03-009

TA-03

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Date: August 29, 2003
Refer to: ER2003-0549

RECEIVED
NMED Hazardous Waste Bureau

Mr. John Young, Corrective Action Project Leader
Permits Management Program
NMED – Hazardous Waste Bureau
2905 Rodeo Park Drive East
Building 1
Santa Fe, NM 87505-6303

SUBJECT: SUBMITTAL OF THE MORTANDAD CANYON GROUNDWATER WORK PLAN

Dear Mr. Young:

Enclosed please find two copies of the "Mortandad Canyon Groundwater Work Plan," and the Certification by Risk Reduction and Environmental Stewardship – Remedial Services (RRES-RS). This addendum addresses the groundwater characterization deficiencies identified by the New Mexico Environment Department - Hazardous Waste Bureau (NMED-HWB), in your letter dated December 12, 2002.

This groundwater work plan describes the investigation activities LANL believes are needed to complete characterization of the nature and extent of contaminants in Mortandad Canyon. The work plan augments the investigation activities described in the "Work Plan for Mortandad Canyon," dated September 1997 (LA-UR-97-3291 and EM/ER: 97-388), and the "Response to Request for Supplemental Information (RSI) Concerning the Work Plan for Mortandad Canyon," dated August 31, 1999 (EM/ER: 99-249). This plan is based on data and sound technical approach. NMED's review of this plan will result in concurrence with LANL's approach or a technically justified alternative.

The US Department of Energy (DOE) and the University of California request approval of this addendum by COB September 30, 2003, in order to meet the agreed upon schedule of delivery of the investigation report for Mortandad Canyon by December 31, 2005. Since the work schedule has been compressed, approval of this addendum later than September 30, 2003, will impact the work schedule and thus delay the submittal of the final investigation report.

The groundwater work plan contains information on radioactive materials and proposed work activities for investigation of radionuclide materials that is provided for information purposes only to the NMED-HWB. The management of radioactive materials is regulated under the Atomic Energy Act and is specifically excluded from regulation under the Resource Conservation and Recovery Act (RCRA) and the New Mexico Hazardous Waste Act. The DOE conducts investigations of radioactive materials in parallel with the corrective action investigations conducted under RCRA and, therefore, the information on radioactive material is included in this work plan as a matter of efficiency and not for approval by the NMED-HWB.

If you have any questions, please contact Kent Rich at (505) 665-4272 or Tom Whitacre at (505) 665-5042.

Sincerely,

David McInroy, Deputy Project Director
Remediation Services
Los Alamos National Laboratory

Sincerely,

Mathew Johansen,
Groundwater Program Compliance Manager
Department of Energy
Los Alamos Site Office

DM/DG/KR/dv

Enclosures: (1) Mortandad Canyon Groundwater Work Plan (ER2003-0541)
(2) Certification by RRES-RS

Cy:(w/enc)
N. Quintana, RRES-RS, MS M992
D. Gregory, LASO, MS A316
J. Kieling, NMED-HWB
V. Maranville, NMED-HWB
S. Yanicak, NMED-OB
M. Leavitt, NMED-SWQB
L. King, EPA Region 6
RRES-RS File, MS M992
CT File # 872
IM-5, MS A150
RPF MS M707

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D. McInroy, RRES-RS, MS M992
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S. Martin, NMED-HWB
C. Voorhees, NMED-OB
K. Rich RRES-RS, MS M992
P. Longmire, EES-6, MS D469

CERTIFICATION

CERTIFICATION BY THE RISK REDUCTION AND ENVIRONMENTAL STEWARDSHIP-REMEDIATION SERVICES (RRES-RS) PROJECT TECHNICAL REPRESENTATIVES

Document Title: **SUBMITTAL OF THE MORTANDAD CANYON GROUNDWATER WORK PLAN**

I certify under penalty of law that these documents and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violation.

Name: ______________________ Date: 8/28/03

David McInroy, Deputy Project Director
Remediation Services
Los Alamos National Laboratory

or

______________________ Date: ____________

Beverly A. Ramsey, Division Leader
Risk Reduction and Environmental Stewardship Division
Los Alamos National Laboratory

______________________ Date: 8/28/03

David Gregory, Project Manager
Environmental Restoration Program
Department Of Energy/Los Alamos Site Office

or

______________________ Date: ____________

Herman LeDoux,
Assistant Area Manager of
Environmental Projects
Department Of Energy/Los Alamos Site Office

LA-UR-03-6221
August 2003
ER2003-0541

Mortandad Canyon Groundwater Work Plan

Los Alamos
NATIONAL LABORATORY

Los Alamos NM 87545

DISCLAIMER

This document contains data regarding radioactive wastes, the management of which is regulated under the Atomic Energy Act and specifically excluded from regulation under the Resource Conservation and Recovery Act and the New Mexico Hazardous Waste Act. These data are provided to the New Mexico Environment Department for information purposes only.

Produced by Risk Reduction and Environmental Stewardship Division–Remediation Services

Mortandad Canyon Groundwater Work Plan

August 2003

Responsible Project Leader:

Printed Name	Signature	Title	Organization	Date
Kent Rich	Kent Rich	Acting Project Team Leader	RRES-RS	8/28/03

Responsible University of California representative:

Printed Name	Signature	Title	Organization	Date
David McInroy	[signature] for	Deputy Project Director	RRES-RS	8/28/03

Responsible Department of Energy representative:

Printed Name	Signature	Title	Organization	Date
Matthew Johansen	[signature]	Groundwater Program Compliance Manger	DOE-LASO	8/28/03

EXECUTIVE SUMMARY

This Resource Conservation and Recovery Act facility investigation groundwater work plan for Mortandad Canyon provides a revised and updated technical approach and methodology for surface water and groundwater investigations in the Mortandad Canyon system at Los Alamos National Laboratory (hereafter "the Laboratory"). The objectives of this groundwater work plan include

- conducting characterization investigations to determine nature and extent of contamination,
- collecting data and information to support present-day human health and ecological risk,
- collecting data and information to support decisions for potential release sites aggregates in the Mortandad Canyon watershed,
- collecting data and information to support modeling uncertainties and assessment of future scenarios, and
- collecting data and information to support recommendations for long-term monitoring.

The work plan for Mortandad Canyon was first submitted by the Laboratory to the New Mexico Environment Department (NMED) in September 1997, and was approved by the NMED in 2002, following resolution of comments in a request for supplemental information. In December 2002, the NMED requested that the Laboratory address groundwater characterization deficiencies in a separate work plan. This work plan addresses these surface water and groundwater characterization deficiencies.

Evaluating the nature and extent of contamination in the subsurface was of primary importance in determining the sample locations described in this work plan. Core samples will be collected from 8 alluvial boreholes, 16 shallow boreholes, 7 intermediate depth wells, and 4 regional aquifer wells. Groundwater samples will be collected during drilling in addition to two rounds of characterization sampling from each well that encounters saturation. The samples will be analyzed for metals, anions including perchlorate, radionuclides, organic compounds, and stable isotopes. Data and information obtained from determining nature and extent of contamination in all media will serve as input for making decisions regarding characterization, contaminant transport, regulatory compliance, pathway analysis, human health and ecological risk assessment, and monitoring.

An investigation report will be prepared and delivered to the NMED by December 31, 2005. This report will present results of sediment, surface water, groundwater, and unsaturated zone (core) investigations. The data will be appropriate and sufficient for comparison to applicable State of New Mexico and federal regulations. The data should also be useful in identifying potential remediation options.

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1.0 INTRODUCTION

This Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) groundwater work plan describes additional investigations to be conducted in the Mortandad Canyon system as part of the Risk Reduction and Environmental Stewardship-Remediation Services Project (RRES-RS) at Los Alamos National Laboratory (hereafter "the Laboratory"). This groundwater work plan for Mortandad Canyon describes revisions and updates to the "Work Plan for Mortandad Canyon Operable Unit (OU) 1049, September 1997" (LANL 1997, 56835).

The work plan for Mortandad Canyon was first submitted by the Laboratory to the New Mexico Environment Department (NMED) in 1997 and was approved by the NMED in 2002 (NMED 2002, 73830), following resolution of comments in an NMED request for supplemental information. In 2002, the NMED requested that the Laboratory address groundwater characterization deficiencies in a separate work plan. This work plan addresses those groundwater characterization deficiencies.

Information on radioactive materials and proposed work activities for investigation of radionuclide materials is provided in this work plan for information purposes only. The management of radioactive materials is regulated under the Atomic Energy Act and is specifically excluded from regulation under the RCRA and the New Mexico Hazardous Waste Act. The US Department of Energy conducts investigations of radioactive materials in parallel with the corrective action investigations conducted under RCRA and therefore the radioactive material information is included in this work plan as a matter of efficiency and not for approval by the NMED, Hazardous Waste Bureau (HWB).

The objectives of this work plan for Mortandad Canyon include

- conducting characterization investigations to determine nature and extent of contamination,
- collecting data and information to support present-day human health and ecological risk,
- collecting data and information to support decisions for potential release sites aggregates in the Mortandad Canyon watershed,
- collecting data and information to support modeling uncertainties and assessment of future scenarios, and
- collecting data and information to support recommendations for long-term monitoring.

Evaluating the nature and extent of contamination in the subsurface is of primary importance in determining the sample locations for this work plan. For the purpose of this document, the nature and extent of contamination is defined as bounding spatial and temporal (100 years) uncertainties in contaminant concentrations and distributions. Data and information obtained from determining the nature and extent of contamination will serve as input for making decisions regarding characterization, regulatory compliance, pathway analysis, risk assessment, and monitoring. Core and water samples will be collected from shallow boreholes (less than 100 ft depth), coreholes, monitoring wells, and surface water stations to determine the nature and extent of contaminants. Data and information collected will support decisions regarding no further action (NFA) or corrective action decisions for Mortandad Canyon. The conceptual model presented in the work plan for Mortandad Canyon will be updated to incorporate findings from this investigation.

This work plan presents only the subsections that supercede corresponding text and tables presented in the work plan for Mortandad Canyon. The sampling and analysis plan for canyon-floor sediments described in the work plan for Mortandad Canyon is unchanged by this work plan, except that drilling and subsurface sampling in the alluvium supercedes that described in the work plan for Mortandad Canyon (LANL 1997, 56835).

2.0 BACKGROUND

Mortandad Canyon extends for 9.8 mi (15.8 km) from near Diamond Drive in Technical Area (TA-)3 east southeast to the Rio Grande and has a total watershed area (excluding Cañada del Buey) of about 6.0 mi^2 (15.5 km^2) (LANL 1997, 56835; LANL 1999, 62777, p. 1-3). Figure 1 shows the location of Mortandad Canyon and its tributaries. The lower part of Mortandad Canyon is on San Ildefonso Pueblo land. Primary tributary drainages on Laboratory land are Effluent Canyon, which heads in TA-48, and Ten Site Canyon, which heads in TA-50. Active technical areas in the watershed include TA-3, TA-35, TA-50, TA-48, TA-55, TA-60, and TA-63. Inactive technical areas include former TA-4, TA-5, former TA-42, and TA-52. Activities at these sites are discussed in the Mortandad Canyon work plan (LANL 1997, 56835; LANL 1999, 62777, pp. 2-9 to 2-26).

A detailed discussion of previous investigations conducted in Mortandad Canyon and its tributaries prior to 1997 is provided in Chapters 2, 3, and 7 of the "Work Plan for Mortandad Canyon Operable Unit (OU) 1049, September 1997" (LANL 1997, 56835). The Laboratory publishes results of sampling of air, sediments, surface water, and groundwater in Mortandad Canyon in annual Laboratory surveillance reports (ESP 2000, 68661; ESP 2001, 73876; ESP 2002, 71301). The US Environmental Agency (EPA) conducted independent groundwater and surface water monitoring in the canyon in 1999, 2001, and 2002 that confirmed the presence of contaminants observed by the Laboratory.

The Laboratory began monitoring sediments, surface water, and groundwater in Mortandad Canyon and its tributaries in the early 1960s. Contaminants have been identified in alluvial and perched intermediate groundwater and in the regional aquifer within Mortandad Canyon. Historically, the following constituents have been detected in surface water and alluvial groundwater: americium-241; cesium-137; plutonium-238 and plutonium-239,240; strontium-90; tritium; uranium-234,235,236,238; nitrate; perchlorate; chloride; sulfate; fluoride; and total dissolved solids ([TDS] ESP 1999, 68661; ESP 2001, 73876; ESP 2002, 71301).

Mortandad Canyon and its tributaries have received effluents from Los Alamos National Laboratory (LANL or the Laboratory) since the early 1950s. These effluents discharged from TA-3, TA-35, TA-48, and TA-50 have contained a variety of contaminants, including nitrate, perchlorate, tritium, cesium-137, strontium-90, americium-241, and several isotopes of uranium and plutonium (LANL 1997, 56835). Active outfalls discharging to Mortandad Canyon include TA-3 and TA-50. Most contaminants found in Mortandad Canyon are associated with TA-50 discharges into Effluent Canyon, except for sources of strontium-90 (LANL 1997, 56835), nitrate, and perchlorate from TA-35, which was discharged into Pratt Canyon. The total mass of nitrate and perchlorate discharged from TA-35 is not known.

The former Environmental Restoration (ER) Project (now Risk Reduction and Environmental Stewardship–Remediation Services Program [RRES–RS]) and the RRES–Groundwater Protection Program (GPP) have drilled several alluvial, perched intermediate, and regional aquifer wells in Mortandad and Ten Site Canyons as part of the approved "Work Plan for Mortandad Canyon Operable Unit (OU) 1049" and the "Hydrogeologic Work Plan" (LANL 1977, 56835; LANL 1998, 59599). These include alluvial wells MCO-0.6 and MCO-7.2, intermediate depth well MCOBT-4.4, intermediate depth borehole MCOBT-8.5, and regional aquifer wells R-13, R-14, and R-15. Figure 2 shows locations of these wells and boreholes and proposed wells and boreholes, in addition to previously installed monitoring wells in Mortandad Canyon and its tributaries.

Analytical results from groundwater samples collected from MCOBT-4.4 showed 12,797 pCi/L tritium, 13.2 mg/L nitrate plus nitrate (as N), and 142 µg/L perchlorate (Broxton et al. 2002, 76006). Activities and concentrations of these solutes measured in this well are elevated above those measured in supply wells (ESP 2001, 73876; ESP 2002, 71301). This well is located immediately below the confluence of Ten Site and Mortandad Canyons (Figure 2). The well has a single screen set in a perched zone within the upper Puye Formation/Cerros del Rio basalt at a depth of 524 ft below ground surface (bgs) (Broxton et al. 2002, 76006).

Core and cuttings samples collected from the upper vadose zone in MCOBT-4.4, MCOBT-8.5, MCO-7.2, and R-15 showed pore-water concentrations of perchlorate ranging from less than 2 to 840 µg/L either near the alluvium/Bandelier Tuff contact or within the Bandelier Tuff (Broxton et al. 2002, 76006; Longmire et al. 2001, 70103). Pore-water concentrations of nitrate (as nitrate) in the Bandelier Tuff range from less than 0.01 to 272 mg/L (Broxton et al. 2002, 76006; Longmire et al. 2001, 70103). Concentrations of perchlorate and nitrate are significantly lower in the unsaturated portions of the Puye Formation and Cerros del Rio basalt in MCOBT-4.4, MCO-7.2, and R-15 and at borehole MCOBT-8.5.

Wells R-13, near the Laboratory and San Ildefonso Pueblo boundary, and R-14, in upper Ten Site Canyon (Figure 2), have not shown contamination in the regional aquifer during drilling and/or subsequent characterization sampling. Perched groundwater was not observed at the time these two wells were drilled. Borehole MCOBT-8.5, drilled east of R-15, also did not contain perched groundwater.

Regional aquifer well R-15 contained concentrations of 2.4 mg/L nitrate (as N) in groundwater sampled at a depth of 1019 ft bgs (Longmire 2002, 72614). Typical concentrations of nitrate (as N) observed in supply wells are less than 0.5 mg/L (ESP 2000, 68661; ESP 2001, 73876; ESP 2002, 71301). Perched groundwater encountered at a depth of 646 ft bgs during the drilling of R-15 contained 3770 pCi/L tritium and 12 parts per billion (ppb) perchlorate (Longmire et al. 2001, 70103). This perched groundwater is in the lower portion of the Cerros del Rio basalt.

A multiple permeable reactive barrier (PRB) was installed in 2003 between alluvial wells MCO-4B and MCO-5 (Figure 2). Four separate cells within the multiple PRB consist of basalt scoria, mineral apatite, pecan shells and cotton-seed meal, and calcium carbonate (calcite). The multiple PRB is designed to remove contaminants present in alluvial groundwater flowing through the engineered structure. For example, it is anticipated that perchlorate should be reduced to chloride by anaerobic bacteria growing on pecan shells and cotton-seed meal within the biobarrier section of the multiple PRB. Strontium-90 should adsorb onto mineral apatite, a constituent of the multiple PRB. The first round of samples collected at the multiple PBR took place in June 2003. The operational life of the PRB is anticipated to be ten years.

A direct current (DC) resistivity survey was conducted in Mortandad Canyon in summer 2002 to determine whether this geophysical method was an effective and appropriate means to identify zones of saturation and moisture within the alluvial and upper vadose zone systems. Geophysical survey lines are shown on Figure 2. Geophex, Charlotte, North Carolina, conducted the geophysical surveys and prepared a summary report that was submitted to NMED on March 26, 2003. Nine DC resistivity profiles were compiled in the upper and middle portions of Mortandad Canyon and shown in Figure 2. One of the profiles was collected continuously along the centerline of the canyon from a point upstream of the PRB to a point near well R-13, a distance of 9290 ft to the east (Figure 2). The remaining profiles consisted of a series of transects across the canyon at selected locations. Profile depths of penetration varied according to the length of the line and the spacing of electrodes. In the upper reaches of the canyon, the shortest profile penetrated approximately 20 to 30 ft bgs. The longest profiles imaged to depths of over 200 ft bgs.

Results and possible interpretations from the resistivity surveys suggest that various moist zones may occur along the profiles (Figure 3). The degree of saturation or moisture within these zones is not known and can only be confirmed by measuring moisture content in the boreholes. The high resistivity areas are inferred to be either "dry" or "dryer" unconsolidated sediments or "dry" bedrock, for example, in the upper portions of the Bandelier Tuff. The "dry" bedrock zones vary in elevation across the deeper portions of the profiles. Vertical zones of lower resistivity appear to cut through dry bedrock zones and extend to greater depths in certain areas. These features are interpreted to be either "moist" or clay-rich fracture zones within the "dryer" bedrock, although some conductive zones may be the result of nearby monitoring wells constructed with stainless steel casing.

Numerical modeling of the vadose zone and the regional aquifer for Mortandad Canyon has been done at both the plateau and the local scale to investigate the factors controlling travel times and potential plume migration to receptors. The RRES-GPP 2002 annual status report (LANL 2003, 76059) describes vadose zone simulations that show the variability in predicted travel times from the ground surface to the water table across the Pajarito Plateau. These simulations showed that travel times through the vadose zone may be on the order of a few decades, leading to the possibility that non-sorbing contaminants such as tritium, nitrate, perchlorate could have already reached the regional aquifer. The annual report also used the regional aquifer flow and transport model to examine potential capture zones for points of discharge of aquifer fluid, including water supply wells. The study concluded that there is a reasonable likelihood that if contamination reaches the regional aquifer it could eventually be captured by water supply wells in the vicinity of Mortandad Canyon.

Ongoing pathways assessment modeling work for Mortandad Canyon has extended the scope of these initial findings to assess the potential fate and transport of perchlorate, predicting plume concentrations from the source to potential receptors. This study uses probabilistic modeling techniques to quantify uncertainties in all processes and parameters relevant to perchlorate migration, so that information relevant to risk reduction can be incorporated into site characterization, monitoring, and remediation plans. Initial results indicate that in the vadose zone reducing uncertainties in the deep infiltration rate, especially in the region of the canyon close to the TA-50 outfall, could help reduce risk by ruling out possible early arrival of perchlorate at water supply wells closest to the canyon. Simulations using the regional aquifer component of the model have illustrated the importance of transient flow in the aquifer, caused by the complex history of water withdrawals at several surrounding wells, in controlling the ultimate fate of contaminants in the aquifer. This finding suggests that greater precision in estimating the time-varying arrival of contaminants at the water table would reduce uncertainties in the ultimate receptor for those contaminants. In addition, regional aquifer modeling has shown that details of the spatial distribution of recharge beneath the canyon have an important influence on the ultimate flow direction and rate of migration.

3.0 SITE CONDITIONS

This section describes the site conditions for Mortandad Canyon including, bedrock geology, hydrology, and aqueous chemistry and contaminant chemistry of both the vadose zone and regional aquifer. The vadose zone consists of the volume of hydrogeologic material from land surface to the regional water table and includes perched intermediate groundwater. The Mortandad Canyon work plan (Chapters 1 and 3) contains a description of surface site conditions including topography, drainages, vegetation, erosional features, and basins. The work plan for Mortandad Canyon and well completion reports for well MCOBT-4.4 and borehole MCOBT-8.5 (Broxton et al. 2002, 76006), R-13 (LANL 2003, 76060), R-14 (LANL 2003, 76062), and R-15 (Longmire et al. 2001, 70103) discuss subsurface hydrostratigraphy including the alluvium, the Bandelier Tuff, the Cerro Toledo interval, the Puye Formation, the Cerros del Rio basalt, the Totavi Lentil, and pumiceous fanglomerates that may be related to the Peralta Tuff. Additional information on hydrostratigraphy and geochemistry of unsaturated and perched saturated zones are contained in well completion reports for R-13 (LANL 2003, 76060), R-14 (LANL 2003, 76062), R-15 (Longmire et al. 2001, 70103), MCOBT-4.4 and MCOBT-8.5 (Broxton et al. 2002, 76006), and in the geochemistry report for R-15 (Longmire 2002, 72614).

3.1 Bedrock Geology

Stratigraphic units of Mortandad Canyon are described in this section in descending order and depicted in Figure 4. Alluvium and colluvium overlie the Bandelier Tuff within the floor of Mortandad Canyon. Ash-flow tuffs of the Tshirege Member of the Bandelier Tuff form the bedrock outcrops in Mortandad Canyon and underlie the alluvial deposits west of MCOBT-4.4.

The Cerro Toledo interval is a bedded valley-fill deposit that underlies the Tshirege Member in the western part of Mortandad Canyon. The Cerro Toledo interval is directly overlain by alluvial deposits east of the sediment traps. The Cerro Toledo interval is present in the western part of Mortandad Canyon, but it is not present in well R-13. The distribution of Cerro Toledo deposits between wells R-15 and R-13 is not known.

The Otowi Member of the Bandelier Tuff underlies the Cerro Toledo interval in the western part of Mortandad Canyon and underlies the Tshirege Member in eastern Mortandad Canyon near well R-13. Ash-flow tuffs of the Otowi Member fill a north-south trending paleovalley and well MCOBT-4.4 is in the axial portion of that paleovalley. The Guaje Pumice Bed, a fall deposit, underlies the Otowi Member throughout the Mortandad Canyon area.

The Cerros del Rio basalt is intercalated with the Puye Formation. The Cerros del Rio basalt is a wedge-shaped stack of lava flows that thicken eastward. The maximum measured thickness of these lava flows in Mortandad Canyon is 427 ft at well R-13 and diminishes to 145 ft at TW-8. The two perched groundwater zones encountered in Mortandad Canyon to date are both associated with the Cerros del Rio basalt. They are located at the top of the Cerros del Rio basalt in well MCOBT-4.4 and at the base of the Cerros del Rio basalt in well R-15.

Beneath Mortandad Canyon, the top of the Cerros del Rio basalt dips to the southwest and the base dips to the south. If these features control hydrology, flow within perched zones may be to the south and west. It appears that transmissivity is highest in open breccia zones, lower in unfractured flow interiors, and lowest in clay-filled breccia zones.

Another distinct lava type was encountered in well R-14, occupying the same stratigraphic position as the Cerros del Rio basalt. This unit is dacitic in composition and probably dips eastward, whereas the Cerros del Rio basalt dips to the west and south. The differences in compositions and probable dip directions may reflect different vent source areas. In Mortandad Canyon, the dacitic lavas are expected to occur west of TW-8.

The nature of the transition from dacite to Cerros del Rio basalt and its effect on groundwater flow is not known with available petrographic information. The dacitic lava flows extend at least as far eastward as well R-14, and the basaltic lava flows extend at least as far west as TW-8. It is not known whether these two lava bodies overlap spatially or whether a gap occupied by the Puye Formation separates them beneath Mortandad Canyon west of TW-8. Recharge pathways through the vadose zone are expected to be influenced by the pre-Bandelier Tuff lithology.

The regional aquifer water table is in the lower Puye Formation or in an unassigned pumiceous unit throughout the central portion of the Laboratory, including Mortandad Canyon. The lower Puye Formation in eastern Mortandad Canyon (east of TW-8) is relatively thick (~200-250 ft) and generally contains coarser dacitic clasts than the upper Puye. The nature of the Puye under western Mortandad Canyon is poorly known but may be dominated by coarse, monolithologic detritus from a Polvadera volcanic source (based on evidence from R-14). Beneath the lower Puye Formation in TW-8, R-15, and R-13 is a pumiceous sedimentary unit that is yet unassigned but apparently related to Peralta Tuff sources to the south and Keres-group volcanic sources to the west. This pumiceous unit is ~100-150 ft thick and generally has greater hydrologic transmissivity than the overlying Puye fanglomerates. A highly transmissive series of river gravels, related to the Totavi Lentil, occurs at the base of the Puye Formation in wells R-13 and R-15 but its thickness is not known.

3.2 Hydrology

Approximately 87% of the Mortandad Canyon watershed upstream from the boundary with San Ildefonso Pueblo burned in the Cerro Grande fire (BAER 2000, 72659, p. 281).However, relatively little hydrologic response was expected because of the changed conditions after the fire. The record of post-fire floods in Mortandad Canyon supports this interpretation, with the gage records indicating similar peak discharges after the fire as before (Shaull et al. 2003, 76042, pp. 33–40; p. 97).

Surface water in Mortandad Canyon includes storm runoff, snowmelt runoff, and discharges from national pollutant discharge elimination system (NPDES) permitted outfalls. Active NPDES outfalls are located in TA-3 and TA-50 and inactive outfalls were at TA-35 and TA-48 (LANL 1997, 56835; LANL 1999, 62777, Table 2.4.4-3, p. 2-17; Table 2.4.5-1, p. 2-19; Table 2.4.6-1, p. 2-20).

Surface water in Mortandad Canyon on Laboratory land generally either infiltrates into the streambed or on occasion reaches the sediment traps where it infiltrates. The last time that water overflowed the sediment traps was in 1991 (EPG 1993, 23249, pp. iv–55; LANL 1997, 56835; LANL 1999, 62777, pp. 3-80, 3-83). Material has been excavated from the sediment traps several times since the current traps were excavated in 1986, most recently in 2000 (LANL 2000, 70735). Surface water flow has been reported extending past the sediment traps three times since 1986: on June 7, 1987; on July 24, 1991; and on August 6, 1991 (LANL 1997, 56835).

Alluvial groundwater flows east-southeastward along the axis of Mortandad Canyon and infiltrates into the underlying Bandelier Tuff and Cerro Toledo interval (LANL 1997, 56835, Figure 3.7.2-4, p. 3-97). The extent of saturation in the alluvium varies with the volume of water discharged to Mortandad Canyon and with runoff. There is an area with a steep hydraulic gradient near the sediment traps, between MCO-7.1 and MCWB-7.4A. This steep gradient may be the result of a combination of loss of alluvial water to the Cerro Toledo interval and an increase in the volume (storage capacity) of alluvium. Groundwater flow velocity in the alluvium has been estimated to be 30 to 40 ft/day (9.1 to 12.2 m/day) between MCO-5 and MCO-8.2 (LANL 1997, 56835).

Perched groundwater was encountered during drilling of R-15 and MCOBT-4.4 within the Cerros del Rio basalt (Figure 4). Groundwater flow in the Cerros del Rio basalt may be controlled by the dip at the top or base of the unit. The top of the Cerros del Rio basalt dips to the southwest, and the base dips to the south. If these features control the hydrology, perched flow may be to the south and west; however, the potentiometric surface may decrease to the east and groundwater flow could be along the canyon axis.

Contaminant migration in Mortandad Canyon is not expected to be affected by major geologic structural features because most structures lie west of potential release sites. Fracturing resulting from cooling of ash-flow tuffs and Cerros del Rio basalt, however, may provide "fast paths" for contaminant migration under locally saturated conditions and/or provide conduits for translocation of clay minerals and other solid phases possibly containing contaminants.

The nature and extent of saturation and contamination in the Puye Formation and the Cerros del Rio basalt has not been completely determined and is probably controlled by sediment characteristics such as sorting, particle size and mineralogy (e.g., clay abundances), fracturing, dip of stratigraphy (sediments and lava flows), geometry, and fracturing.

Groundwater flow in the regional aquifer is generally eastward (Purtymun 1984, 6513; LANL 2003, 76059) but may vary under the influence of pumping wells on Pajarito Mesa (PM) including PM-1, -3, -4, and -5 and Otowi-4. Regional saturation was encountered in the Puye Formation when R-13, R-14, and R-15 were drilled.

3.3 Aqueous Chemistry and Contaminant Chemistry

The hydrochemical compositions of surface water and alluvial groundwater in Mortandad Canyon show evidence of Laboratory discharges based on similarities in major ion and trace solute chemistries observed between the different waters (LANL 1997, 56835). The magnitude of nature and extent of contaminants dissolved in groundwater and/or adsorbed onto aquifer material is controlled by geochemical processes including solute speciation, adsorption, and precipitation. As alluvial groundwater infiltrates the subsurface and mixes with native (probably pre-Laboratory) perched groundwater within the Cerros del Rio basalt and Puye Formation (Broxton et al. 2002, 76006), mobile contaminants including nitrate, perchlorate, and tritium are detected in this groundwater. Current data also indicate that perched groundwater infiltrates the regional aquifer, based on concentrations of nitrate (2.3 to 2.4 mg/L as N) observed at well R-15 (Longmire 2002, 72614). Chemical compositions of the alluvium, perched intermediate groundwater, and the regional aquifer are distinct with TDS decreasing with depth (Longmire 2002, 72614; Broxton et al. 2002, 76006).

The major ion chemistries of surface water and alluvial groundwater consist of a mixed calcium-sodium-bicarbonate-chloride-nitrate-sulfate composition. The TDS of alluvial groundwater typically ranged between 250 and 430 mg/L based on sampling conducted by the Laboratory in 2001 (ESP 2002, 71301). The monitoring data suggest that the largest inventory of adsorbing chemicals is probably in the alluvial groundwater system (ESP 2002, 73876; ESP 2001, 71301; ESP 2000, 68661; LANL 1997, 56835). Concentrations (activities) of isotopic americium, cesium, plutonium, and strontium generally decreased along the alluvial groundwater flowpath. Concentrations of strontium-90 strongly decreased between alluvial monitoring wells MCO-6 and MCO-7, whereas concentrations of mobile chemicals, including tritium, nitrate, and perchlorate, were constant. Strontium-90 is attenuated possibly through an adsorption process.

The major ion chemistry of perched groundwater in the Puye Formation and Cerros del Rio basalt impacted by Laboratory discharges consists of a mixed calcium-sodium-bicarbonate-chloride-sulfate-nitrate composition. The TDS of a groundwater sample collected from MCOBT-4.4 in April 2002 were 168 mg/L (Broxton et al. 2002, 76006). The age of a component of this perched water is less than 50 years based on the presence of tritium, nitrate, and perchlorate. Concentrations of nitrate (as N) and perchlorate ranged between 12 and 13 mg/L and 140 and 180 µg/L, respectively. Concentrations of tritium ranged between 13,000 and 17,000 pCi/L. Concentrations of isotopic americium, cesium, plutonium, and strontium were less than detection at MCOBT-4.4 during characterization sampling.

The major ion chemistry of the regional aquifer at well R-15 consists of a mixed calcium-sodium-bicarbonate composition. The TDS typically ranged between 150 and 160 mg/L during characterization sampling (four rounds) at the well (Longmire 2002, 72614). At well R-15, concentrations of nitrate (as N) ranging between 2.2 and 2.4 mg/L exceeded those typically found in supply wells (0.3 to 0.5 mg/L). Concentrations of perchlorate, analyzed by ion chromatography, ranged from less than detection to 4.2 µg/L (J value) during characterization sampling at the well. Isotopic americium, cesium, plutonium, and strontium were less than detection limits at well R-15. Concentrations of tritium ranged from less than detection to 3.29 pCi/L during characterization sampling.

4.0 SCOPE OF PROPOSED ACTIVITIES AND INVESTIGATION METHODS

This section describes the sampling and analysis plan (SAP) for investigating surface water and groundwater in the Mortandad Canyon system. This SAP supercedes and replaces the surface water and groundwater investigations outlined in Chapter 7 of the Mortandad Canyon work plan (LANL 1997, 56835). The strategy for sampling surface water, alluvial and perched intermediate groundwater, and the regional aquifer is described below. Borehole cores will also be sampled and analyzed to determine contaminant geochemistry and hydraulic properties. A total of 25 wells are proposed for installation: eight alluvial wells, six piezometers, seven intermediate wells, and four regional aquifer wells. Sixteen additional characterization boreholes (<100 ft) are proposed to determine the extent of infiltration and contamination in the alluvium, Bandelier Tuff, and Cerro Toledo interval.

The revised SAP consists of three phases: (1) a field investigation phase, (2) a data analysis phase, and (3) a developmental and refinement phase to develop a detailed conceptual model of the canyon's hydrogeological and geochemical/contaminant chemistry system. The execution of this SAP will interface with each of the other phases in an iterative fashion until all phases have merged successfully into both conceptual and computer models that quantitatively describe the hydraulic and contaminant mass transport relationships between surface water, unsaturated material, and groundwater. A corrective measures evaluation (CME) may be identified during the field investigation. The potential CME study would be implemented after this field investigation is completed and the data have been evaluated and reported.

4.1 Conceptual Model

The observed distribution of contaminants and other supporting data (e.g., vadose zone pore moisture and chloride profiles) indicative of groundwater and vadose zone transport provides the basis for a physical conceptual model for Mortandad Canyon. For the purposes of this work plan, the conceptual model focuses on the physical aspects that explain the distribution of contaminants, primarily the sources and transport mechanisms. This conceptual model is shown schematically on Figure 5.

Some conceptual model components and processes described in this work plan are based on empirical observations as detailed in the Mortandad Canyon work plan (1997, 56835), Broxton et al. (2002, 76006), Longmire et al. (2001, 70103), and Longmire (2002, 72614). Other processes and components are based on scientific hypotheses. The current state of knowledge represented in models of the vadose zone and regional aquifer beneath Mortandad Canyon supports the hypothesis that contaminants in the alluvial system and vadose zone (including the intermediate perched zones) could reach the Pajarito Mesa well field within one hundred years. For human receptors, excluding site workers, the most likely potential for exposure under current conditions is associated with contamination derived from production wells.

The primary source of contaminants in Mortandad Canyon has been the TA-50 Radioactive Liquid Waste Treatment Facility effluent discharged into Mortandad Canyon since 1963. The volume of discharge from 1963 to 2002 was approximately 1,124 acre-feet (1.387E+09 L) of liquid containing radionuclides (americium-241, cesium-137, plutonium-238,239,240, strontium-90, tritium, and uranium-234,235,236,238), nitrate, and perchlorate. Generally, much higher volumes were discharged until about 1981. In 2002, the discharge volume was 20% of the 1981 volume.

The TA-50 effluent is discharged into Effluent Canyon and flows into the upper portion of Mortandad Canyon, which is a steep, narrow canyon with thin, locally discontinuous alluvium. Effluent from TA-50 combines with smaller volume effluent discharges from cooling towers up-canyon and infrequent storm water runoff to generate surface water flow down-canyon to the approximate vicinity of TW-8, where the canyon widens and surface water typically infiltrates.

Another source of contaminants (strontium-90, nitrate, and perchlorate) was the TA-35 effluent discharged into Pratt Canyon from 1951 to 1963. This effluent flowed into Ten Site Canyon and infiltrated the alluvium upstream (west) of the confluence with Mortandad Canyon. Approximately 8.27 ac-ft (1.02 E+07 L) of water were discharged into Pratt Canyon. Primary contaminants associated with the TA-35 effluent included strontium-90 and strontium-89.

Alluvial wells in Mortandad Canyon have been routinely monitored since discharges to the canyon began from TA-50. The analytical data from the monitoring have been evaluated to identify the contaminants present in alluvial water and other constituents that are important in understanding the hydrologic system. The radiological contaminants historically detected in the alluvial groundwater system include americium-241, cesium-137, plutonium-238,239,240, strontium-90, tritium, and uranium-234,235,236,238 (LANL 1997, 56835). The non-radiological contaminants include nitrate and perchlorate and other constituents of interest include TDSs and fluoride.

The contaminant transport mechanisms are different for non-adsorbing and moderately adsorbing contaminants than they are for strongly-adsorbing contaminants. While the strongly-adsorbing contaminants are transported largely by flood transport of contaminants sorbed to sediment, the non- and moderately adsorbing contaminants are transported predominantly by infiltration of surface water into alluvium and underlying geologic media between land surface and the regional water table. Strongly sorbing contaminants interact with the sediments in the streambed by adsorbing preferentially onto fine-grained sediment. Floods redistribute sediments down-canyon within the channel and onto floodplains. Geomorphic investigations conducted to date indicate that over half of the inventory of strongly adsorbing radionuclides (e.g., cesium-137 and americium-241) released in the TA-50 effluent has been deposited within the canyon reach between TW-8 and the sediment traps.

Non-adsorbing contaminants (tritium, nitrate, and perchlorate) are transported as a dissolved fraction in the surface water. The surface water infiltrates the alluvial aquifer primarily in the upper canyon reach and down to where the canyon widens and surface water flow disappears. Flow in the alluvial aquifer is down-canyon with an estimated velocity on the order of one km/yr. Time series plots of contaminant concentration suggests the time scale for flushing of non-adsorbing contaminants through the alluvial system is on the order of years (LANL 1997, 56835).

Where the canyon widens down stream of the confluence with Ten Site Canyon, there is a steep, decrease in the water-level and contaminant gradient in the alluvial aquifer, as a result of an increase in the volume of alluvium. Concentrations of strontium-90 in surface water and alluvial groundwater decrease markedly in this area. Geochemical modeling suggests that the decreasing concentration results from adsorption rather than mineral precipitation.

The contaminants in alluvial groundwater percolate downward and are residing within the vadose zone beneath the alluvium, including perched intermediate groundwater. The alluvium (for strongly adsorbing constituents) and the vadose zone (for moderately adsorbing and non-adsorbing constituents) are considered secondary sources of contamination and are described below.

- *Non-adsorbing constituents:* Measurement of tritium, perchlorate, and nitrate in the vadose zone core shows the presence of these contaminants in concentrations exceeding those found in water supply wells. Furthermore, the limited presence of these constituents in regional aquifer may indicate they are largely contained in the vadose zone at present.
- *Moderately adsorbing constituents:* These constituents (strontium-90, plutonium-238,239,240, and uranium-234,235,236,238) are present in the alluvial system and perhaps the upper portion

of the vadose zone. They are generally absent in the intermediate perched groundwater, which suggests they have migrated a finite depth in the vadose zone beneath the alluvium.

- *Strongly adsorbing constituents:* These solutes (cesium-137 and americium-241) adsorb onto sediments in the alluvial system and are not present in significant concentrations in the vadose zone beneath the alluvium.

The transport mechanism from the secondary sources is percolation through the vadose zone to the regional water table. Intermediate perched groundwater has been encountered in different stratigraphic positions at two well locations in Mortandad Canyon. At MCOBT-4.4, intermediate perched groundwater was present at the top of the Cerros del Rio basalt at a depth of 492 ft bgs, and at R-15, groundwater was perched at the base of the Cerros del Rio basalt at a depth of 750 ft bgs. There is insufficient information to distinguish between the two conceptual models for the perched groundwater described below.

- *Bathtub model:* Water percolates from the alluvial system and moves downward until it reaches a perching horizon of low permeability. If the topography of this low-permeability zone is bowl-shaped, groundwater perches but is relatively stagnant. Slow leakage through the perching horizon is balanced by percolation from above if the perched zone is in steady state, whereas the presence of the perched zone may be temporary, a remnant of increased percolation from anthropogenic water sources that have since been reduced.
- *Pathway model:* The perched groundwater is an intermediate but active step between the alluvial aquifer and the regional aquifer. If the topography of the perching layers form a dipping, low-permeability zone, water could move laterally for a significant distance through high permeability rocks above the perching horizon. The presence of nitrate and tritium in both intermediate groundwater (MCOBT-4.4 and R-15) and in the regional aquifer (TW-8 and R-15) supports the pathway model but does not confirm it, while the bathtub model also allows for a pathway from the surface to the regional aquifer.

Percolation through the vadose zone transports contaminants to the regional aquifer. Contaminants are distributed in the regional aquifer through groundwater flow. Groundwater flow in the regional aquifer is generally from west to east. However, pumping of the Pajarito Mesa and other well fields causes local perturbations in flow direction. Water quality in the regional aquifer in and near Mortandad Canyon is known at five wells: PM-5, TW-8, R-13, R-14, and R-15. Two of these wells (TW-8 and R-15) show contamination:

- *TW-8*: tritium, nitrate, possibly perchlorate with concentrations below maximum contaminant levels (MCLs) and proposed risk levels and
- *R-15*: regional aquifer at 964 ft; contaminants include nitrate (as N) (2.2–2.4 ppm) and perchlorate (4.2 ppb, J value). Nitrogen isotopic analysis indicates the nitrate is derived from neutralized nitric acid, not from a sewage source. From February 2000 to May 2001, nitrate concentrations were consistent during characterization sampling.

Results from initial groundwater modeling indicates that of the contaminants known to be present as secondary sources in the alluvium and vadose zone only perchlorate has a potential for reaching water-supply well PM-5 at a concentration of 1 µg/l within 100 yr. Sensitivity analyses for the hydrologic modeling have identified two key data needs that would reduce the uncertainty of these models' predictions. The key data needs for hydrologic modeling are to confirm that the infiltration rate is no higher than 1.56 m/yr and to confirm that that porosity of the Otowi Member of the Bandelier Tuff is equal to or greater than 0.44 (volume-pore space/volume-total).

The conceptual model for Mortandad Canyon has several key uncertainties considered important for understanding the nature and extent and fate and transport of contaminants. The data collected in the investigation proposed in this work plan will provide information to update and refine the conceptual model and support future work in the canyon. Key conceptual model uncertainties include

- the location(s) and rate(s) of infiltration in Mortandad and Ten Site Canyons;
- hydraulic properties (porosity, conductivity of the Bandelier Tuff, and other hydrogeologic units);
- the location and extent of non-adsorbing, moderately adsorbing, and strongly adsorbing contaminants in the alluvial system and the underlying vadose zone;
- the nature of contamination in intermediate perched groundwater zones, and the relation of those zones to the regional aquifer; and
- flow direction within the perched intermediate groundwater and in the regional aquifer.

4.2 Proposed Field Activities

The proposed field activities detailed in this work plan represent a comprehensive approach for characterizing the nature and extent of contaminants and are based on the conceptual model and uncertainties presented in Section 4.1. The activities include drilling and monitoring of groundwater monitoring wells and piezometers, sampling of persistent surface water, drilling of characterization boreholes, and conducting geophysical investigations. Each well and characterization borehole described in this work plan has its own set of characterization objectives for both the unsaturated zone and the groundwater.

The data quality objectives (DQOs) are identified in Tables 1, 2, and 3. At each drill site where saturation is not encountered within the target depth, the borehole will be backfilled with native materials and plugged and abandoned according to appropriate procedures and requirements. Core samples will be collected from the seven intermediate wells, a selected alluvial well (MCO-6.8), 16 shallow boreholes (up to 100 ft depth), and two of the four regional aquifer wells (R-1 and R-28) to determine vertical distributions of contaminants and moisture in the upper portions of the vadose zone. Information for the sitewide three-dimensional geologic model will be provided by examining cuttings and core samples and interpreting the geophysical logs. Under this work plan, a dry hole encountered at proposed alluvial and intermediate-depth well locations will be considered a successful achievement of the nature and extent objective and will not require drilling additional wells.

4.2.1 Surface Water Sampling Locations

Sampling and analysis of surface water will be conducted to evaluate the relationship between constituents in surface water and alluvial groundwater and to support an assessment of potential human health and ecological risk. Sample locations have been selected from areas where persistent surface water is present. Persistent surface water results from effluent releases or from periodic storm or other surface water runoff that is retained in bedrock pools or in alluvium from where it may eventually surface. Sampling of alluvial groundwater and surface water will be coordinated to provide a "snapshot" in time. The snapshot sampling efforts will include two sampling events that will be scheduled to coincide with periods of relatively dry and wet hydrologic conditions. Field reconnaissance during a relatively dry period in June and July 2003 identified areas where persistent surface water occurred and thus where sampling is recommended. Tables 4 and 5 provide a list of the analytes for surface water sampling to be conducted during the characterization investigation.

The proposed surface water sampling locations include the following:

- A location at the head of Mortandad Canyon east of Diamond Drive where small amounts of surface water emerge from the culvert under Diamond Drive and occur on a predominantly bedrock channel.
- A location below a wetland down canyon from NPDES outfall EPA03A-021 at TA-3.
- A location in upper Effluent Canyon in a small wetland located behind a berm at the head of the canyon.
- A location below the wetland down-canyon from NPDES outfall EPA03A-181 at TA-55.
- A location within 300 ft down-canyon of the TA-50 RLWTF outfall (NPDES outfall EPA03A-051) in Effluent Canyon.
- A location in Mortandad Canyon down-canyon of the Effluent Canyon confluence near the terminus of surface water flow supported by the TA-50 RLWTF outfall.
- One location in Ten Site Canyon down canyon from TA-35, where surface water occurs in persistent bedrock pools.

4.2.2 Well Installation and Sampling Locations

The proposed locations of six piezometers, eight alluvial wells, seven intermediate wells, and four regional aquifer wells are shown in Figures 1 and 2 and the DQOs for drilling the wells and piezometers is provided in Tables 1, 2, and 3. The wells and piezometers are located in areas of Mortandad Canyon in which there are uncertainties in the conceptual model including location and rate of infiltration, suspected contaminant inventories, and presence of intermediate perched zones. Geologic, hydrologic, geochemical, and geophysical data will be collected at each well site to reduce uncertainties in the conceptual model.

The part of Mortandad Canyon between Effluent Canyon and TW-8 has a very narrow canyon bottom with relatively lush riparian vegetation. Currently, an access road extends a short distance west of TW-8 to the PRB and a steep access route to the confluence of Mortandad and Effluent Canyons along a pipeline corridor. To minimize environmental disruption, the western-most well in the canyon bottom will be placed where a full drill rig can access the road that ends at the PRB. Drilling can be accomplished immediately upstream and downstream of the confluence of Effluent and Mortandad Canyons using the current pipeline route for access. Only portable equipment will be transported to the site.

The proposed order of drilling the intermediate wells is as follows:

- well I-4 (replacement well for MCOBT-4.4),
- well I-5 (intermediate well at R-15),
- well I-6 (north of R-15),
- well I-8 (upstream of confluence with Ten Site Canyon),
- well I-3 (lower Ten Site Canyon),
- well I-1 (east of TA-50 outfall),and
- well I-10 (mesa top south of Mortandad Canyon).

This sequence of drilling targets the early replacement of MCOBT-4.4, which is believed to be leaking, and emphasizes characterizing the extent of contamination within perched groundwater in areas where it has been recognized previously (i.e., MCOBT-4.4 and R-15).

Three additional intermediate wells may be drilled after results are obtained from the seven other intermediate wells. These include a well in upper Ten Site Canyon near R-14 (I-2), a well on the bench south of Mortandad Canyon and south of GS-2 (I-2), and a well on the mesa top south of Mortandad Canyon 1500 ft east of supply well PM-5 (I-9). The well near R-14 is designated by the NMED to investigate the occurrence of perched groundwater near the TA-35 outfall. Since there was no perched groundwater encountered when drilling nearby well R-14, and the regional aquifer has not shown the presence of contaminants, including perchlorate, nitrate, and tritium, I-2 is not considered essential for determining the nature and extent of contaminants in this area.

Intermediate well I-7, requested by NMED, may be drilled after results of drilling well I-1 are evaluated. Wells I-1 and I-7 are designed to determine if infiltration of contaminated surface water has resulted in zones of contaminated intermediate perched groundwater beneath the canyon between the TA-50 outfall and TW-8. Well I-1 will be drilled 0.25 mi east of the TA-50 outfall (Table 1). If saturated conditions are encountered beneath the alluvium at well I-1, then the need to drill well I-7 will be evaluated. Well I-7 will not be drilled if perched intermediate groundwater is not encountered at well I-1.

Intermediate well I-9, requested by NMED, will not be drilled until results of drilling I-10 are evaluated. Both wells, which are located on the mesa top south of Mortandad Canyon, are designed to evaluate whether contaminated perched groundwater is migrating southward along geologically controlled features such as bedding surfaces or paleochannels. Well I-10 will be drilled approximately 3500 ft east of PM-5 on the mesa top to investigate potential southerly groundwater flow and contaminant movement within the Cerro Toledo interval and Cerros del Rio basalt. Well I-10 was selected for drilling before well I-9 because it is located most closely to areas of Mortandad Canyon that are known to contain contaminated perched groundwater (i.e., at R-15). If saturated conditions are encountered beneath the alluvium at well I-10, then the need to drill well I-9 will be evaluated. Well I-9 will not be drilled if perched intermediate groundwater is not encountered at well I-10.

A series of boreholes are proposed to evaluate the relationship between the results from the 2002 resistivity survey and the moisture profiles and potential perched groundwater in the upper vadose zone. Boreholes RES-2, RES-3, and RES-4 and the upper portion of R-28 will be used for this purpose, and their locations are shown in Figure 2. Samples collected from these boreholes will be used to constrain interpretations of the resistivity surveys by comparing the resistivity survey data to core data for moisture content, grain size, porosity, and clay content. If successful correlations between saturation and conductivity are made, the planned DC resistivity data will be used to re-evaluate and optimize the planned locations of shallow wells and boreholes in this groundwater work plan. Core from the four boreholes will be analyzed at 10-ft intervals for moisture content, grain-size distributions, porosity, and clay content. During coring at R-28, the upper 150 ft will be targeted to determine the nature of the high conductivity zone identified by the DC resistivity survey between depths of 15 and 60 ft bgs at this location as shown in Figure 3. The core analyses will also examine the distribution of moisture across the sharp boundary at 80-ft depth that separates a conductive zone above from a resistive zone below.

Data collected from RES-2 will be compared to the moisture profile collected from existing well MCOBT-4.4. The DC resistivity profiles suggest that MCOBT-4.4 was drilled in an area where high conductivity extends to greater depths than the proposed location of RES-2 (Figure 3). RES-2 will be cored to 225 ft depth. Similarly, RES-3 and RES-4 are paired boreholes targeting adjacent areas with quite different DC resistivity profiles (Figure 3). At RES-3, the most conductive zone is in the upper 25 ft at the proposed borehole location. At RES-4, the conductive zone extends to depths greater than 180 ft. The target depth for RES-3 and RES-4 is 200 ft. Boreholes RES-2, RES-3, and RES-4 will be plugged and abandoned after borehole geophysical data are collected.

4.2.3 Piezometer Installations

Six piezometers, including one nested, will be installed using direct-push and/or hollow-stem augering to determine alluvial groundwater movement east of the sediment traps (Figure 2). The water-level data collected from the piezometers should provide hydrologic information including flow direction, hydraulic gradient saturated thickness, and extent of saturation south and north of the MT-3 to MT-4 area (Table 1). The maximum depth of each of the piezometers is 100 ft.

4.2.4 Characterization Boreholes

Sixteen shallow boreholes (≤100 ft) are proposed for drilling in Mortandad and Ten Site Canyons to determine areas and rates of infiltration or recharge, saturation, and accumulation of contaminants within the alluvium and Bandelier Tuff including the Cerro Toledo interval (Figure 2). Information regarding conceptual model uncertainty, projected depth, geology, hydrology, and geochemistry for these boreholes is provided in Table 6.

The boreholes are planned to be drilled by using the direct-push method and will not be completed as piezometers or characterization wells. If this drilling method does not work for the shallow boreholes, then the hollow-stem auger method will be attempted. The boreholes will be backfilled with bentonite and/or native material and abandoned after core samples have been collected. Proposed locations and number of boreholes include

- two boreholes in Effluent Canyon (B-1 and B-2),
- three boreholes between MCO-3 and MCO-4b (B-3, B-4, and B-5)
- two boreholes between TW-8 and MCO-6 (B-6 and B-7),
- one borehole in the old sediment traps (B-8),
- one borehole in the new sediment trap 2 (B-9),
- four boreholes between MCO-7.2 and MCO-8.2 (B-10, B-11, B-12, and B-13),
- two boreholes in middle-lower Ten Site Canyon west of TSCM-1 (B-14, and B-15), and
- one borehole near R-13 (B-16).

Up to ten core samples will be collected from each characterization borehole. Samples will be collected from all major stratigraphic units, including the alluvium, and will be analyzed for moisture content, metals, anions, stable isotopes, and radionuclides. The analyte suite for core collected from these boreholes is described in Table 7. Data and information collected from the boreholes will be used to determine moisture content, adsorption capacity, and nature and the extent of contamination in the alluvium and upper portions of the Bandelier Tuff/Cerro Toledo interval. The borehole data will also serve the site-specific data needs for modeling hydrological and geochemical-contaminant transport mechanisms. Boreholes B-1 through B-4 will have total depth of 100 ft within the Tshirege Member of the Bandelier Tuff. Measurement of effective distribution coefficients (Kd) will be conducted on borehole samples collected from seven different locations with three samples collected from each borehole (Table 7). The Kd will be calculated from both measurement of a given radionuclide concentration on the solid sample and concentration of the dissolved radionuclide. Distribution coefficients will be determined for americium-241, cesium-137, total isotopic plutonium (collectively as plutonium-238,239,240), strontium-90, and total isotopic uranium (collectively as uranium-234,235,236,238). The field-determined Kd parameters for these radionuclides will be used as site-specific adsorption constants for contaminant transport modeling and pathway analysis.

4.2.5 Analysis of Core, Surface Water, and Groundwater Samples

The proposed wells and boreholes provide the opportunity to evaluate the geochemistry of groundwater and unsaturated and saturated geologic materials within Ten Site Canyon and Mortandad Canyon. During drilling operations, core, cuttings, and groundwater samples will be collected for geochemical and contaminant characterization as described in Tables 7, 8, 9, and 10. The locations for samples will depend on the hydrologic and geologic conditions found during drilling and the quality of core recovered. After each well is completed and developed, two rounds of groundwater samples will be collected and analyzed for metals, anions including perchlorate, organic compounds, radionuclides, stable isotopes, TOC, and DOC as described in Tables 4 and 5.

4.2.5.1 Sampling and Analysis of Core

During coring of the boreholes and intermediate (I) and regional (R) aquifer wells, anion, cation, metal, stable isotope, radionuclide, and tritium profiles will be determined from the level of the canyon floor to depths specified in Tables 1, 2, and 3 or depth of core refusal. Core samples will not be collected during drilling of alluvial wells for chemical and radiochemical analyses, except at MCO-6.8. Core samples collected from drilling MCO-6.8 will be analyzed for the above parameters. Sample intervals are similar for all proposed boreholes and wells. For the upper 100 ft, samples will be collected every 10 ft (Table 8). For depths greater than 100 ft, samples will be collected at a frequency of one per 50 ft. Major stratigraphic contacts will also be sampled. The depth of coring depends on the type of borehole and well. For example, proposed alluvial wells and characterization boreholes will be cored to the total depth of the hole (<100 ft) and intermediate and regional aquifer wells will be cored to greater depths to obtain data required to determine nature and extent of contamination. Table 9 lists the analytical suite, analytical methods, and detection limits for geochemical and contaminant characterization of core samples.

4.2.5.2 Sampling and Analysis of Groundwater

Up to five borehole groundwater screening samples will be collected during drilling for geochemical and contaminant characterization. These screening samples will provide an early indication of whether contaminants could be present in perched and regional groundwater before characterization samples are collected from the completed well. Table 10 lists the analytical suite, sample volume, and containerization requirements for samples to be collected.

Characterization sampling will be conducted for two rounds at surface water locations and wells as described in Table 11. Analytical suite, estimated detection limits, half-life for radionuclides, analytical methods, and analytical protocols for inorganic chemicals and radionuclides in groundwater and surface water for characterization sampling conducted after well development are provided in Tables 4 and 5, respectively. Volatile and semivolatile organic compounds, high explosive compounds, polychlorinated biphenyls, and pesticides will be analyzed by gas chromatography-mass spectrometry and high-pressure liquid chromatography after each well has been developed. Total organic carbon and dissolved organic carbon will be analyzed by using a carbon analyzer (combustion in oxygen coupled with a carbon dioxide detector). Table 12 specifies chemical parameters to be measured in the field during characterization sampling after well development.

Surface water sample locations (see Section 4.2.1 of this work plan), alluvial wells, intermediate wells (excluding MCOBT-4.4), and regional aquifer wells, excluding R-13 and R-14, will be sampled twice as part of this work plan. The excluded wells will not be sampled because they have already been adequately characterized. The two rounds of sampling will be scheduled to coincide with periods of relatively dry and wet hydrologic conditions to evaluate potential variations in contaminant concentration associated with variations in groundwater level.

4.2.6 Surface Geophysics

A surface-based DC resistivity survey will be conducted in those portions of Mortandad Canyon that were not covered by the summer 2002 survey. The objective of the new resistivity work is to identify regions of higher conductivity beneath the canyon floor that may be related to perched alluvial groundwater and to zones of infiltration in subcropping bedrock units. The survey will be optimized to allow characterization of the variations in electrical conductivity in the upper 150 to 200 ft of the vadose zone. The resistivity survey will be scheduled as soon as possible during the execution of this work plan so that the results can be used to evaluate, and perhaps modify, the locations of characterization boreholes and alluvial wells planned for upper Mortandad Canyon and lower Ten Site Canyon. The 2002 resistivity data were used to locate shallow boreholes in middle and lower Mortandad Canyon.

The new DC resistivity survey will cover two canyon floor segments: upper Mortandad Canyon and lower Ten Site Canyon. The new resistivity survey in Mortandad Canyon will consist of a longitudinal profile starting above the TA-50 outfall in Effluent Canyon and will proceed eastward to the confluence with Mortandad Canyon, and then it will extend further east down Mortandad Canyon to the PRB, which was the western terminus of the 2002 survey (Figure 2). The Ten Site Canyon resistivity survey will extend from the western end of the wide portion of lower Ten Site Canyon to the confluence of Ten Site and Mortandad Canyons (Figure 2). The Ten Site Canyon survey will include a longitudinal profile along the canyon axis and two cross canyon profiles.

4.2.7 Borehole Geophysics

Borehole geophysical logs will be collected in the intermediate and regional wells to determine the geologic and hydrologic characteristics of the vadose zone, perched saturated zones, and the regional aquifer. Gamma logs and induction will be performed in boreholes B-5 through B-16 to help identify deposits of the Cerro Toledo interval, which has a lower gamma response and a more variable induction compared to overlying and underlying units of the Bandelier Tuff units.

Gamma, resistivity, and neutron density logs will be collected in boreholes RES-2, RES-3, and RES-4 as well as in the upper 200 ft of R-28. These geophysical data will be used in conjunction with moisture, grain size, and clay data collected from cores in the boreholes to determine the distribution of bound versus free water in the uppermost vadose zone at these locations. These data will be compared to conductivity profiles from the summer 2002 DC resistivity survey to assist with borehole placement.

Borehole and well geophysical data will be obtained from two sources: (1) borehole video, caliper, spontaneous potential, single point resistance and induction (conductivity), and natural gamma radiation surveys and (2) a wire-line logging service will be used to obtain a suite of borehole geophysical logs. The number and types of logs will vary as a function of borehole condition, the presence or absence of drill or well casing, and technical issues being addressed by a particular logging run. Table 13 provides typical suite of logs that have been run by wire-line logging services in cased and uncased boreholes during installation of previous hydrogeologic work plan wells.

4.3 Other Investigations

Two other investigations will be implemented in anticipation of data requirements to guide potential future mitigations, modeling, and long-term groundwater monitoring in Mortandad Canyon. These investigations will be incorporated into the investigation report, including information on recharge and discharge locations, infiltration rates and volumes, evapotranspiration, and stream flows, as necessary, to define nature, extent, and migration potential of contaminants. These investigations are briefly described as follows.

4.3.1 Infiltration Investigation

The objective of the infiltration investigation is to constrain the various terms of the water budget to quantify the deep percolation contaminant transport pathway. The investigation will provide estimates of the volumes and rates of water input to, and output from, the Mortandad Canyon alluvial aquifer and to determine the proportions that can be attributed to each component. The results will be used along with existing data to construct and calibrate a numerical model of saturated flow in the alluvial system. The model will support future assessment of groundwater infiltration under varying conditions and for differing scenarios (e.g., elimination of TA-50 discharges). After calibration, the model will then be used to simulate rates of infiltration from the alluvial system along with spatial and temporal variability for this parameter. The results of the model simulations will be corroborated and further constrained with field measurements of subsurface moisture potential and subsurface flow velocities and directions.

4.3.2 Colloid Investigation

The objective of the colloid investigation is to evaluate the potential importance of colloids in the transport of sorbed contaminants such as plutonium and americium. Colloidal transport of contaminants in Mortandad Canyon has been discussed in Penrose et al. (1990, 11770) and LANL (1997, 56835), but important aspects of colloid transport are still unknown. Colloids of unknown mineralogical composition are present in both TA-50 effluent and alluvial groundwater based on sample results at TA-50, MCO-3, and MCO-6. Water samples were analyzed for colloid concentration and particle size at the Laboratory's Chemistry Division during 1997 and 1999. Results of geochemical modeling using the computer program MINTEQA2 (Allison et al. 1991, 49930) suggest that transport of radionuclides by colloids is possible. Americium and plutonium, stable as cations, are predicted to adsorb onto negatively-charged silica and calcium carbonate (calcite). These two solid phases are stable as colloidal-size material under neutral pH conditions. Higher concentrations of colloids were measured at MCO-3 (1.1E+09 particles/mL) than at the TA-50 facility (2E+07 particles/mL) and MCO-6 (2.4E+07 particles/mL), suggesting that two sources of colloids occur including TA-50 effluent and natural sources. This study will be conducted by collecting water samples from developed wells and analyzing for the concentration and size of colloids. These water samples will also be analyzed for americium, plutonium, uranium, and strontium to determine if a correlation occurs between the colloids and these contaminants.

4.4 Modeling

The modeling activities are designed to serve two goals: (1) to provide relevant interpretations during data collection to guide later decisions in the characterization efforts and (2) to provide an overall synthesis of the data after they are collected.

To achieve the first goal, real-time data analysis of characterization borehole and well data will be performed to create an up-to-date interpretation of the nature and extent of contamination during data collection. As measurements of contaminant concentrations are made, the model of the extent of contamination will be updated using standard plume interpolation techniques. For each new well drilled, a one-dimensional model of water and contaminant transport into the deeper vadose zone will be applied. Numerical inverse modeling can estimate the rate of water percolation and contaminant velocities at each location. This information will be used to assess and update the water budget data available for the canyon. Since the leakage term from the alluvial groundwater to the deeper vadose zone is a key component of this water budget, such analyses will help to determine the overall water budget.

For the second longer-term goal, numerical models of the shallow alluvial groundwater system and the underlying vadose zone will be constructed to provide the overall water and contaminant budgets for the entire watershed. Such a synthesis can help to estimate and predict fate and transport of contaminants. The models will also focus on quantifying fate and transport uncertainties to evaluate whether sufficient data have been collected. Finally, geochemical transport modeling is required to provide a scientific basis for understanding contaminant transport. Decisions regarding remediation (including monitored natural attenuation) will be based on an integration of contaminant transport models.

5.0 MONITORING PROGRAM

Based on the results of the investigations conducted in Mortandad Canyon, a surface water and groundwater monitoring recommendation will be developed. Monitoring will be conducted under a facility-wide groundwater monitoring plan. The recommendation for long-term monitoring will be included in the Mortandad Canyon Investigation Report.

6.0 SCHEDULE, DELIVERABLES, AND REPORTING

6.1 Schedule

The schedule for the work outlined in this work plan is summarized in Table 14. The activities presented in this schedule are contingent upon regulatory approval of this work plan. The schedule is also contingent upon the availability of funding, resources, and contractual mechanisms at the appropriate times to complete fieldwork and comply with reporting requirements.

6.2 Investigation Report

An investigation report will be prepared following collection and analysis of environmental data and is currently scheduled for delivery to the NMED by December 31, 2005. The report, will document results of field investigations including

- details of well construction;
- analytical results of borehole core, surface water, and groundwater sampling;
- results of the DC geophysical survey;
- results of the human health and ecological risk assessments;
- a revised conceptual model;
- recommendations for long-term monitoring; and
- other conclusions and recommendations.

Supplemental reports detailing results of geophysical investigations, infiltration studies, modeling, and geochemistry and contaminant chemistry investigations will be provided separately.

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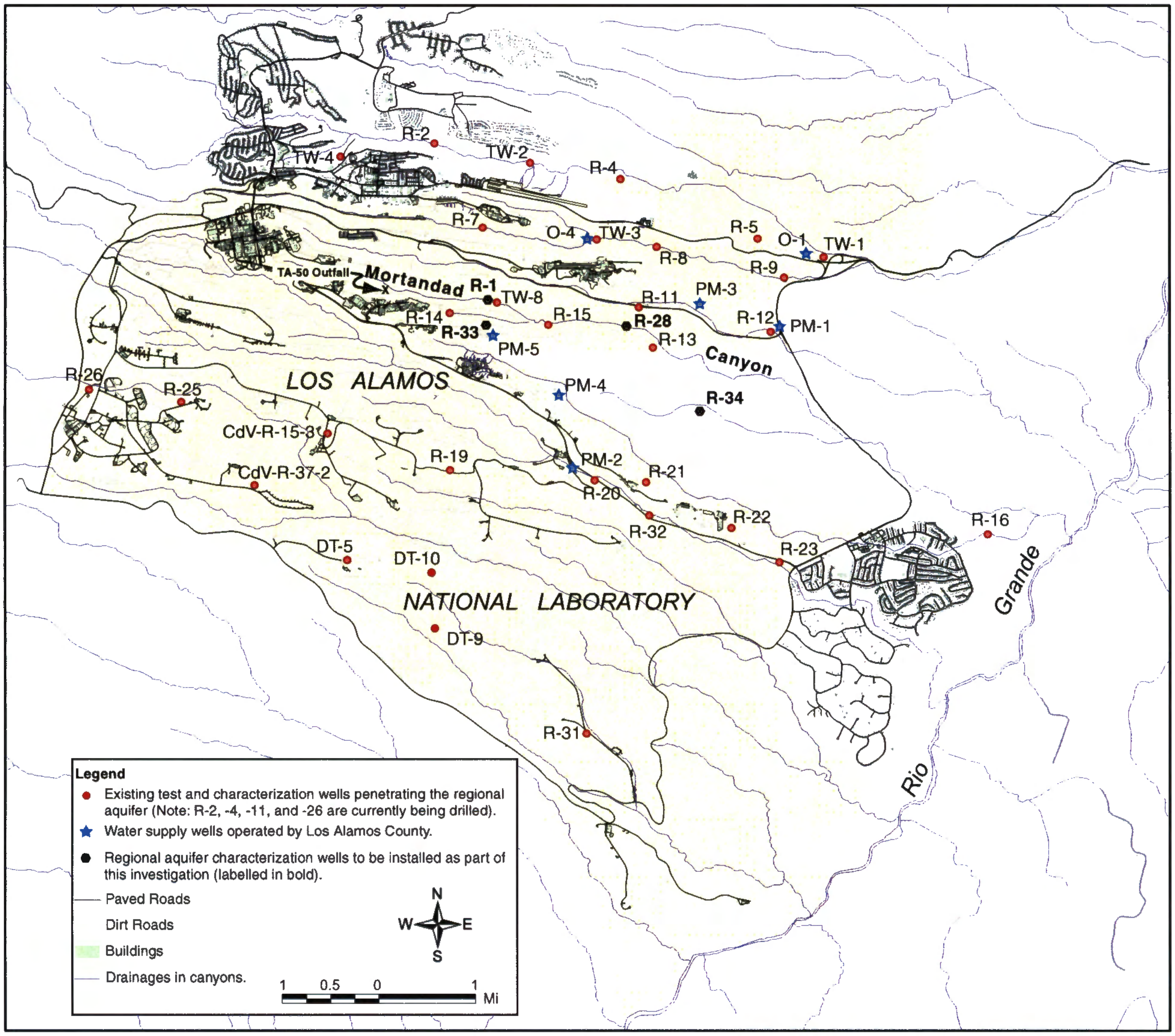


Figure 1. **Location of Mortandad Canyon showing the TA-50 outfall, existing, and planned wells penetrating the regional zone of saturation**

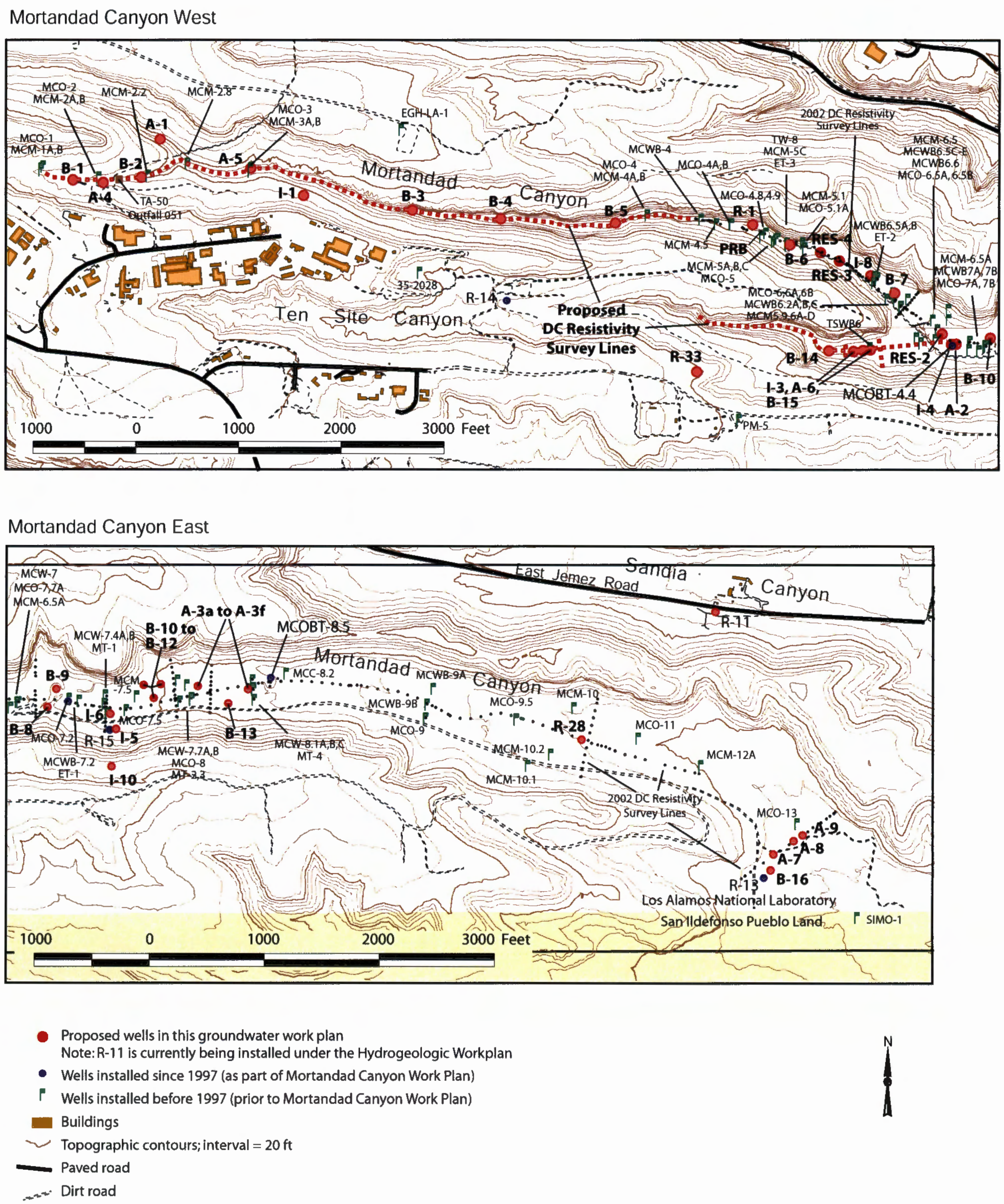
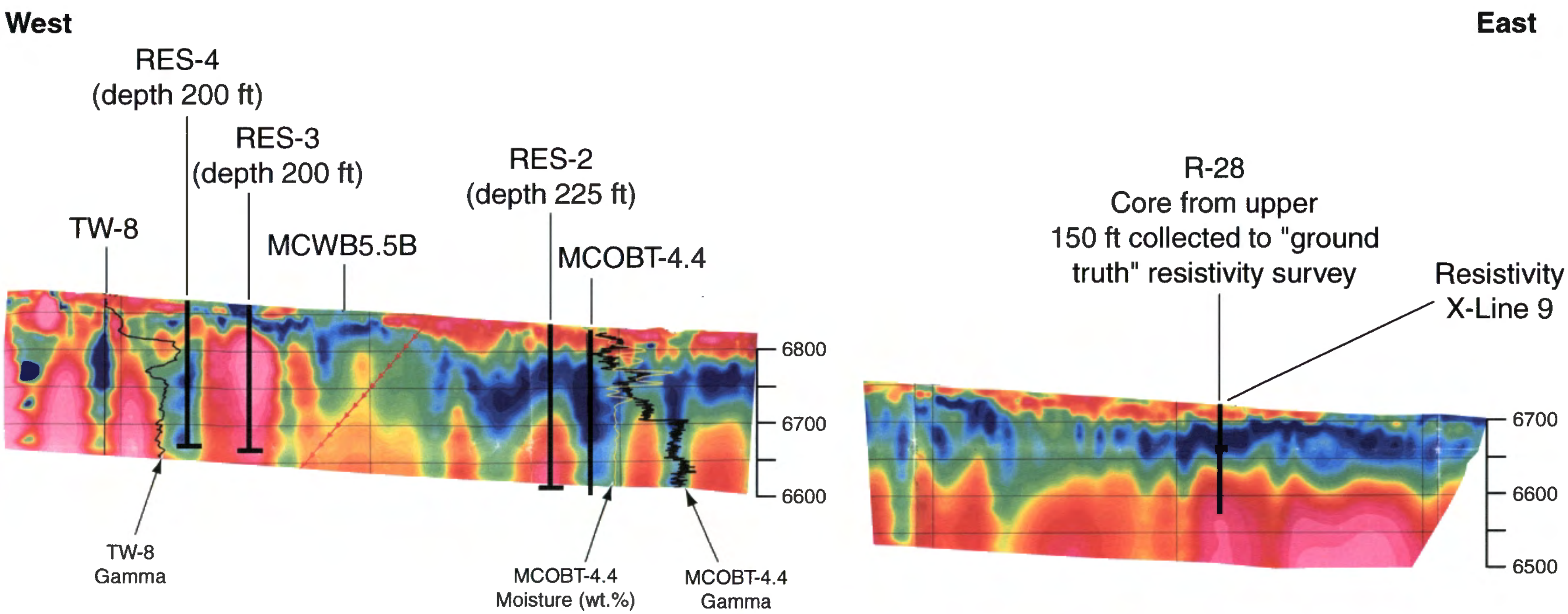


Figure 2. **Locations of proposed wells and boreholes, selected existing wells, and existing and proposed DC resistivity lines**



The colored scale is nonlinear with blue gradients representing conductive zones of 0 to ~150 Ohm-m, yellow representing zones of ~600 to 700 Ohm-m, and red representing resistive zones of 2000 to >6400 Ohm-m.

Figure 3. **Modeled DC resistivity results in Mortandad Canyon**

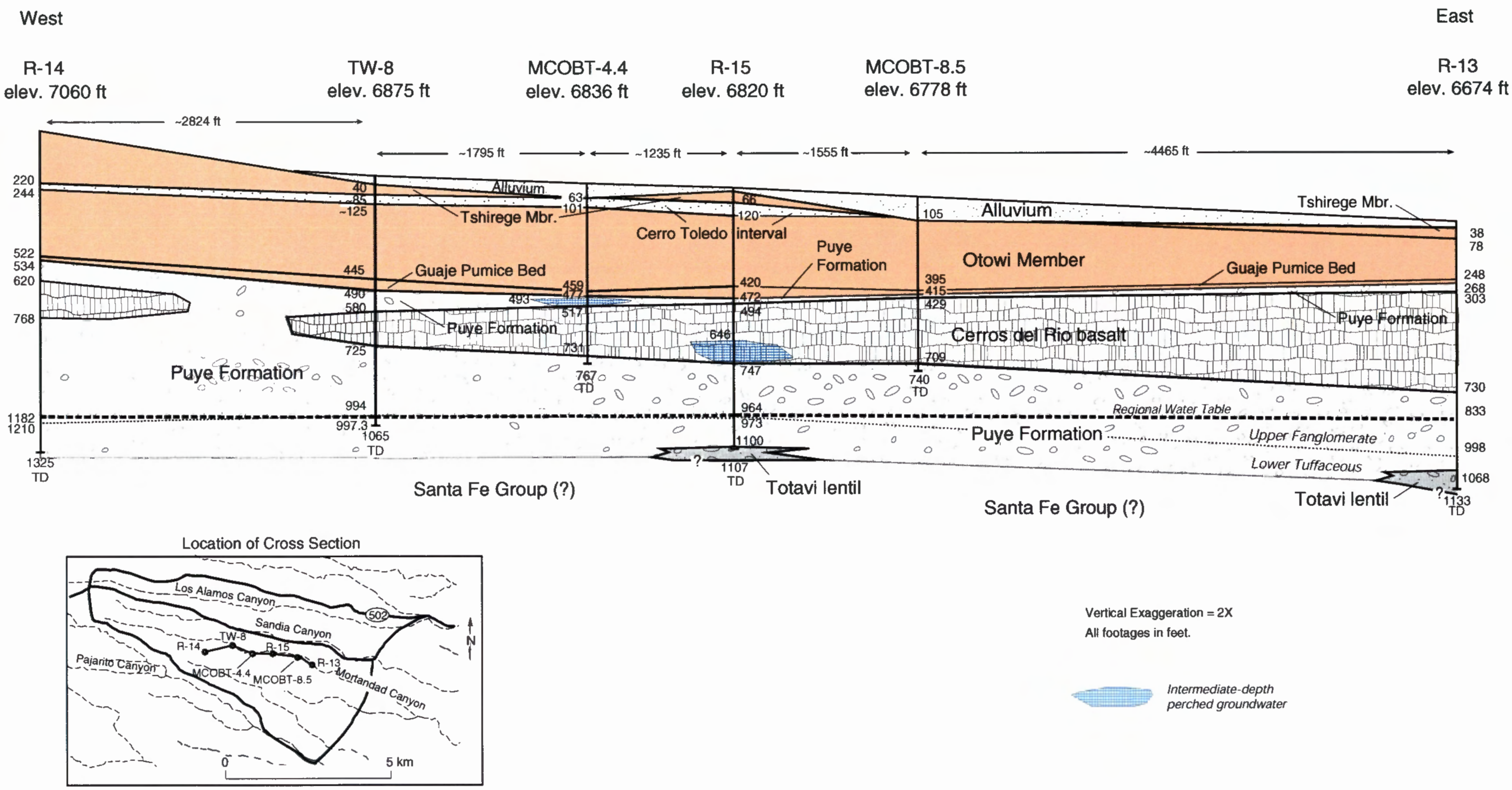


Figure 4. **Cross section showing stratigraphy and occurrence of intermediate perched groundwater in Mortandad Canyon**

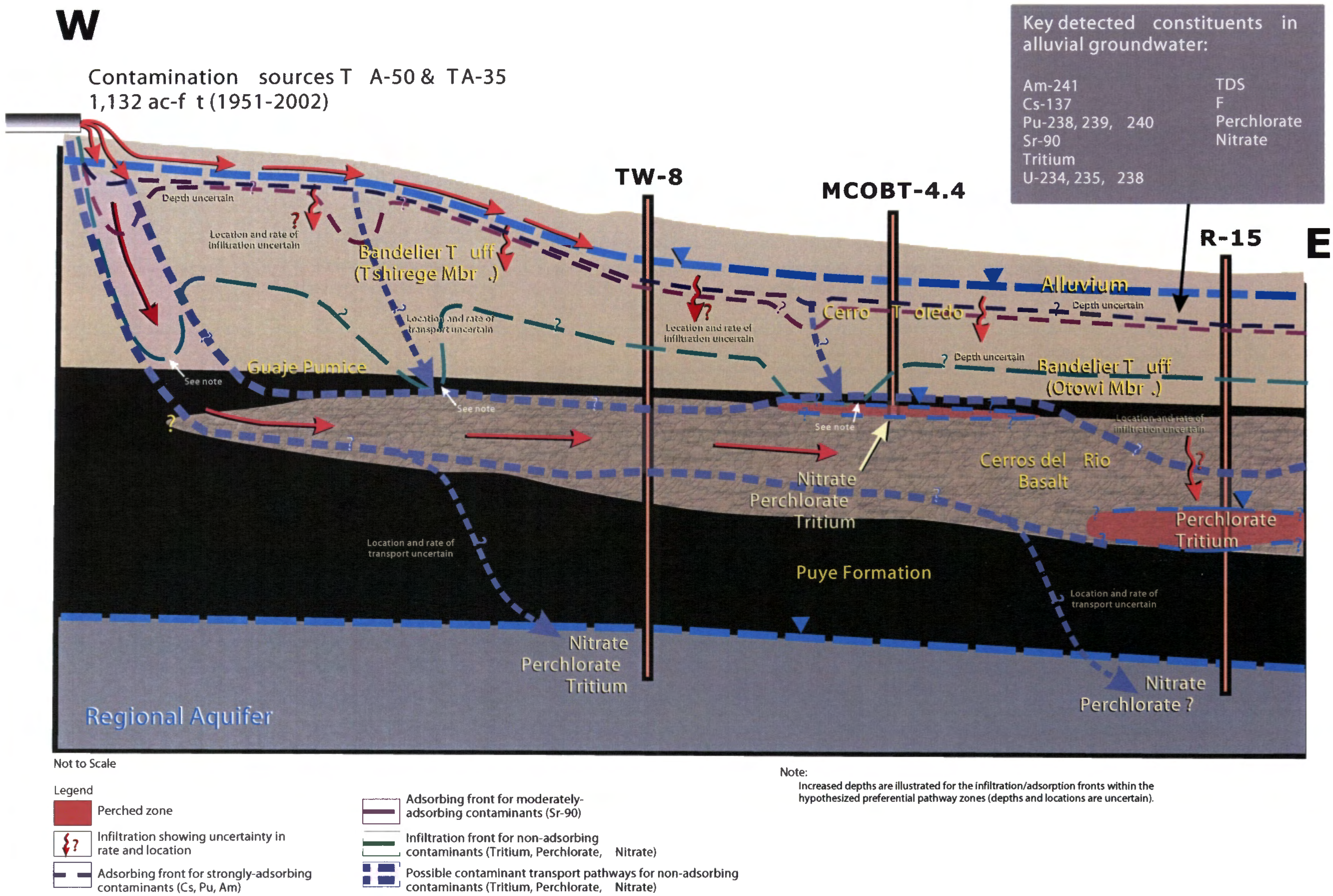


Figure 5. **Mortandad Canyon hydrogeologic and contaminant conceptual model**

Table 1
DQO Matrix for Alluvial Wells in Mortandad Canyon

	Well A-1	Well A-2	Well A-3a–f	Wells A-4, A-5	Well A-6	Wells A-7, A-8, and A-9
Conceptual Model Uncertainty	A-1 will define the limits on baseline/contaminant content in alluvial groundwater upstream of confluence with Effluent Canyon. Constrain location and rate of effluent infiltration in the upper portion of Mortandad Canyon	A-2 will provide data on the alluvial system where moderately-adsorbing contaminants (e.g., Sr) are accumulated. Constrain location and rate of effluent infiltration in the middle portion of Mortandad Canyon and the extent of saturation in the alluvium between MCO-6 and MCO-7	Install piezometers to reduce uncertainty in hydraulic gradients. The A-3 series will provide data on alluvial hydrology for modeling contaminant transport. Constrain location and rate of effluent infiltration	A-4 will define location and rate of infiltration within Effluent Canyon and A-5 will define location and rate of infiltration in Mortandad Canyon just below the confluence with Effluent Canyon. Replace wells that are not usable: MCO-2 (A-4) and MCO-3 (A-5).	A-6 is located in an area that may be a "hydrological sink" or a zone of enhanced infiltration. A-6 will determine whether adsorptive contaminants released into Ten Site Canyon have accumulated in the alluvium and will help to constrain location and rate of effluent infiltration.	This series of alluvial wells across the eastern portion of Mortandad Canyon will provide a check on whether non-adsorptive contaminants (e.g., ^3He, ClO_4) migrate over large distances in periodically saturated alluvium and help to constrain location and rate of effluent infiltration.
Projected Depth	12 ft; penetrate 5 ft into Bandelier Tuff	90 ft; penetrate 20 ft into Bandelier Tuff	45 ft; penetrate to base of alluvium	2-3 ft at A-4 and 10 ft at A-5; penetrate to base of alluvium	90 ft; penetrate to base of alluvium	90 ft for each well; penetrate to base of alluvium and/or colluvium
Geology	Determine thickness and composition of alluvium in upper Mortandad Canyon west of confluence with Effluent Canyon	Determine thickness, reactive phases, and composition of alluvium between MCO-6 and MCO-7.	Determine thickness and composition of alluvium and/or colluvium between MT-3 and MT-4	Determine thickness and composition of alluvium at MCO-2 and MCO-3	Determine thickness and composition of alluvium in Ten Site Canyon 1000 ft west of confluence with Mortandad Canyon	Determine thickness and composition of alluvium and/or colluvium near MCO-13
Hydrology	Determine hydraulic gradient, hydraulic conductivity, flow direction, and extent of saturation in alluvium	Determine hydraulic gradient, hydraulic conductivity, flow direction, and extent of saturation between MCO-6 and MCO-7	Determine vertical and horizontal gradients, hydraulic conductivity, flow direction, and extent of saturation between MT-3 and MT-4	Determine hydraulic gradient, hydraulic conductivity, flow direction, and extent of saturation at MCO-2 and MCO-3	Determine hydraulic gradient, hydraulic conductivity, flow direction, and extent of saturation 1000 ft west of confluence with Mortandad Canyon	Determine hydraulic gradient, flow direction, and extent of saturation in the alluvium and/or colluvium near MCO-13 Act as characterization wells, if saturation is encountered

Table 1 (continued)

	Well A-1	Well A-2	Well A-3a–f	Wells A-4, A-5	Well A-6	Wells A-7, A-8, and A-9
Geochemistry /Contaminant Chemistry	Evaluate hydrochemistry of alluvium in upper Mortandad Canyon west of confluence with Effluent Canyon	Evaluate attenuation of strontium-90 between MCO-6 and MCO-7. Characterize mineralogy that controls migration of strontium-90 and other contaminants	None	Evaluate hydrochemistry of alluvium at MCO-2 and MCO-3	Evaluate hydrochemistry of alluvium in Ten Site Canyon	Evaluate hydrochemistry of alluvium and/or colluvium near MCO-13
Saturated Zone Sampling	Collect and analyze water samples after well development	Collect and analyze water samples after well development	None	Collect and analyze water samples after well development	Collect and analyze water samples after well development	Collect and analyze water samples after well development
Core Needs	None	Collect core samples from surface to total depth (90 ft) for radionuclide, metal, and anion analyses	None	None	None	None
Hydraulic Testing	Slug tests	Slug tests	Slug tests	Slug tests	Slug tests	Slug tests
Geophysical Testing	None	Gamma induction	Gamma induction	Gamma induction	Gamma induction	Gamma induction
Number of Well Screens	One	One	Install one per well (total 6); placed at different depths to determine vertical gradients	One per well	One	One per well

Table 2
DQO Matrix for Intermediate Wells in Mortandad Canyon

	Well I-1	Well I-3	Well I-4	Wells I-5, I-6	Well I-8	Well I-10
Conceptual Model Uncertainty	Well I-1 will determine whether contaminant-bearing perched zones occur within ~1000 ft of the confluence of Effluent and Mortandad Canyons. Either a well or borehole (if no saturation is encountered) at this location is considered to satisfy NMED requirements.	Well I-3 will determine whether perched zones occur beneath lower Ten Site Canyon and if so, whether the contaminant contents indicate any component of lateral migration from Mortandad Canyon. Either a well or borehole (if no saturation is encountered) at this location is considered to satisfy NMED requirements.	Replace MCOBT-4.4., which encountered a perched zone with ^3H, ClO_4, U, and NO_3 contamination; however, the well was not constructed properly to monitor this perched zone. Therefore, a replacement well will be used to monitor this zone.	Well I-5 will provide a more complete record of the contaminated perched zone sampled when regional well R-15 was drilled. Well I-6 will provide constraints on how this contaminant zone extends toward the axis of Mortandad Canyon (see well I-10 for extent to the south). Either a well or borehole (if no saturation is encountered) at this location is considered to satisfy NMED requirements.	Determine if perched zones occur upstream of the confluence of Mortandad Canyon and Ten Site Canyon. Define nature and extent of contamination in basalt. Contaminant signatures in I-8 can be used to test possibility of perched-zone contamination between I-8 and I-3. Either a well or borehole (if no saturation is encountered) at this location is considered to satisfy NMED requirements.	Well I-10 will determine whether the perched contaminated zone discovered at R-15 extends southward beneath the mesa and towards PM-5 (see wells I-5 and I-6 for extent to the north). Either a well or borehole (if no saturation is encountered) at this location is considered to satisfy NMED requirements.
Projected Depth	800 ft: penetrate to base of dacitic lavas	770 ft: penetrate to base of Cerros del Rio basalt	517 ft: penetrate to base of upper Puye Formation	760 ft: penetrate to base of Cerros del Rio basalt	750 ft: penetrate to base of Cerros del Rio basalt	1000 ft: penetrate to base of Cerros del Rio basalt
Geology	Determine thickness of Bandelier Tuff and Cerro Toledo interval, upper Puye Formation, and dacitic lavas 0.25 mi east of TA-50 discharge	Determine thickness of alluvium, Bandelier Tuff and Cerro Toledo interval, upper Puye Formation, and Cerros del Rio lavas Determine distribution of basalts (potential fast pathways) hosting perched zone(s)	None: Characterized during installation of MCOBT-4.4	Determine thickness of alluvium, Bandelier Tuff and Cerro Toledo interval, upper Puye Formation, and Cerros del Rio basalt Determine distribution of basalts (potential fast pathways) hosting perched zone(s)	Determine thickness of alluvium/colluvium, Bandelier Tuff and Cerro Toledo interval, upper Puye Formation, and Cerros del Rio basalt Determine distribution of basalts (potential fast pathways) hosting perched zone(s)	Determine thickness of Bandelier Tuff and Cerro Toledo interval, upper Puye Formation, and Cerros del Rio basalt Determine distribution of basalts (potential fast pathways) hosting perched zone(s)
Hydrology	Determine hydraulic gradient, flow direction, recharge, discharge, and extent of saturation in the Guaje Pumice Bed or above dacitic lavas 0.25 mi east of TA-50 discharge	Determine hydraulic gradient, flow direction, recharge, discharge, and extent of saturation in the Cerros del Rio basalt in Ten Site Canyon southeast of TW-8	Determine hydraulic gradient, flow direction, recharge, discharge, and extent of saturation in the upper Puye Formation at MCOBT-4.4	Determine hydraulic gradient, flow direction, recharge, discharge, and extent of saturation in the Cerros del Rio basalt in Mortandad Canyon at R-15 (I-5) and north of R-15 (I-6)	Determine hydraulic gradient, flow direction, recharge, discharge, and extent of saturation in the Cerros del Rio basalt in Mortandad Canyon west of MCOBT-4.4 near MCO-6	Determine hydraulic gradient, flow direction, recharge, discharge, and extent of saturation in the Cerros del Rio basalt south of Mortandad Canyon near R-15

Table 2 (continued)

	Well I-1	Well I-3	Well I-4	Wells I-5, I-6	Well I-8	Well I-10
Geochemistry	Evaluate hydrochemistry of Cerro Toledo interval, Guaje Pumice Bed, or above dacitic lavas 0.25 mi east of TA-50 discharge	Evaluate hydrochemistry of Cerros del Rio basalt. Evaluate effect of releases from TA-35 on water quality in perched groundwater	Evaluate hydrochemistry of upper Puye Formation. Evaluate effect of releases from TA-50 and TA-35 on water quality in perched groundwater	Evaluate hydrochemistry of Cerros del Rio basalt. Evaluate effect of releases from TA-35 and TA-50 on water quality in perched groundwater	Evaluate hydrochemistry of Cerros del Rio basalt Evaluate effect of releases from TA-35 and TA-50 on water quality in perched groundwater	Evaluate hydrochemistry of Cerros del Rio basalt Evaluate possible effect of releases from TA-35 and TA-50 on water quality in perched groundwater
Vadose Zone Sampling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling	None: samples collected during drilling and subsequent sampling of MCOBT-4.4 Collect water samples if perched water is encountered during drilling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling
Core Needs	Collect core samples from surface to core refusal (550 ft) for contaminant, metal, and anion analyses	Collect core samples from surface to core refusal (560 ft) for contaminant, metal, and anion analyses	None: samples collected during drilling of MCOBT-4.4	Collect core samples from surface to core refusal (500 ft) for contaminant, metal, and anion analyses	Collect core samples from surface to core refusal (530 ft) for contaminant, metal, and anion analyses	Collect core samples from 300 to 800 ft for contaminant, metal, and anion analyses
Hydraulic Testing	Conduct slug test and/or injection/straddle packer test in the screen completely below the perched water table	Conduct slug test and/or injection/straddle packer test in the screen completely below the perched water table	Conduct slug test and/or injection/straddle packer test in the screen completely below the perched water table	Conduct slug tests and/or injection/straddle packer test in the screen completely below the perched water table	Conduct slug tests and/or injection/straddle packer test in the screen completely below the perched water table	Conduct slug tests and/or injection/straddle packer test in the screen completely below the perched water table
Geophysical Testing	Suite and timing of geophysical logging to depend on borehole conditions (suite of possible logs provided in Table 13) Laboratory borehole video camera to be used when open-hole conditions in the vadose zone are favorable for logging	Suite and timing of geophysical logging to depend on borehole conditions (suite of possible logs provided in Table 13) Laboratory borehole video camera to be used when open-hole conditions in the vadose zone are favorable for logging	None: geophysical logs were collected during the installation of MCOBT-4.4	Suite and timing of geophysical logging to depend on borehole conditions (suite of possible logs provided in Table 13) Laboratory borehole video camera to be used when open-hole conditions in the vadose zone are favorable for logging	Suite and timing of geophysical logging to depend on borehole conditions (suite of possible logs provided in Table 13) Laboratory borehole video camera to be used when open-hole conditions in the vadose zone are favorable for logging	Suite and timing of geophysical logging to depend on borehole conditions (suite of possible logs provided in Table 13) Laboratory borehole video camera to be used when open-hole conditions in the vadose zone are favorable for logging
Number of Well Screens	One in Guaje Pumice Bed or dacite lava flows	One in Cerros del Rio basalt	One in upper Puye Formation	One in Cerros del Rio basalt	One in Cerros del Rio basalt	One in Cerros del Rio basalt

Note: Intermediate wells I-2 (upper Ten Site Canyon near R-14), I-7 (on the bench south of GS-2), and I-9 (1500 ft of PM-5) will be evaluated for relocation and drilling after the other I- and R-wells are drilled.

Table 3
DQO Matrix for Regional Aquifer Wells in Mortandad Canyon

	Well R-1	Well R-28	Well R-33	Well R-34
Conceptual Model Uncertainty	R-1 is located at the critical location where Mortandad Canyon widens and there are significant changes in the alluvial aquifer gradient. This area may have enhanced infiltration of alluvial water containing contaminants. Therefore this is an important well for contaminant monitoring at the regional aquifer. Replace TW-8, a well with flawed construction that may allow movement of contaminated alluvial water along the well bore to the regional aquifer	Well R-28 will provide a contaminant analysis and monitoring point for comparison with regional wells R-15 (upstream Mortandad), R-11 (to the north in Sandia Canyon), and R-13 (to the southeast in downstream Mortandad Canyon).	R-33 will be used to provide sentinel contaminant monitoring for supply well PM-5 along with R-14 and R-15. Known contamination of nitrate, perchlorate, and tritium occurs in perched groundwater in this section of Mortandad Canyon. The perched groundwater probably provides a source of recharge to the regional aquifer. This well will be cited north of PM-5 south of Mortandad Canyon Drill and sample this well after R-1 and R-28 are drilled	R-34 will help constrain the nature and extent of potential contamination in the regional aquifer in the eastern (lower) portion of Mortandad Canyon. It may be used to provide a credible monitoring point for San Ildefonso Pueblo between R-13 and R-22. Drill and sample after R-1, R-28, and R-33 are drilled
Projected Depth	1095 ft: penetrate to a depth of 100 ft below the regional water table	950 ft: penetrate to a depth of 100 ft below the regional water table	1300 ft: penetrate to a depth of 100 ft below the regional water table	1100 ft: penetrate to a depth of 100 ft below the regional water table
Geology	Confirm stratigraphic contacts identified in the TW-8 lithologic log	Identify contacts for Bandelier Tuff and Cerro Toledo interval, Cerros del Rio basalt, Puye fanglomerates, and Totavi Lentil for site-wide models	Identify contacts for Bandelier Tuff and Cerro Toledo interval, Cerros del Rio basalt, Puye fanglomerates, and Totavi Lentil for site-wide models	Identify contacts for Bandelier Tuff and Cerro Toledo interval, Cerros del Rio basalt, Puye fanglomerates, and Totavi Lentil for site-wide models
Hydrology	Determine hydraulic gradient, hydraulic conductivity, and extent of saturation in Puye Formation. Conduct if necessary cross-hole pumping test with TW-8 Evaluate localized flow patterns in the regional aquifer	Determine hydraulic gradient, hydraulic conductivity, flow direction, and extent of saturation in Puye Formation Evaluate localized flow patterns in the regional aquifer	Determine hydraulic gradient, hydraulic conductivity, flow direction, and extent of saturation in upper Puye Formation Evaluate localized flow patterns in the regional aquifer	Determine hydraulic gradient, hydraulic conductivity, flow direction, and extent of saturation in upper Puye Formation Evaluate localized flow patterns in the regional aquifer
Geochemistry	Evaluate effect of releases from TA-48, TA-50, and other surface release sites on water quality in the regional aquifer. Constrain location and rate of percolation from vadose zone to regional aquifer. Evaluate groundwater chemistry in Mortandad Canyon in relationship to R-14, R-15, and R-13	Evaluate effect of releases from TA-48, TA-50, and other surface release sites on water quality in the regional aquifer Constrain location and rate of percolation from vadose zone to regional aquifer Evaluate groundwater chemistry in Mortandad Canyon in relationship to R-14, R-15, and R-13	Evaluate effect of releases from TA-48, TA-35, TA-50, and other surface release sites on water quality in the regional aquifer Constrain location and rate of percolation from vadose zone to regional aquifer Evaluate groundwater chemistry in Mortandad Canyon in relationship to PM-5, R-14, R-15, and R-13	Evaluate effect of releases from TA-48, TA-50, and other surface release sites on water quality in the regional aquifer Constrain location and rate of percolation from vadose zone to regional aquifer Evaluate groundwater chemistry in Mortandad Canyon in relationship to R-14, R-15, and R-13

Table 3 (continued)

	Well R-1	Well R-28	Well R-33	Well R-34
Vadose Zone Sampling	Collect core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling	Collect vadose zone core and analyze for anions, metals, radionuclides, and stable isotopes Collect water samples if perched water is encountered during drilling
Core Needs	Collect core samples from surface to core refusal (target 580 ft) for contaminant, metal, and anion analyses Identify contacts for Bandelier Tuff and Cerro Toledo interval, Cerros del Rio basalt, Puye fanglomerates, and Totavi Lentil for site-wide models	Collect core samples from surface to core refusal (target 300 ft) for contaminant, metal, and anion analyses	If the well is in Mortandad Canyon, collect core samples from surface to core refusal (target ~100-400 ft) for contaminant, metal, and anion analyses. If well is on mesa top, no core will be collected Identify contacts for Bandelier Tuff and Cerro Toledo interval, Cerros del Rio basalt, Puye fanglomerates, and Totavi Lentil for site-wide models	None
Regional Aquifer Sampling	Collect screening water samples during drilling at the top of the regional aquifer Install well screen to collect water quality data for the regional aquifer	Collect screening water samples during drilling at the top of the regional aquifer Install well screen to collect water quality data for the regional aquifer	Collect screening water samples during drilling at the top of the regional aquifer Install well screen to collect water quality data for the regional aquifer	Collect screening water samples during drilling at the top of the regional aquifer Install well screen to collect water quality data for the regional aquifer
Hydraulic Testing	Conduct slug test and/or injection/straddle packer test in the screen completely below the regional water table. Conduct (if necessary) cross-hole pumping test with TW-8	Conduct slug test and/or injection/straddle packer test in the screen completely below the regional water table	Conduct slug test and/or injection/straddle packer test in the screen completely below the regional water table	Conduct slug tests and/or injection/straddle packer test in the screen completely below the regional water table
Geophysical Testing	Run cased hole geophysical suite, including neutron log, in TW-8 prior to plugging and abandonment In replacement borehole, suite and timing of geophysical logging to depend on borehole conditions (see Table 13 for suite of possible logs) In replacement borehole, laboratory borehole video camera to be used when open hole conditions in the vadose zone are favorable for logging	Suite and timing of geophysical logging to depend on borehole conditions (see Table 13 for suite of possible logs) Laboratory borehole video camera to be used when open hole conditions in the vadose zone are favorable for logging	Suite and timing of geophysical logging to depend on borehole conditions (see Table 13 for suite of possible logs) Laboratory borehole video camera to be used when open hole conditions in the vadose zone are favorable for logging	Suite and timing of geophysical logging to depend on borehole conditions (see Table 13 for suite of possible logs) Laboratory borehole video camera to be used when open hole conditions in the vadose zone are favorable for logging
Number of Well Screens	One in the Puye Formation	One in the Puye Formation	To be determined	One in the Puye Formation

Table 4
Analytical Suite, Estimated Detection Limits, Analytical Methods, and Analytical Protocols for Inorganic Chemicals in Groundwater Samples for Post-Development Characterization Sampling[a]

Analyte	EDL (µg/L)	Analytical Method	Analytical Protocol[b]
Metals (total and dissolved)			
Aluminum	10	ICPMS	SW-6020
Antimony	0.1	ICPMS	SW-6020
Arsenic	1	ICPMS	SW-6020
Barium	2	ICPMS	SW-6020
Beryllium	5	ICPMS	SW-6020
Boron	10	ICPMS	SW-6020
Cadmium	0.1	ICPMS	SW-6020
Calcium	10	ICPES	SW-6010B
Chromium	2	ICPMS	SW-6020
Cobalt	2	ICPMS	SW-6010B
Copper	2	ICPMS	SW-6020
Iron	10	ICPMS	SW-6020
Lead	0.1	ICPMS	SW-6020
Magnesium	10	ICPES	SW-6010B
Manganese	2	ICPMS	SW-6020
Mercury	0.2	CVAA	SW-7470A
Nickel	2	ICPMS	SW-6020
Potassium	10	ICPES	SW-6010B
Selenium	0.2	ICPMS	SW-6020
Silver	0.2	ICPMS	SW-6020
Sodium	50	ICPES	SW-6010B
Thallium	0.1	ICPMS	SW-6020
Uranium	0.1	ICPMS	SW-6020
Vanadium	2	ICPMS	SW-6020
Zinc	1	ICPMS	SW-6020
Anions (dissolved)			
Bromide	20	IC	SW-300
Chlorate	20	IC	SW-300
Chloride	20	IC	SW-300
Fluoride	20	IC	SW-300
Nitrate	40	IC	SW-300
Nitrite	40	IC	SW-300
Perchlorate	4	IC	SW-300
Orthophosphate	20	IC	SW-300
Sulfate	100	IC	SW-300
Other Inorganic Chemicals (dissolved)			
Silica	200	Colorimetry	EPA Method 370.1
Total cyanide	50	Colorimetry	SW-9012A

[a] Both unfiltered (total) and filtered (dissolved) water samples will be collected. Water samples will be filtered at the time of collection to remove particles larger than 0.45 µm.

[b] EPA SW-846 Method (EPA 1986, 31732) or equivalent.

Table 5
Analytical Suite, Half-Life, Detection Emission, Minimum Detectable Activity, and Analytical Method for Radionuclides in Groundwater Samples for Post-Development Characterization Sampling[a]

Analyte	Half-Life (yr)	Detected Emission	MDA (pCi/L)	Analytical Method
^{241}Am	432.2	α	0.05	α-Spectrometry
^{238}Pu	87.7	α	0.05	α-Spectrometry
$^{239,240}Pu$[b]	2.411×10^4	α	0.05	α-Spectrometry
^{90}Sr	28.7	β	1.0	GPC
Tritium	12.3	β	250	LSC
Tritium (low level)	12.3	β	1	Electrolytic enrichment/DC
^{99}Tc	2.13×10^5	β	5	LSC
^{234}U	2.46×10^5	α	0.1	α-Spectrometry[c]
^{235}U	7.04×10^8	α	0.1	α-Spectrometry[c]
^{236}U[d]	2.342×10^7	α	0.1	TIMS
^{238}U	4.47×10^9	α	0.1	α-Spectrometry[c]
Gamma spectroscopy[e]	n/a[f]	γ	10[g]	γ-Spectroscopy
Gross-alpha	n/a	α	1.0	GPC or LSC
Gross-beta	n/a	β	1.0	GPC or LSC
Gross-gamma	n/a	γ	20	NaI(Tl) or HPGe detection

[a] Both filtered and non filtered samples will be collected for radionuclide analyses, excluding tritium and Tc-99.
[b] The ^{239}Pu and ^{240}Pu isotopes cannot be distinguished by alpha spectrometry. The half-life of ^{239}Pu is given.
[c] Radionuclide may also be analyzed by ICPMS.
[d] Water sampling for ^{236}U analysis should use clean protocols including EPA 1669 or United States Geological Survey 94-539.
[e] The gamma spectroscopy analyte list includes gamma-emitting isotopes including Cs-137.
[f] n/a = Not applicable.
[g] The MDA for ^{137}Cs is 15 pCi/L; the MDAs for other analytes will vary.

Table 6
DQO Matrix for Characterization Boreholes in Mortandad Canyon

	Boreholes 1-6	Boreholes 7-9	Boreholes 10-13	Boreholes 14 and 15	Borehole 16
Conceptual Model Uncertainty	Reduce uncertainty in contaminant distributions, adsorption capacity, and infiltration in alluvium and upper Bandelier Tuff in Effluent Canyon and Upper Mortandad Canyon upstream (west) of TW-8 Constrain location of effluent infiltration	Reduce uncertainty in contaminant distributions, adsorption capacity, and infiltration in alluvium and upper Bandelier Tuff in Mortandad Canyon between MCO-6.6 and sediment trap #2 Constrain location of effluent infiltration	Reduce uncertainty in contaminant distributions, adsorption capacity, and infiltration in alluvium and upper Bandelier Tuff in Mortandad Canyon between MCO-7.2 and MCO-8.2 Constrain location of effluent infiltration	Reduce uncertainty in contaminant distributions, adsorption capacity, and infiltration in alluvium and upper Bandelier Tuff in Ten Site Canyon upstream of confluence with Mortandad Canyon Constrain location of effluent infiltration	Reduce uncertainty in anion/tritium distributions and infiltration near R-13 in upper 100 ft of alluvium and Bandelier Tuff
Projected Depth	100 ft	100 ft	100 ft	100 ft	100 ft
Geology	Determine thickness, reactive phases, and composition of alluvium/Bandelier Tuff in Effluent Canyon and upper Mortandad Canyon west and east of confluence with Effluent Canyon	Determine thickness, reactive phases, and composition of alluvium/Bandelier Tuff in Mortandad Canyon between MCO-6.6A and sediment trap #2	Determine thickness, reactive phases, and composition of alluvium/Bandelier Tuff in Mortandad Canyon between MCO-7.2 and MCO-8.2	Determine thickness, reactive phases, and composition of alluvium/Bandelier Tuff in Ten Site Canyon upstream of confluence with Mortandad Canyon	Determine thickness, and composition of alluvium/Bandelier Tuff near R-13
Hydrology	Determine moisture content in Bandelier Tuff	Determine moisture content in Bandelier Tuff	Determine moisture content in Bandelier Tuff	Determine moisture content in Bandelier Tuff	Determine moisture content in Bandelier Tuff
Geochemistry /Contaminant Chemistry	Determine contaminant profiles for radionuclides, anions, and metals. Measure effective Kd values for radionuclides in 3 boreholes at 3 depths/borehole	Determine contaminant profiles for radionuclides, anions, and metals. Measure effective Kd values for radionuclides in 1 borehole at 3 depths	Determine contaminant profiles for radionuclides, anions, and metals. Measure effective Kd values for radionuclides in 1 borehole at 3 depths	Determine contaminant profiles for radionuclides, anions, and metals. Measure effective Kd for radionuclides in 2 boreholes at 3 depths/borehole	Determine contaminant profiles for anions.
Core Needs	Collect core samples (every 10 ft) from surface to total depth (100 ft) for radionuclide, metal, and anion analyses and moisture content	Collect core samples (every 10 ft) from surface to total depth (100 ft) for radionuclide, metal, and anion analyses and moisture content	Collect core samples (every 10 ft) from surface to total depth (100 ft) for radionuclide, metal, and anion analyses and moisture content	Collect core samples (every 10 ft) from surface to total depth (100 ft) for radionuclide, metal, and anion analyses and moisture content	Collect core samples (every 10 ft) from surface to total depth (100 ft) for anions, tritium, and moisture content

Table 7
Analytical Suites for Core Samples Collected from Boreholes

	Number of Core Samples for Analyte Data	Analytical Suite	Number of K_d Determinations (rad only – Cs, Sr, Am, Pu, U, Sr)	Number of Samples for Geologic Characterization	Geologic Analytical Suite
Alluvial Wells					
MCO-6.8 (80 ft)	8	A		3	C, D, E
Other alluvial wells				A-5 (3) and A-8 (3)	C, D, E
Characterization Boreholes (100 ft)					
B-1	10	A, G	3, plus 3 type A leachate analyses	3	C, D, E
B-2	10	A, G			
B-3	10	A, G	3, plus 3 type A leachate analyses	3	C, D, E
B-4	10	A, G			
B-5	10	A, G			
B-6	10	A, G	3, plus 3 type A leachate analyses	3	C, D, E
B-7	10	A, G			
B-8	10	A, G	3, plus 3 type A leachate analyses	3	C, D, E
B-9	10	A, G			
B-10	10	A, G			
B-11	10	A, G	3, plus 3 type A leachate analyses	3	C, D, E
B-12	10	A, G			
B-13	10	A, G			
B-14	10	A, G	3, plus 3 type A leachate analyses	3	C, D, E
B-15	10	A, G	3, plus 3 type A leachate analyses	3	C, D, E
B-16	10	A, G			
I- and R- Boreholes					
I-1 (550 ft)	32	B		6	C, D, F
I-3 (560 ft)	33	B			
I-5 (500 ft)	30	B			
I-6 (500 ft)	30	B			
I-8 (530 ft)	31	B			
I-10 (500 ft; 300-800 ft bgs)	25	B			
R-1 (580 ft)	34	B		5	C, D, F
R-28 (300 ft; also a RES hole)	20	B		20	D (all 20); E (4 samples)
R-33				5	C, D, F
R-34				10	C, D, F

Table 7 (continued)

	Number of Core Samples for Analyte Data	Analytical Suite	Number of K_d Determinations (rad only – Cs, Sr, Am, Pu, U, Sr)	Geologic Characterization	Geologic Analytical Suite
Resistivity Boreholes					
RES-2 (200 ft)	20	G			
RES-3 (200 ft)	20	G			
RES-4 (225 ft)	23	G			
TOTALS		168 A 235 B 223 G	21 K_d samples, 21 A		56 C, 76 D, 31 E, 26 F

[a] Analysis of leachates for anions, cations, Al, Fe, and Mn, by LANL and ^3H by external lab; analysis of core for moisture content by LANL and of radionuclides (isotopes of Am, Pu, U, Cs, and Sr) by external lab.

[b] Analysis of leachates from core as in A plus stable isotopes (H, O, N).

[c] Petrographic analysis by LANL.

[d] Quantitative X-ray diffraction (QXRD) by LANL.

[e] Clay-mineral separation and analysis by LANL.

[f] X-ray fluorescence analysis by LANL.

[g] Moisture analysis by LANL.

Table 8
Sampling of Core and Cuttings During Drilling of Intermediate and Regional Aquifer Wells

Sample Description	Test	Sample Size	Container	Sample Frequency
Coring				
Core	Anions and moisture	0.4 ft of 2-in. diameter core	8 oz pre-weighed glass jar	For upper 100 ft: Every 10 ft when drilling dry For below 100 ft: Every 50 ft to refusal
	Tritium	0.5 ft of 2-in. diameter core	Sealed plastic bag wrapped with tape and core-protected	For upper 100 ft: 10 samples will be collected when drilling dry For below 100 ft: Every 50 ft to refusal
	Radiological screening for gross alpha, beta, and gamma (for off-site transport of samples)	0.2 ft of 2-in. diameter core	Sealed plastic bag	Every 50 ft
	Radionuclides	0.5 ft of 2-in. diameter core	Sealed plastic bag and core-protected	For upper 100 ft: 10 samples to be collected when drilling dry For below 100 ft: Every 50 ft to refusal
	Metals and cations	0.5 ft of 2-in. diameter core	Sealed plastic bag and core protected	For upper 100 ft: 10 samples will be collected when drilling dry For below 100 ft: Every 50 ft to refusal
	Stable isotopes	0.5 ft of 2-in diameter core	Sealed plastic bag and core protected	For upper 100 ft: 10 samples will be collected when drilling dry For below 100 ft: Every 50 ft to refusal
Drilling				
Cuttings	Bulk cuttings systematically collected for archival purposes and for supplemental sample needs	500–700 ml	Plastic ziplock bag	One sample every cuttings run (nominally every 5 ft), beginning at the bottom of the core hole or throughout the hole if no core is collected
	Sieved cuttings for lithology description, binocular microscope examination	Enough to partly fill trays	Plastic chip trays	One sample every cuttings run (nominally every 5 ft), including overdrilling of the core hole. Normally, an unsieved sample, a >10 mesh sample, and a >35 mesh sample every cuttings run
	Sieved cuttings for x-ray diffraction (XRD), x-ray fluorescence (XRF), petrography	200–300 ml sieved, or bulk if necessary	Plastic ziplock bag	One >10-mesh sample every cuttings run (nominally every 5 ft); finer sizes or bulk split will be substituted where >10-mesh size cannot be obtained

Note: Priority of sample core collection when recovery is less than 100% should be anions, moisture, and stable isotopes; radionuclides and tritium; and radiological screening, cations, and metals.

Table 9
Analyses of Core and Cuttings During Drilling of Intermediate and Regional Aquifer Wells

Analyte	EDL[a]	Analytical Technique	Analytical Method
Anions and Cations[b]/Stable Isotopes			
Bromide, chloride, fluoride, iodide, nitrate, nitrite, oxalate, phosphate, sulfate	0.02 mg/L	IC	SW-846-EPA Method 300
Carbonate Alkalinity	1 mg/L	Titration	SW-846 – EPA Method 310.1
Perchlorate	0.004 mg/L[c] 0.002 mg/L[d]	IC	SW-846-EPA Method 300 LCMS/MS[e]
Arsenic, strontium, uranium	0.001 mg/L	Inductively coupled mass spectrometry (ICPMS)	SW-846-EPA Method 6020
Aluminum, calcium, iron, magnesium, manganese, sodium, potassium	0.01 mg/L	Inductively coupled optical emission spectroscopy (ICPOES)	SW-846-EPA Method 6010B
$^{18}O/^{16}O$	n/a[f] (permil)	Isotope ratio mass spectrometry	Generic – oxygen isotope ratio
$^{2}H/^{1}H$	n/a (permil)	Isotope ratio mass spectrometry	Generic – deuterium ratio
Nitrogen Isotopes	n/a (permil)	Isotope ratio mass spectrometry	Generic – nitrogen isotope ratio
Contaminant Characterization Constituents			
Tritium	700 pCi/L	Liquid scintillation counting	EPA Method 906.0
Tritium	0.5 pCi/L	Direct counting or electrolytic enrichment	Generic low-level tritium
Americium-241	0.05 pCi/g	α-spectrometry	HASL-300: americium-241
Plutonium-238	0.05 pCi/g	α-spectrometry	HASL-300: isotopic plutonium
Plutonium-239,240	0.05 pCi/g	α-spectrometry	HASL-300: isotopic plutonium
Strontium-90	0.5 pCi/g	Gas proportional counting	EPA Method 905.0
Technetium-99	5 pCi/g	Gas proportional counting	HASL-300: Technetium-99
Uranium-234	0.1 pCi/g	α-spectrometry	HASL-300: isotopic uranium
Uranium-235,236	0.1 pCi/g	α-spectrometry	HASL-300: isotopic uranium
Uranium-238	0.1 pCi/g	α-spectrometry	HASL-300: isotopic uranium
Gamma spectroscopy	1.0 pCi/g	γ-spectroscopy	EPA Method 901.1

[a] EDL= listed as milligrams per liter for anions and picocuries per gram for radionuclide constituents except tritium (which is listed in picocuries per liter) in extracted or leached water.

[b] Anion and cation analyses will be performed on the leachate formed from a deionized water slurry of the homogenized core sample.

[c] Offsite laboratory.

[d] Onsite screening.

[e] LCMS = Liquid chromatography mass spectrometry; used for low-level perchlorate analysis (0.25 µg/L).

[f] n/a = Not applicable.

Table 10
Sampling and Analysis of Intermediate and Regional Aquifer Groundwater During Drilling

Estimated Number of Water Samples/ Borehole	Analysis	Container	Preservation	Filtered Through Acetate 0.45 Micrometer	Volume of Each Sample (L)	Collect Archival Sample	Archival Sample Volume (L)
5	Metals (dissolved)	100 ml plastic	HNO_3 to pH 2, 4°C	Yes	0.25		
5	Anions (dissolved)	100 ml plastic	No field preservation	Yes	0.25		
5	γ spec, ^{241}Am, ^{137}Cs, ^{238,239,240}Pu, ^{234,235,238}U, ^{90}Sr	1 gal. plastic	HNO_3 to pH 2, 4°C	No	3.78	X	3.78
5	Stable isotopes ($^{18}O/^{16}O$, D/H)	30 ml glass w/ poly-seal cap	Ambient temperature	No	0.03	X	0.03
5	Stable isotopes ($^{15}N/^{14}N$)	1 gal. plastic	HCL or H_2SO_4 to pH 2, 4°C	No	3.78	X	3.78
5	Tritium[a]	500 ml poly	Ambient temperature	No	0.5	X	0.5
5	Tritium (low-level or direct-counting)[a]	500 ml poly	Ambient temperature	No	0.5	X	1
5	Gross α,β ,γ (for off-site shipping)	500 ml poly	Ambient temperature	No	0.5	X	0.5
5	TKN	1 L poly	H_2SO_4 to pH 2, 4°C[b]	No	1	X	1
5	ClO_4^-	250 ml poly	Ambient temperature	Yes	0.25	X	0.25
Total volume of each sample event: filtered and nonfiltered					10.84		10.84
Part of total volume to be filtered					0.75		

[a] Initially analyze tritium using liquid scintillation. If activity is less than 300 pCi/L, analyze archival sample using direct counting or electrolytic enrichment at University of Miami.

[b] No preservation for ClO_4^-, Br^-, Cl^-, F^-, NO_3^-, NO_2^-, SO_4^{2-}, and PO_4^{3-}.

Table 11
Surface Water and Well Locations Selected for Characterization Sampling

Location/Well	Zone Targeted for Completion	Sampling Frequency*
Surface Water		
Seven locations (described in Section 4.2.1)	Sampling during and baseflow locations	Two sampling rounds
Alluvial Wells		
MCO-0.6 (Drilled)	Alluvium	Two additional sampling rounds
MCO-0.9 (A-1)	Alluvium	Two sampling rounds
MCO-2 (A-4)	Alluvium	Two sampling rounds
MCO-3 (A-5)	Alluvium	Two sampling rounds
MCO-6.8 (A-2)	Alluvium	Two sampling rounds
MCO-7.2 (Drilled)	Cerro Toledo interval	No groundwater historically available for sampling
MCO-13ABC (A-7,-8, and -9)	Alluvium	Two sampling rounds
TSCO-6A (A-6)	Alluvium	Two sampling rounds
A-3a–f	Alluvium	Six piezometers for water level measurements
Perched Intermediate Zone(s)		
I-1	Volcanic rock	Two sampling rounds
I-2	To be determined	To be determined
I-3	Ten Site Canyon, Cerros del Rio Basalt	Two sampling rounds
I-4	Replaces MCOBT-4.4, Cerros del Rio Basalt	Two sampling rounds
I-5	Cerros del Rio Basalt at R-15	Two sampling rounds
I-6	Cerros del Rio Basalt north of R-15	Two sampling rounds
I-7	To be determined	To be determined
I-8	Cerros del Rio Basalt near MCO-6	Two sampling rounds
I-9	To be determined	To be determined
I-10	Cerros del Rio Basalt east of PM-5 on mesa top	Two sampling rounds
Regional Aquifer		
R-A (R-1)	Puye Formation	Two sampling rounds
R-B(R-28)	Puye Formation	Two sampling rounds
R-C (R-33)	Puye Formation	Two sampling rounds
R-D (R-34)	Puye Formation	Two sampling rounds
R-15 (Drilled)	Puye Formation	Four characterization sampling rounds conducted and two additional sampling rounds

*Sampling schedule will be guided by variations in hydrologic conditions rather than a fixed sampling schedule.

Table 12
Parameters to be Measured in the Field During Characterization Groundwater Sampling

Measurement	Precision[a]
pH	±0.02
Specific conductance	±1 μmho/cm (25 °C)
Dissolved oxygen	0.1 mg/L
Carbonate alkalinity	mg $CaCO_3$/L
Temperature	±1 °C
Turbidity (nephelometric)	±1 NTU[b]

[a] Precision with which measurement shall be recorded.
[b] NTU = Nephelometric turbidity unit.

Table 13
Typical Wire-Line Geophysical Logging Tools

Cased Hole	Cased Hole	Open Hole	Uncased Hole
Array Induction Tool (AIT)		X	Measures open-hole formation conductivity with multiple depths of investigation at varied vertical resolution
Triple LithoDensity Tool (TLD)	X	X	Evaluates formation porosity where grain density can be estimated
Combinable Magnetic Resonance Tool (CMR)		X	Provides information on water content and relative abundance of hydrous minerals and capillary-bound versus mobile water
Natural Gamma Tool	X	X	Used to distinguish lithologies by their gross gamma signature; also used to calibrate depth of other geophysical tool readings
Natural Gamma Ray Spectrometry Tool (NGS; also called the spectral gamma tool)	X	X	Used to distinguish lithologies where formations vary in relative and overall concentrations of potassium, thorium and/or uranium
Epithermal Compensated Neutron Log (CNL)	X	X	Measures moisture content in unsaturated conditions and porosity in saturated conditions
Caliper		X	Measures rugosity of borehole wall
Fullbore Formation Microimager (FMI)		X	Provides high-quality image of borehole based on electrical properties; used to determine lithologies, bedding attitudes, fracture characteristics, and borehole deviation
Elemental Capture Spectrometer (ECS)	X	X	Determines formation lithology from bulk geochemistry; primary use in determining elemental concentrations of Si, Ca, Fe, Ti and Gd

Table 14
Proposed Schedule of Activities

Activity	Start Date	Finish Date
Groundwater Work Plan Regulatory Approval	29 August 03	30 September 03
Drilling and Field Activities	1 October 03	31 December 04
Sample Collection and Analysis	1 July 04	1 July 05
Report Preparation	1 July 05	31 December 05