	IT	Organophosphorus pesticide sample fraction exceeded holding time one day, nothing detected; resampled on Nov. 30 for reanalysis
	HSE-9	None detected.
MCO-7	HSE-9	1,1,2-Trichloro-1,2,2-trifluoroethane 6 ug/L, analyst judges to be from sample preparation or storage.

Notes:

[1] This table notes only compounds detected and summarizes related interpretations.
See the detailed report (ERP 1990) for listings of all compounds analyzed, limits of quantification, and quality assurance information.

[2] Entry indicates particular sampling date and analytical laboratory performing analyses.
IT samples collected on November 1 (MCO-6B and MCO-7A) and November 2 (MCO-4B),1990, and analyzed by IT Corporation.

HSE-9 samples collected on September 11 (MCO-4B, MCO-4, MCO-6B, MCO-7A, and MCO-7) or September 12, 1990 (MCO-6) and analyzed by Los Alamos National Laboratory, Environmental and Health Chemistry Group, HSE-9.

TABLE 6.2.1-IV

SUMMARY OF GENERAL CHEMICAL PARAMETER ANALYSES OF SAMPLES FROM PERCHED ZONE MONITORING WELLS

		PARAMETER (mg/L except where noted)													
WELL	LAB[1]	Ca	Mg	K	Na	P	SO4	Cl	NO3-N	Al	Fe	Mn	TDS	pH (pH)	Cond. (µmho/cm)
MCO-4B	HSE-9	55.4	5.66	45.1	209	0.361	46.5	<0.5	50.2	15	–	0.518	712	7.54	717
MCO-4	HSE-9	55.4	3.64	46.5	142	0.276	40.9	19.2	40.5	1.5	–	0.030	568	7.47	635
MCO-6B	HSE-9	53	10.2	32.8	278	0.876	54.9	34.4	15	113	–	2.56	834	7.31	905
MCO-6	HSE-9	57.6	6.61	54.9	268	0.333	49.4	29.3	70.1	8.3	–	0.265	884	7.37	894
MCO-7A	HSE-9	25	5.78	11.3	112.6	0.924	22.9	28.1	18.8	57.4	–	1.62	220	6.96	220
MCO-7	HSE-9	26.9	5.42	8.90	89.6	0.566	21.6	<0.5	13.7	280	–	0.206	280	7.06	300

Notes:

[1] Entry indicates particular sampling date and analytical laboratory performing analyses.

HSE-9 samples collected on September 11 (MCO-4B, MCO-4, MCO-6B, MCO-7A, and MCO-7) or September 12, 1990 (MCO-6) and analyzed by Los Alamos National Laboratory, Environmental and Health Chemistry Group, HSE-9.

TABLE 6.2.1-V

Distribution of Dissolved and Filterable Plutonium in MCO Wells

Well	Dissolved		Suspended		Mass of Solids	Suspended		Total		Percent Dissolved	
	238-Pu pCi/L	239-Pu pCi/L	238-Pu pCi/g	239-Pu pCi/g	g/L	238-Pu pCi/L	239-Pu pCi/L	238-Pu pCi/L	239-Pu pCi/L	238-Pu	239-Pu
MCO-4	0.371	1.420	14.400	60.300	0.027	0.385	1.613	0.756	3.033	49.06	46.82
MCO-4B	0.053	0.112	0.327	0.543	1.750	0.572	0.950	0.625	1.062	8.46	10.54
MCO-6	1.120	3.180	0.039	0.088	0.640	0.025	0.056	1.145	3.236	97.84	98.27
MCO-6B	0.019	0.033	0.104	0.280	4.430	0.461	1.240	0.479	1.273	3.90	2.57
MCO-7	0.018	0.044	0.047	0.128	0.573	0.027	0.073	0.045	0.118	39.71	37.73
MCO-7A	0.017	0.034	0.021	0.064	2.098	0.043	0.135	0.060	0.169	28.57	20.30

6.2.2 Core Samples

The results of analyses of the cores from the four core holes provide the basic data for evaluating the movement of contaminants into the tuff beneath the perched aquifer. Each of the following subsections includes summary tables presenting the analytical results. Complete details of the laboratory results, including associated quality assurance samples, are reproduced in Appendixes 8.5 Radiochemical Analytical Results, 8.6 Inorganic Analytical Results and 8.7 Organic Analytical Results.

Plutonium-238 and -239 results for many cores from holes 5.1 and 5.9 have detection limits higher than the nominal 0.002 pCi/g detection limit for the procedure because natural thorium interferences were passed through the chemical separation steps. The samples will be reanalyzed with additional separation steps to obtain better detection limits. Americium-241 analyses are not yet completed, and will be reported when available.

6.2.2.1 Cores from MCM- 5.1

The analytical results for cores from MCM--5.1 are presented in five tables as follows:

Table 6.2.2.1-I Tritium and Gravimetric Moisture in Cores from Hole MCM-5.1
Table 6.2.2.1-II Radiochemical Analyses of Cores from Hole MCM-5.1
Table 6.2.2.1-III Extractable Metals by EP Toxicity Procedure in Cores from Hole MCM-5.1
Table 6.2.2.1-IV Metal Scan by ICPMS in Leachate from Cores from Hole MCM 5.1

The gravimetric moisture and tritium concentration results (Table 6.2.2.1-I) are presented graphically in Figure 6.2.2.1-1. The figure indicates the depths for the saturated zone, and the interfaces between the Tshirege Unit 1a, the Tsankawi, and the Otowi members as determined from the geologic logs. The gravimetric moisture content reaches a peak as expected in the saturated zone, and another peak at the contact between the Tshirege Unit 1a and the Tsankawi members. This second peak represents almost 90 percent of saturation of the weathered tuff (see hydrologic data in Section 6.3). By contrast, the tritium concentration (i.e., from the unsaturated water distilled from the core) reaches one peak with a concentration about 3 times that in the perched aquifer about 8 to 20 feet (depth 39 to 52 ft) into the Tshirege Unit 1a, then declines rapidly (more than three orders of magnitude) to detection limits in another 10 feet (depth 62 ft), reaches a secondary peak in another 10 feet (depth 72 ft), drops again below detection limits, and rises to the highest concentration about 4.5 times that in the perched aquifer water, within three feet (depth 97 ft) of the top of the Tsankawi. There may be some possibility that the intermediate tritium concentration peak is an artifact of sample cross contamination--

there was some observation of moisture on the outside of the core barrel during runs from 64-69, 69-74, and 74-79 feet, which could have been from slight leakage from the perched aquifer around the secondary auger casing. However, cross contamination is not consistent with other observations: the cores did not appear abnormally wet (confirmed by review of color photographs of the cores), the moisture data do not indicate any discontinuity, and the tritium levels are higher than observed in the water in the saturated zone.

The gravimetric moisture content is generally increasing through the Tshirege member, through the same 46-93 foot interval. The tritium concentration varies through this interval but generally declines to detection limits. This may suggest some possibility of dilution of tritiated water by other, non-contaminated water. The highest tritium concentration, 390 nCi/L, found at 97 foot depth in the Tsankawi, is at a higher level (including accounting for decay) than observed in all but a few years in observation wells MCO-5 and MCO-6 (see Fig. 6.2-1). More detailed hydrologic transport analysis, such as discussed in Section 7.5.1 may permit use of such data to estimate moisture movement rates and volumes.

The radiochemical results (Table 6.2.2.1-I) indicate that there is apparently no significant movement beneath the perched aquifer of plutonium, cesium, or other isotopes that would be detectable by gross gamma, gross alpha, or gross beta measurements. The samples taken between the surface and 39 feet show distinct but relatively low concentrations of plutonium-238 and -239. The sample at 43-44 feet was the first collected beneath the aquifer, and the core barrel contained about a foot of sand that had collapsed in from the saturated zone. Starting with that sample and continuing through the remaining cores, both the Pu-238 and -239 concentrations are near or below detection limits. The samples from 39, 44, 49, 62, and 77 feet show reported values 2 to 4 times the standard deviation of the measurement. Taking twice the standard deviation as an indication of detection limit, only the 39, 44, 49, and 77 foot samples might show a trace of Pu-239; and the 62 foot sample a trace of Pu-238. However, given the analysts interpretation of the presence of significant amounts of natural thorium, which has distorted the alpha spectrometry results, it is likely that there is no plutonium present in any of the samples from 39 feet and deeper. Additional aliquots of the cores will be reanalyzed with additional chemical separation to remove the thorium interference and obtain better detection limits for the plutonium analyses.

The analyses for metals extractable by the EP Toxicity method (Table 6.2.2.1-III) indicate that there are none of the cores either above, in, or beneath the perched aquifer that exceed, or even approach the toxicity criteria.

TABLE 6.2.2.1-I

Tritium and Gravimetric Moisture in Cores from Hole MCM-5.1

Depth	Moisture[a] (% by mass)	H-3[b] (nCi/L)
4	4.9	-
9	2.3	66.0
13	5.8	-
19	15.9	61.0
22	20.1	78.0
27[c]	29.3	86.0
34	16.3	-
39	-	210.0
44	20.1	92.0
46	15.1	-
49	15.7	160.0
52	15.7	290.0
55	15.3	-
57	14.8	41.0
62	15.8	-0.2
65	16.0	-
67	16.4	160.0
70	18.2	-
72	18.6	200.0
75	18.4	-
77	19.0	25.0
80	19.1	-
82	21.3	0.5
85	24.1	-
87	29.8	0.0
90	36.8	-
92[d]	35.2	57.0
95	36.5	-
97	25.9	390.0
98	25.0	-
102	17.6	250.0
103	19.0	-
107	18.8	160.0
109[e]	10.6	240.0

[a] Moisture measurement made by hydrologic laboratory

[b] Tritium as tritiated water in moisture distilled from core samples, detection limit 0.7 nCi/L

[c] Base of alluvium or perched aquifer 31 ft.

[d] Base of Tshirege Unit 1A at 93 ft.

[e] Base of Tsankowi Member below 109 ft.

TABLE 6.2.2.1-II

Radiochemical Analyses of Cores from Hole MCM-5.1[a]

Depth (ft)	H^3 (nCi/L)	Cs^{137} (pCi/g)	Pu^{238} (pCi/g)	Pu^{239} (pCi/g)	Gamma (pCi/g)	U (µg.g)	Alpha (pCi/g)	Beta (pCi/g)
4-9	66.0(6.0)	2.56(0.40)	0.117(0.006)	0.095(0.005)	2.5(0.5)	2.8(0.3)	3.6(0.8)	3.9(0.4)
14-19	61.0(5.0)	0.42(0.14)	0.026(0.002)	0.025(0.002)	3.3(0.5)	3.9(0.4)	5.0(1.0)	3.0(0.4)
21.5-22	78.0(7.0)	0.01(0.09)	0.007(0.001)	0.006(0.001)	3.5(0.5)	4.4(0.4)	6.0(1.0)	3.0(0.4)
26.5-27[b]	86.0(7.0)	0.31(0.14)	0.015(0.002)	0.035(0.003)	3.5(0.5)	2.5(0.2)	5.0(1.0)	3.9(0.4)
39.0	-210.0(20.0)	0.06(0.09)	0.002(0.001)	0.004(0.001)	6.3(0.7)	8.0(0.8)	2.8(0.7)	2.3(0.3)
43-44	92.0(9.0)	0.20(0.15)	0.002(0.001)	0.004(0.001)	5.7(0.7)	8.0(0.8)	2.9(0.7)	1.7(0.2)
48-49	160.0(10.0)	0.16(0.10)	0.002(0.001)	0.003(0.001)	6.6(0.8)	8.3(0.8)	2.8(0.7)	1.7(0.2)
51.5-52	290.0(30.0)	0.36(0.12)	0.002(0.02)	0.004(0.01)	6.0(0.7)	7.8(0.8)	3.4(0.8)	1.4(0.2)
56.5-57	41.0(4.0)	0.39(0.16)	0.02(0.02)	0.001(0.01)	5.8(0.7)	8.2(0.8)	3.4(0.8)	1.1(0.2)
61.5-62	-0.2(0.3)	0.22(0.11)	0.04(0.02)	0.001(0.01)	6.8(0.8)	8.1(0.8)	2.3(0.6)	1.1(0.2)
66.5-67	160.0(20.0)	0.51(0.17)	0.02(0.02)	0.001(0.01)	7.2(0.8)	8.5(0.9)	2.4(0.6)	1.3(0.2)
71.5-72	200.0(20.0)	0.17(0.10)	0.001(0.02)	0.001(0.01)	6.9(0.8)	8.6(0.9)	2.3(0.5)	1.3(0.2)
76.5-77	25.0(3.0)	0.36(0.16)	0.009(0.02)	0.03(0.01)	6.5(0.8)	8.0(0.8)	3.5(0.8)	1.6(0.2)
81.5-82	0.5(0.3)	0.03(0.09)	0.01(0.02)	0.00(0.01)	7.0(0.8)	8.3(0.8)	5.0(1.0)	4.5(0.5)
86.5-87	0.0(0.3)	0.05(0.16)	0.00(0.02)	0.001(0.01)	7.5(0.9)	7.6(0.8)	5.0(1.0)	3.0(0.4)
91.5-92[c]	57.0(6.0)	0.05(0.09)	0.005(0.02)	0.001(0.01)	6.2(0.7)	8.3(0.8)	3.4(0.8)	2.0(0.3)
96.5-97	390.0(40.0)	0.13(0.09)	0.011(0.02)	0.00(0.01)	6.2(0.7)	6.6(0.6)	10.0(2.0)	6.7(0.7)
101-102	250.0(30.0)	0.25(0.15)	0.01(0.02)	0.01(0.01)	4.4(0.6)	4.8(0.5)	5.0(1.0)	4.3(0.5)
106-107	160.0(20.0)	0.20(0.10)	0.001(0.02)	0.002(0.01)	4.6(0.6)	5.1(0.5)	5.0(1.0)	3.9(0.5)
109-109[d]	240.0(20.0)	0.10(0.16)	0.000(0.001)	0.001(0.001)	5.0(0.6)	5.5(0.5)	1.1(0.3)	1.3(0.2)

[a] Standard deviation of radioactivity counting statistics shown in parentheses

[b] Base of alluvium or perched aquifer 31 ft.

[c] Base of Tshirege Unit 1A at 93 ft.

[d] Base of Tsankowi Member below 109 ft.

TABLE 6.2.2.1-III

Extrable Metals by EP Toxicity Procedure in Cores from Hole MCM-5.1

Sample Depth (ft)	Analyses in mg/L							
	Ag	As	Ba	Cd	Cr	Hg	Pb	Se
7-8	0.010	0.002	0.310	0.004	0.007	0.000	0.010	0.005
18-19	0.010	0.002	0.390	0.004	0.007	0.000	0.010	0.006
23-24	0.010	0.002	0.380	0.004	0.007	0.000	0.010	0.006
28-29[a]	0.010	0.002	0.170	0.004	0.007	0.000	0.010	0.005
38-39	0.010	0.002	0.180	0.004	0.007	0.000	0.010	0.004
47-48	0.010	0.002	0.180	0.004	0.007	0.000	0.010	0.005
53-54	0.010	0.002	0.210	0.002	0.010	0.000	0.020	0.004
58-59	0.010	0.002	0.220	0.002	0.010	0.000	0.020	0.003
63-64	0.010	0.002	0.250	0.002	0.010	0.000	0.020	0.005
68-69	0.010	0.002	0.250	0.002	0.010	0.000	0.020	0.005
73-74	0.010	0.002	0.250	0.002	0.010	0.000	0.020	0.005
78-79	0.010	0.002	0.240	0.002	0.010	0.000	0.020	0.004
83-84	0.010	0.002	0.230	0.002	0.010	0.000	0.020	0.005
88-89[b]	0.010	0.002	0.220	0.002	0.010	0.000	0.020	0.005
93-94	0.010	0.002	1.400	0.002	0.010	0.000	0.020	0.005
95S	0.010	0.002	0.090	0.002	0.010	0.000	0.020	0.006
598-99	0.010	0.002	0.210	0.002	0.010	0.000	0.100	0.001
103-104	0.010	0.002	0.220	0.002	0.010	0.000	0.020	0.003
108-109	0.010	0.002	0.220	0.002	0.010	0.000	0.020	0.003
110-111[c]	0.010	0.002	0.200	0.002	0.010	0.000	0.020	0.004
SB	0.010	0.002	0.096	0.002	0.010	0.000	0.020	0.007

[a] Base of alluvium or perched aquifer 31 ft.

[b] Base of Tshirege Unit 1A at 93 ft.

[c] Base of Tsankowi Member below 111 ft.

TABLE 6.2.2.1-IV

Metal Scan by ICPMS in Leachate from Cores from Hole MCM-5.1

Depth (ft)	Analyses in µg/g																		
	Ag	Al	As	Au	Ba	Be	Bi	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu	Ga	Gd	Ge
7-8	0.5	3000.0	2	0	100	5	0.5	0	42	6.6	0.5	0.5	15	3.9	2	0.5	4.7	6.8	5.1
18-19	0.5	3600.0	8	0	250	5	0.5	0	66	12.0	3.6	0.5	33	9.4	4	0.89	10	14	10
23-24	0.5	4400.0	6	0	140	5	0.5	0	55	7.9	1.1	0.5	19	5.8	3	0.87	6.2	12	9.2
28-29[a]	0.5	1800.0	4	0	34	5	0.5	0	19	1.2	0.5	0.5	16	2.9	0	0.5	1.6	3.3	4.2
38-39	0.5	2800	8	0.5	110	5	0.5	0.5	35	0.5	0.8	0.5	19	5.8	2	0.5	5	9.3	5.3
47-48	0.5	5400	5	0.5	110	5	0.5	0	29	1.1	1.0	0.5	32	4.8	1.7	0.5	5.4	6.4	4.5
53-54	0.5	590	0.5	0.5	8.9	5	0.5	0.5	9.4	0.5	0.5	0.5	0.5	0.77	0.5	0.5	0.5	1.3	0.5
58-59	0.5	530.0	0	0	7	5	0.5	0	6	0.5	0.5	0.5	0	0.8	0	0.5	0.5	1.3	0.5
63-64	0.5	580.0	0	0	8	5	0.5	0	5	0.5	0.5	0.5	0	0.9	0	0.5	0.5	1.2	0.58
68-69	0.5	520.0	0	0	8	5	0.5	0	7	0.5	1.0	0.5	0	1.0	0	0.5	0.5	1.5	0.68
73-74	0.5	450.0	0	0	7	5	0.5	0	5	0.5	0.5	0.5	0	0.9	0	0.5	0.5	2	1.9
78-79	0.5	530.0	0	0	7	5	0.5	0	5	0.5	0.5	0.5	0	1.0	0	0.5	0.5	1.9	0.77
83-84	0.5	600.0	0	0	6	5	0.5	0	5	0.5	0.5	0.5	0	0.5	0	0.5	0.5	1.3	0.57
88-89[b]	0.5	520.0	0	0	6	5	0.5	0	6	0.5	0.5	0.5	0	1.0	0	0.5	0.5	0.98	0.71
93-94	0.5	1500	0.5	0.5	58	5	0.5	0.5	32	0.5	0.5	0.5	0	4.9	2.8	0.5	1.6	5.2	2.7
95S	0.5	67	0.5	0.5	1.5	5	0.5	0	3	0.5	0.5	0.5	0	0.5	0.5	0.5	0.5	0.64	0.5
98-99	0.5	1800	0.5	0.5	11	5	0.5	0.5	12	0.67	0.84	1.1	0.85	1.9	1.2	0.5	0.5	2	1.2
103-104	0.5	1100.0	0	0	13	5	0.5	0	11	0.5	0.5	0.5	0	1.5	0	0.5	0.5	1.9	1.1
108-109	0.5	970.0	0	0	11	5	0.5	0	5	0.5	0.5	0.5	0	0.5	0	0.5	0.5	0.56	0.82
110-111[c]	0.5	1300.0	0	0	9	5	0.5	0	9	1.1	1.3	0.5	0	0.7	0	0.5	0.5	0.76	1.9
SB	0.5	52.0	0	0	1	5	0.5	0	1	0.5	0.5	0.5	0	0.5	0	0.5	0.5	0.5	0.5

[a] Base of alluvium or perched aquifer 31 ft.

[b] Base of Tshirege Unit 1A at 93 ft.

[c] Base of Tsankowi Member below 111 ft.

TABLE 6.2.2.1-IV (Continued)

Metal Scan by ICPMS in Leachate from Cores from Hole MCM-5.1

Depth (ft)	Analyses in μg/g																				
	Hf	Ho	In	Ir	La	Li	Lu	Mn	Mo	Nb	Nd	Ni	Pb	Pd	Pr	Pt	Rb	Rh	Ru	Sb	Se	Sm
7-8	0.5	0.5	0.5	0.5	26	5	0.5	1200	0.5	0.5	29	0.5	23	0.5	8.2	0.5	2	0.5	0.5	0.5	22	6.2
18-19	0.5	1.9	0.5	0.5	66	5	0.56	2100	0.5	0.5	59	3.2	30	0.5	19	0.5	3.2	0.5	0.5	0.5	55	13
23-24	0.5	1.5	0.5	0.5	48	5	0.5	950	0.5	0.5	47	0.5	25	0.5	13	0.5	2.9	0.5	0.5	0.5	26	10
28-29[a]	0.5	0.56	0.5	0.5	17	5	0.5	290	0.5	0.5	17	0.5	12	0.5	5.5	0.5	1.3	0.5	0.5	0.5	7.3	4
38-39	0.5	1	0.5	0.5	27	5	0.5	300	0.5	0.5	42	0.5	20	0.5	9.6	0.5	35	0.5	0.5	0.5	18	10
47-48	0.5	0.64	0.5	0.5	20	7	0.5	240	0.5	0.5	28	0.5	24	0.5	6.8	0.5	29	0.5	0.5	0.5	15	5.7
53-54	0.5	0.5	0.5	0.5	3.3	7.8	0.5	31	0.5	0.5	4.3	0.5	3.7	0.5	1.3	0.5	5.2	0.5	0.5	0.5	5	1.1
58-59	0.5	0.5	0.5	0.5	3.3	7.8	0.5	36	0.5	0.5	4.5	0.5	2.4	0.5	1.2	0.5	3.3	0.5	0.5	0.5	5	1.2
63-64	0.5	0.5	0.5	0.5	3.1	7.5	0.5	35	0.5	0.5	4.3	0.5	1.9	0.5	1.3	0.5	3.4	0.5	0.5	0.5	5	1.3
68-69	0.5	0.5	0.5	0.5	3.3	6.1	0.5	34	0.5	0.5	4.9	0.5	1.7	0.5	1.3	0.5	5.3	0.5	0.5	0.5	5	1.4
73-74	0.5	0.5	0.5	0.5	3.3	5	0.5	100	0.5	0.5	5.3	0.5	1.7	0.5	1.1	0.5	4.8	0.5	0.5	0.5	5	1.7
78-79	0.5	0.5	0.5	0.5	3	5	0.5	29	0.5	0.5	4.1	0.5	1.4	0.5	1	0.5	5	0.5	0.5	0.5	5	1.7
83-84	0.5	0.5	0.5	0.5	2.6	5	0.5	25	0.5	0.5	4.1	0.5	1.3	0.5	0.97	0.5	5.4	0.5	0.5	0.5	5	0.99
88-89[b]	0.5	0.5	0.5	0.5	3.4	5	0.5	32	0.5	0.5	4.4	0.5	1.5	0.5	1.2	0.5	6.1	0.5	0.5	0.5	5	1.2
93-94	0.5	0.92	0.5	0.5	11	5	0.5	220	0.5	0.5	13	0.5	9.1	0.5	3.5	0.5	6.4	0.5	0.5	0.5	5	4.2
95S	0.5	0.5	0.5	0.5	1.7	5	0.5	1.5	0.5	0.5	1.5	0.5	0.51	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5	0.5
98-99	0.5	0.5	0.5	0.5	6.3	9.4	0.5	77	0.5	0.5	6.3	0.5	81	0.5	2	0.5	14	0.5	0.5	0.5	5	1.6
103-104	0.5	0.5	0.5	0.5	5	5	0.5	59	0.5	0.5	4.5	0.5	2	0.5	1.5	0.5	14	0.5	0.5	0.5	5	3.2
108-109	0.5	0.5	0.5	0.5	2.4	5	0.5	44	0.5	0.5	2	0.5	1.8	0.5	0.7	0.5	9.5	0.5	0.5	0.5	5	0.5
110-111[c]	0.5	0.5	0.5	0.5	3.2	5	0.5	61	0.5	0.5	2.8	2.6	1.4	0.5	0.99	0.5	9.4	0.5	0.5	0.5	5	0.75
SB	0.5	0.5	0.5	0.5	1.1	5	0.5	1.2	0.5	0.5	1.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5	0.5

[a] Base of alluvium or perched aquifer 31 ft.
[b] Base of Tshirege Unit 1A at 93 ft.
[c] Base of Tsankowi Member below 111 ft.

TABLE 6.2.2.1-IV (Continued)

Metal Scan by ICPMS in Leachate from Cores from Hole MCM-5.1

Depth (ft)	Analyses in µg/g																
	Sn	Sr	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr	Fe
7-8	0.5	13	0.5	0.59	0.5	18	71	0.5	0.5	0.5	—	0.5	14	1.2	24	0.5	1900
18-19	0.5	28	0.5	1.6	0.5	4.3	92	0.5	0.72	0.5	—	0.5	41	3.2	49	0.5	2400
23-24	0.5	20	0.5	1.5	0.5	40	86	0.5	0.5	0.5	—	0.5	23	2.8	34	0.67	3300
28-29[a]	0.5	6.7	0.5	0.5	0.5	14	56	0.5	0.5	0.5	—	0.5	9	0.55	20	0.5	1400
38-39	0.5	14	0.5	1.4	0.5	86	37	0.5	0.5	0.5	—	0.5	15	1.5	27	0.5	550
47-48	0.5	20	0.5	0.57	0.5	110	56	0.5	0.5	0.5	—	0.5	10	1.3	21	8.7	770
53-54	0.5	3.1	0.5	0.5	0.5	16	5	0.5	0.5	0.5	5	0.5	3.8	0.5	1.1	0.5	—
58-59	0.5	2.1	0.5	0.5	0.5	18	5	0.5	0.5	0.5	5	0.5	4.2	0.5	1.6	0.5	—
63-64	0.5	2.2	0.5	0.5	0.5	16	5	0.5	0.5	0.5	5	0.5	3.4	0.5	1.7	0.5	—
68-69	0.5	1.9	0.5	0.5	0.5	16	5	0.5	0.5	0.5	5	0.5	4.3	0.5	1.2	0.5	—
73-74	0.5	1.7	0.5	0.5	0.5	18	5	0.5	0.5	0.5	5	0.5	4	0.5	3.1	0.5	—
78-79	0.5	1.3	0.5	0.5	0.5	19	5	0.5	0.5	0.5	5	0.5	4.3	0.73	1.5	0.5	—
83-84	0.5	1.7	0.5	0.5	0.5	20	5	0.5	0.5	0.5	5	0.5	4	0.5	1.3	0.5	—
88-89[b]	0.5	1.5	0.5	0.5	0.5	18	5	0.5	0.5	0.5	5	0.5	5.2	0.5	1.4	0.5	—
93-94	0.5	9.1	0.5	0.67	0.5	110	5	0.5	0.5	0.7	5	0.5	29	3.3	12	0.5	—
95S	0.5	0.5	0.5	0.5	0.5	3.1	5	0.5	0.5	0.5	5	0.5	0.5	0.5	0.5	0.5	—
98-99	0.5	8.3	0.5	0.5	0.5	26	5.1	0.5	0.5	0.5	5	0.5	12	1.3	14	0.5	—
103-104	0.5	7.6	0.5	0.5	0.5	23	5	0.5	0.5	0.5	5	0.5	6.4	0.71	1.9	0.5	—
108-109	0.5	6	0.5	0.5	0.5	13	5	0.5	0.5	0.5	5	0.5	2.7	0.5	1.7	0.5	—
110-111[c]	0.5	7.5	0.5	0.5	0.5	17	5.6	0.5	0.5	0.5	5	0.5	2.7	0.5	3.4	0.5	—
SB	0.5	0.5	0.5	0.5	0.5	1.6	5	0.5	0.5	0.5	5	0.5	0.5	0.5	0.5	0.5	—

[a] Base of alluvium or perched aquifer 31 ft.

[b] Base of Tshirege Unit 1A at 93 ft.

[c] Base of Tsankowi Member below 109 ft.

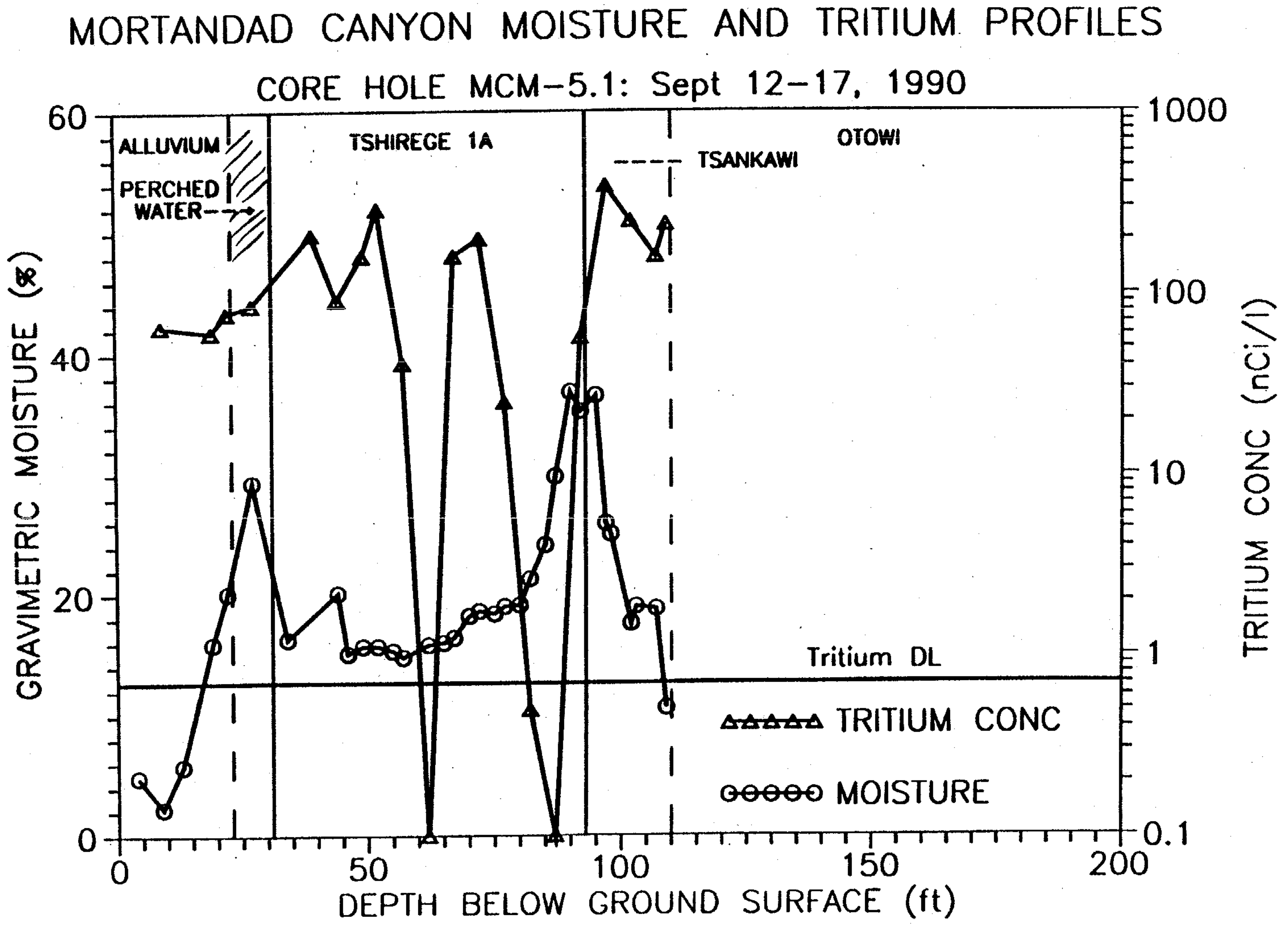

MORTANDAD CANYON MOISTURE AND TRITIUM PROFILES
CORE HOLE MCM-5.1: Sept 12-17, 1990
ALLUVIUM
PERCHED WATER
TSHIREGE 1A
TSANKAWI
OTOWI
Tritium DL
TRITIUM CONC
MOISTURE
GRAVIMETRIC MOISTURE (%)
0
20
40
60
TRITIUM CONC (nCi/l)
0.1
1
10
100
1000
DEPTH BELOW GROUND SURFACE (ft)
0
50
100
150
200

Fig. 6.2.2.1-1

The metal scan of the acid leachate (Table 6.2.2.1-IV) is included as data that may be useable in conjunction with contaminant transport modelling, or to gain insights on geochemical properties of the tuff. Some work has been done on trace elements for geochemical characterization of the tuff and that work will be used to make initial evaluations of naturally occurring constituents (Crowe 1978). For example, this previous work has found significant amounts of Ba, Ce, Cr, Dy, La, Rb, Th, Yb, and Zn in Bandelier tuff; so the presence of such materials is expected in leachate. One qualitative observation is that there appears to be more of some of these metals available for leaching in cores taken at depths extending down to 39 to 48 feet, from the alluvium and the top 8 to 18 feet of Tshirege tuff. This may be an indication of weathering induced by the presence of moisture from the perched aquifer.

The analysis of the cores for organic compounds showed no target compounds listed in the RCRA Regualtions Appendix IX detected in any of the core samples. Detailed chemistry laboratory results are reproduced in Appendix 8.7.

6.2.2.2. Cores from MCM-5.9A

The analytical results for cores from MCM--5.9A are presented in four tables as follows:

Table 6.2.2.2-I Tritium and Gravimetric Moisture in Cores from Hole MCM-5.9A
Table 6.2.2.2-II Radiochemical Analyses of Cores from Hole MCM-5.9A
Table 6.2.2.2-III Extractable Metals by EP Toxicity Procedure on Cores from Hole MCM-5.9A
Table 6.2.2.2-IV Metal Scan by ICPMS in Leachate from Cores from Hole MCM-5.9A

The gravimetric moisture and tritium concentration results (Table 6.2.2.2-I) are presented graphically in Figure 6.2.2.2-1. The figure indicates the depths for the saturated zone (depth 27 to 38 ft), the contact between the Tshirege Unit 1a and the Tsankawi Member (depth 98 ft), and the top of the Otowi member (depth 118 ft) as determined from the geologic logs. The moisture content is relatively constant at around 20 percent (gravimetric) from a point in the alluvium about 8 feet above the saturated zone (depth 29 ft) and extending about 40 feet (depth 71 ft) below the saturated zone in the Tshirege Unit 1a. Then it generally increases through the rest of the Tshirege and peaks a few feet deeper (depth (104) in the Tsankawi member. This peak represents about 89 percent of saturation (see hydrologic data in Section 6.3). There are two low gravimetric moisture content measurements, at 94 and 102 feet that are just above and just below the contact between the Tshirege and Tsankawi members. The porosity of the material in the 94 foot sample is much lower and thus the percentage of saturation does not change nearly so much. There was also a small decrease in gravimetric moisture content at the same contact in hole MCM-5.1.

By contrast, the tritium concentration (in water extracted from the core) reaches a peak with concentration about 2 times that in the perched aquifer at 49 foot depth (about 12 feet into the Tshirege Unit 1a), then declines rapidly (more than three orders of magnitude) reaching detection limits by about 89 feet depth, and then increases within about 10 feet at depth 99 feet) to a secondary peak concentration, about the same level as that in the perched aquifer water, within about a foot of the top of the Tsankawi.

As in hole MCM-5.1, the gravimetric moisture content generally increases through the bottom half of the Tshirege member, through the same 65-89 foot interval where the tritium concentration drops to detection limits. This again suggests some possibility of dilution of tritium-bearing water vapor by other, non-contaminated water. The highest tritium concentration, 280 nCi/L, found at 49 foot depth in the Tshirege, is at a higher level (including accounting for decay) than observed in all but a few years in observation well MCO-6 (see Fig. 6.2-1). More detailed hydrologic transport analysis, such as discussed in Section 7.5.1 may permit use of such data to estimate moisture movement rates and volumes.

The radiochemical results (Table 6.2.2.2-II) indicate that, to the degree permitted by the detection limits of the analytical processes, there is apparently no significant movement beneath the perched aquifer at the location of hole MCM-5.9A of plutonium, cesium, or other isotopes that would be detectable by gross gamma, gross alpha, or gross beta measurements. The samples taken down to 19 feet show distinct but relatively low concentrations of plutonium-238 and -239. The samples from 24 to 124 feet, and 164 to 194 feet have significant natural thorium (see Table 6.2.2.2-IV) that interferes with the plutonium analysis and raises the limit of detection. The core sample from 59 to 64 feet was the first collected beneath the aquifer with the large-diameter auger in place as a casing, where there was no likely leakage from the perched aquifer to contaminate the core sample, and the core barrel contained about a foot of sand that had collapsed in from the saturated zone. Starting with that sample and continuing through the remaining cores, both the Pu-238 and -239 concentrations are near or below the effective detection limits. The samples from 71.5, 98, 124, and 164 feet are not interpretable because the undertainties are so large. Taking twice the standard deviation as an indication of detection limit, only the 129-foot samples might show a trace of Pu-239; and the 49-foot sample a trace of Pu-238. However, given the analysts interpretation of the presence of significant amounts of natural thorium, which has distorted the alpha spectrometry results, it is likely that there is no plutonium present in any of the samples from 24 feet

TABLE 6.2.2.2-I

Tritium and Gravimetric Moisture in Cores from Hole MCM-5.9A

Depth[a]	Moisture (% by mass)	H-3[b] (nCi/L)
4	–	3.7
9	5.8	5.4
14	–	8.0
19	–	8.5
24	–	13.0
29	21.3	68.0
34[c]	–	92.0
39	14.9	150.
40	19.5	150.
44	18.9	180.
47	10.4	270.
49	19.2	280.
54	23.8	260.
64	18.3	230.
69	19.4	140.
71	18.1	65.0
79	25.6	2.6
85.	39.4	–
89.	44.2	0.4
94.[d]	11.4	17.0
99	–	160.
102	6.5	110.
104.	60.5	110.
109.	49.3	82.0
114[e]	24.8	78.0
119.	21.4	78.0
124.	16.1	70.0
129.	18.5	60.0
134.	18.7	68.0
139.	18.9	69.0
144.	17.7	62.0
149.	19.0	66.0
154.	17.4	71.0
159	15.5	56.0
164.	16.8	47.0
169.	15.8	42.0
174.	15.9	36.0
179.	15.9	20.0
184.	16.5	15.0
189	15.2	4.4
194[f]	–	5.1

[a] Decimal following number indicates moisture measurement made from hydrologic laboratory, others made by radiochemical laboratory

[b] Tritium as tritiated water in moisture distilled from cores, detection limit 0.7 nCi/L

[c] Base of alluvium or perched water at 38 ft.

[d] Base of Tshirege Unit 1A at 94 ft.

[e] Base of Tsankowi Member at 114 ft.

[f] Base of Otowi member below 194 ft.

TABLE 6.2.2.2-II

Radiochemical Analyses of Cores from Hole MCM-5.9A

Depth (ft)	Radiochemical Analyses								Analyses by Gamma Spectral Scan					
	^3H (nCi/L)	Pu^{238} (pCi/g)	Pu^{239} (pCi/g)	Gross Gamma (cpm/g)	Sr^{90} (pCi/g)	U (UG/G)	Alpha (pCi/g)	Beta (pCi/g)	Am^{241} (pCi/g)	Co^{57} (pCi/g)	Co^{60} (pCi/g)	Cs^{134} (pCi/g)	Cs^{137} (pCi/g)	Sc^{75} (pCi/g)
4	3.7(0.5)	0.055(0.009)	0.20(0.02)	3.0(0.5)	0.65(0.20)	3.0(0.3)	5.0(1.0)	2.2(0.3)	0.100(2.7)	0.000(0.89)	-0.027(2.1)	0.023(1.1)	0.570(1.8)	0.024(0.83)
9	5.4(0.6)	0.011(0.002)	0.034(0.004)	2.4(0.5)	0.40(0.20)	2.4(0.2)	4.4(1.0)	1.6(0.2)	0.058(2.7)	0.001(0.89)	0.150(2.1)	-0.005(1.1)	-0.001(1.8)	0.000(0.83)
14	8.0(0.9)	-0.007(0.005)	0.007(0.005)	1.6(0.4)	0.04(0.20)	1.8(0.2)	4.3(0.9)	1.9(0.3)	0.000(2.7)	-0.006(0.89)	0.120(2.1)	0.036(1.1)	-0.002(1.8)	0.000(0.83)
19	8.5(0.9)	0.016(0.006)	0.013(0.004)	1.4(0.4)	0.20(0.20)	1.6(0.2)	4.1(1.0)	1.4(0.2)	2.700(2.7)	0.140(0.89)	0.260(2.1)	-0.012(1.1)	0.140(1.8)	0.024(0.83)
24	13.0(1.0)	0.010(0.010)	0.005(0.015)	1.0(0.4)	0.55(0.20)	1.8(0.2)	2.1(0.5)	1.7(0.2)	0.001(2.7)	-0.000(0.89)	-0.040(2.1)	0.024(1.1)	-0.002(1.8)	0.002(0.83)
29	68.0(7.0)	0.03(0.02)	0.009(0.003)	4.2(0.6)	0.32(0.20)	5.3(0.5)	9.0(2.0)	2.8(0.4)	0.014(2.7)	-0.011(0.89)	-0.045(2.1)	0.010(1.1)	-0.002(1.8)	0.064(0.83)
34[a]	92.0(9.0)	0.006(0.02)	0.019(0.02)	1.9(0.4)	0.62(0.20)	2.5(0.3)	4.2(0.9)	2.0(0.3)	0.000(2.7)	-0.013(0.89)	0.082(2.1)	0.033(1.1)	-0.001(1.8)	0.002(0.83)
39	150.0(10.0)	0.03(0.02)	0.03(0.02)	2.5(0.5)	0.77(0.20)	3.3(0.3)	8.0(2.0)	3.0(0.4)	0.003(2.7)	0.062(0.89)	0.180(2.1)	-0.005(1.1)	-0.003(1.8)	0.006(0.83)
40	150.0(10.0)	0.04(0.02)	0.014(0.02)	3.3(0.5)	0.52(0.17)	3.6(0.4)	9.0(2.0)	4.7(0.5)	0.049(2.7)	-0.017(0.89)	0.047(2.1)	0.064(1.1)	-0.010(1.8)	0.049(0.83)
44	180.0(20.0)	0.03(0.02)	0.05(0.05)	4.3(0.6)	0.51(0.16)	4.5(0.4)	8.0(2.0)	3.0(0.4)	0.000(2.7)	-0.002(0.89)	0.190(2.1)	0.021(1.1)	-0.008(1.8)	0.002(0.83)
47	270.0(30.0)	0.03(0.02)	0.02(0.02)	3.7(0.5)	1.18(0.25)	4.6(0.5)	8.0(2.0)	3.4(0.4)	-0.003(2.7)	-0.019(0.89)	0.024(2.1)	-0.000(1.1)	0.075(1.8)	-0.016(0.83)
49	280.0(30.0)	0.05(0.02)	0.03(0.02)	6.4(0.8)	0.32(0.16)	6.6(0.7)	16.0(3.0)	5.3(0.6)	-0.003(2.7)	0.010(0.89)	0.010(2.1)	0.036(1.1)	0.033(1.8)	0.065(0.83)
54	260.0(30.0)	0.02(0.02)	0.01(0.02)	7.7(0.9)	-0.09(0.20)	8.3(0.8)	2.7(0.6)	0.9(0.2)	-0.160(2.7)	0.002(0.89)	0.079(2.1)	-0.002(1.1)	0.065(1.8)	-0.006(0.83)
64	230.0(20.0)	0.02(0.02)	0.02(0.02)	7.8(0.9)	0.06(0.20)	8.8(0.9)	3.5(0.8)	1.5(0.2)	-0.170(2.7)	-0.013(0.89)	0.070(2.1)	-0.048(1.1)	0.010(1.8)	0.130(0.83)
69	140.0(10.0)	0.04(0.02)	0.02(0.02)	7.6(0.9)	0.07(0.20)	8.7(0.9)	2.8(0.6)	1.8(0.2)	-0.006(2.7)	0.003(0.89)	0.170(2.1)	0.027(1.1)	0.015(1.8)	0.063(0.83)
71.5	65.0(7.0)	0.14(?)	0.16(?)	8.1(0.9)	-0.08(0.20)	8.2(0.8)	5.0(1.0)	2.0(0.3)	-0.063(2.7)	0.007(0.89)	0.041(2.1)	-0.013(1.1)	0.002(1.8)	-0.035(0.83)
79	2.6(0.4)	0.03(0.03)	0.03(0.03)	8.4(0.9)	0.61(0.20)	9.7(1.0)	9.0(2.0)	3.6(0.4)	-0.030(2.7)	0.004(0.89)	0.082(2.1)	-0.020(1.1)	0.007(1.8)	-0.030(0.83)
89	0.4(0.2)	0.08(?)	0.001(0.005)	5.7(0.7)	0.17(0.20)	5.4(0.5)	11.0(2.0)	4.2(0.5)	0.130(2.7)	0.000(0.89)	0.110(2.1)	0.007(1.1)	-0.002(1.8)	0.038(0.83)
94[b]	17.0(2.0)	0.005(0.005)	0.005(0.005)	5.1(0.7)	0.34(0.20)	6.4(0.6)	8.0(2.0)	3.1(0.4)	0.330(2.7)	0.004(0.89)	0.047(2.1)	-0.002(1.1)	-0.012(1.8)	0.016(0.83)
99	160.0(20.0)	0.06(0.06)	0.002(0.005)	5.3(0.7)	0.43(0.20)	6.3(0.6)	12.0(3.0)	3.7(0.4)	0.000(2.7)	0.000(0.89)	0.066(2.1)	0.031(1.1)	0.031(1.8)	0.006(0.83)
102	110.0(10.0)	0.002(0.02)	0.008(0.02)	2.5(0.5)	0.47(0.20)	4.0(0.4)	6.0(1.0)	1.9(0.3)	0.037(2.7)	-0.008(0.89)	0.140(2.1)	0.029(1.1)	-0.005(1.8)	0.002(0.83)
104	110.0(10.0)	0.003(0.02)	0.010(0.02)	3.6(0.5)	0.01(0.20)	4.9(0.5)	8.0(2.0)	3.0(0.4)	0.022(2.7)	-0.006(1.30)	0.089(2.2)	0.020(1.3)	0.053(1.8)	-0.016(2.00)
109	82.0(8.0)	0.02(0.02)	0.001(0.02)	3.9(0.6)	-0.10(0.20)	4.2(0.4)	2.3(0.5)	1.2(0.2)	0.024(2.7)	-0.003(0.89)	-0.049(2.1)	0.011(1.1)	0.000(1.8)	0.050(0.83)
114[c]	78.0(8.0)	0.03(0.02)	0.001(0.02)	4.2(0.6)	0.13(0.20)	4.9(0.5)	2.3(0.6)	1.5(0.2)	0.044(2.7)	0.000(1.30)	0.031(2.2)	-0.002(1.3)	0.028(1.8)	0.037(2.00)
119	78.0(8.0)	0.03(0.03)	0.002(0.02)	2.6(0.5)	0.07(0.20)	2.9(0.3)	1.2(0.3)	0.8(0.2)	0.000(2.7)	-0.011(0.89)	0.042(2.1)	0.047(1.1)	-0.002(1.8)	0.019(0.83)
124	70.0(7.0)	0.06(?)	0.003(0.02)	5.0(0.6)	0.47(0.20)	5.3(0.5)	1.4(0.4)	1.1(0.2)	-0.016(2.7)	0.088(1.30)	-0.006(2.2)	-0.026(1.3)	0.062(1.8)	0.100(2.00)
129	60.0(6.0)	0.003(0.003)	0.007(0.003)	4.4(0.6)	0.32(0.20)	5.8(0.6)	1.8(0.5)	1.2(0.2)	0.055(2.7)	-0.011(0.89)	0.160(2.1)	0.058(1.1)	-0.002(1.8)	0.004(0.83)
134	68.0(7.0)	0.005(0.005)	0.004(0.003)	5.5(0.7)	0.15(0.20)	5.9(0.6)	1.9(0.5)	1.6(0.2)	0.000(2.7)	-0.008(1.30)	0.051(2.2)	0.000(1.3)	0.018(1.8)	-0.006(2.00)
139	69.0(7.0)	0.013(0.02)	0.03(0.03)	4.5(0.6)	0.03(0.20)	5.9(0.6)	1.4(0.4)	1.1(0.2)	0.019(2.7)	-0.002(0.89)	0.230(2.1)	0.052(1.1)	-0.003(1.8)	-0.001(0.83)
144	62.0(6.0)	0.006(0.010)	0.01(0.01)	5.0(0.6)	0.31(0.20)	6.0(0.6)	1.6(0.4)	1.4(0.2)	0.010(2.7)	0.025(1.30)	-0.001(2.2)	0.016(1.3)	0.024(1.8)	0.009(2.00)
149	66.0(7.0)	0.001(0.001)	0.001(0.001)	5.1(0.7)	0.08(0.20)	5.9(0.6)	2.2(0.5)	1.3(0.2)	0.032(2.7)	-0.004(0.89)	0.170(2.1)	0.008(1.1)	0.037(1.8)	0.053(0.83)
154	71.0(7.0)	0.003(0.002)	0.002(0.001)	4.7(0.6)	0.26(0.20)	5.6(0.6)	1.7(0.4)	1.4(0.2)	-0.005(2.7)	0.005(1.30)	0.025(2.2)	0.010(1.3)	0.020(1.8)	-0.490(2.00)
159	56.0(6.0)	0.002(0.001)	0.002(0.001)	5.2(0.7)	0.19(0.20)	6.0(0.6)	2.2(0.5)	1.2(0.2)	0.110(3.7)	-0.038(0.89)	-0.030(2.1)	0.071(1.1)	-0.007(1.8)	0.000(0.83)
164	47.0(5.0)	0.12(?)	0.13(?)	5.2(0.7)	0.45(0.30)	5.9(0.6)	1.5(0.4)	1.4(0.2)	0.032(2.7)	-0.014(1.30)	0.100(2.2)	0.023(1.3)	0.022(1.8)	-0.018(2.00)
169	42.0(4.0)	0.002(0.002)	0.003(0.002)	5.2(0.7)	0.25(0.20)	5.9(0.6)	1.8(0.5)	1.3(0.2)	0.008(2.7)	-0.052(0.89)	0.190(2.1)	0.083(1.1)	0.000(1.8)	0.046(0.83)
174	36.0(4.0)	0.000(0.002)	0.001(0.002)	5.4(0.7)	0.44(0.30)	5.9(0.6)	1.7(0.4)	0.9(0.2)	-0.048(2.7)	0.077(1.30)	0.080(2.2)	0.002(1.3)	0.005(1.8)	0.019(2.00)
179	20.0(2.0)	0.01(0.01)	0.001(0.002)	6.2(0.7)	0.68(0.30)	6.6(0.6)	3.3(0.8)	2.4(0.3)	-0.009(2.7)	0.000(0.89)	0.100(2.1)	0.033(1.1)	-0.002(1.8)	0.076(0.83)
184	15.0(2.0)	0.000(0.002)	0.002(0.002)	4.8(0.6)	0.07(0.20)	5.6(0.6)	2.7(0.6)	1.8(0.2)	0.200(2.7)	0.066(1.30)	0.041(2.2)	0.025(1.3)	0.018(1.8)	0.004(2.00)
189	4.4(0.5)	0.000(0.002)	0.003(0.002)	4.9(0.6)	0.30(0.30)	5.6(0.6)	2.5(0.6)	1.9(0.2)	0.009(2.7)	-0.029(0.89)	-0.014(2.1)	0.098(1.1)	0.004(1.8)	0.003(0.83)
194[d]	5.1(0.6)	0.002(0.02)	0.02(0.02)	4.8(0.6)	0.43(0.20)	5.5(0.5)	2.3(0.6)	1.3(0.2)	0.000(2.7)	0.002(1.30)	0.110(2.2)	0.031(1.3)	0.002(1.8)	-0.170(2.00)

[a] Base of alluvium or perched water at 38 ft.

[b] Base of Tshirege Unit 1A at 98 ft

[c] Base of Tsankowi Member at 118 ft.

[d] Base of Otowi member below 194 ft.

TABLE 6.2.2.2-III

Extractable Metals by EP Toxicity Procedure on Cores from Hole MCM-5.9A

Depth (ft)	Analyses in mg/L							
	AG	AS	BA	CD	CR	HG	PB	SE
4	0.010	0.003	0.040	0.030	0.100	0.000	1.000	0.001
9	0.010	0.002	0.050	0.030	0.100	0.000	1.000	0.001
14	0.010	0.002	0.100	0.030	0.100	0.000	1.000	0.001
19	0.010	0.002	0.020	0.030	0.100	0.000	1.000	0.001
24	0.010	0.002	0.010	0.030	0.100	0.000	1.000	0.001
29	0.010	0.002	0.130	0.030	0.100	0.000	1.000	0.001
34[a]	0.010	0.003	0.009	0.030	0.100	0.000	1.000	0.002
39	0.010	0.002	0.030	0.030	0.100	0.000	1.000	0.003
40	0.010	0.003	0.030	0.030	0.100	0.000	1.000	0.003
44	0.010	0.002	0.014	0.030	0.100	0.000	1.000	0.002
47	0.010	0.002	0.020	0.030	0.100	0.000	1.000	0.001
49	0.010	0.002	0.630	0.030	0.100	0.000	1.000	0.001
54	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.002
64	0.010	0.002	0.006	0.030	0.100	0.000	1.000	0.002
69	0.010	0.002	0.130	0.030	0.100	0.000	1.000	0.001
79	0.010	0.002	0.240	0.030	0.100	0.000	1.000	0.002
89	0.010	0.002	0.030	0.030	0.100	0.000	1.000	0.001
94[b]	0.010	0.002	0.020	0.030	0.100	0.000	1.000	0.002
99	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
102	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
104	0.010	0.002	0.003	0.030	0.100	0.001	1.000	0.001
109	0.010	0.002	0.003	0.030	0.100	0.001	1.000	0.001
114[c]	0.010	0.002	0.008	0.030	0.100	0.001	1.000	0.001
119	0.010	0.002	0.003	0.030	0.100	0.001	1.000	0.001
124	0.010	0.002	0.006	0.030	0.100	0.001	1.000	0.001
129	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
134	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
139	0.010	0.002	0.003	0.050	0.100	0.000	1.000	0.001
144	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
149	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
154	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
159	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
164	0.010	0.002	0.004	0.030	0.100	0.000	1.000	0.001
169	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
174	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
179	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
184	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
189	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001
194[d]	0.010	0.002	0.003	0.030	0.100	0.000	1.000	0.001

[a] Base of alluvium or perched water at 38 ft.

[b] Base of Tshirege Unit 1A at 98 ft.

[c] Base of Tsankowi Member at 118 ft.

[d] Base of Otowi member below 194 ft.

TABLE 6.2.2.2-IV

Metal Scan by ICPMS in Leachate from Cores from Hole MCM-5.9A

Depth (ft)	Analyses in µg/g																								
	Ag	As	Au	B	Ba	Be	Bi	Cd	Ce	Cl	Co	Cr	Cs	Cu	Dy	Er	Eu	F	Ga	Gd	Ge	Hf	Ho	In	Ir
4	0.5	0.5	0.5	5	19	5	0.5	0.5	5.5	10.0	0.5	0.5	0	0.5	0.62	0.5	0.5	2.5	0.5	1	0.5	0.5	0.5	0.5	0.5
9	0.5	0.5	0.5	5	11	5	0.5	0	3.2	10	0.5	0.5	0.5	0.5	0.56	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
14	0.5	0.5	0	5	8	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
19	0.5	0.5	0	5	5	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
24	0.5	0.5	0	5	4	5	0.5	0	1	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
29	0.5	0.5	0	5	21	5	0.5	0	4	22.7	0.5	0.5	0	0.5	1	0.54	0.5	3.15	0.5	1.3	0.5	0.5	0.5	0.5	0.5
34[a]	0.5	0.5	0	5	6	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	5.75	0.5	0.67	0.5	0.5	0.5	0.5	0.5
39	0.5	0.5	0	5	13	5	0.5	0	2.7	19.2	0.5	0.5	0	0.5	0.6	0.5	0.5	8.1	0.5	0.76	0.5	0.5	0.5	0.5	0.5
40	0.5	0.5	0.5	5	14	5	0.5	0	2.3	22.68	0.5	0.5	0.5	0.5	0.76	0.5	0.5	8.45	0.5	0.74	0.5	0.5	0.5	0.5	0.5
44	0.5	0.5	0.5	5	5.2	5	0.5	0.5	4.8	12.38	0.5	0.5	0.5	0.5	0.96	0.51	0.5	2.75	0.5	1.3	0.5	0.5	0.5	0.5	0.5
47	0.5	0.5	0	5	12	5	0.5	0	2.4	30.53	0.5	0.5	0.5	0.5	0.7	0.5	0.5	4.85	0.5	0.85	0.5	0.5	0.5	0.5	0.5
49	0.5	0.5	0	5	83	5	0.5	0	7.3	51.06	0.5	0.5	0.5	0.5	3.4	1.8	0.5	5.75	0.5	2.5	0.5	0.5	0.59	0.5	0.5
54	0.5	0.5	0	5	3	5	0.5	0	3.2	10	0.5	0.5	0.5	0.5	1.5	0.71	0.5	2.5	0.5	1.1	0.5	0.5	0.5	0.5	0.5
64	0.5	0.5	0	5	5	5	0.5	0	3.2	10	0.5	0.5	0.5	0.5	1.4	0.67	0.5	2.5	0.5	1.2	0.5	0.5	0.5	0.5	0.5
69	0.5	0.5	0	5	17	5	0.5	0	3.1	10.43	0.5	0.5	0.5	0.5	1.6	0.82	0.5	2.5	0.5	1.5	0.5	0.5	0.5	0.5	0.5
71.5	0.5	0.5	0	5	57	5	0.5	0	7.4	87.12	0.5	0.5	0.5	0.5	2.6	1.5	0.5	5.05	0.5	2.2	0.5	0.5	0.5	0.5	0.5
79	0.5	0.5	0.5	5	44	5	0.5	0.5	6.3	38.35	0.5	0.5	0.5	0.5	3.4	1.9	0.5	6.85	0.5	3.1	0.5	0.5	0.72	0.5	0.5
89	0.5	0.5	0.5	5	19	5	0.5	0.5	8	15.22	0.5	0.5	0.5	0.5	1.9	0.98	0.5	3.75	0.5	1.9	0.5	0.5	0.5	0.5	0.5
94[b]	0.5	0.5	0.5	5	11	5	0.5	0.5	4.3	10	0.5	0.5	0.5	0.5	1.1	0.62	0.5	2.85	0.5	1.2	0.5	0.5	0.5	0.5	0.5
99	0.5	0.5	0.5	5	13	5	0.5	0.5	3.1	13.19	0.5	0.64	0.5	0.5	1.3	0.83	0.5	2.5	0.5	1.4	0.5	0.5	0.5	0.5	0.5
102	0.5	0.5	0	5	5	5	0.5	0	4	11.4	0.5	0.5	0	0.5	0	0.5	0.5	2.65	0.5	0.54	0.5	0.5	0.5	0.5	0.5
104	0.5	0.5	0	5	12	5	0.5	0	6	14.5	0.5	0.5	0	0.5	0	0.54	0.5	4.45	0.5	1.2	0.5	0.5	0.5	0.5	0.5
109	0.5	0.5	0	5	4	5	0.5	0	4	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.71	0.5	0.5	0.5	0.5	0.5
114[c]	0.5	0.5	0	5	9	5	0.5	0	4	11.2	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.64	0.5	0.5	0.5	0.5	0.5
119	0.5	0.5	0	5	5	5	0.5	0	8	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	1.5	0.5	0.5	0.5	0.5	0.5
124	0.5	0.5	0	5	7	5	0.5	0	2	10.0	0.5	0.54	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
129	0.5	0.5	0.5	5	6.7	5	0.5	0.5	2.5	10.0	0.5	0.5	0	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
134	0.5	0.5	0.5	5	7.1	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
139	0.5	0.5	0.5	5	9.1	5	0.5	0.5	2.5	10	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
144	0.5	0.5	0	5	10	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.54	0.5	0.5	0.5	0.5	0.5
149	0.5	0.5	0	5	13	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
154	0.5	0.5	0	5	13	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
159	0.5	0.5	0	5	15	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
164	0.5	0.5	0	5	13	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
169	0.5	0.5	0.5	5	11	5	0.5	0.5	1.8	10.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
174	0.5	0.5	0.5	5	10	5	0.5	0.5	2	10.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
179	0.5	0.5	0.5	5	18	5	0.5	0	2	10.0	0.5	0.5	0	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
184	0.5	0.5	0.5	5	13	5	0.5	0.5	2.6	10.0	0.5	0.5	0	0.5	0.5	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
189	0.5	0.5	0.5	5	12	5	0.5	0.5	2	10.0	0.5	0.5	0	0.5	0	0.5	0.5	25	0.5	0.5	0.5	0.5	0.5	0.5	0.5
194[d]	0.5	0.5	0	5	12	5	0.5	0	2	3.7	0.5	0.57	0	0.5	0	0.5	0.5	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

[a] Base of alluvium or perched water at 38 ft.

[b] Base of Tshirege Unit 1A at 98 ft.

[c] Base of Tsankowi Member at 118 ft.

[d] Base of Otowi member below 194 ft.

TABLE 6.2.2.2-IV (Continued)

Metal Scan by ICPMS in Leachate from Cores from Hole MCM-5.9A

Depth (ft)	Analyses in µg/g																
	La	Li	Lu	Mn	Mo	Nb	Nd	Ni	NO_3N	Pb	Pd	Ph	Pr	Pt	Rb	Rh	Ru
4	3.2	5	0.5	54	0.5	0.5	3.8	0.5	1.76	2.6	0.5	6.64	1	0.5	0.5	0.5	0.5
9	2.2	5	0.5	27	0.5	0.5	2.7	0	1.28	2.2	0.5	6.97	0.8	0.5	0.5	0.5	0.5
14	1.4	5.0	0	18	0	0	1.9	0	0	1.8	0.5	7.12	0	0.5	0	0.5	0.5
19	1.1	5.0	0	18	0	0	1.3	0	0	1.6	0.5	7.43	0	0.5	0	0.5	0.5
24	0.95	5.0	0	14	0	0	1.3	0	0	1.6	0.5	7.18	0	0.5	0	0.5	0.5
29	3.8	5.0	0	28	0	0	6.0	0	8	3.5	0.5	6.8	1	0.5	0	0.5	0.5
34[a]	1.5	5.0	0	17	0	0	2.2	0	5	2.2	0.5	7.06	0	0.5	0	0.5	0.5
39	2.4	5.0	0	32	0	0	3.3	0	15.35	4.0	0.5	7.1	0	0.5	0.5	0.5	0.5
40	2.7	5	0.5	16	0.5	0.5	4.1	0	14.55	3.4	0.5	7.31	1.1	0.5	0.5	0.5	0.5
44	4	5	0.5	15	0.5	0.5	6.2	0.5	18.5	2.4	0.5	7.8	1.5	0.5	0.5	0.5	0.5
47	2.7	5.0	0	12	0	0	4.0	0	19.95	2.1	0.5	6.93	0.98	0.5	0.5	0.5	0.5
49	6.7	5.0	0	13	0	0	8.9	0	19.65	6.1	0.5	7.16	2.4	0.5	0.5	0.5	0.5
54	2.5	5.0	0	7	0	0	4.0	0	7.2	2	0.5	7.07	0.91	0.5	0.54	0.5	0.5
64	2.2	5.0	0	6	0	0	4.0	0	12.6	2.1	0.5	6.75	0.9	0.5	0.6	0.5	0.5
69	2.8	5.0	0	5	0	0	4.5	0	7.2	2.9	0.5	6.82	0.97	0.5	0.5	0.5	0.5
71.5	4.8	5.0	0	18	0	0	7.1	0	6.15	8.3	0.5	7.1	1.9	0.5	0.77	0.5	0.5
79	6.2	5	0.5	10	0.5	0.5	8.5	0.5	1.55	10	0.5	7.26	2.1	0.5	0.75	0.5	0.5
89	5.3	5	0.5	15	0.5	0.5	6.8	0.5	0.934	5.5	0.5	7.06	1.6	0.5	1.2	0.5	0.5
94[b]	2.4	5	0.5	21	0.5	0.5	3.6	0.5	0.585	4.9	0.5	7.06	0.75	0.5	1.3	0.5	0.5
99	3.5	5	0.5	16	0.5	0.5	4.8	0.5	24.4	6.4	0.5	6.49	1.2	0.5	1.3	0.5	0.5
102	2.4	5.0	0	18	0	0	3.3	2	10	3.8	0.5	6.54	0	0.5	0	0.5	0.5
104	3.8	5.0	0	17	0	0	5.0	0	26	6.6	0.5	6.81	1	0.5	1	0.5	0.5
109	2.1	5.0	0	15	0	0	3.4	0	431	1.6	0.5	6.75	0	0.5	0	0.5	0.5
114[c]	2.7	5.0	0	23	0	0	3.5	0	18	1.5	0.5	6.88	0	0.5	1	0.5	0.5
119	3.8	5.0	0	22	0	0	6.5	0	6	1.3	0.5	7.18	1	0.5	0	0.5	0.5
124	1.5	5.0	0	10	0	0	1.7	0	5	0.9	0.5	6.76	0	0.5	1	0.5	0.5
129	1.2	5	0.5	14	0.5	0.5	1.5	0.5	5.13	1.0	0.5	6.85	0	0.5	1.2	0.5	0.5
134	1.4	5	0.5	11	0.5	0.5	1.6	0	4	0.9	0.5	6.72	0	0.5	1.4	0.5	0.5
139	1.4	5	0.5	19	0.5	0.5	1.8	0.5	4.88	1.6	0.5	6.68	0.54	0.5	1.9	0.5	0.5
144	1.5	5.0	0	12	0	0	1.9	0	3	1.2	0.5	6.59	0	0.5	1	0.5	0.5
149	1.5	5.0	0	21	0	0	1.7	0	2	1.2	0.5	6.83	0	0.5	1	0.5	0.5
154	1.1	5.0	0	13	0	0	1.7	0	2	1.3	0.5	6.87	0	0.5	1	0.5	0.5
159	1.3	5.0	0	19	0	0	1.4	0	0	0.9	0.5	7.05	0	0.5	1	0.5	0.5
164	1.2	5.0	0	20	0	0	1.5	0	1	1.0	0.5	6.92	0	0.5	1	0.5	0.5
169	1.1	5	0.5	17	0.5	0.5	1.2	0.5	1.19	1.0	0.5	6.99	0.5	0.5	1.6	0.5	0.5
174	1.1	5	0.5	20	0.5	0.5	1.7	0.5	0.93	1.3	0.5	7.93	0.5	0.5	1.5	0.5	0.5
179	1.5	5	0.5	32	0.5	0.5	1.7	0	1	1.8	0.5	7.64	0	0.5	2.2	0.5	0.5
184	1.3	5	0.5	24	0.5	0.5	1.7	0.5	0.938	1.1	0.5	7.86	0	0.5	1.7	0.5	0.5
189	1.2	5	0.5	22	0.5	0.5	1.4	0.5	0	1.2	0.5	7.61	0	0.5	1	0.5	0.5
194[d]	1.3	5.0	0	28	0	0	1.7	0	0	1.4	0.5	8.32	0	0.5	1	0.5	0.5

[a] Base of alluvium or perched water at 38 ft.
[b] Base of Tshirege Unit 1A at 98 ft.
[c] Base of Tsankowi Member at 118 ft.
[d] Base of Otowi member below 194 ft.

TABLE 6.2.2.2-IV (Continued)

Metal Scan by ICPMS in Leachate from Cores from Hole MCM-5.9A

Depth (ft)	Analyses in µg/g																		
	Sb	Se	Sm	Sn	Sr	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr
4	0.5	5	0.96	0.5	1.6	0.5	0.5	0.5	0.5	5.0	0.5	0.5	0	5	0.5	1.3	0.5	2.2	0.5
9	0.5	5	0.77	0.5	1	0.5	0.5	0	0.5	5	0.5	0.5	0.5	5	0.5	0.9	0.5	2.5	0.5
14	0.5	5.0	0	0	0	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.5	0.5	0.72	0.5
19	0.5	5.0	0	0	0	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.5	0.5	1.4	0.5
24	0.5	5.0	0	0	0	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.5	0.5	0.86	0.5
29	0.5	5.0	1	0	1	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	2.1	0.5	1.3	0.5
34[a]	0.5	5.0	0	0	0	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.59	0.5	1.6	0.5
39	0.5	5.0	0	0	0	0	0.5	0	0.76	5.0	0.5	0.5	0	5	0.5	1.1	0.5	1.8	0.5
40	0.5	5	1	0.5	0.85	0.5	0.5	0	0.63	5	0.5	0.5	0.5	5	0.5	1.2	0.5	1.9	0.5
44	0.5	5	1.5	0.5	0.5	0.5	0.5	0.5	1.5	5	0.5	0.5	0.5	5	0.5	1.9	0.5	1.4	0.5
47	0.5	5.0	0	0	0	0	0.5	0	0.5	5	0.5	0.5	0.5	5	0.5	1	0.5	0.96	0.5
49	0.5	5.0	2	0	0	0	0.6	0	9.3	5	0.5	0.5	1.5	5	0.5	5	1.7	4.3	0.5
54	0.5	5.0	1	0	0	0	0.5	0	2.6	5	0.5	0.5	0.57	5	0.5	2.3	0.64	1.9	0.5
64	0.5	5.0	1	0	0	0	0.5	0	2.4	5	0.5	0.5	0.74	5	0.5	2.1	0.64	1.5	0.5
69	0.5	5.0	1	0	0	0	0.5	0	3.2	5	0.5	0.5	1.4	5	0.5	2.5	0.8	1.4	0.5
71.5	0.5	5.0	2	0	1	0	0.5	0	10	5	0.5	0.5	2.1	5	0.5	3.8	1.7	3	0.5
79	0.5	5	2.5	0.5	1.4	0.5	0.5	0.5	7.1	5	0.5	0.5	2.4	5	0.5	6.1	1.8	3.9	0.5
89	0.5	5	1.9	0.5	2.2	0.5	0.5	0.5	3.1	5	0.5	0.5	1.1	5	0.5	4.1	0.98	5.1	0.5
94[b]	0.5	5	1.1	0.5	2.1	0.5	0.5	0.5	1.5	5	0.5	0.5	0.59	5	0.5	2.6	0.57	5	0.5
99	0.5	5	1.4	0.5	2.7	0.5	0.5	0.5	2.2	5	0.5	0.5	1.5	5	0.5	3.5	0.87	4.3	0.5
102	0.5	5.0	0	0	1	0	0.5	0	2	5.1	0.5	0.5	0	5.0	0	1.3	0.5	4.4	0.5
104	0.5	5.0	0	0	2	0	0.5	0	2	5.0	0.5	0.5	0	5.0	0	2.7	0.64	4.2	0.5
109	0.5	5.0	0	0	0	0	0.5	0	1	5.0	0.5	0.5	0	5.0	0	1.5	0.5	1.9	0.5
114[c]	0.5	5.0	0	0	1	0	0.5	0	1	5.0	0.5	0.5	0	5.0	0	1.9	0.5	3.4	0.5
119	0.5	5.0	1	0	1	0	0.5	0	1	5.0	0.5	0.5	0	5.0	0	2.7	0.5	2.3	0.5
124	0.5	5.0	0	0	0	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.79	0.5	1	0.5
129	0.5	5	0.5	0.5	0.87	0.5	0.5	0.5	0.5	5.0	0.5	0.5	0	5	0.5	0.5	0.5	0.51	0.5
134	0.5	5	0.5	0.5	0.99	0.5	0.5	0	0	5.0	0.5	0.5	0	5.0	0.5	0.6	0.5	0.66	0.5
139	0.5	5	0.5	0.5	1.1	0.5	0.5	0.5	0.64	5	0.5	0.5	0.5	5	0.5	0.77	0.5	1.7	0.5
144	0.5	5.0	0	0	1	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.74	0.5	1.4	0.5
149	0.5	5.0	0	0	1	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.85	0.5	1.3	0.5
154	0.5	5.0	0	0	1	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.79	0.5	1.2	0.5
159	0.5	5.0	0	0	1	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.81	0.5	0.82	0.5
164	0.5	5.0	0	0	1	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.62	0.5	2	0.5
169	0.5	5	0.5	0.5	1.9	0.5	0.5	0.5	0.86	5.0	0.5	0.5	0.5	5	0.5	0.65	0.5	0.81	0.5
174	0.5	5	0.5	0.5	2.1	0.5	0.5	0.5	0.6	5.0	0.5	0.5	0.5	5	0.5	0.64	0.5	2	0.5
179	0.5	5	0.62	0.5	2.9	0.5	0.5	0	1	5.0	0.5	0.5	0	5.0	0.5	0.86	0.5	1.4	0.5
184	0.5	5	0.5	0.5	2.2	0.5	0.5	0.5	0.89	5.0	0.5	0.5	0	5	0.5	0.79	0.5	1.9	0.5
189	0.5	5	0.5	0.5	1.9	0.5	0.5	0.5	1	5.0	0.5	0.5	0	5.0	0	0.66	0.5	1.5	0.5
194[d]	0.5	5.0	0	0	2	0	0.5	0	0	5.0	0.5	0.5	0	5.0	0	0.69	0.5	1.4	0.5

[a] Base of alluvium or perched water at 38 ft.

[b] Base of Tshirege Unit 1A at 98 ft.

[c] Base of Tsankowi Member at 118 ft.

[d] Base of Otowi member below 194 ft.

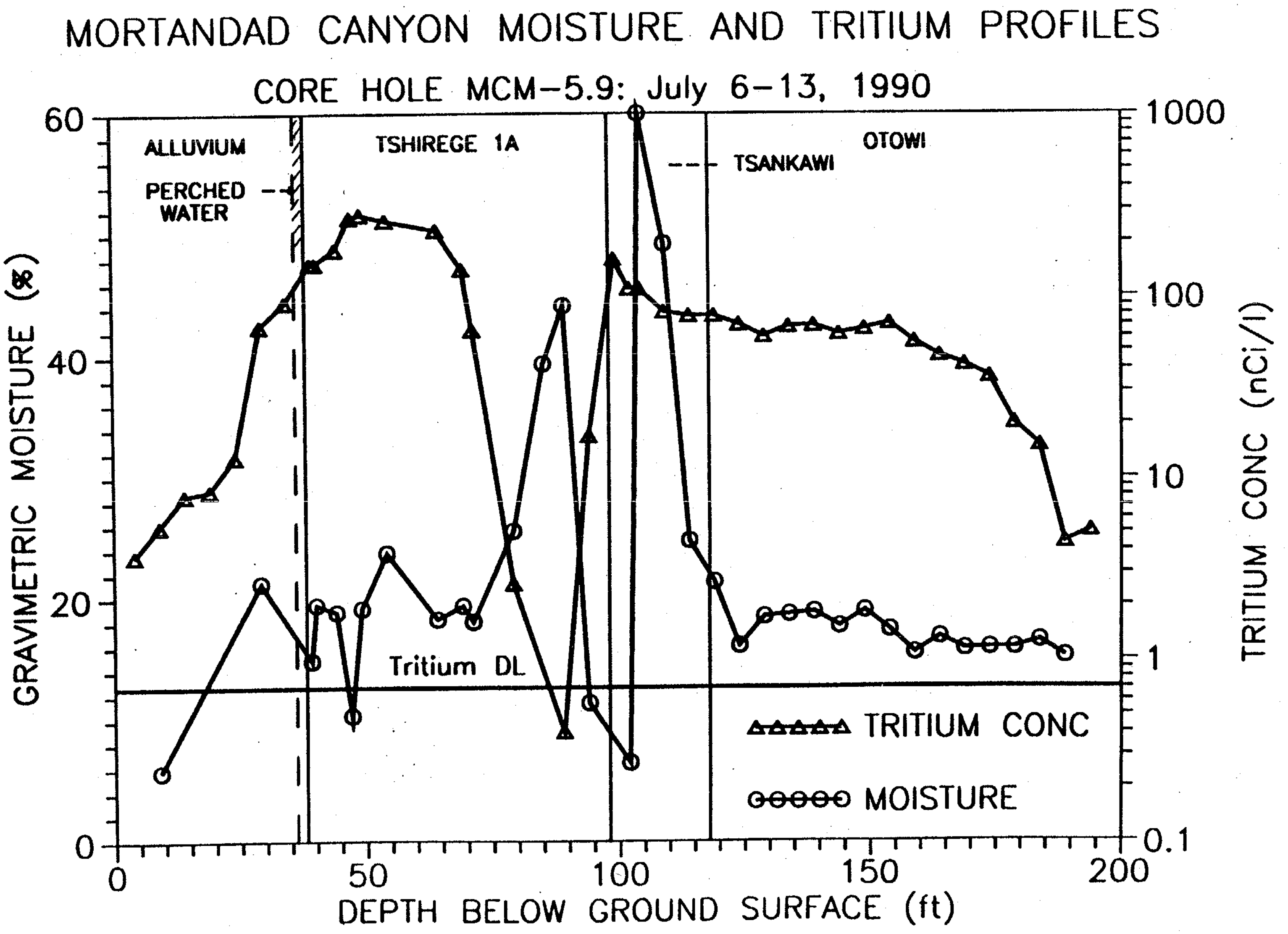

MORTANDAD CANYON MOISTURE AND TRITIUM PROFILES
CORE HOLE MCM-5.9: July 6-13, 1990
ALLUVIUM
PERCHED WATER
TSHIREGE 1A
TSANKAWI
OTOWI
Tritium DL
TRITIUM CONC
MOISTURE
GRAVIMETRIC MOISTURE (%)
0
20
40
60
TRITIUM CONC (nCi/l)
0.1
1
10
100
1000
DEPTH BELOW GROUND SURFACE (ft)
0
50
100
150
200

Fig. 6.2.2.2-1

and deeper. Additional aliquots of the cores will be reanalyzed with additional chemical separation to remove the thorium interference and obtain better detection limits for the plutonium analyses.

The analyses for metals extractable by the EP Toxicity method (Table 6.2.2.2-III) indicate that there are none of the cores either above, in, or beneath the perched aquifer that exceed, or even approach the toxicity criteria.

The metal scan of the acid leachate (Table 6.2.2.2-IV) is included as data that may be useable in conjunction with contaminant transport modelling, or to gain insights on geochemical properties of the tuff. One qualitative observation is that there appears to be less these metals available for leaching in cores taken from hole MCM-5.9A than from MCM-5.1 at comparable depths. This may be an indication of differences in weathering induced by the presence of moisture from the perched aquifer.

The perched aquifer has contained high concentrations of chlorides and nitrates at times from the treatment plant effluent. Chloride and nitrate behave in solution in the perched aquifer much as does tritiated water. Their behavior in the unsaturated media is not understood; however, chloride and nitrate concentrations vary considerably and are generally higher in the saturated allucvum to a depth of 114 ft in the tuff (Table 6.2.2.2-IV).

6.2.2.3. Cores from MCC-8.2

The analytical results for cores from MCC-8.2 are presented in three tables as follows:

Table 6.2.2.3-I Tritium and Gravimetric Moisture in Cores from Hole MCC-8.2
Table 6.2.2.3-II Radiochemical Analyses of Cores from Hole MCC-8.2
Table 6.2.2.3-III Metal Scan by ICPMS in Leachate from Cores from Hole MCC-8.2

The gravimetric moisture and tritium concentration results (Table 6.2.2.3-I) are presented graphically in Figure 6.2.2.3-1. The figure indicates the depths for the saturated zone, and the interfaces between the Tshirege Unit 1a, the Tsankawi, and the Otowi members as determined from the geologic logs. The moisture content is relatively constant less than 10% (gravimetric) through the 49 foot depth in the alluvium, then rises starting at 52 foot depth (about 7 feet above the saturated zone). The gravimetric moisture content decreases slightly through the 8 foot thickness of the Tshirege Unit 1a (depths 76 to 84 feet). Then it generally increases through the Tsankawi member and peaks at the contact with the Otowi (104 foot depth). The gravimetric moisture then decreases to the 12-14% range by the 134 foot sample and remains relatively constant to the 179 foot depth.

The samples at 125 and 184 foot depth show an apparent increase, but the reliability of these samples is somewhat suspect because some water was observed leaking into the inside of the hollow stem auger and could have introduce some moisture and higher concentrations of tritium from the saturated zone.

The tritium concentration (in water extracted from the core) reaches a peak concentration in the saturated zone (about 300 nCi/L) and then decreases by a factor of about 5 (to 63 nCi/L) near the base (depth 99 feet) of the Tsankawi member. The lowest tritium concentrations correspond with the highest moisture contents, in fashion similar to that observed in holes MCM-5.1 and MCM-5.9A, though the effect is not as extreme. In the Otowi member, the tritium concentrations generally increase with a broad maximum between 129 and 154 foot depth and then start to decrease down to a depth of 169 feet. As noted above, the last four data points are somewhat suspect and may or may not show an actual increase in apparent concentration. Down to a depth of 169 feet, the shape of the tritium concentration curve is similar to that observed in hole MCM-5.9A.

The radiochemical results (Table 6.2.2.3-II) indicate that, to the degree permitted by the detection limits of the analytical processes, there is apparently no movement beneath the perched aquifer at the location of hole MCM-8.2 of plutonium, americium, cesium, strontium, or other isotopes that would be detectable by gross gamma, gross alpha, or gross beta measurements. None of the plutonium measurements, not even those in the saturated zone (i.e. 64 and 74 foot samples), show any plutonium-239 at the detection limit for the method (0.002 pCi/g) or greater than twice the standard deviation of the measurement. Only one plutonium-238 measurement (at 179 feet) was above the detection limit, but there is no reason to believe it is other that a statistical outlier, and in the context of the pattern of measurements does not likely represent any real contamination. The Americium measurements are uniformly reported at about 1.5 times the normal detection limit for the method (0.002 pCi/g) or about three times the standard deviation of the individual measurements. It is also necessary to consider that the Americium measurement is more subject to difficulty because of the presence of natural thorium, and therefore the measurements do not likely show any actual movement of contamination.

The metal scan of the acid leachate (Table 6.2.2.3-III) is included as data that may be useable in conjunction with contaminant transport modelling, or to gain insights on geochemical properties of the tuff. One qualitative observation is that there appears to be less of these metals available for leaching in cores taken from hole MCM-8.2 than from MCM-5.1 at comparable depths. This may be an indication of differences in weathering induced by the presence of moisture from the perched aquifer.

TABLE 6.2.2.3-I

Tritium and Gravimetric Moisture in Cores from Hole MCC-8.2

Depth[a] (ft)	Tritium[b] (nCi/L)	±s.d.	H2O (% by mass)	±s.d.
4	0.6	0.3	11.3	1.1
9	1.8	0.4	4.6	0.4
14	0.2	0.3	4.7	0.5
19	0.3	0.3	1.7	0.1
24	0.2	0.3	3.7	0.4
29	-0.1	0.3	3.9	0.3
34	0.2	0.3	6.3	0.6
39	0.0	0.3	2.9	0.3
44	0.1	0.3	5.2	0.5
49	0.0	0.3	8.2	0.8
52	0.0	0.3	22.4	2.2
54	5.5	0.7	14.7	1.5
59	220.0	20.0	21.7	2.2
64	310.0	30.0	20.1	2.0
64.	240.0	20.0	22.0	2.2
69	280.0	30.0	23.0	2.3
74[c]	210.0	20.0	21.3	2.1
79	220.0	20.0	17.3	1.7
84	120.0	10.0	20.5	2.1
84.[d]	130.0	10.0	21.1	2.1
89	210.0	20.0	27.3	2.7
94	64.0	6.0	19.8	2.0
99	63.0	6.0	26.7	2.7
104[e]	140.0	10.0	31.0	3.1
109	74.0	8.0	17.2	1.7
114	81.0	8.0	17.4	1.7
114.	76.0	8.0	15.8	1.6
119	79.0	8.0	17.9	1.8
124	87.0	9.0	17.4	1.7
129	160.0	20.0	25.2	2.5
134	110.0	10.0	14.7	1.5
139	120.0	10.0	13.8	1.4
144	120.0	10.0	13.6	1.4
144.	120.0	10.0	12.5	1.2
149	120.0	10.0	13.4	1.3
154	120.0	10.0	12.8	1.3
159	110.0	10.0	14.2	1.4
164	96.0	10.0	13.9	1.4
164.	92.0	9.0	12.2	1.2
169	88.0	9.0	14.3	1.4
174	110.0	10.0	16.7	1.7
179	100.0	10.0	14.2	1.4
184	150.0	20.0	19.7	2.0
184.[f]	160.0	20.0	23.1	2.3

[a] Decimal following number indicates duplicate sample analyzed at different time.

[b] Tritium as tritiated water in moisture distilled from cores, detection limit 0.7 nCi/L

[c] Base of alluvium or perched water at 76 ft.

[d] Base of Tshirege Unit 1A at 84 ft.

[e] Base of Tsankowi Member at 104 ft.

[f] Base of Otowi Member below 184 ft.

TABLE 6.2.2.3-II

Radiochemical Analyeses of Cores from Hole MCC-8.2[a]

Depth (ft)	H^3 (nCi/L)	Cs^{137} (pCi/g)	Pu^{238} (pCi/g)	Pu^{239} (pCi/g)	Am^{241} (pCi/g)	Sr^{90} (pCi/g)	U (µg/g)	Gamma (pCi/g)
04	0.6(0.3)	0.014(0.062)	0.000(0.000)	0.001(0.001)	0.020(0.011)	-0.030(0.430)	4.2(0.4)	5.2(0.6)
14	0.2(0.3)	0.102(0.095)	0.002(0.001)	0.001(0.001)	0.030(0.011)	-0.186(0.250)	4.2(0.4)	5.5(0.7)
24	0.2(0.3)	0.001(0.060)	0.001(0.001)	0.001(0.001)	0.034(0.084)	-0.223(0.260)	2.8(0.3)	2.5(0.4)
34	0.2(0.3)	0.174(0.100)	0.001(0.001)	0.000(0.001)	0.013(0.010)	-0.180(0.230)	4.2(0.4)	5.6(0.7)
44	0.1(0.3)	0.071(0.064)	0.001(0.001)	0.002(0.001)	-0.004(0.008)	-0.080(0.230)	2.5(0.3)	2.5(0.4)
54	5.5(0.7)	0.092(0.096)	0.001(0.000)	0.001(0.000)	0.009(0.009)	-0.050(0.246)	4.4(0.4)	5.9(0.7)
64	310.0(30.0)	0.063(0.063)	0.001(0.001)	0.000(0.001)	0.021(0.010)	-0.120(0.220)	4.3(0.4)	5.8(0.7)
74[b]	210.0(20.0)	0.125(0.096)	0.000(0.001)	0.000(0.000)	0.020(0.010)	0.057(0.190)	6.4(0.6)	6.3(0.7)
84[c]	120.0(10.0)	0.207(0.094)	0.002(0.001)	0.001(0.000)	0.034(0.012)	0.100(0.220)	4.5(0.5)	5.6(0.7)
94	64.0(6.0)	0.056(0.090)	0.001(0.001)	0.001(0.001)	0.057(0.014)	0.070(0.260)	5.7(0.6)	7.1(0.8)
104[d]	140.0(10.0)	0.170(0.068)	0.000(0.000)	0.002(0.001)	0.030(0.012)	0.130(0.280)	5.7(0.3)	8.1(0.9)
114	81.0(8.0)	0.179(0.099)	0.000(0.000)	0.001(0.000)	0.030(0.011)	0.060(0.330)	5.9(0.6)	-2.6(0.4)
124	87.0(9.0)	0.065(0.062)	0.000(0.000)	0.000(0.000)	0.030(0.011)	0.080(0.340)	5.9(0.6)	7.2(0.8)
134	110.0(10.0)	0.185(0.110)	0.000(0.000)	0.001(0.000)	0.030(0.012)	-0.050(0.440)	5.4(0.5)	7.2(0.8)
144	120.0(10.0)	0.038(0.063)	0.000(0.001)	0.000(0.000)	0.037(0.012)	-0.110(0.340)	6.0(0.6)	7.1(0.8)
154	120.0(10.0)	0.083(0.108)	0.000(0.000)	0.000(0.000)	0.032(0.013)	0.250(0.190)	5.9(0.6)	6.1(0.7)
164	96.0(10.0)	-0.032(0.062)	0.000(0.001)	0.001(0.001)	0.055(0.014)	0.090(0.220)	6.6(0.7)	7.6(0.9)
174	110.0(10.0)	0.226(0.100)	0.001(0.001)	0.001(0.001)	—	-0.090(0.280)	7.0(0.7)	8.2(0.9)
179	100.0(10.0)	0.133(0.066)	0.005(0.001)	0.001(0.001)	0.004(0.001)	0.680(0.526)	6.2(0.6)	7.1(0.8)
194[e]	150.0(20.0)	0.035(0.095)	0.001(0.001)	0.002(0.001)	—	0.513(0.563)	6.2(0.6)	7.4(0.8)

[a] Standard Deviation of radioactivity counting statistics shown in parenthesis

[b] Base of alluvium or perched water at 76 ft.

[c] Base of Tshirege Unit 1A at 84 ft.

[d] Base of Tsankowi Member at 104 ft.

[e] Base of Otowi Member below 184 ft.

TABLE 6.2.2.3-III

Metal Scan by ICPMS in Leachate from Cores from Hole MCC-8.2

Depth (ft)	Analysis in µg/g																	
	Ag	As	Au	B	Ba	Be	Bi	Br	Cd	Ce	Co	Cr	Cs	Cu	Dy	Er	Eu	Fe	Ga
04	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	24.0	1.0
14	1.0	16.0	3.0	100.0	16.0	65	4.2	1.0	1.0	4.6	3.4	4.9	2	13.0	1.0	1.0	1.0	2.0	4.0
24	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	34.0	1.0
34	1.0	15.0	1.0	100.0	23.0	59	1.1	1.0	1.0	3.2	1.1	3.9	1.0	1.5	1.0	1.0	1.0	1.2	3.8
44	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.8	1.0
54	1.0	1.0	1.0	100.0	2.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	62.0	1.0
64	1.0	17.0	1.0	100.0	36.0	47	3.3	1.0	1.0	13.0	1.7	12.0	1.0	13.0	1.7	1.6	1.0	9.1	9.0
74[a]	1.0	15.0	1.0	100.0	35.0	51	1.3	1.0	1.0	15.0	1.9	13.0	1.0	21.0	1.5	1.0	1.0	9300.0	8.1
84[b]	1.0	5.4	1.0	100.0	23.0	48	2.7	1.0	1.0	9.8	2.5	11.0	1.0	14.0	1.0	1.0	1.0	6000.0	7.1
94	1.0	1.0	1.0	160.0	6.0	67	1.0	1.0	1.0	1.4	1.0	6.8	1.0	6.4	1.0	1.0	1.0	1200.0	3.6
104[c]	1.0	6.4	1.0	100.0	5.0	56	1.0	1.0	1.0	2.7	1.0	3.7	1.0	15.0	1.0	1.0	1.0	1900.0	4.3
114	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
124	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
134	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	15.0	1.0
144	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
154	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
164	1.0	1.0	1.0	100.0	1.0	10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
174[d]	1.0	3.6	1.0	100.0	5.2	40	1.0	1.0	1.0	1.2	1.0	2.8	1.0	13.0	1.0	1.0	1.0	1.0	1.2

[a] Base of alluvium or perched water at 76 ft.
[b] Base of Tshirege Unit 1A at 84 ft.
[c] Base of Tsankowi Member at 104 ft.
[d] Base of Otowi Member below 174 ft.

TABLE 6.2.2.3-III (Continued)

Metal Scan by ICPMS in Leachate from Cores from Hole MCC-8.2

Depth (ft)	Analysis in μg/g																			
	Gd	Ge	Hf	Hg	Ho	I	Ir	La	Li	Lu	Mn	Mo	Nb	Nd	Ni	Pb	Pd	Pr	Pt	Rb
04	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
14	1.5	2.5	3.1	10.0	1.0	4.5	1.0	1.0	18.0	1.0	28.0	18.0	1.6	1.4	52.0	2.1	2.9	1.0	1.0	7.8
24	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
34	1.0	1.1	2.6	10.0	1.0	27.0	1.0	1.0	10.0	1.0	19.0	15.0	1.0	1.0	18.0	1.7	1.2	1.0	1.0	4.8
44	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
54	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.7	1.0	1.0	1.0	1.0	1.0
64	3.1	1.0	2.4	10.0	1.0	8.6	1.0	5.0	31.0	1.0	88.0	16.0	4.3	8.2	77.0	3.4	1.0	2.0	1.0	21.0
74[a]	3.2	1.0	1.0	10.0	1.0	14.0	1.0	5.0	25.0	1.0	97.0	15.0	4.1	8.1	86.0	3.3	1.4	1.8	1.0	17.0
84[b]	2.7	1.0	3.2	10.0	1.0	13.0	1.0	2.5	29.0	1.0	56.0	34.0	6.3	5.6	51.0	1.9	2.5	1.5	1.0	14.0
94	1.0	1.2	1.0	10.0	1.0	10.0	1.0	1.0	13.0	1.0	23.0	3.5	1.4	2.1	24.0	1.0	1.0	1.0	1.0	6.5
104[c]	1.0	1.3	1.0	10.0	1.0	10.0	1.0	1.0	16.0	1.0	35.0	14.0	1.1	1.6	35.0	1.2	1.0	1.0	1.0	16.0
114	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.4
124	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1
134	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.5	1.0	1.0	1.0	3.9	1.0	1.0	1.0	1.0	2.1
144	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1
154	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
164	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.2
174[d]	1.0	1.0	1.0	10.0	1.0	4.0	1.0	1.0	23.0	1.0	10.0	4.4	1.0	1.0	12.0	7.7	1.0	1.0	1.0	24.0

[a] Base of alluvium or perched water at 76 ft.
[b] Base of Tshirege Unit 1A at 84 ft.
[c] Base of Tsankowi Member at 104 ft.
[d] Base of Otowi Member below 174 ft.

TABLE 6.2.2.3-III (Continued)

Metal Scan by ICPMS in Leachate from Cores from Hole MCC-8.2

Depth (ft)	Analysis in µg/g																			
	Re	Rh	Ru	Sb	Se	Sm	Sn	Sr	Ta	Tb	Th	Ti	Tl	Tm	V	W	Y	Yb	Zn	Zr
04	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	1.0	1.0	1.0	3.4	1.0	1.0	1.8	1.8	1.0	1.0	2.9	1.0
14	1.0	1.0	2.0	2.1	22.0	1.0	8.5	33.0	1.0	1.0	1.6	91.0	1.0	1.0	51.0	14.0	5.1	1.0	120.0	7.3
24	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.4	1.0	1.0	1.0	4.1	1.0	1.0	1.6	1.0	1.0	1.0	2.9	1.0
34	1.0	1.0	1.4	1.0	43.0	1.0	1.9	100.0	1.0	1.0	1.0	110.0	1.0	1.0	66.0	5.5	3.8	1.0	39.0	4.6
44	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	1.0	1.0	1.6	1.0	1.0	1.0	2.5	1.0
54	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.6	1.0	1.0	1.0	7.6	1.0	1.0	2.8	1.0	1.0	1.0	12.0	1.0
64	1.0	1.0	1.0	1.0	1.0	1.0	4.2	10.0	1.0	1.0	1.8	470.0	1.0	1.0	63.0	5.1	10.0	1.0	100.0	23.0
74[a]	1.0	1.0	1.0	1.0	4.0	1.0	3.5	13.0	1.0	1.0	1.6	470.0	1.0	1.0	46.0	17.0	7.2	1.0	78.0	24.0
84[b]	1.0	1.0	1.0	1.0	30.0	1.0	5.2	6.4	1.0	1.0	1.8	380.0	1.0	1.0	32.0	31.0	6.0	1.0	85.0	25.0
94	1.0	1.0	1.0	1.0	85.0	1.0	1.3	1.6	1.0	1.0	1.0	1.0	1.0	1.0	11.0	3.1	1.8	1.0	42.0	3.7
104[c]	1.0	1.0	1.0	1.0	62.0	1.0	2.4	4.5	1.0	1.0	1.0	11.0	1.0	1.0	8.6	9.7	2.0	1.0	54.0	5.7
114	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.3	1.0
124	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.6	1.0
134	1.0	1.0	1.0	1.0	1.4	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.0	1.0	1.0	1.0	1.0	1.0	6.8	1.0
144	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.8	1.0
154	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
164	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.2	1.0
174[d]	1.0	1.0	1.0	1.0	8.3	1.0	1.1	25.0	1.0	1.0	1.0	11.0	1.0	1.0	1.0	5.5	1.0	1.0	110	3.7

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[a] Base of alluvium or perched water at 76 ft.
[b] Base of Tshirege Unit 1A at 84 ft.
[c] Base of Tsankowi Member at 104 ft.
[d] Base of Otowi Member below 174 ft.

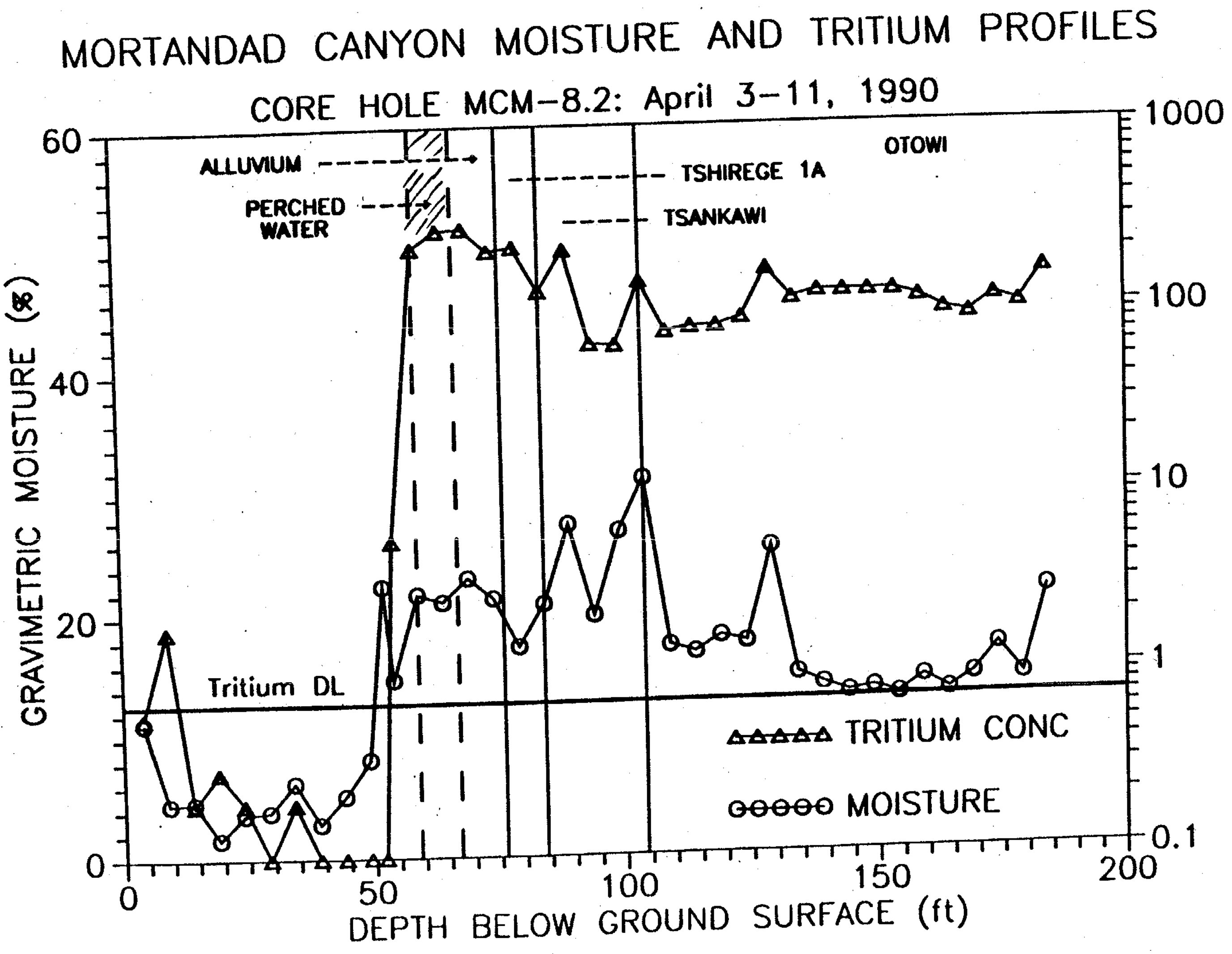
MORTANDAD CANYON MOISTURE AND TRITIUM PROFILES
CORE HOLE MCM-8.2: April 3-11, 1990
ALLUVIUM
PERCHED WATER
TSHIREGE 1A
TSANKAWI
OTOWI
Tritium DL
TRITIUM CONC
MOISTURE
GRAVIMETRIC MOISTURE (%)
TRITIUM CONC (nCi/l)
DEPTH BELOW GROUND SURFACE (ft)
0
20
40
60
0
50
100
150
200
0.1
1
10
100
1000

Fig. 6.2.2.3-1

6.2.2.4. Cores from SIMO-1

The analytical results for cores from SIMO-1 are presented in two tables as follows:

Table 6.2.2.4-I Tritium and Gravimetric Moisture in Cores from Hole SIMO-1
Table 6.2.2.4-II Radiochemical Analyses of Cores from Hole SIMO-1

The gravimetric moisture and tritium concentration results (Table 6.2.2.4-I) are presented graphically in Figure 6.2.2.4-1. The figure indicates the depths of the contact between the Tshirege Unit 1a, the Tsankawi, and the Otowi members as determined from the geologic logs. The hole encountered no perched water and the alluvium appeared as badly weathered tuff of Tshirege Unit 1A. Weathering of the upper 11 fe of Thsirege Unit 1A is the result of normal precipitation, and there is no indication of a perched aquifer as present or in the past. The moisture content is relatively constant through the weathered tuff of Tshirege Unit 1a in a range of 4 to 8 percent (gravimetric). Just below the contact with the Tsankawi (47 feet) there is a dip to about 3 percent in the 49 foot sample. The gravimetric moisture content increases in the Tsankawi to a maximum of about 9 percent, and then decreases to about 4 percent near the contact with the otowi member (64 feet). It decreases further in the top few feet of the Otowi to about 2 percent (69 foot sample) and then generally varies between 9 and 19 percent from 84 to 104 feet. The data suggest that the gravimetric moisture content is relatively constant after penetrating about 30 feet of the Otowi member, as was observed in holes MCM-5.9A and MCM-8.2. The gravimetric moisture content here is slightly lower than observed in either of those holes.

The radiochemical results (Table 6.2.2.4-II) indicate that, to the degree permitted by the detection limits of the analytical processes, there is apparently no measureable plutonium, cesium, or other isotopes that would be detectable by gross gamma, gross alpha, or gross beta measurements beneath the surface at the location of Hle SIMO-1. A few of the plutonium measurements show values above the general detection limit for the method (0.002 pCi/g) and greater than twice the standard deviation of the individual measurement. Only one plutonium-238 measurement (at 9 feet) and one plutonnium-239 measurement (94 feet) exceeded three times the standard deviation of the individual measurements. However, in the context of the pattern of measurements, there is no reason to believe these values are other than statistical outliers, and do not likely represent any real transport of contamination.

Data from routine monitoring has never shown any indication of surface water transport to or past the boundary either, as previously discussed in Section 3.3 and as shown in the special study reproduced in Appendix 8.2.

TABLE 6.2.2.4-I

Tritium and Gravimetric Moisture in Cores from Hole SIMO-1

Depth (ft)	Moisture (% by mass)	H-3[a] (nCi/L)
4	4.5	1.6
9	4.0	1.4
14	8.0	1.1
19	7.7	0.4
24	5.7	0.2
29	6.1	0.6
33	5.3	0.0
39	7.0	-0.1
44[b]	8.1	0.3
49	2.8	0.2
54	8.8	0.2
59	3.9	0.1
64[c]	4.1	0.0
69	2.3	-0.2
74	7.9	0.1
79	7.3	-0.2
84	11.2	-0.4
89	10.3	-0.1
94	19.2	-0.2
99	9.3	0.3
104[d]	9.4	0.0

[a] Tritium as tritiated water in moisture distilled from core samples, detection limit 0.7 nCi/L

[b] Base of Tshirege Unit 1A at 47 ft.

[c] Base of Tsankowi Member at 64 ft.

[d] Base of Otowi Member below 104 ft.

Table 6.2.2.4-II

Radiochemical Analyses of Core Samples from Hole SIMO-1

Sample depth (ft)	H^3 (nCi/L)[a]	Cs^{137} (pCi/g)	Gamma (cpm/g)	Pu^{238} (pCi/g)	Pu^{239} (pCi/g)	U (ug/g)	Gross Alpha (pCi/g)	Gross Beta (pCi/g)
4	1.6(0.3)	0.043(0.077)	2.7(0.5)	0.001(0.001)	0.002(0.001)	2.2(0.2)	3.7(0.8)	1.4(0.2)
9	1.4(0.3)	0.347(0.135)	4.0(0.6)	0.008(0.001)	0.003(0.001)	2.9(0.3)	6.0(1.0)	2.1(0.3)
14	1.1(0.3)	0.124(0.079)	4.0(0.6)	0.000(0.000)	0.002(0.001)	4.6(0.5)	14.0(3.0)	5.5(0.6)
19	0.4(0.3)	0.185(0.126)	4.4(0.6)	0.002(0.002)	0.001(0.001)	4.6(0.4)	14.0(3.0)	5.9(0.7)
24	0.2(0.3)	0.161(0.081)	4.0(0.6)	0.000(0.000)	0.002(0.001)	4.1(0.4)	10.0(2.0)	5.4(0.6)
29	0.6(0.3)	0.243(0.133)	4.0(0.6)	0.002(0.001)	0.003(0.002)	3.6(0.4)	13.0(3.0)	5.0(0.6)
33.5	0.0(0.3)	0.128(0.081)	4.8(0.6)	0.000(0.001)	0.006(0.006)	3.9(0.4)	9.0(2.0)	4.0(0.5)
39	-0.1(0.3)	0.043(0.116)	2.9(0.5)	0.000(0.001)	0.002(0.001)	3.9(0.4)	9.0(2.0)	2.9(0.4)
44[b]	0.3(0.3)	0.032(0.085)	3.9(0.6)	0.006(0.006)	0.001(0.001)	4.0(0.4)	8.0(2.0)	3.3(0.4)
49	0.2(0.3)	0.150(0.126)	2.4(0.5)	0.000(0.000)	0.000(0.001)	1.6(0.2)	2.7(0.6)	2.0(0.3)
54	0.2(0.3)	0.057(0.079)	6.7(0.8)	0.001(0.000)	0.001(0.001)	5.4(0.5)	7.0(2.0)	3.1(0.4)
59	0.1(0.3)	0.119(0.119)	4.0(0.6)	0.001(0.000)	0.002(0.001)	2.8(0.3)	4.1(0.9)	1.5(0.2)
64[c]	0.0(0.3)	0.094(0.078)	3.7(0.5)	0.003(0.001)	0.002(0.001)	2.8(0.3)	5.0(1.0)	1.7(0.2)
69	-0.2(0.3)	0.147(0.117)	1.8(0.4)	0.000(0.000)	0.001(0.001)	1.5(0.2)	3.0(0.7)	1.2(0.2)
74	0.1(0.3)	0.107(0.081)	7.0(0.8)	0.001(0.001)	0.001(0.001)	6.7(0.7)	8.0(2.0)	2.7(0.3)
79	-0.2(0.3)	0.202(0.132)	5.6(0.7)	0.001(0.000)	0.001(0.001)	5.9(0.6)	7.0(1.0)	2.2(0.3)
84	-0.4(0.3)	-0.077(0.080)	7.1(0.8)	0.001(0.000)	0.001(0.001)	6.3(0.6)	8.0(2.0)	3.5(0.4)
89	-0.1(0.3)	0.189(0.120)	4.1(0.6)	0.000(0.000)	0.001(0.000)	3.9(0.4)	9.0(2.0)	3.1(0.4)
94	-0.2(0.3)	0.102(0.079)	5.0(0.6)	0.000(0.000)	0.004(0.001)	5.6(0.6)	3.7(0.8)	1.8(0.2)
99	0.3(0.3)	0.090(0.118)	3.9(0.6)	0.000(0.010)	0.003(0.001)	5.6(0.6)	3.1(0.7)	1.6(0.2)
104[d]	0.0(0.3)	0.004(0.086)	5.3(0.7)	0.000(0.010)	0.001(0.001)	5.5(0.5)	2.4(0.6)	1.6(0.2)

[a] Tritiated water distilled from core sample
[b] Base of Tshirege Unit 1A at 47 ft.
[c] Base of Tsankowi Member at 64 ft.
[d] Base of Otowi Member below 104 ft.

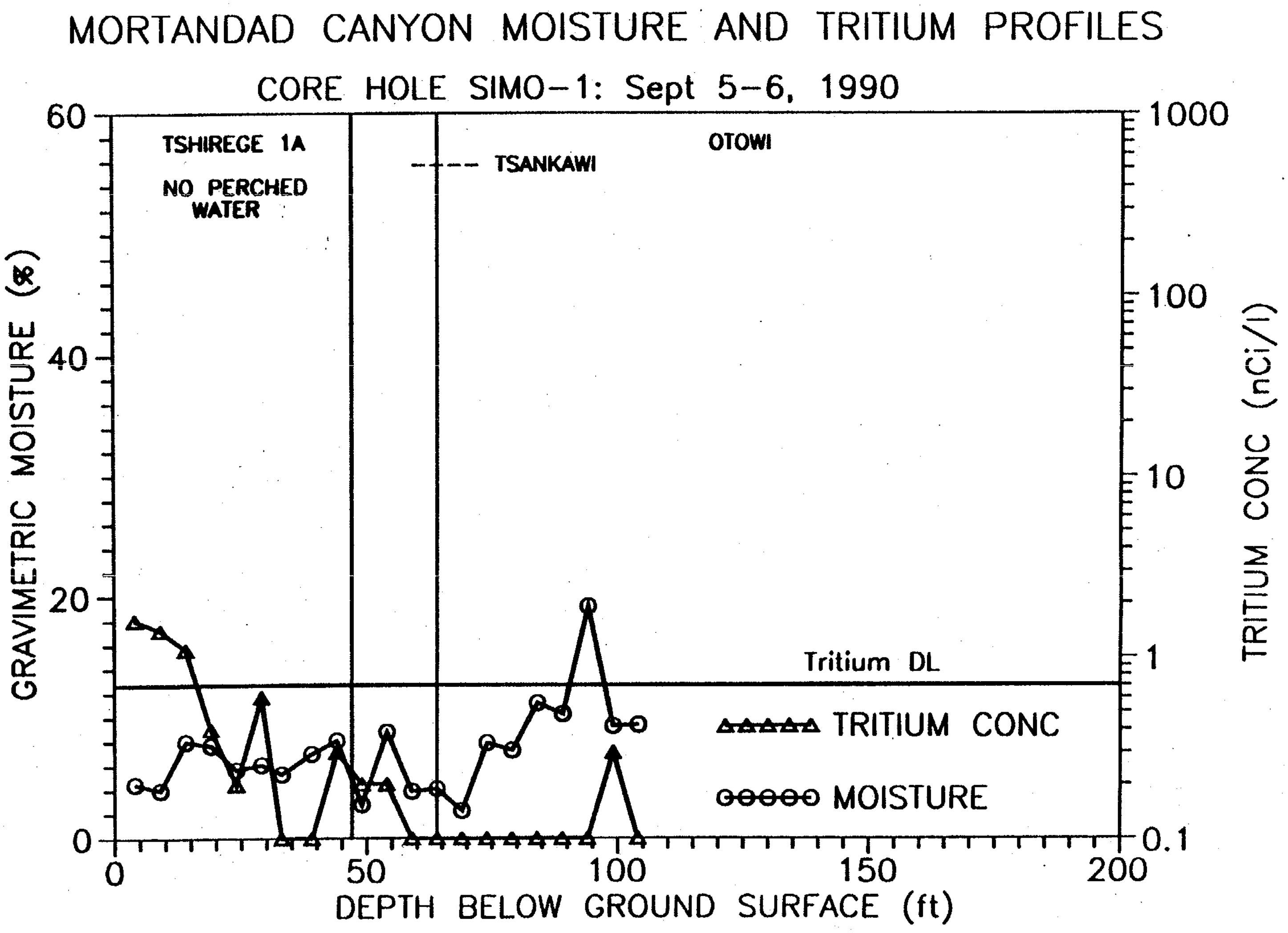
MORTANDAD CANYON MOISTURE AND TRITIUM PROFILES
CORE HOLE SIMO-1: Sept 5-6, 1990
TSHIREGE 1A
NO PERCHED WATER
TSANKAWI
OTOWI
Tritium DL
TRITIUM CONC
MOISTURE
GRAVIMETRIC MOISTURE (%)
0
20
40
60
TRITIUM CONC (nCi/l)
0.1
1
10
100
1000
DEPTH BELOW GROUND SURFACE (ft)
0
50
100
150
200

Fig. 6.2.2.4-1

6.3 Hydrologic Properties of Tuff

Basic physical and hydrologic properties of core samples from holes MCM5.1 and MCM-5.9A selected for hydrologic property testing are summarized in Section 6.3.1. A summary of the depth distributions of volumetric moisture, percentage of saturation and saturated hydraulic conductivities are presented in Section 6.3.2

6.3.1 Hydrologic Property Data for Cores from Holes MCM-5.1 and MCM-5.9A

The Hydrologic Testing Laboratory completed laboratory analyses of core samples from holes MCM-5.1 and MCC-5.9A as summarized in Table 6.3-I. Tables 6.3-II through 6.3-VII summarize the results of specified tests. Laboratory worksheets and graphical plots of data (where appropriate) are contained in Appendices 8.8-A through 8.8-G. Appendix 8.8-H references methods used in these analyses.

Appendix 8.8-I details the Quality Assurance and Quality Control Program. This appendix gives an overview of the program, followed by specific requirements for sample handling, data analysis, report view, and program implementation.

Test results on samples from holes MCM-5.1 and MCC-5.9A have been tabulated and illustrated in the attached tables and plots. In general, intact MCC-5.9A samples yielded lower density (higher porosity) values than samples from the same Bandelier Tuff subunits found in hole MCM-5.1. This may be due to a number of factors, including spatial variability of hydraulic properties and/or sample disturbance occurring during any combination of the following activities: coring, handling, shipping, and storage. Measurements of sample diameter made during Phase I testing of MCM-5.1 samples suggest that some degree of expansion of samples may have occurred between the time they were collected and delivered for analysis. Samples from MCC-5.9A are approximately 0.15 cm larger in diameter than samples from MCM-5.1. These differences suggest that samples from MCC5.9A may have expanded (as a result of unloading) during storage, because samples from both holes were obtained with equivalent core barrels and cutting shoes.

Water content data for cores from both MCC-5.9A and MCM-5.1 suggest that a nearly saturated perched zone exists near the Tshirege-Tsankowi contact. (Water potential data near this contact are not completely consistent with water content data. However, greater reliance is generally not placed upon psychrometer readings above potentials of approximately negative three bar.)

Air permeabilities are summarized in Table 6.3-V. Permeabilities were measured at one and five bars negative potential. Unexpectedly, measured permeability did not increase significantly from one to five bars negative potential. Air permeability can also be estimated from hydraulic conductivity (Table 6.3-V). Estimated and measured permeabilities are of similar magnitude.

N and alpha parameters calculated from equilibrium measurements agree well with parameters obtained from one-step outflow data (Tables 6.3-VI-A and 6.3-VI-B vs. Tables 6.3-VII-A and 6.3-VII-B). One-step outflow alphas tend to be slightly smaller than the estimate obtained from equilibrium measurements. One-step N values tend to be slightly larger than N from equilibrium data.

Overall, the data appear internally consistent for extracted parameters from individual cores. In addition, hydraulic property behavior as a function of depth appears consistent and reasonable.

TABLE 6.3-I SUMMARY OF PROGRESS AS OF MARCH 31, 1991

UNIT	SAMPLE NUMBER	SATURATED HYDRAULIC CONDUCTIVITY	MOISTURE RETENTION SPOC	UNSATURATED HYDRAULIC CONDUCTIVITY CALCULATED	UNSATURATED HYDRAULIC CONDUCTIVITY ONE-STEP
Upper Tshirege	MCM 5.1 - 43.0-43.5	1	2	4	3
Middle Tshirege	MCM 5.1 - 53.0-54.0 Chem	1	1	1	1
	MCM 5.1 - 57.5-58.0	1	1	1	5
	MCM 5.1 - 63.0-64.0 Chem	1	1	1	5
Lower Tshirege	MCM 5.1 - 67.0-67.5	1	1	1	5
	MCM 5.1 - 72.0-72.5	1	1	1	5
	MCM 5.1 - 82.0-82.5	1	1	1	1
	MCM 5.1 - 87.0-87.5	1	1	1	5
	MCC 5.9A - 85.5-86.0	1	1	1	5
	MCC5.9A - 94.5-95.0	1	1	1	5

LEGEND:

1 - Test completed.
2 - Test in progress.
3 - Test completed, data analysis dependent upon completion of moisture retention tests.
4 - Test not started
5 - Test not specified

TABLE 6.3-I SUMMARY OF PROGRESS AS OF MARCH 31, 1991 (CONTINUED)

UNIT	SAMPLE NUMBER	SATURATED HYDRAULIC CONDUCTIVITY	MOISTURE RETENTION SPOC	UNSATURATED HYDRAULIC CONDUCTIVITY CALCULATED	UNSATURATED HYDRAULIC CONDUCTIVITY ONE-STEP
Tsankawi	**MCM 5.1 - 92.5-93.0**	1	1	1	5
	MCM 5.1 - 94.5-95.0	1	2	4	5
	MCM 5.1 - 97.0-97.5	1	1	1	5
	MCM 5.1 - 102.0-102.5	4	4	4	5
	MCM 5.1 - 107.0-107.5	1	1	1	1
	MCC 5.9A - 104.5-105.0	1	1	1	1
	MCC 5.9A - 109.0-109.5	1	1	1	1
Otowi	**MCC 5.9A - 119.5-120.0**	1	1	1	1
	MCC 5.9A - 124.5-125.0	1	2	4	5
	MCC 5.9A - 129.5-130.0	1	2	4	5
	MCC 5.9A - 149.5-150.0	1	2	4	5
	MCC 5.9A - 164.5-165.0	1	2	4	5

LEGEND:

1 - Test completed.
2 - Test in progress.
3 - Test completed, data analysis dependent upon completion of moisture retention tests.
4 - Test not started
5 - Test not specified

TABLE 6.3-IIA SUMMARY OF DENSITY AND POROSITY DATA (MOISTURE RETENTION SAMPLES)

	PHASE I		PHASE II			
SAMPLE NUMBER	DRY BULK DENSITY (g/cm^3)	CALCULATED POROSITY[1] (cm^3/cm^3)	DRY BULK DENSITY (g/cm^3)	GRAIN DENSITY (g/cm^3)	CALCULATED POROSITY (cm^3/cm^3)	SATURATED POROSITY (cm^3/cm^3)
MCM 5.1-53-54 CHEM P.P			1.16	2.32	50.21[2]	43.81
MCM 5.1-53-54 CHEM SPOC			1.15	2.32	50.50[2]	45.43
MCM 5.1-57.0-57.5	1.09	55.51				
MCM 5.1-57.5-58.0			1.18	2.32	49.14	51.97
MCM 5.1-63-64 CHEM P.P			1.17	2.32	49.35[2]	43.98
MCM 5.1-67.0-67.5			1.15	2.32	50.56[2]	51.92
MCM 5.1-67.5-68.0	1.23	49.80				
MCM 5.1-72.0-72.5			1.19	2.32	48.87	51.47
MCM 5.1-72.5-73.0	1.09	55.51				
MCM 5.1-82.0-82.5			1.20	2.32	48.29[2]	58.93
MCM 5.1-87.0-87.5			1.09	2.32	53.07[2]	51.17
MCM 5.1-87.5-88.0	1.13	53.88				

[1] Assumes a grain density of 2.45 g/cm^3.

[2] Assumes grain density of Tshirege unit = 2.32 g/cm^3

[3] Assumes grain density of Tsankawi unit = 2.48 g/cm^3

[4] Assumes grain density of Otowi unit = 2.31 g/cm^3

TABLE 6.3-IIA SUMMARY OF DENSITY AND POROSITY DATA (CONTINUED) (MOISTURE RETENTION SAMPLES)

SAMPLE NUMBER	PHASE I		PHASE II			
	DRY BULK DENSITY (g/cm^3)	CALCULATED POROSITY[1] (cm^3/cm^3)	DRY BULK DENSITY (g/cm^3)	GRAIN DENSITY (g/cm^3)	CALCULATED POROSITY (cm^3/cm^3)	SATURATED POROSITY (cm^3/cm^3)
MCM 5.1-92.0-92.5	1.24	49.39				
MCM 5.1-92.5-93.0			1.32	2.48	46.71[3]	47.24
MCM 5.1-97.0-97.5			1.37	2.48	44.79	45.54
MCM 5.1-97.5-98.0	1.42	42.04				
MCM 5.1-107.0-107.5			1.46	2.48	41.18[3]	47.76
MCC 5.9A-85.5-86.0			1.08	2.32	53.23[2]	68.63
MCC 5.9A-94.5-95.0			1.35	2.32	41.75[2]	49.85
MCC 5.9A-104.5-105.0			1.27	2.48	48.81[3]	55.71
MCC 5.9A-109.0-109.5			1.01	2.48	59.20[3]	64.65
MCC 5.9A-119.5-120.0			1.11	2.31	51.95	43.53

---

[1] Assumes a grain density of 2.45 g/cm^3.

[2] Assumes grain density of Tshirege unit = 2.32 g/cm^3

[3] Assumes grain density of Tsankawi unit = 2.48 g/cm^3

[4] Assumes grain density of Otowi unit = 2.31 g/cm^3

TABLE 6.3-IIB SUMMARY OF INITIAL MOISTURE CONTENT, DRY BULK DENSITY, POROSITY, AND WATER POTENTIAL MCM 5.1 SAMPLES

PHASE I COMPLETE

Sample Number	Initial Moisture Content: Gravimetric (%,g/g)	Initial Moisture Content: Volumetric (%,cm^3/cm^3)	Initial Moisture Content: Saturation %	Density (g/cm^3)	Calculated Porosity (%)	Water Potential (-bars)
[1] MCM 5.1 - 3.5-4.0	4.86	6.53	14.41	1.34	45.31	5.9
[1] MCM 5.1 - 7.5-8.0	2.34	8.29	19.34	1.40	42.86	0.4 [2]
[1] MCM 5.1 - 13.0-13.5	5.80	8.13	18.97	1.40	42.86	0.4 [2]
[1] MCM 5.1 - 17.5-18.0	15.86	21.57	48.48	1.36	44.49	1.0
[1] MCM 5.1 - 22.0-22.5	20.55	25.76	52.59	1.25	48.98	0.8 [2]
[1] MCM 5.1 - 27.5-28.0	29.03	41.78	101.35	1.44	41.22	0.8 [2]
[3] MCM 5.1 - 33.5-34.0	16.29	28.45	99.58	1.75	28.57	1.2
[1] MCM 5.1 - 42.5-43.0	20.28	24.06	46.78	1.19	51.43	0.3 [2]
[1] MCM 5.1 - 46.0-46.5	15.09	14.93	25.05	0.99	59.59	0.4 [2]

[1] Samples immediately adjacent to these samples have been selected for Phase II testing including saturated hydraulic conductivity, moisture retention characteristics, and unsaturated hydraulic conductivity.

[2] Water potentials between -0.1 and -1.0 bars fall outside of the calibration range of DBS&A's thermocouple psychrometer instrumentation and therefore should be considered only approximations. The level of uncertainty associated with these values is unknown and probably increases as values approach 0.0 bars. These values have not been reported simply as -1.0 because DBS&A believes the *relative values of the data are useful*. For example, -0.2 bars is greater than -0.5 bars, which in turn is greater than -0.7 bars. DBS&A is in the process of developing techniques to calibrate this apparatus to values closer to -0.1 bars.

[3] Sample consists of alluvium which caved into the borehole. It is not tuffaceous bedrock.

TABLE 6.3-IIB SUMMARY OF INITIAL MOISTURE CONTENT, DRY BULK DENSITY, POROSITY, AND WATER POTENTIAL (CONTINUED)
MCM 5.1 SAMPLES
PHASE I COMPLETE

	Initial Moisture Content					
Sample Number	Gravimetric (%,g/g)	Volumetric (%,cm^3/cm^3)	Saturation %	Density (g/cm^3)	Calculated Porosity (%)	Water Potential (-bars)
MCM 5.1 - 50.0-50.5	15.67	N/A	N/A	N/A	N/A	0.4 [2]
[1] MCM 5.1 - 52.5-53.0	15.72	17.06	30.73	1.09	55.51	0.3 [2]
MCM 5.1 - 55.0-55.5	15.32	N/A	N/A	N/A	N/A	0.4 [2]
[1] MCM 5.1 - 57.0-57.5	14.88	16.15	29.09	1.09	55.51	0.2 [2]
[1] MCM 5.1 - 62.5-63.0	15.77	14.40	22.91	0.91	62.86	0.4 [2]
MCM 5.1 - 65.0-65.5	15.99	19.20	37.63	1.20	51.02	1.0
[1] MCM 5.1 - 67.5-68.0	16.37	20.15	40.46	1.23	49.80	0.6 [2]
[1] MCM 5.1 - 70.0-70.5	18.20	N/A	N/A	N/A	N/A	0.5 [2]
MCM 5.1 - 72.5-73.0	18.64	20.34	36.64	1.09	55.51	0.4 [2]

[1] Samples immediately adjacent to these samples have been selected for Phase II testing including saturated hydraulic conductivity, moisture retention characteristics, and unsaturated hydraulic conductivity.

[2] Water potentials between -0.1 and -1.0 bars fall outside of the calibration range of DBS&A's thermocouple psychrometer instrumentation and therefore should be considered only approximations. The level of uncertainty associated with these values is unknown and probably increases as values approach 0.0 bars. These values have not been reported simply as -1.0 because DBS&A believes the relative values of the data are useful. For example, -0.2 bars is greater than -0.5 bars, which in turn is greater than -0.7 bars. DBS&A is in the process of developing techniques to calibrate this apparatus to values closer to -0.1 bars.

[3] Sample consists of alluvium which caved into the borehole. It is not tuffaceous bedrock.

TABLE 6.3-IIB SUMMARY OF INITIAL MOISTURE CONTENT, DRY BULK DENSITY, POROSITY, AND WATER POTENTIAL (CONTINUED)
MCM 5.1 SAMPLES
PHASE I COMPLETE

Sample Number	Initial Moisture Content Gravimetric (%,g/g)	Volumetric (%,cm³/cm³)	Saturation %	Density (g/cm³)	Calculated Porosity (%)	Water Potential (-bars)
MCM 5.1 - 75.0-75.5	18.40	21.67	41.80	1.18	51.84	0.4 [2]
MCM 5.1 - 77.5-78.0	19.03	22.82	44.73	1.20	51.02	0.4 [2]
MCM 5.1 - 80.0-80.5	19.10	23.22	45.51	1.22	50.20	0.1 [2]
[1] MCM 5.1 - 82.5-83.0	21.26	25.05	48.32	1.18	51.84	0.6 [2]
MCM 5.1 - 85.0-85.5	24.16	28.77	55.94	1.19	51.43	0.5 [2]
[1] MCM 5.1 - 87.5-88.0	29.83	33.84	62.80	1.13	53.88	0.8 [2]
MCM 5.1 - 90.0-90.5	36.76	43.30	83.52	1.18	51.84	0.2 [2]
[1] MCM 5.1 - 92.0-92.5	35.26	43.75	88.58	1.24	49.39	0.1 [2]
[1] MCM 5.1 - 94.5-95.0	36.49	N/A	N/A	N/A	N/A	0.3 [2]

[1] Samples immediately adjacent to these samples have been selected for Phase II testing including saturated hydraulic conductivity, moisture retention characteristics, and unsaturated hydraulic conductivity.

[2] Water potentials between -0.1 and -1.0 bars fall outside of the calibration range of DBS&A's thermocouple psychrometer instrumentation and therefore should be considered only approximations. The level of uncertainty associated with these values is unknown and probably increases as values approach 0.0 bars. These values have not been reported simply as -1.0 because DBS&A believes the relative values of the data are useful. For example, -0.2 bars is greater than -0.5 bars, which in turn is greater than -0.7 bars. DBS&A is in the process of developing techniques to calibrate this apparatus to values closer to -0.1 bars.

[3] Sample consists of alluvium which caved into the borehole. It is not tuffaceous bedrock.

TABLE 6.3-IIB SUMMARY OF INITIAL MOISTURE CONTENT, DRY BULK DENSITY, POROSITY, AND WATER POTENTIAL (CONTINUED)
MCM 5.1 SAMPLES
PHASE I COMPLETE

	Initial Moisture Content					
Sample Number	Gravimetric (%,g/g)	Volumetric (%,cm^3/cm^3)	Saturation %	Density (g/cm^3)	Calculated Porosity (%)	Water Potential (-bars)
[1] MCM 5.1 - 97.5-98.0	25.87	36.85	87.65	1.42	42.04	0.9 [2]
[1]MCM 5.1 - 98.0-98.5	24.98	33.06	71.68	1.32	46.12	0.5 [2]
MCM 5.1 - 102.5-103.0	17.61	22.43	46.57	1.27	48.16	0.7 [2]
MCM 5.1 - 103.0-103.5	19.02	N/A	N/A	N/A	N/A	0.9 [2]
[1] MCM 5.1 - 107.5-108.0	18.82	24.30	51.32	1.29	47.35	0.8 [2]
[1] MCM 5.1 - 110.0-110.5	10.62	17.01	49.03	1.60	34.69	1.0

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[1] Samples immediately adjacent to these samples have been selected for Phase II testing including saturated hydraulic conductivity, moisture retention characteristics, and unsaturated hydraulic conductivity.

[2] Water potentials between -0.1 and -1.0 bars fall outside of the calibration range of DBS&A's thermocouple psychrometer instrumentation and therefore should be considered only approximations. The level of uncertainty associated with these values is unknown and probably increases as values approach 0.0 bars. These values have not been reported simply as -1.0 because DBS&A believes the relative values of the data are useful. For example, -0.2 bars is greater than -0.5 bars, which in turn is greater than -0.7 bars. DBS&A is in the process of developing techniques to calibrate this apparatus to values closer to -0.1 bars.

[3] Sample consists of alluvium which caved into the borehole. It is not tuffaceous bedrock.

TABLE 6.3-IIC SUMMARY OF INITIAL MOISTURE CONTENT, DRY BULK DENSITY, POROSITY, AND WATER POTENTIAL
MCC 5.9A SAMPLES
PHASE I COMPLETE

	Initial Moisture Content					
Sample Number	Gravimetric (%,g/g)	Volumetric (%,cm^3/cm^3)	Saturation %	Density (g/cm^3)	Calculated Porosity (%)	Water Potential (-bars)
MCC 5.9A - 84.5-85.0	39.06	38.91	65.58	1.00	59.33	0.7 [1]
[3] MCC 5.9A - 85.5-86.0	35.38	38.79	69.89	1.09	55.50	0.8 [1]
MCC 5.9A - 89.5-90.0	44.21	42.21	69.15	0.95	61.04	0.6 [1]
[3] MCC 5.9A - 94.5-95.0	11.36	17.22	45.15	1.52	38.14	1.8
[3] MCC 5.9A - 104.5-105.0	60.53	55.75	89.33	0.92	62.41	1.5
[3] MCC 5.9A - 109.0-109.5	49.33	44.46	70.34	0.90	63.21	1.2
[3] MCC 5.9A - 119.5-120.0	21.37	23.18	41.59	1.08	55.73	0.7 [1]
[3] MCC 5.9A - 124.5-125.0	16.12	17.93	32.83	1.11	54.61	0.3 [1]
[3] MCC 5.9A - 129.5-130.0	18.50	19.49	34.20	1.05	56.99	0.4 [1]

[1] Water potentials between -0.1 and -1.0 bars fall outside of the calibration range of DBS&A's thermocouple psychrometer instrumentation and therefore should be considered only approximations. The level of uncertainty associated with these values is unknown and probably increases as values approach 0.0 bars. These values have not been reported simply as <1.0 because DBS&A believes the relative values of the data are useful. For example, -0.2 bars is greater than -0.5 bars, which in turn is greater than -0.7 bars. DBS&A is in the process of developing techniques to calibrate this apparatus to values closer to -0.1 bars.

[2] Water potentials were measured in [illegible]atory as positive values and therefore are outside of the calibration range of the thermocouple psychrometer (see Footnote 1). DBS&A believes these numbers are close to zero and is therefore reporting them as such.

[3] Samples from these intervals have been selected for Phase II testing.

TABLE 6.3-IIC SUMMARY OF INITIAL MOISTURE CONTENT, DRY BULK DENSITY, POROSITY, AND WATER POTENTIAL (CONTINUED)
MCC 5.9A SAMPLES

PHASE I COMPLETE

Sample Number	Initial Moisture Content Gravimetric (%,g/g)	Volumetric (%,cm³/cm³)	Saturation %	Density (g/cm³)	Calculated Porosity (%)	Water Potential (-bars)
MCC 5.9A - 134.5-135.0	18.65	N/A	N/A	N/A	N/A	0.8 [1]
MCC 5.9A - 139.5-140.0	18.94	N/A	N/A	N/A	N/A	0.8 [1]
MCC 5.9A - 144.5-145.0	17.66	N/A	N/A	N/A	N/A	0.6 [1]
[3] MCC 5.9A - 149.5-150.0	18.98	22.10	42.10	1.16	52.49	0.2 [1]
MCC 5.9A - 154.5-155.0	17.42	21.67	44.01	1.24	49.24	0.0 [2]
[3] MCC 5.9A - 164.5-165.0	16.82	21.23	43.79	1.26	48.48	0.0 [2]
MCC 5.9A - 169.5-170.0	15.83	N/A	N/A	N/A	N/A	0.0 [2]
MCC 5.9A - 174.5-175.0	15.92	N/A	N/A	N/A	N/A	0.0 [2]
MCC 5.9A - 179.5-180.0	15.92	N/A	N/A	N/A	N/A	0.0 [2]
MCC 5.9A - 184.5-185.0	16.49	N/A	N/A	N/A	N/A	0.0 [2]

[1] Water potentials between -0.1 and -1.0 bars fall outside of the calibration range of DBS&A's thermocouple psychrometer instrumentation and therefore should be considered only approximations. The level of uncertainty associated with these values is unknown and probably increases as values approach 0.0 bars. These values have not been reported simply as <1.0 because DBS&A believes the relative values of the data are useful. For example, -0.2 bars is greater than -0.5 bars, which in turn is greater than -0.7 bars. DBS&A is in the process of developing techniques to calibrate this apparatus to values closer to -0.1 bars.

[2] Water potentials were measured in the laboratory as positive values and therefore are outside of the calibration range of the thermocouple psychrometer (see Footnote 1). DBS&A believes these numbers are close to zero and is therefore reporting them as such.

[3] Samples from these intervals have been selected for Phase II testing.

TABLE 6.3-IIIA SUMMARY OF SATURATED HYDRAULIC CONDUCTIVITY TESTS
MCM 5.1 Samples

Sample Number	Ks(cm/sec)	Method of Analysis	
		Constant Head	Falling Head
MCM 5.1 - 31.5-32.0	1.0×10^{-3}	X	
MCM 5.1 - 43.0-43.5	2.4×10^{-4}	X	
MCM 5.1 - 53.0-54.0 CHEM	1.5×10^{-4}		X
MCM 5.1 - 57.5-58.0	1.8×10^{-4}	X	
MCM 5.1 - 63.0-64.0 CHEM	1.3×10^{-4}		X
MCM 5.1 - 67.0-67.5	1.1×10^{-4}	X	
MCM 5.1 - 72.0-72.5	1.4×10^{-4}	X	
MCM 5.1 - 82.0-82.5	1.2×10^{-4}	X	
MCM 5.1 - 87.0-87.5	1.1×10^{-4}	X	
MCM 5.1 - 92.5-93.0	4.7×10^{-5}	X	
MCM 5.1 - 94.5-95.0	6.8×10^{-4}	X	
MCM 5.1 - 97.0-97.5	5.8×10^{-5}	X	
MCM 5.1 -107.0-107.5	1.3×10^{-3}	X	

TABLE 6.3-IIIB SUMMARY OF SATURATED HYDRAULIC CONDUCTIVITY TESTS MCC 5.9A SAMPLES

Sample Number	Ks(cm/sec)	Method of Analysis Constant Head	Falling Head
MCC 5.9A - 85.5-86.0	3.9×10^{-3}	X	
MCC 5.9A - 94.5-95.0	1.1×10^{-3}	X	
MCC 5.9A - 104.5-105.0	2.0×10^{-3}	X	
MCC 5.9A - 109.0-109.5	4.3×10^{-3}	X	
MCC 5.9A - 119.5-120.0	7.9×10^{-4}	X	
MCC 5.9A - 124.5-125.0	2.8×10^{-4}	X	
MCC 5.9A - 129.5-130.0	7.8×10^{-3}	X	
MCC 5.9A - 149.5-150.0	1.7×10^{-3}	X	
MCC 5.9A - 164.5-165.0	2.9×10^{-4}	X	

TABLE 6.3-IVA SUMMARY OF MOISTURE CHARACTERISTICS OF THE INITIAL DRAINAGE CURVE (REPORTED JANUARY 1991)

Sample Number	Pressure Head (-cm water)	Moisture Content (%,cm^3/cm^3)
MCM 5.1 - 57.5-58.0	0	52.0
	61	45.2
	102	41.9
	510	20.9
	1020	15.6
	3060	12.2
	5100	9.9
	15300	8.9
	* 15000	6.1
MCM 5.1 - 67.0-67.5	0	52.0
	61	45.9
	102	42.7
	510	20.6
	1020	17.0
	3060	14.3
	5100	12.7
	* 15300	10.1
	23000	4.9
MCM 5.1 - 72.0-72.5	0	51.5
	61	45.3
	102	40.2
	510	21.7
	1020	17.8
	3060	13.3
	5100	11.4
	15300	9.9
	* 23000	4.0

* Measured with Richards Thermocouple Psychrometer

TABLE 6.3-IVA SUMMARY OF MOISTURE CHARACTERISTICS OF THE INITIAL DRAINAGE CURVE (CONTINUED)
(REPORTED JANUARY 1991)

Sample Number	Pressure Head (-cm water)	Moisture Content (%,cm^3/cm^3)
MCM 5.1 - 87.0-87.5	0	51.2
	61	45.2
	102	41.7
	510	25.9
	1020	20.5
	3060	14.2
	5100	11.1
	15300	6.3
	* 19000	4.9
MCM 5.1 - 92.5-93.0	0	47.2
	61	42.7
	102	41.7
	510	35.2
	1020	31.1
	3060	22.8
	5100	19.2
	15300	13.0
	* 12000	13.54
MCM 5.1 - 97.0-97.5	0	45.4
	61	42.7
	102	42.1
	510	40.3
	1020	38.6
	3060	32.8
	5100	30.7
	15300	23.6
	* 12000	14.67

* Measured with Richards Thermocouple Psychrometer

TABLE 6.3-IVB SUMMARY OF MOISTURE RETENTION CHARACTERISTICS (SPOC)

MCM 5.1 SAMPLES

Sample Number	Pressure Head (-cm water)	Moisture Content (%,cm^3/cm^3)
MCM 5.1 53-54 CHEM	0	45.43
	62	41.99
	102	38.50
	510	24.14
	918	21.50
	3070	18.94
	4977	17.15
	14277	16.82
	* 8209	16.82
MCM 5.1 82.0-82.5	0	58.94
	62	52.73
	102	49.65
	510	36.03
	918	33.22
	3070	27.19
	4977	23.04
	14277	22.04
	* 6109	22.04
MCM 5.1 107.0-107.5	0	47.77
	62	36.45
	102	33.00
	510	24.64
	918	22.97
	3070	18.52
	4977	16.69
	14277	14.99
	* 13176	14.99

* Measured with Richards Thermocouple Psychrometer

TABLE 6.3-IVC SUMMARY OF MOISTURE RETENTION CHARACTERISTICS (SPOC)
MCC 5.9A SAMPLES

Sample Number	Pressure Head (-cm water)	Moisture Content (%,cm³/cm³)
MCC 5.9A 85.5-86.0	0	68.63
	62	45.44
	102	41.18
	510	34.64
	918	32.25
	3070	28.72
	4977	26.21
	14277	20.91
	* 5874	20.91
MCC 5.9A 94.5-95.0	0	49.85
	62	33.65
	102	30.04
	510	22.15
	918	20.03
	3070	15.44
	4977	14.10
	14277	12.42
	* 15226	12.42
MCC 5.9A 104.5-105.0	0	53.71
	62	52.71
	102	50.37
	510	42.69
	918	40.58
	3070	35.64
	4977	33.62
	14277	32.91
	* 12962	32.91

* Measured with Richards Thermocouple Psychrometer

TABLE 6.3-IVC SUMMARY OF MOISTURE RETENTION CHARACTERISTICS (CONTINUED) (SPOC)
MCC 5.9A SAMPLES

Sample Number	Pressure Head (-cm water)	Moisture Content (%,cm^3/cm^3)
MCC 5.9A 109.0-109.5	0	64.64
	62	57.17
	102	55.71
	510	45.56
	918	39.50
	3070	30.40
	4977	27.80
	14277	19.85
	* 4712	19.85
MCC 5.9A 119.5-120.0	0	43.53
	62	34.95
	102	30.46
	510	17.69
	918	15.56
	3070	9.74
	4977	6.90
	14277	5.15
	* 8525	5.15

* Measured with Richards Thermocouple Psychrometer

TABLE 6.3-V SUMMARY OF CALCULATED AIR PERMEABILITY DATA

SAMPLE NUMBER	SAMPLE STATUS		Q_A (cc/sec)	$\bar{P}_{mean\ air}$ (cm)	k_{data} (mD)	ESTIMATION	
	θ	ψ (-cm)				K_s (cm/sec)	k = 1040 K_s (mD)
MCM 5.1 - 53.0-54.0 CHEM	21.50	918	0.57	2.29	413.4	1.5×10^{-4}	156.0
	17.15	4998	0.57	2.52	378.2		
MCM 5.1 - 82.0-82.5	33.22	918	0.58	1.80	576.4	1.2×10^{-4}	124.8
	23.04	4998	0.58	1.92	543.1		
MCM 5.1 - 107.0-107.5	22.97	918	0.61	1.46	751.2	1.3×10^{-3}	135.2
	16.69	499	0.57	1.43	717.9		
MCC 5.9 - 94.5-95.0	20.03	918	0.58	1.43	710.57	1.1×10^{3}	112.2
	14.10	4998	0.57	1.55	641.7		
MCC 5.9 - 104.5-105.0	40.58	918	0.79	6.72	205.6	2.0×10^{-3}	208.0
	33.62	4988	0.98	2.86	597.5		
MCC 5.9 - 119.5-120.0	15.56	918	0.58	1.46	710.0	7.9×10^{-4}	82.1
	6.90	4998	0.57	1.61	624.5		

TABLE 6.3-VIA SUMMARY OF UNSATURATED HYDRAULIC PROPERTIES (CALCULATED) MCM 5.1 SAMPLES

Sample Number	α (cm^{-1})	N (dimensionless)	θ_r (%, cm^3/cm^3)	θ_s (%, cm^3/cm^3)	K_{sat} (cm/sec)
MCM 5.1 - 53-54 CHEM	0.00873	1.88477	16.8	45.4	1.5×10^{-4}
MCM 5.1 - 57.5-58.0	0.00972	1.66746	6.1	52.0	1.8×10^{-4}
MCM 5.1 - 67.0-67.5	0.01016	1.55430	4.9	52.0	1.1×10^{-4}
MCM 5.1 - 72.0-72.5	0.01178	1.49131	4.0	51.5	1.4×10^{-4}
MCM 5.1 - 82.0-82.5	0.01059	1.59133	22.0	58.9	1.2×10^{-4}
MCM 5.1 - 87.0-87.5	0.00915	1.51023	4.9	51.2	1.1×10^{-4}
MCM 5.1 - 92.5-93.0	0.00292	1.67416	10.2	47.2	4.7×10^{-5}
MCM 5.1 - 97.0-97.5	0.00073	1.59926	10.7	45.5	5.8×10^{-5}
MCM 5.1 - 107.0-107.5	0.02968	1.48191	15.0	47.8	1.3×10^{-3}

TABLE 6.3-VIB SUMMARY OF UNSATURATED HYDRAULIC PROPERTIES (CALCULATED)
MCC 5.9A SAMPLES

Sample Number	α (cm^{-1})	N (dimensionless)	θ_r (%, cm^3/cm^3)	θ_s (%, cm^3/cm^3)	K_{sat} (cm/sec)
MCC 5.9A - 85.5-86.0	0.10449	1.34112	20.9	68.6	3.9×10^{-3}
MCC 5.9A - 94.5-95.0	0.04433	1.47491	12.4	49.8	1.1×10^{-3}
MCC 5.9A - 104.5-105.0	0.00508	1.72981	32.9	53.7	2.0×10^{-3}
MCC 5.9A - 109.0-109.5	0.00818	1.45120	19.8	64.6	4.3×10^{-3}
MCC 5.9A - 119.5-120.0	0.01582	1.55108	5.2	43.5	7.9×10^{-4}

TABLE 6.3-VIIA SUMMARY OF UNSATURATED HYDRAULIC PROPERTIES
(ONE-STEP OUTFLOW METHOD - 0-1 BAR)
MCM 5.1 SAMPLES

Laboratory Sample No.	α* (cm^{-1})	N* (dimensionless)	θ_r (%, cm^3/cm^3)	θ_s (%, cm^3/cm^3)	K_s (cm/sec)	r^2 (dimensionless)
MCM 5.1 - 53-54 CHEM	0.00775	1.98333	16.82	45.43	1.5×10^{-4}	0.99187
MCM 5.1 - 82.0-82.5	0.00709	1.80499	22.04	58.94	1.2×10^{-4}	0.99696
MCM 5.1 - 107.0-107.5	0.04110	1.34772	14.99	47.77	1.3×10^{-3}	0.99898

* These values are calculated by the ONESTEP program.

TABLE 6.3-VIIB SUMMARY OF UNSATURATED HYDRAULIC PROPERTIES (ONE-STEP OUTFLOW METHOD - 0-1 BAR) MCC 5.9A SAMPLES

Laboratory Sample No.	α^* (cm^{-1})	N^* (dimensionless)	θ_r (%, cm^3/cm^3)	θ_s (%, cm^3/cm^3)	K_s (cm/sec)	r^2 (dimensionless)
MCC 5.9A - 94.5-95.0	0.03116	2.05202	12.42	49.85	1.1×10^{-3}	0.93906
MCC 5.9A - 104.5-105.0	0.0294	2.05526	32.91	55.71	2.0×10^{-3}	0.86446
MCC 5.9A - 119.5-120.0	0.08343	1.22356	5.64	43.53	7.9×10^{-4}	0.99525

* These values are calculated by the ONESTEP program.

6.3.2. Distributions of Saturation, Conductivity, and Pressure Head

The volumetric moisture contents of cores and the percentage of saturation as measured for cores from holes MCM-5.1 and MCM-5.9A are presented graphically in Figures 6.3.2-1 and 6.3.2-2.

The perched zone shows clearly in Fig. 6.3.2-1 for hole MCM-5.1, followed at increasing depth by a rapid drop to low percentage of saturation from about 45 to 65 feet. Then the degree of saturation increases sharply to nearly saturated conditions, about 90 percent, just at the contact between the Tshirege Unit 1A and the Tsankawi member. It decreases down to less than 40 percent of saturation at the contact with the Otowi member

The same pattern of an increasing degree of saturation, to about 90 percent, also occurs in hole MCM-5.9A as depicted in Fig. 6.3.2-2. Here the apparent peak in the graph occurs a few feet into the Tsankawi member; however, photographs of the core barrel contents suggests that a high degree of saturation was reached by 98 feet, and there simply was no hydrologic core sample collected closer to the contact than the one at 104.5-105 feet. Thus the pattern is essentially identical in both holes.

In hole SIMO-1, which is located in the lower portion of the canyon where there is no saturated alluvium, a similar pattern of volumetric moisture distribution occurs in the Tshirege Unit 1A and Tsankawi members, though at a lower absolute level. The graph in Fig. 6.3.2.3-3 shows an estimated volumetric moisture calculated from the gravimetric moisture measured in the core samples (collected (9/5-6/90) and the average dry bulk densities for the Tshirege Unit 1A, Tsankawi, and Otowi members, and relative volumetric moisture measured with a neutron moisture probe 7 months later (4/9/91). (The neutron moisture probe data is based on the manufacturers calibration, and may not exactly represent the percentage moisture content (volumetric) for the particular access tube, though the relative pattern is correct.) The data show a general decline through the Tshirege Unit 1A down to a depth of about 35 to 40 feet, followed by an increase just above the interface with the Tsankawi member. Then there is a general decline through the Tsankawi to the contact with the Otowi member. This part of the pattern is similar to that observed in holes MCM-5.1, MCM-5.9A, though the absolute volumetric moisture levels in SIMO-1 are about one-third to one-half of those seen in the other holes. At this point the SIMO-1 pattern is different in that there is a general increase through the first 30 feet of the Otowi, with a leveling off at about 12 percent moisture by volume, based on the core sample data. The moisture probe data shows the same pattern, but, especially for the measurements in the Otowi member, are significantly lower. This may be due to probe calibration or it may be attributable to some temporal change in the moisture condition. This will be addressed by future measurements at regular intervals.

The depth distribution of saturated hydraulic conductivities measured on core samples from holes MCM-5.1 and MCM-5.9A is shown graphically in Figure 6.3.2-4. (For purpose of this illustration, the data from hole MCM-5.9A are plotted with a 5 foot upward adjustment in depth so that the values fall in the same relative locations in the geologic units as depicted for hole MCM-5.1)

Based on data from hole MCM-5.1, there is a steady decline in saturated hydraulic conductivity through the portion of the Tshirege Unit 1A beneath the perched aquifer, from about 0.001 cm/sec. (at 32 foot depth) to about 0.00005 cm/sec. (93 foot depth) just at the contact with the Tsankawi member. The data from hole MCM-5.9A include only two cores from the Tshirege Unit 1A, which are about an order of magnitude higher in saturated conductivity. Some of this difference may be attributable to sample expansion (from unloading, see Section 6.3.1) during a longer storage period prior to measurement. The Tsankawi member data based on cores from hole MCM-5.1 range from about 0.00007 to about 0.001 cm/sec., generally higher that the Tshirege member for the same hole. The Tsankawi member saturated conductivities from hole MCM-5.9A follow a similar pattern, ranging from about 0.002 to 0.004 cm/sec. The saturated conductivities in the Otowi based on data from hole MCM-5.9A are generally lower than those observed in the Tsankawi member, ranging from about 0.0003 to 0.008 cm/sec. Four additional core samples of Otowi member tuff from hole MCM-5.1 are currently undergoing a multistep outflow analysis and are expected to help clarify the pattern of saturated and unsaturated hydraulic conductivity in the Otowi member.

The depth distribution of unsaturated hydraulic conductivity is presented in one simplified fashion in Figure 6.3.2-5. This graph shows the apparent unsaturated hydraulic conductivity for the actual in-situ volumetric moisture content present in the cores from holes MCM-5.1 and MCM-5.9A when they were collected. (For purpose of this illustration, the data from hole MCM-5.9A are plotted with a 5 foot upward adjustment in depth so that the values fall in the same relative locations in the geologic units as depicted for hole MCM-5.1) The data points were calculated by taking the saturated hydraulic conductivity measured for a given core and multiplying out the relative hydraulic conductivity for that core at the moisture content measured as its initial condition. This shows a low effective unsaturated hydraulic conductivity in the Tshirege Unit 1A, ranging from about 10^{-11} cm/sec to about 10^{-7} cm/sec at a point about 5 feet above the contact with the Tsankawi member. Then the effective unsaturated hydraulic conductivity rapidly increases by about 4 orders of magnitude reaching a peak between 10^{-3} and 10^{-2} in the Tsankawi member. At the depth of the contact between the Tsankawi and the Otowi members the effective unsaturated hydraulic conductivity declines by about 5 orders of magnitude to between 10^{-8} and 10^{-9} cm/sec. This distribution represents only the point in time when the cores were collected; it can, and probably does, change during the course of a year with different seasonal moisture trends and possibly with infiltration of runoff events.

The unsaturated zone pressure head is depicted graphically in Figure 6.3.2-6. The pressure heads were taken from the hydrologic laboratory moisture characteristic curves for each core sample at the moisture content initially present when the core was collected, which should represent the in-situ condition at that time. (For purpose of this illustration, the data from hole MCM-5.9A are plotted with a 5 foot upward adjustment in depth so that the values fall in the same relative locations in the geologic units as depicted for hole MCM-5.1) Though the data show considerable variability, the general pattern is increasing potential (i.e. smaller negative values) with depth through the Tshirege Unit 1A and the top few feet of the Tsankawi member. Even if the uppermost point is disregarded, the general trend persists. Through this region, for the time represented by the data, water in the unsaturated zone is evidently moving upwards, from the zone of high moisture content near the contact between the Tshirege unit 1A and the Tsankawi toward the surface. This could represent evapotranspiration dominated movement during the relatively dry time from July through September 1990 when there were no significant runoff events in Mortandad Canyon. As with the unsaturated hydraulic conductivity, this distribution represents only the point in time when the cores were collected; it can, and probably does, change during the course of a year with different seasonal moisture trends and possibly with infiltration of runoff events.

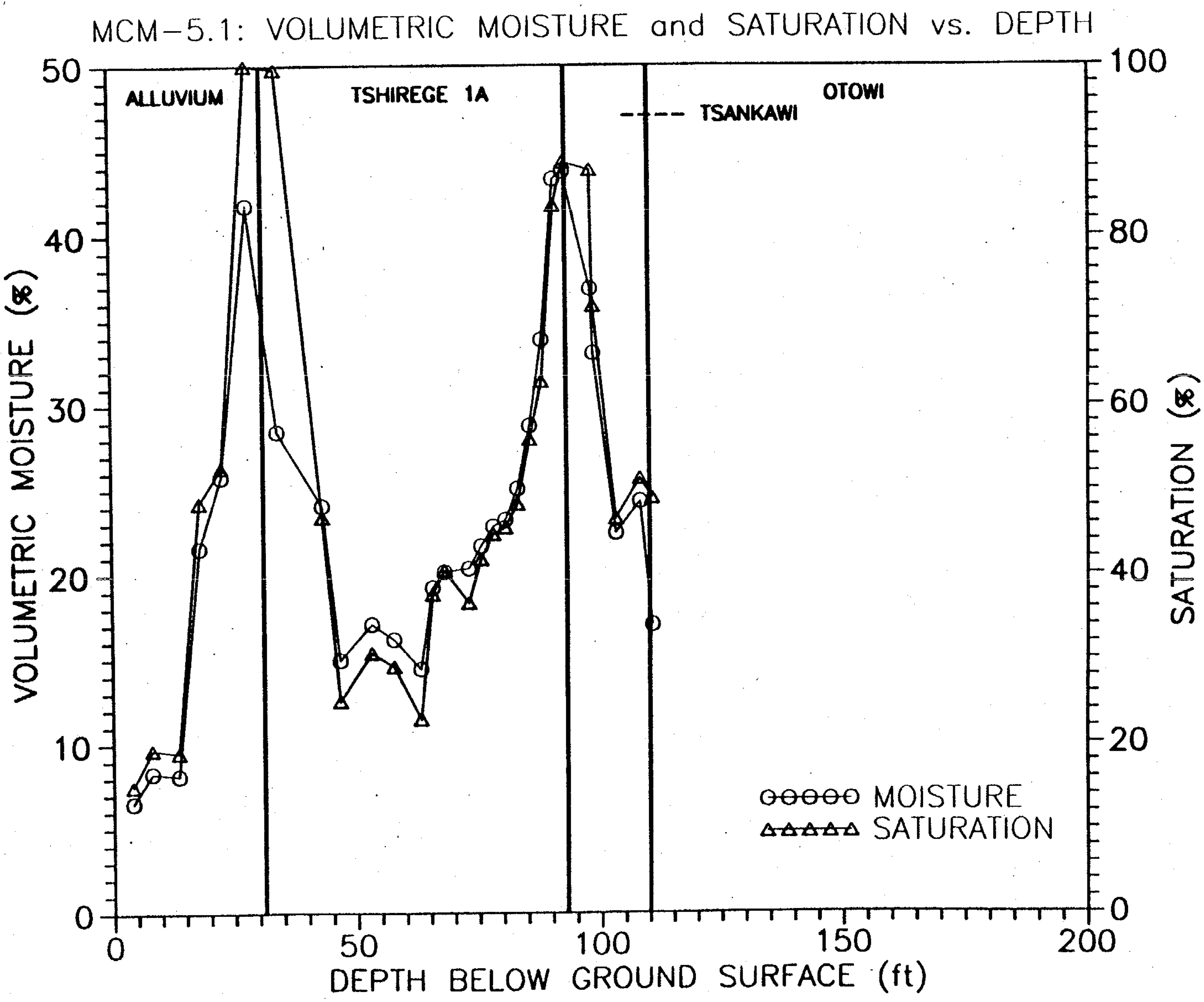
MCM-5.1: VOLUMETRIC MOISTURE and SATURATION vs. DEPTH
ALLUVIUM
TSHIREGE 1A
OTOWI
TSANKAWI
VOLUMETRIC MOISTURE (%)
SATURATION (%)
DEPTH BELOW GROUND SURFACE (ft)
0
10
20
30
40
50
0
20
40
60
80
100
0
50
100
150
200
MOISTURE
SATURATION

Fig. 6.3.2-1

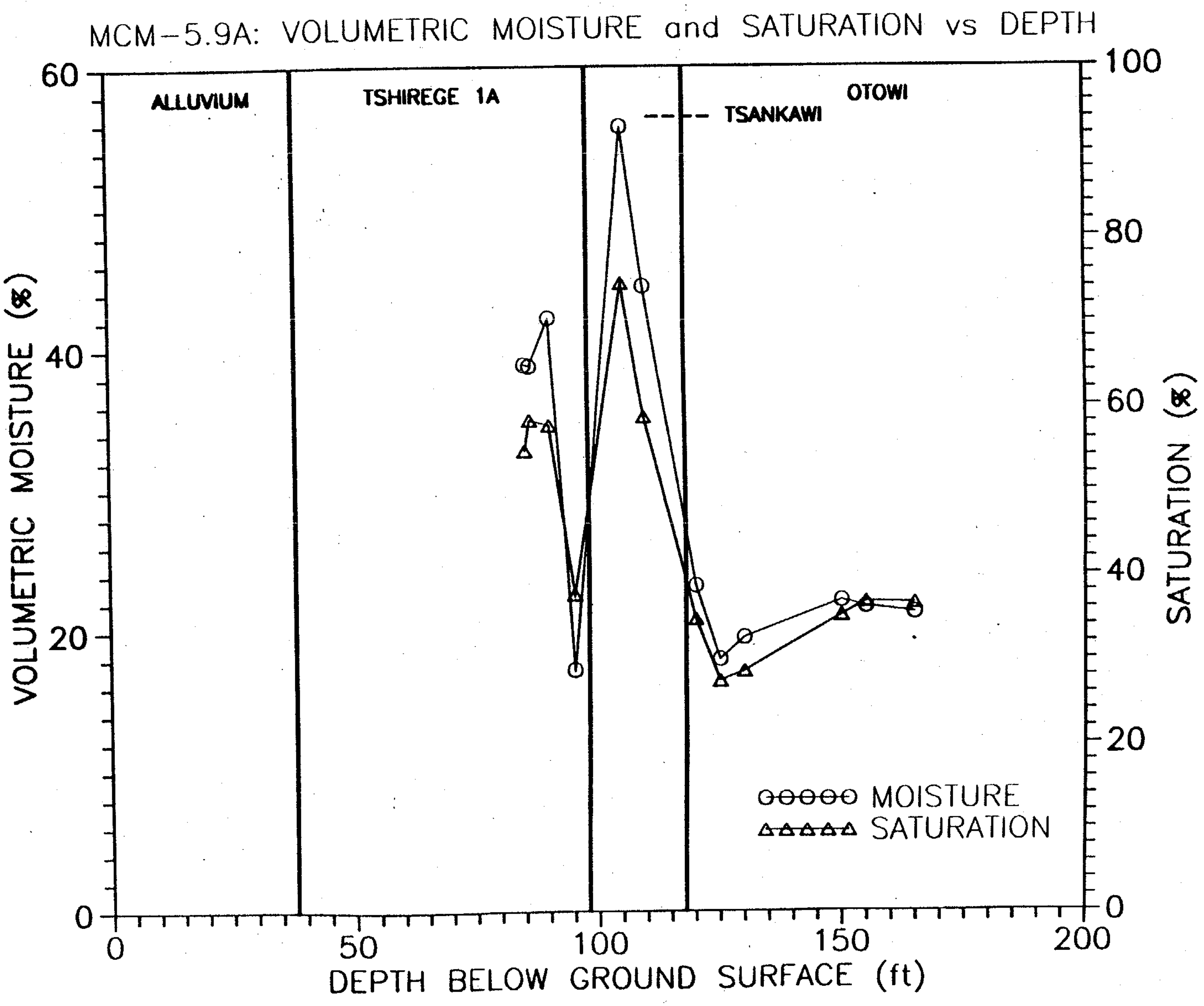
MCM-5.9A: VOLUMETRIC MOISTURE and SATURATION vs DEPTH
ALLUVIUM
TSHIREGE 1A
TSANKAWI
OTOWI
VOLUMETRIC MOISTURE (%)
0
20
40
60
SATURATION (%)
0
20
40
60
80
100
DEPTH BELOW GROUND SURFACE (ft)
0
50
100
150
200
MOISTURE
SATURATION

Fig. 6.3.2-2

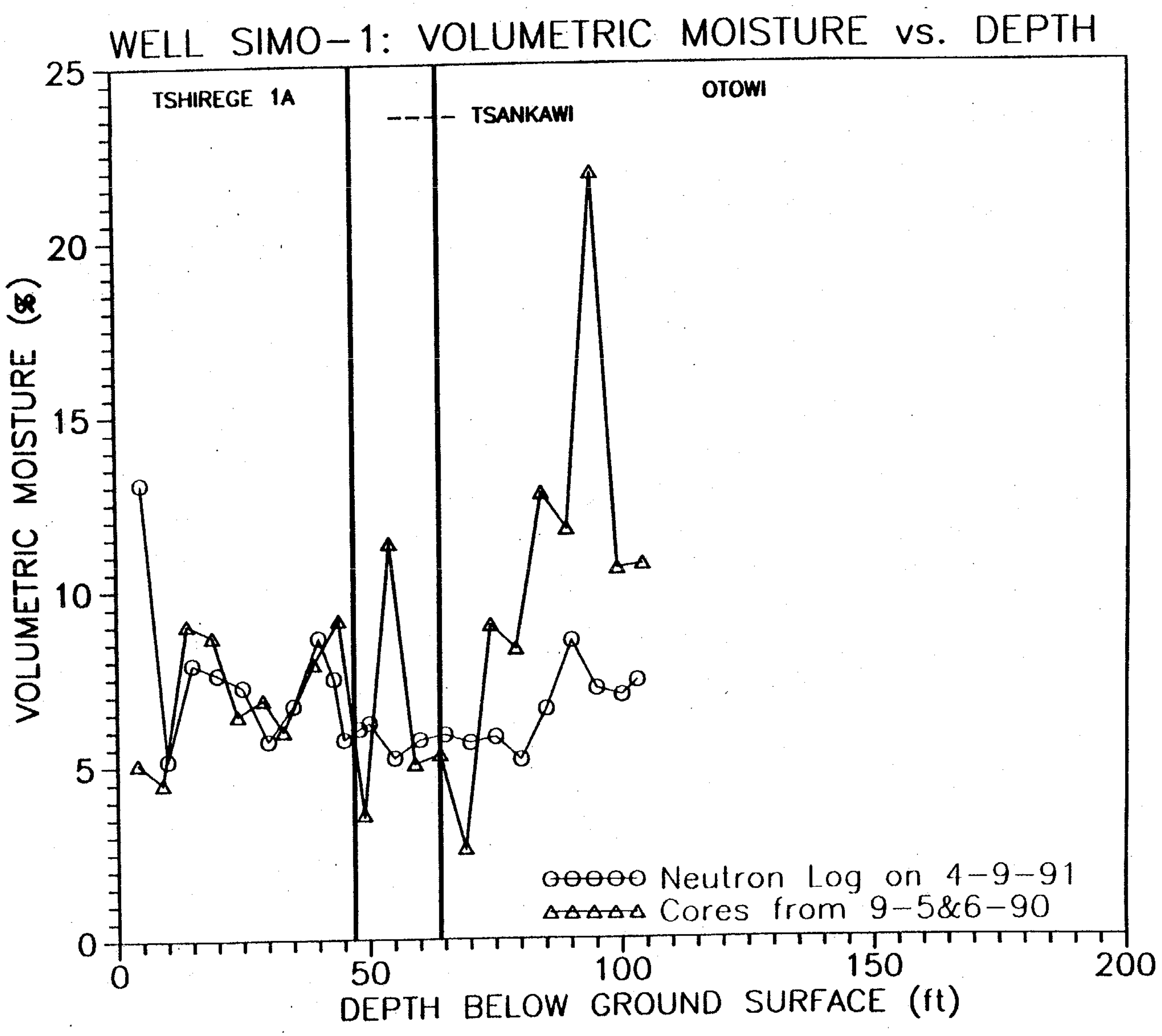
WELL SIMO-1: VOLUMETRIC MOISTURE vs. DEPTH
TSHIREGE 1A
---- TSANKAWI
OTOWI
VOLUMETRIC MOISTURE (%)
0
5
10
15
20
25
0
50
100
150
200
DEPTH BELOW GROUND SURFACE (ft)
ooooo Neutron Log on 4-9-91
ΔΔΔΔΔ Cores from 9-5&6-90

Fig. 6.2.3-3

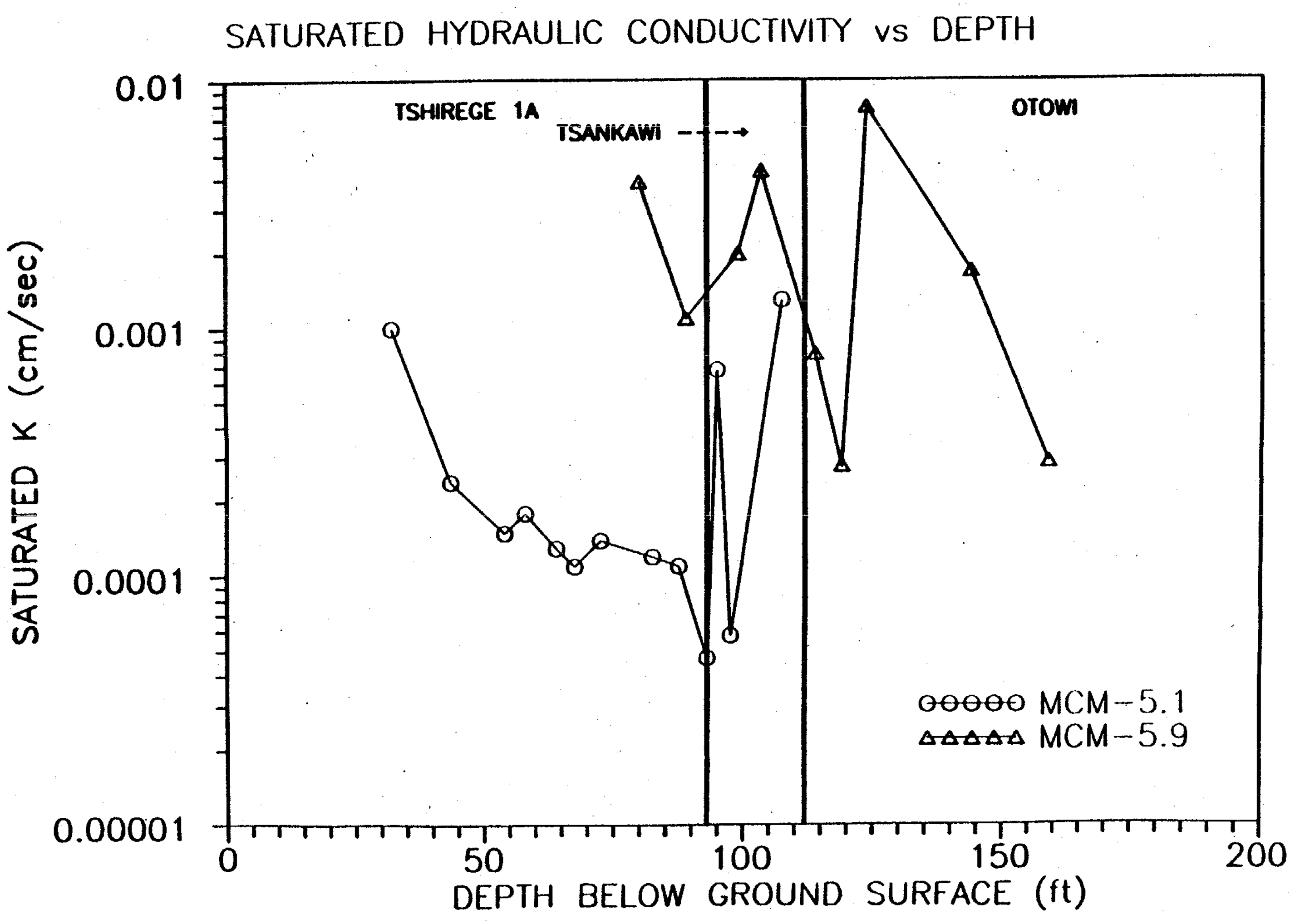
SATURATED HYDRAULIC CONDUCTIVITY vs DEPTH
SATURATED K (cm/sec)
0.01
0.001
0.0001
0.00001
TSHIREGE 1A
TSANKAWI
OTOWI
MCM-5.1
MCM-5.9
0
50
100
150
200
DEPTH BELOW GROUND SURFACE (ft)

Fig. 6.2.3-4

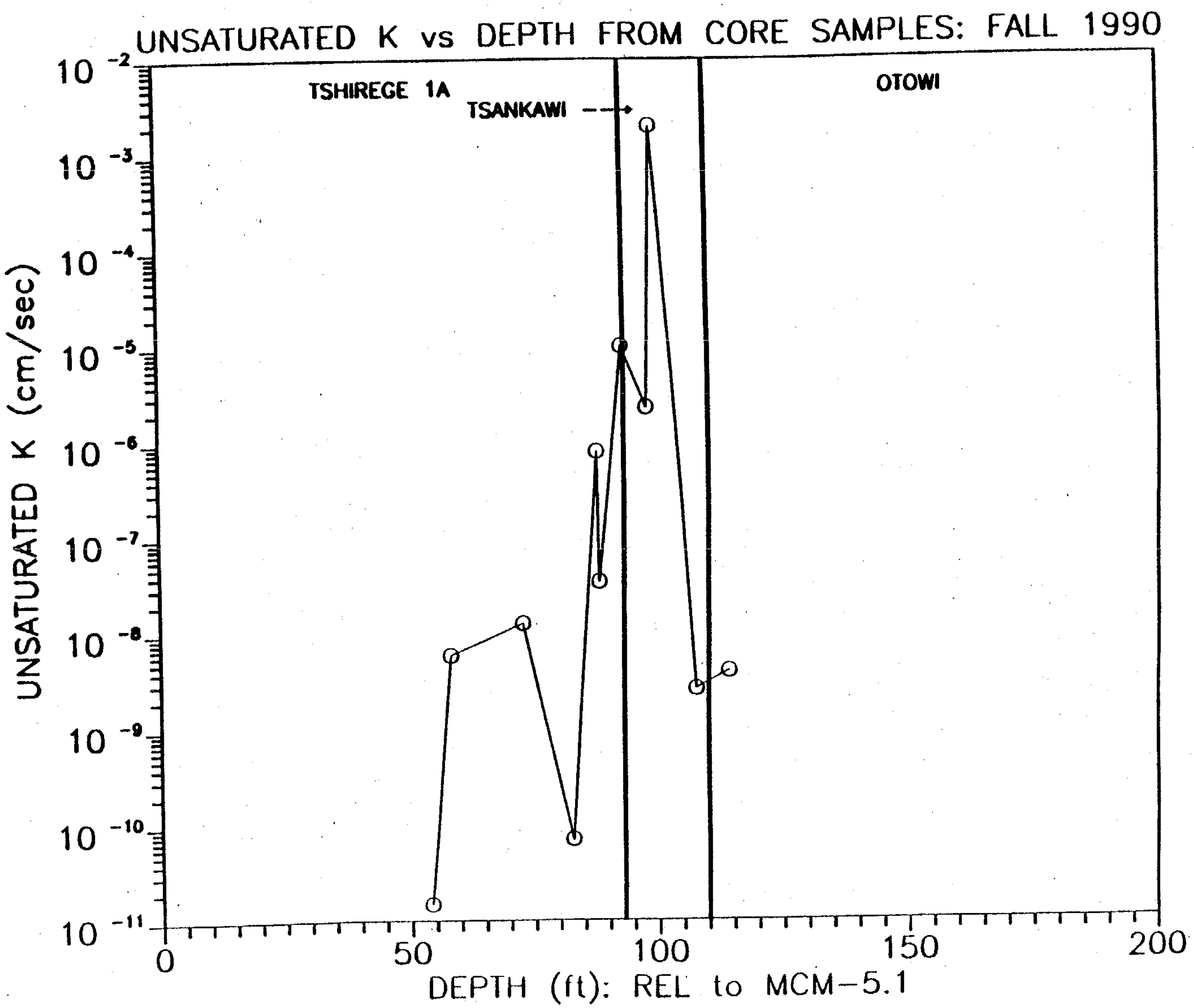
UNSATURATED K vs DEPTH FROM CORE SAMPLES: FALL 1990
TSHIREGE 1A
TSANKAWI
OTOWI
UNSATURATED K (cm/sec)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
0
50
100
150
200
DEPTH (ft): REL to MCM-5.1

Fig. 6.2.3-5

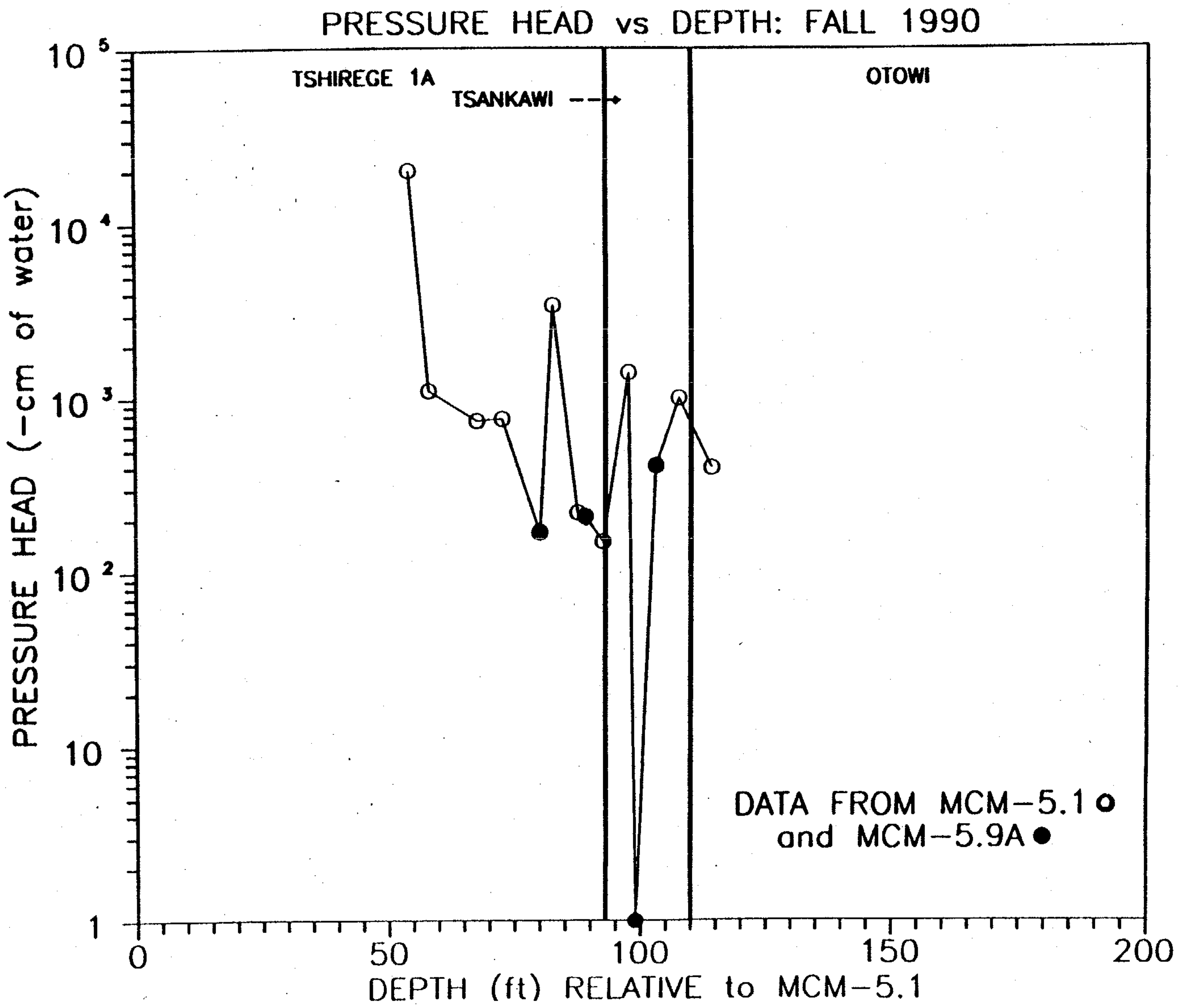
PRESSURE HEAD vs DEPTH: FALL 1990
TSHIREGE 1A
TSANKAWI
OTOWI
PRESSURE HEAD (−cm of water)
10^5
10^4
10^3
10^2
10
1
0
50
100
150
200
DEPTH (ft) RELATIVE to MCM−5.1
DATA FROM MCM−5.1 ○
and MCM−5.9A ●

Fig. 6.2.3-6

7.0 CONCLUSIONS

7.1 Extent of Saturation

The release of industrial effluents, waste water, and storm runoff into Mortandad Canyon recharge the shallow aquifer in the alluvium. Hydrologic data collected prior to 1989 and collected from observation wells, test holes, and moisture probe access holes indicate that since 1960 the alluvial aquifer has not changed significantly in size or moved further toward the east to the Laboratory boundary. The aquifer extends from the plant outfall about 3.5 km to the lower canyon (near the center of the Pajarito Plateau). The saturated alluvium consists of silt, clay, sands, and gravels overlying silts and clays of tuff weathered in place. The development of silts and clays by weathering decrease with increased depth.

Saturation is confined to a relatively thin layer of alluvium, perched above unweathered tuff in the Tshirege Unit 1A Member. The thickness varies both temporally and with distance down canyon. In the upper reach of the canyon, the saturated thickness may be as much as 15 to 20 feet (with water level about 5 feet below surface) in the vicinity of the MCO-4 observation wells in wet times, decreasing to as little as 5 feet (with water level of about 22 feet below surface) in drier times. In the middle portion of the canyon, in the vicinity of the MCO-6 wells, the saturated thickness is generally less than 5 feet thick, with water level fluctuations of 3 to 5 feet in a year (water levels 30 to 33 feet below surface). In the lower portion of the canyon, in the vicinity of MCO-8 wells, the saturated thickness may be as much as 13 feet, with water levels fluctuating as little as 2 feet in 3 years (general water level about 50 to 60 feet below surface). One possible explanation for the greater thickness of saturation is that there is infiltration of water through the sediment traps after large runoff events, resulting in more water in storage in the reach between the traps and MCO-8.

Saturation in the alluvium thins toward the sides of the canyon, and there may be some mounding or sloping of the upper surface away from the general location of the stream channel.

Saturation extends continuously down the canyon to about the location of MCM-8.2, as observed by holes and confirmed by shallow seismic refraction. Shallow seismic refraction also suggests possible near-saturation conditions as far as about 4.3 km downstream toward the south side of the canyon; however, none of the observation wells or moisture probe holes that far downstream nearer the center of the canyon show saturated conditions.

7.2 Extent of Contamination

Radionuclides other than tritium have not moved more than a few feet beneath the perched alluvial aquifer. This is consistent with the well developed weathered layers at the bottom of the perched zone, which have developed over probably thousands of years that natural runoff has maintained the perched aquifer.

Tritium is chemically bonded into the water molecule as a hydrogen atom, and thus moves directly with the water subject to the same physical and chemical interactions as any other water molecule. Tritium (as tritiated water) has moved to depths approaching 200 feet in unsaturated flow; data from one hole suggests that the maximum extent of tritium movement may be about 200 feet, additional, deeper samples will be needed to confirm that possibility.

There is no contamination by metals extractable from core samples by the EP Toxicity procedure above, in, or below the perched alluvial aquifer.

There is no contamination by organic substances including volatiles semi-volatile, herbicides, pesticides, or PCBs extractable from core samples above, in, or below the perched alluvial aquifer.

7.3 Hydrologic Properties of Tuff

The overall pattern of saturated hydraulic conductivities of the tuff beneath the perched aquifer is extremely low. Saturated conductivities are mostly less than 0.001 cm/sec.

Unsaturated hydraulic conductivities through the Tshirege Unit 1A beneath the perched aquifer (for the in-situ moisture conditions at the time the cores were collected) increase dramatically approaching the contact between the Tshirege Unit 1A and Tsankawi members. The unsaturated conductivity peaks in the Tsankawi and drops down rapidly at the depth of the contact between the Tsankawi and the Otowi members. The layer of higher conductivity in between those with lower conductivity appears to be forming a barrier impeding the downward movement of moisture. This is reflected in the pattern of moisture observed in core holes MCM-5.1 and MCM-5.9A, with moisture levels increasing and reaching a peak just at or below the contact between the Tshirege Unit 1A and the Tsankawi members, and then declining with depth at the contact between the Tsankawi and Otowi members.

The pressure head, or water potential, in the unsaturated zone at the time the core samples were collected from holes MCM-5.1 and MCM-5.9, was increasing with depth through the Tshirege Unit 1A and into the top half of the Tsankawi member. At that time, the flux of moisture in the unsaturated zone was apparently upwards, from the high moisture content near the top of the Tsankawi toward the surface. The data exhibit considerable variability and the movement, if any, would probably be at a slow rate. This phenomena may well change through the year with different overall moisture conditions. Periodic neutron moisture probe measurements of moisture profiles should contribute data to permit description of the temporal changes.

7.4 Identified Data Needs

7.4.1 Additional Deeper Cores for Tritium and Hydrologic Properties

The data from hole MCM-5.9A suggest that the maximum extent of tritium movement in the unsaturated region may occur in the vicinity of 200 feet deep. It will be necessary to collect cores from depths down to 300 or 400 feet, to determine whether the decrease in concentration is the furthest extent of movement or caused by dilution. In order to maximize understanding of the lateral extent of variation in moisture patterns, it would be important to have a similarly deep core hole on a transect at some distance from the center of the canyon and also under an adjacent mesa.

7.4.2 Additional Hydrologic Properties

Cores from hole SIMO-1, or another new hole in the eastern portion of the canyon where there is no perched aquifer, need to be subject to hydrologic property testing to determine their comparability with the tuff properties obtained from cores from holes MCM-5.1 and MCM-5.9A. These measurements are needed to determine the water potential gradient and compare both direction and magnitude of water flux beneath the saturated and unsaturated alluvium. Cores from a proposed companion hole adjacent to MCM-5.1 down to a depth of at least 200 feet are needed to confirm vertical patterns of moisture content and conductivity suggested by data from hole MCM-5.9A. Special attention will be given to collecting cores from near the saturated zone and at the interfaces between tuff members, as these locations may be controlling features in overall water and contaminant movement patterns.

One or more shallow core holes should be completed in the lower portion of Mortandad Canyon south of the stream channel where the seismic study suggested a possibility of perched water (see map in Appendix 8.1).

7.4.3 Stable/Radioactive Isotope Dating

Other isotopic measurements, such as for deuterium-oxygen ratios, chlorine-36, carbon-14, carbon-13/carbon-12 ratio, helium-4, neon-20, and argon-36 and argon-40 may be able to contribute understanding to the ages of different components of the hydrologic system.

7.4.4 Time Series of Moisture and Water Level Data

Neutron moisture probe data for selected access tube locations and perched zone saturated water levels for selected monitoring wells will be collected at regular intervals. This data will be used as part of the input to the lumped parameter model (described below in Section 7.5.1) to verify understanding of the water movement relationships in portions of the canyon. The moisture probe data will be needed to develop a description of temporal changes in the unsaturated zone, especially the moisture dependant properties relative conductivity and pressure head, that may contribute to understanding the movement of water.

7.5 Identified Interpretation Tasks

The data contained in this report, both the new field study data collected in 1990 and the compiled data from earlier efforts, provide the basis for the general conclusions needed to address the special permit condition requirements of identifying the present extent of saturation and the extent of contaminant occurrence in Mortandad Canyon. This data also provides the basis for many more detailed and more quantitative interpretations that will yield more understanding of the processes involved. Interpretive tasks already underway, as well as some that suggest likelihood of good return are briefly discussed in the next several sections.

7.5.1 Hydrologic Modeling

An initial simple modelling effort is underway to make use of existing water and contaminant data to provide a more quantitative description of the water and chemical mass balance in the three general sections of Mortandad Canyon. It is based on a dynamically connected stream-aquifer system represented by the lumped parameter model. The structural simplicity of this technique is inherently related to the systems operation approach it takes; the system is described only to the degree that it relates averaged input-output-storage changes over time (Dooge, 1973). Hence this type of modeling is applicable when system-wide temporal responses in groundwater levels or water quality resulting from distributed input stresses are of interest. This approach has been successfully implemented in the Mesilla Valley of south-central New Mexico (McLin and Gelhar, 1979), and the Arkansas River Valley near La Junta, Colorado (McLin, 1983). The major advantage to this modeling approach is that it can indicate long-term trends in water quality, including individual radionuclide concentrations. The generalized lumped parameter model for the perched alluvial aquifer system in Mortandad Canyon is briefly described below. It is anticipated that the application to Mortandad Canyon will focus attention on optimizing future field data collection efforts, in addition to providing a systematic methodology for existing data analysis.

7.5.1.1 Water and Contaminant Mass Balance in the Alluvial Aquifer in Mortandad Canyon

For the stream connected phreatic aquifer system located in Mortandad Canyon, a simple water balance equation may be written as:

$$n\,dh/dt = q_s - q_o - q_{et} - q_t \qquad (1)$$

where

n = average effective aquifer porosity,
h = average saturated alluvial aquifer thickness,
d/dt = total derivative with respect to time,
q_s = stream leakage rate (volume/area/time),
q_o = net alluvial aquifer outflow rate (volume/area/time),
q_{et} = evapotranspiration rate (volume/area/time),
q_t = seepage rate to unsaturated tuff (volume/area/time).

The net aquifer outflow term, q_o, can be approximated by a linear relationship given as:

$$q_o = a(h-h_o) \qquad (2)$$

where h_o is the stream referenced level and the parameter a is a lumped outflow constant having units of inverse time; it is inherently related to Darcy's law. In general, h_o can be a function of time, but is usually assumed constant since fluctuation in h_o are usually much smaller than those for h. Substituting (2) into (1) yields a differential equation of the form:

$$n\,dh/dt + a(h-h_o) = E \qquad (3)$$

where E represents the lumped time dependent inputs minus outputs. The model represented by (3) is a lumped parameter model in the form of a well mixed linear reservoir. The term n/a represents the hydraulic response time (t_h) of the system since it characterizes the average response time of the water balance equation. Typically t_h will vary between one and three months, and suggests an optimal data collection interval for water level measurements in the alluvial aquifer system. Numerous analytical solutions for (3) are available for a wide variety of initial conditions.

The corresponding mass balance equation for the stream connected phreatic aquifer system in Mortandad Canyon would be:

$$n\,d(hc)/dt = q_s c_s - q_o c - q_{et} c_{et} - q_t c + nhr \qquad (4)$$

where r is a volumetric source-sink term that accounts for contaminant additions or degradation within the flow zone, c is the average alluvial aquifer concentration, and c_s and c_{et} are the respective contaminant concentration levels for surface water flows and evapotranspiration. Generally, c_{et} is zero for most contaminants except tritium, in which case it is simply c. It is implied in (4) that the aquifer is a well mixed linear reservoir and that any system outflows will carry this average aquifer concentration. This assumption has been related to the nature of two-dimensional advective transport by Gelhar and Wilson (1974). Multiplying (1) by c and substituting the resulting expression into (4) yields:

$$dc/dt + c(e/nh + k) = c_s(q_s/nh) \qquad (5)$$

where

$e = q_s$ for tritium contaminated waters, and
$e = q_s - q_{et}$ for most other contaminants of interest,
$r = -kc$, a first order decay process.

The combined parameter nh/e is referred to as the solute response time (t_c) since it characterizes the average response time of (5). Physically it represents the average solute residence time in the alluvial aquifer. Typically this value will vary widely, ranging from several months to years.

The water and mass balance statements given by (3) and (5), together with (2), form a coupled systems description of subsurface water and mass transport in a lumped parameter format. These equations are easily manipulated to supply a variety of explicit analytical solutions to a wide range of specified initial conditions. Purtymun (1968) collected monthly field data in Mortandad Canyon from July 1963 to June 1965; hence, a preliminary model calibration can be made. Once t_h and t_c values are established for Mortandad Canyon, then projections of tritium concentrations over time will be made, and compared to actual surveillance monitoring results. This modeling approach will initially suggest optimal sample collection frequencies for water level measurements and water quality analyses. Ultimately the lumped model will provide guidance on future modeling requirements.

7.5.1.2 Transport from Saturated Into Unsaturated Zone

This study has assembled sufficient data regarding the hydrologic properties, occurrence of moisture, and occurrence of contaminants to attempt some modelling in the unsaturated zone beneath the perched aquifer. A Los Alamos National Laboratory numerical model, TRACR3D (Travis, 1991) developed over the last decade, will be used to evaluate the plausibility of some of the possible conclusions regarding movement of water and contaminants, especially tritium. The code models time-dependent mass flow and chemical species transport in a three dimensional, heterogeneous, sorptive porous medium, under a variety of flow conditions including saturated or unsaturated conditions.

7.5.2 Geochemical Interactions

7.5.2.1 Transport of Different Classes of Contaminants

The possibility of using some of the data collected on various trace metals and the contaminants known to be in the effluent and the perched aquifer in conjunction with the TRACR3D model will be evaluated for application to understanding the kinds of geochemical interactions important in this canyon system.

7.5.2.2 Transport of Colloid Related Contaminants

Colloids represent a small fraction of the total contaminant inventory, less than 1 percent, and have apparently not been responsible for any significant movement (i.e. more than a few feet) of contaminants into the tuff beneath the perched aquifer. Colloid transport mechanisms may be important within the perched aquifer.

8.0 APPENDICES

8.1 Locations of Studies in Mortandad Canyon

Large-scale, foldout map showing topographic elevation contours, location of holes, wells, seismic refraction, and other important features.

8.2 Previous Studies

8.2.1 Copies of abstracts of selected special studies, taken from annotated bibliography;

8.2.2 Reproduction of list of past monitoring reports;

8.2.3 Reproduction of article from 1987 Environmental Surveillance Report on sediment transport; and

8.2.4 Reproduction of Tables from Appendix G of 1989 Environmental Surveillance Report.

8.3 Inventory of Mortandad Canyon Holes and Wells

Data Tables for depths, elevations, measuring points, locations, water levels, etc.

8.4 Logs for Holes and Wells in Mortandad Canyon

Figures with lithology, completion, and casing information as appropriate, in order of physical location sequence from upstream to downstream.

8.5 Radiochemical Analytical Results

8.5.1. Hole MCM-5.1

8.5.2. Hole MCM-5.9A

8.5.3. Hole MCC-8.2

8.5.4. Hole SIMO-1

8.5.5. Perched Zone Monitoring Wells

8.6 Inorganic Analytical Results

8.6.1. Hole MCM-5.1

8.6.2. Hole MCM-5.9A

8.6.3. Hole 8.2

8.6.4. Perched Zone Monitoring Wells

8.7 Organic Analytical Results

8.7.1. Hole MCM-5.1

8.7.2. Perched Zone Monitoring Wells

8.8 Hydrologic Property Data

Reproduction of Appendices from final Hydrologic Laboratory Report from Daniel B. Stephens, Inc.

8.9 Seismic Refraction Study

Reproduction of final Seismic Refraction Report from Charles Reynolds, Assoc.

8.10 References

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