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# Corrective Measures Evaluation Report, Intermediate and Regional Groundwater, Consolidated Unit 16-021(c)-99

Los Alamos
NATIONAL LABORATORY
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Prepared by the Environmental Programs Directorate

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## EXECUTIVE SUMMARY

This report describes the results of the corrective measures evaluation (CME) conducted for contaminated intermediate and regional groundwater associated with Consolidated Unit 16-021(c)-99, located within Technical Area (TA) 16 at Los Alamos National Laboratory. This site contains a former outfall that discharged wastewater contaminated with high explosives into Cañon de Valle, resulting in the contamination of canyon soil, spring water, alluvial groundwater, and intermediate and regional groundwater.

The CME proposes media cleanup standards (MCSs) for groundwater, presents monitoring points, evaluates remediation technologies, provides corrective measure alternatives, and recommends preferred alternatives. The CME is based on a previous investigation of intermediate and regional groundwater, which identified the chemicals of potential concern (COPCs) as hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and 2,4,6-trinitrotoluene (TNT). This investigation concluded that groundwater contamination does not pose an imminent threat to public water supply wells located approximately 3 mi to the east.

The proposed MCSs for intermediate and regional groundwater consist of U.S. Environmental Protection Agency Region 6 tap water screening levels adjusted to the $10^{-5}$ lifetime carcinogenic risk specified in the Compliance Order on Consent. These levels are 6.1 and 22.2 µg/L for RDX and TNT, respectively. Proposed monitoring points consist of existing monitoring wells completed within intermediate and regional groundwater [R-25, CdV-16-1(i), and CdV-16-2(i)r].

Remedial technologies capable of attaining the MCSs were identified through a literature search, classified as either standard or innovative depending on history of deployment, and evaluated with respect to several preliminary screening criteria. Important site constraints include difficult site access in several areas of TA-16 and site heterogeneities. Favorable technologies were assembled into remediation alternatives. These alternatives are groundwater recovery and treatment (either granular activated carbon or ultraviolet photooxidation) with in situ flushing by reinjection, monitored natural attenuation (MNA), and no action.

An evaluation of the alternatives was conducted using several criteria, including applicability, technical practicability, effectiveness, implementability, human health and ecological protectiveness, and cost. Rather than select a single alternative, a phased remediation strategy is recommended consisting of intermediate and regional groundwater MNA and the performance of a pump test in intermediate groundwater to assess the feasibility of groundwater recovery and treatment more fully.

Groundwater modeling and transport studies completed in support of the MNA and no-action alternatives show that site COPCs do not pose an imminent threat to municipal water supply wells and that existing downgradient monitoring wells can serve as effective monitoring wells under MNA. As part of the MNA alternative, these wells will be periodically monitored and sampled, and a contingency plan will be developed if these wells show evidence of contamination.

## CONTENTS

**Figures**

## Tables

## Appendixes

# 1.0 INTRODUCTION

## 1.1 Purpose and Regulatory Context

The purpose of this corrective measures evaluation (CME) report is to identify and evaluate alternatives for the cleanup of intermediate and regional groundwater contamination resulting from Consolidated Unit 16-021(c)-99 at Los Alamos National Laboratory (the Laboratory, or LANL).

The Laboratory is a multidisciplinary research facility owned by the U.S. Department of Energy (DOE) and managed by Los Alamos National Security, LLC. The Laboratory is located in north-central New Mexico, approximately 60 mi northeast of Albuquerque and 20 mi northwest of Santa Fe. The Laboratory site covers approximately 40 $mi^2$ of the Pajarito Plateau, which consists of a series of fingerlike mesas separated by deep canyons that contain ephemeral and intermittent streams running from west to east. Mesa tops range in elevation from approximately 6200 to 7800 ft. The eastern portion of the plateau stands 300 to 900 ft above the Rio Grande.

The Laboratory's Environmental Programs (EP) Directorate is participating in a national effort by DOE to investigate and remediate sites formerly involved in weapons research and development. The goal of EP is to ensure that past operations under DOE do not threaten human or environmental health and safety in and around Los Alamos County, New Mexico. To achieve this goal, EP personnel are investigating sites potentially contaminated by past Laboratory operations.

Investigation and remediation actions at the Laboratory are conducted under the Compliance Order on Consent (hereafter, the Consent Order) signed by the New Mexico Environment Department (NMED), DOE, and the Regents of the University of California on March 1, 2005. The Consent Order was issued pursuant to the New Mexico Hazardous Waste Act, New Mexico Statutes Annotated (NMSA) 1978, §74-4-10, and the New Mexico Solid Waste Act, NMSA 1978, §74-9-36(D). Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to the NMED in accordance with DOE policy.

## 1.2 Site Location

Technical Area (TA) 16 is located in the southwestern corner of the Laboratory (Figure 1.2-1). It covers 2410 acres, or 3.8 $mi^2$. The land was acquired by the U.S. Department of the Army for the Manhattan Project in 1943. TA-16 is bordered by Bandelier National Monument along State Highway 4 to the south and by the Santa Fe National Forest along State Highway 501 to the west. To the north and east, it is bordered by TA-08, -09, -11, -14, -15, -37, and -49. TA-16 is fenced and posted along State Highway 4. Water Canyon, a 200-ft-deep ravine with steep walls, separates State Highway 4 from active sites at TA-16 (Figure 1.2-2). Cañon de Valle forms the northern border of TA-16. A complete discussion of the TA-16 environmental setting is presented in the TA-16 Phase III Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) report (LANL 2003, 077965, section 6.0).

TA-16 was established to develop explosive formulations, cast and machine explosive charges, and assemble and test explosive components for the nuclear weapons program. Almost all the work has been conducted in support of developing, testing, and producing explosive charges for atomic weapons. Present-day use of this site is essentially unchanged, although the facilities have been upgraded and expanded as explosives and manufacturing technologies have advanced.

The administrative boundary for the study area is shown in Figure 1.2-2. The boundary runs along State Highway 501 to the west, follows a drainage divide (between Cañon de Valle and Water Canyon) across the TA-16 mesa to the south, and follows Cañon de Valle to its confluence with Water Canyon to the north and east. This area is referred to as the Cañon de Valle basin. The administrative boundary is intended to incorporate contaminant sources and fate and transport mechanisms within part of the Cañon de Valle drainage. The 260 Outfall is believed to be the major source of contaminants in the basin. Monitoring and data analysis performed at the basin scale will support decisions about remedial activities at other potential contaminant source locations as well. Other potential contaminant sources within this area are being addressed by other EP activities such as the Water Canyon/Cañon de Valle watershed investigations.

### 1.3 Corrective Measures Evaluation Report Overview

This CME report identifies corrective measure alternatives and proposes the preferred alternatives for remediation of intermediate and regional groundwater contamination associated with the 260 Outfall. The nature and extent of contamination were determined in a prior investigation (LANL 2006, 093798), which identified hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX, or research department explosive) and 2,4,6-trinitrotoluene (TNT) as chemicals of potential concern (COPCs). The CME is a multistep process involving the identification of cleanup levels and potential remedial technologies, the development and evaluation of remedial alternatives, and the selection of preferred alternatives. Figure 1.3-1 presents a flow chart that summarizes this process.

The following chapters in this report present the site history, review previous EP site activities and reports, review current site conditions with respect to the important hydrogeological components of the site, identify exposure pathways and sensitive receptors, identify candidate remediation technologies for groundwater, screen these technologies, develop remediation alternatives composed of favorable technologies, evaluate these alternatives, and propose preferred alternatives. Appendixes to the report consist of abbreviations and acronyms, a glossary, and a metric conversion table (Appendix A); remediation alternative cost estimates (Appendix B); groundwater modeling reports (Appendix C); a public involvement plan (Appendix D); a proposed schedule (Appendix E); “Interim Facility-Wide Ground water Monitoring Plan” (Appendix F); and a CD of relevant prior reports (Appendix G).

## 2.0 SITE HISTORY

### 2.1 Site History and Description

Building 260, located on the north side of TA-16 (Figure 2.1-1), has been used for processing and machining high explosives (HE) since 1951. Water is used to machine HE, which is slightly watersoluble, so wastewater from machining operations contains dissolved HE and may contain entrained HE cuttings. At 260, wastewater treatment consists of routing the water to 13 settling sumps to recover any entrained HE cuttings. From 1951 to 1996, the water from these sumps was discharged to the 260 Outfall that drained into Cañon de Valle. In 1994, outfall discharge volumes were measured at several million gallons per year. The discharge volumes were probably higher during the 1950s when HE production output from 260 was substantially greater than it was in the 1990s (LANL 1994, 076858). In the past, barium has been a constituent of certain HE formulations and inert components, and so barium was also present in the outfall wastewater from building 260.

During the late 1970s, the 260 Outfall was permitted by the U.S. Environmental Protection Agency (EPA) to operate as EPA Outfall No. 05A056 under the Laboratory’s National Pollutant Discharge Elimination System (NPDES) permit (EPA 1990, 012454). The last NPDES-permitting effort for the 260 Outfall occurred in 1994. The NPDES-permitted 260 Outfall was deactivated in November 1996; EPA officially removed it from the Laboratory's NPDES permit in January 1998. This waste stream is currently managed by pumping the sumps and treating the water at the TA-16 HE wastewater treatment plant.

As a result of the discharge, soil in the 260 Outfall drainage channel is contaminated, primarily with HE and barium. The sumps and drainlines of this facility are designated as Solid Waste Management Unit (SWMU) 16-003(k), and the 260 Outfall and drainage are designated as SWMU 16-021(c), according to Module VIII of the Laboratory's Hazardous Waste Facility Permit (EPA 1990, 001585). Because of the Laboratory's consolidation of SWMUs, these two SWMUs are now collectively referred to as Consolidated Unit 16-021(c)-99.

The Consent Order stipulates separate investigations and remedial evaluations for the shallow and deep hydrogeological systems at the site. This CME addresses the deep system, specifically intermediate and regional groundwater at TA-16. The groundwater COPCs in this system consist of RDX and TNT. A previous CME (LANL 2003, 085531) addressed the shallow system, for which the COPCs include RDX, TNT and barium.

SWMU 16-021(c) consists of two portions: an upper drainage channel and former settling pond, and a lower drainage channel leading to Cañon de Valle. The entire length from the 260 Outfall to Cañon de Valle is approximately 600 ft. The former settling pond, which was removed during a 2000–2001 interim measure (IM) cleanup (LANL 2002, 073706), was approximately 50 ft long, 20 ft wide, and was located approximately 45 ft below the 260 Outfall. The upper drainage channel continues approximately 350 ft northeast from the former settling pond to a 15-ft near-vertical cliff that marks the break between the upper and lower drainage channels. Beyond this cliff, the lower channel runs another 200 ft to Cañon de Valle.

The IM cleanup removed more than 1300 $yd^3$ of contaminated soil from the settling pond and channel. Approximately 90% of HE in the Consolidated Unit 16-021(c)-99 source area was removed (LANL 2002, 073706).

## 2.2 Adjacent SWMUs

Other SWMUs located in the vicinity of the 260 Outfall are shown in Figure 2.2-1. Several of these SWMUs are described below.

- *Material Disposal Area (MDA) R (SWMU 16-019*). MDA R is located northwest of the 260 Outfall area (Figure 2.2-1). This MDA was constructed in the mid-1940s and was used as a burning ground and disposal area for waste explosives and other debris. COPCs at this MDA include HE, HE byproducts, and metals (particularly barium). Use of the site was discontinued in the early 1950s. Soil removal and related site investigations were conducted at MDA R after the Cerro Grande fire (LANL 2001, 069971).
- *Burning Ground SWMUs [16-010(b), 16-010(c), 16-010(d), 16-010(e), 16-010(f), 16-010(j), and 16-028(a)] and Consolidated Units [16-010(h)-99 and 16-016(c)-99].* These sites are located on a level portion of the mesa in the northeast corner of TA-16. The burning ground was constructed in 1951 for HE waste treatment and disposal. Over the years, hundreds of thousands of pounds of HE and HE-contaminated waste material were destroyed by burning. After burning, the remaining noncombustible material was either placed in MDA P, north of the burning ground (through 1984), or transferred to off-site facilities for treatment of non-HE hazardous constituents for scrap metal recycle or for disposal (1984 to present). Site investigations were conducted at several of these SWMUs during 1995 and later (LANL 2003, 076876). Information was also obtained from investigations conducted between 1997 and 2002 at Flash Pad 387 and

Consolidated Unit 16-016(c)-99. Flash Pad 387 underwent clean closure, and the sites representing Consolidated Unit 16-016(c)-99 underwent a voluntary corrective action (LANL 2003, 085530) concurrently with the MDA P clean closure (LANL 2003, 076876). NMED approved these SWMUs for no further action (NMED 2006, 093249). Other closures include the HE Burn Tray 394 [SWMU 16-010(j)] (NMED 2002, 095630) and Filter Vessels 401 [SWMU 16-010(e)], 406 [SWMU 16-010(f)] (NMED 2005, 092226), and the Burning Ground industrial incinerator (NMED 2001, 071423).

- *MDA P (SWMU 16-018)*. This MDA contained wastes from synthesizing, processing, and testing HE; residues from burning HE-contaminated equipment; and construction debris. Disposal of HE waste at this site started in the early 1950s and ceased in 1984. The site is located on the south slope of Cañon de Valle. MDA P underwent clean closure in which approximately 55,000 $yd^3$ of soil and debris was removed (LANL 2003, 076876). NMED approved the MDA P closure certification report in 2005 (NMED 2005, 093247).
- *The 90s Line Pond Portion of Consolidated Unit 16-008(a)-99.* The 90s Line Pond is an inactive, unlined, settling pond located a few hundred feet west of building 260. The pond may have received HE, barium, uranium, and other inorganic and organic chemicals from machining operations discharges from TA-16, -89, -90, and -91. As recently as 2002, HE solids were observed at the pond area. Further investigation into this area is continuing in 2007 in accordance with the Consent Order.

## 2.3 Current and Future Land Use

Current and future land use at TA-16 is designated as HE research, development, and testing, according to the Laboratory's comprehensive site plan of 2000 and the 2001 update (Barnes et al. 1990, 070209; LANL 2000, 076100). Most areas within TA-16 are active sites for the Weapons Engineering Technology Division of the Laboratory, and construction of new buildings and other facilities in the area is possible. As shown in Figure 2.1-1, numerous roads and utilities are present at the site in the vicinity of SWMU 16-021(c).

## 2.4 Previous Environmental Investigations

Six investigations into Consolidated Unit 16-021(c)-99 have been conducted, including a postremediation investigation of the outfall drainage channel conducted after the IM removal of drainage channel soils. These investigations are summarized below chronologically.

A RCRA facility assessment (RFA) (LANL 1990, 007512) summarized soil and water sampling results dating from the 1970s for the outfall area.

The Phase I RFI site characterization (April 1995–November 1995) and Phase I RFI report (LANL 1996, 055077) concentrated on the drainage channel and its intersection with Cañon de Valle, including alluvial sediment, surface water, and groundwater. NMED approved the report in 1998 (NMED 1998, 093664).

The Phase II RFI site characterization (November 1996–November 1997) and the Phase II RFI report (LANL 1998, 059891) further delineated contamination in tuff surge beds beneath the drainage channel and in Cañon de Valle sediment and waters. The Phase II RFI included the sampling of surface and near-surface material within the drainage and the sampling of 13 boreholes drilled to depths between 17 and 115 ft in and near the drainage. The Phase II RFI also included extensive field screening for RDX and TNT using immunoassay methods, as well as sampling for other chemicals. A risk characterization was also performed. NMED approved the report in September 1999 (NMED 1999, 093666).

An IM remedial excavation was conducted in the outfall drainage channel and settling basin during 2000 and 2001. More than 1300 $yd^3$ of contaminated material containing approximately 8500 kg of HE was removed from these areas. The investigation results are presented in the IM report (LANL 2002, 073706).

The Phase III RFI site characterization (October 1998–March 2002) and Phase III RFI report (LANL 2003, 077965) included analysis of water and sediment data collected since the Phase II RFI report (post-1998), a study of spring dynamics, a geomorphic alluvial sediment study, geophysical studies, and baseline risk assessments for the outfall source area and for selected reaches of Cañon de Valle and Martin Spring Canyon. In addition, a baseline ecological risk assessment was performed for Cañon de Valle. NMED approved the Phase III RFI report in June 2004 (NMED 2004, 093248).

An investigation of intermediate and regional groundwater (LANL 2006, 093798) included monitoring well installation and collection and analysis of groundwater samples. The purpose was to determine the nature and extent of groundwater HE contamination resulting from the 260 Outfall. The results of this investigation, including identification of COPCs, are used in this report.

A more detailed chronology of Laboratory activities at Consolidated Unit 16-021-(c)-99 is presented in Table 2.4-1.

## 3.0 CURRENT SITE CONDITIONS

This section describes current site conditions with respect to current and future site usage and the current concentration and distribution of HE. The latter discussion uses the conceptual site model (CSM) as a framework. The CSM presents a unified description of the local hydrogeological and contaminant transport systems. Other sections summarize contaminant environmental fate, potential contaminant exposure pathways and receptors, and uncertainties in the CSM.

### 3.1 Intermediate and Regional Groundwater COPCs

An investigation of intermediate and regional groundwater (LANL 2006, 093798) was conducted to investigate the nature and extent of contamination and to identify COPCs for this CME. Based on this investigation, it was determined that the COPCs for regional and intermediate groundwater are RDX and TNT. Further discussion on the nature and extent of these COPCs in intermediate and regional groundwater is provided in section 3.2.4.

### 3.2 Current Conceptual Site Model

The results from previous investigations contributed to the development of the CSM, which presents a unified description of the local hydrogeological and contaminant transport systems. Important features of the model are the outfall source area, canyon alluvial system, intermediate zone (also called the mesa vadose zone), and regional aquifer. These components of the CSM are shown in Figure 3.2-1. Past investigations have focused on shallow components, the intermediate-depth zone, and regional groundwater. The results of previous investigations are summarized in the following sections by area.

Although several contaminant migration routes are depicted in Figure 3.2-1, the primary migration route on a contaminant mass basis likely consisted of transport of HE by the outfall discharges into the canyon, then infiltration of canyon waters into intermediate groundwater, followed by infiltration of intermediate groundwater into regional groundwater. An estimate of the current RDX contaminant inventory for the CSM components was conducted as part of the intermediate and regional groundwater investigation (LANL 2006, 093798); because of the uncertainties in the data, the total mass of RDX estimated to have been discharged ranged between 2000 and 31,000 kg (Appendix C1, section 5). Of the groundwater components of the CSM, intermediate groundwater contains a large inventory of RDX mass. Although concentrations of RDX in intermediate groundwater are currently generally less than spring or alluvial groundwater concentrations, the volume of intermediate groundwater is considerable, contributing to greater estimates of total RDX mass.

### 3.2.1 Outfall Source Area

The RFA documented data collected for the 260 Outfall [SWMU 16-021(c)] since the early 1970s and showed substantially elevated HE contamination in the sediment, outfall, and sump water. Levels up to 27 weight percent (wt%) (270,000 mg/kg) of 1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX, or high-melting explosive) and RDX had been documented in the area of the former settling pond. The data showed HE contamination extending from the discharge point to Cañon de Valle (Baytos 1971, 005913; Baytos 1976, 005920). The historical data have also been summarized in the Phase I and II RFI reports for SWMUs 16-003(k) and 16-021(c) (LANL 1996, 055077; LANL 1998, 059891).

Phase I and II results showed elevated concentrations of HE and barium within the outfall drainage from the surface down to the soil/tuff interface. Phase I and II surface samplings showed surface contamination did not extend laterally beyond the reasonably well-defined drainage. Barium, HMX, RDX, and TNT were detected downgradient within the drainage and decreased rapidly beyond the settling pond, although substantial levels of HMX and barium were present at the base of the colluvial slope in Cañon de Valle.

Subsurface sampling indicated that HE concentrations also decreased rapidly below the soil/tuff interface. However, up to 1000 mg/kg of HE was found within the uppermost tuff unit (unit 4 of the Tshirege Member of the Bandelier Tuff, Qbt 4) beneath the upper part of the drainage, including in the former settling pond area. Almost 1 wt% (10,000 mg/kg) HE was reported in a saturated sample from a borehole at a depth of about 17 ft beneath the former settling pond (LANL 1998, 059891, p. 2-79). The sample was collected from a surge bed within unit 4 of the Tshirege Member of the Bandelier Tuff. Below the level of this surge bed, HE was detected sporadically and at much lower concentrations (<5 mg/kg). However, thin surge bed deposits were reported in borehole (BH)-16-06370, drilled into the center of the former settling pond during the IM at depths of 40 and 46 ft below ground surface (bgs), indicating multiple potential transmissive zones at depth (LANL 2002, 073706, p. 35).

HE and barium were the principal contaminants found at the 260 Outfall, although several other metals, including cadmium, chromium, copper, lead, nickel, vanadium, and zinc, were consistently detected above background levels in the drainage. Other organic compounds (semivolatile organic compounds and volatile organic compounds [VOCs]) were also detected in multiple samples. Details and results from the Phase I and II RFIs are presented in two RFI reports (LANL 1996, 055077; LANL 1998, 059891).

The IM cleanup removed more than 1300 yd$^3$ of contaminated soil from the settling pond and channel. An IM report for SWMU 16-021(c) (LANL 2002, 073706, p. 72) detailing the postremoval sampling results indicated that approximately 90% HE at the source area had been removed by the IM.

The Phase III baseline risk assessment (LANL 2003, 077965, section 6.0) for the source area identified COPCs and assessed potential exposures to an on-site environmental worker, a trail user, and a construction worker. The cumulative excess cancer risk to the environmental worker from potential exposures to COPCs in soil and tuff is slightly above the NMED target level of $10^{-5}$. The cumulative excess cancer risk for the other receptors is below the NMED target level of $10^{-5}$. A noncancer hazard index (HI) of greater than 1.0 is associated with exposure to the outfall source area COPCs for the construction worker scenario but not for the other receptors (HI <1.0). These residual areas of soil contamination were addressed by the Consolidated Unit 16-021(c)-99 corrective measures implementation (CMI) (LANL 2007, 096003).

### 3.2.2 Alluvial System

Phase II sampling in the Cañon de Valle alluvial system included collecting surface and subsurface sediment samples, overbank sediment samples, filtered and unfiltered surface water samples, and one quarterly round of filtered and unfiltered alluvial groundwater samples. These samples were collected during three different investigations that took place in 1994, 1996, and 1997–1998.

The Phase II investigation report (LANL 1998, 059891) included the following results.

- Barium was the most abundant inorganic chemical contaminant in sediment. For the surface samples, barium ranged from 6.3 to 40,300 mg/kg. Other inorganic chemicals consistently greater than background levels included cadmium, chromium, copper, lead, nickel, vanadium, and zinc. Several types of HE were detected: amino-dinitrotoluenes (A-DNTs), HMX, nitrobenzene, 3-nitrotoluene, RDX, 1,3,5-trinitrobenzene (TNB), and TNT. The two HE compounds highest in abundance and concentration were HMX (170 mg/kg) and RDX (42 mg/kg).
- Surface water samples and alluvial groundwater samples from five alluvial wells and Peter Seep were collected in Cañon de Valle. Filtered/unfiltered sample pairs were collected during 1994 and 1997–1998; primarily unfiltered samples were collected in 1996. The inorganic chemicals identified as COPCs in water were antimony, barium, chromium, lead, manganese, mercury, nickel, vanadium, and zinc. Barium is the most abundant, with concentrations ranging from 99 to 16,000 µg/L. As with sediment, HE appears to be the other major COPC in Cañon de Valle surface water and alluvial groundwater. The HE COPCs identified were A-DNTs, HMX, nitrobenzene, 2-nitrotoluene, RDX, TNB, and TNT. RDX is the HE with the highest concentration, with a maximum of 818 µg/L in surface water. COPC concentrations generally decrease downgradient of Peter Seep to the confluence with Water Canyon (LANL 1998, 059891).
- The intermediate-depth perched aquifer investigation included drilling five wells (91 to 207 ft bgs) at locations likely to intersect the saturated zones at TA-16. The local trend of subunit/subunit contacts is to the north and east. When installed, two of these wells intersected ephemeral perched water, which disappeared in less than 1 month. Analysis of this perched water indicated the presence of HE.
- The springs investigation included quarterly sampling of Sanitary Wastewater Systems Consolidation (SWSC) Spring, Burning Ground Spring, and Martin Spring. The results showed detectable RDX and other HE in all three springs. Several major cations and anions, including calcium, magnesium, sodium, and boron, were detected. Boron is particularly elevated (1800 µg/L) in Martin Spring. Aluminum, iron, barium, phosphate, and nitrate concentrations were also elevated. Although VOCs were detected in all three springs, the detections were sporadic and occurred primarily during the quarterly sampling round of June 1997.
- Time-series analysis of the springs data indicates extreme variability in the concentration of constituents (up to a factor of 20 in RDX concentration at Martin Spring). Similarities in element variability and flow-rate changes over time indicated that SWSC Spring and Burning Ground Spring are hydrogeologically related but that Martin Spring probably represents a different hydrogeological system.
- A potassium bromide tracer was deployed at SWMU 16-021(c) during April 1997. A breakthrough of bromide ions was observed in SWSC Spring during August 1997. The breakthrough may also have occurred at Burning Ground Spring during August 1997, but the effects were more subtle

because of partial masking of bromide by variability in all the anions (LANL 1998, 059891, p. 4-91). This finding indicates that the springs are hydrologically connected to the SWMU 16-021(c) source area.

The Phase III investigation (LANL 2003, 077965) and aquifer testing (LANL 2006, 095626) resulted in the following conclusions about the alluvial system.

- Sediments in Cañon de Valle and Martin Spring Canyon represent a secondary source for HE and barium that is potentially mobilized by surface water and alluvial groundwater. Moreover, the perennial reach of Cañon de Valle alluvial groundwater provides a high potential for subsequent infiltration of mobile contaminants.
- For the Cañon de Valle alluvial area, a trail-user exposure scenario was assessed. The cumulative excess cancer risk to the trail user from potential exposure to all COPCs in sediment and surface water was below the $10^{-5}$ target risk specified by NMED. The noncancer hazard was below an HI of 1.0.
- The ecological risk assessment followed EPA guidance (EPA 1997, 059370). For the terrestrial system in Cañon de Valle, elevated metals concentrations were found in small mammals but not at levels that are likely to cause adverse effects to the Mexican spotted owl. The numbers of species, population densities, and reproductive classes for those species indicate that the Cañon de Valle small-mammal community is not being adversely affected by contaminants. In Cañon de Valle, a viable benthic macroinvertebrate community is present, which is a meaningful indicator that site contaminants have caused minimal negative ecological effects.
- For Martin Spring Canyon, a trail-user scenario was assessed. Cumulative excess cancer risk to the trail user from potential exposures to all COPCs in sediment and surface water is below the $10^{-5}$ target risk specified by NMED. The noncancer hazard is below an HI of 1.0.
- Hydraulic conductivities in Martin Spring Canyon and Cañon de Valle range from $6.7 \times 10^{-7}$ to $1.8 \times 10^{-2}$ cm/s.

Remediation of springs, surface water, and alluvial groundwater was addressed by the Consolidated Unit 16-021(c)-99 CMI (LANL 2007, 096003).

### 3.2.3 Mesa Vadose Zone

The Phase III RFI (LANL 2003, 077965) reached the following conclusions about the mesa vadose zone.

- The isotopic differences in composition between mesa vadose zone groundwater (groundwater within tuff between the mesa top and canyon bottom) and Cañon de Valle alluvial groundwater (groundwater within the Cañon de Valle alluvial system in the canyon) indicated that mesa groundwater probably comes from local precipitation and snowmelt on the mesa top, whereas Cañon de Valle alluvial groundwater is at least partially derived from spring flow that is recharged at higher elevations.
- Borehole sampling in the mesa vadose zone indicated no contamination in the unsaturated depth intervals in any boreholes, except in the immediate vicinity of the former settling pond. These results indicate that mesa vadose zone contamination is concentrated beneath source area SWMUs such as the former and current ponds and drainages (90s Line Pond, V-Site Pond, and 30s Line Pond) on the mesa top. However, the ephemeral groundwater from mesa vadose zone wells not located in the vicinity of the former settling pond also showed contamination, indicating lateral movement (possibly through surge beds) of water and contaminants within the mesa subsurface. Based on the oxygen and deuterium stable isotope results, mesa vadose zone

groundwater from wells near Martin Spring Canyon and the 90s Line Pond, as well as surface water from the 90s Line Pond, shows evaporative signatures, but spring water does not. These results support the CSM of a mesa vadose zone groundwater flow regime dominated by fractures and surge beds and in general the importance of hydrologic heterogeneity at TA-16.

- Contaminant transport in the mesa vadose zone is dominated by a fracture or surge bed flow regime of which contaminated springs are a known manifestation. Since the IM source removal, a substantial source for this contamination is no longer present, although reductions in spring contaminant concentrations are not yet evident.

Remediation of a portion of the mesa vadose zone under the former 260 Outfall settling pond was addressed by the Consolidated Unit 16-021(c)-99 CMI (LANL 2007, 096003).

### 3.2.4 Intermediate and Regional Groundwater

An investigation of intermediate and regional groundwater (LANL 2006, 093798) was conducted to investigate the nature and extent of contamination and identify COPCs for this CME. In addition, the Laboratory conducted an evaluation (LANL 2007, 095787) of area-monitoring well screens to assess the validity of intermediate and regional groundwater analytical data. Current monitoring well data are available at the Laboratory's Water Quality Database website http://wqdbworld.lanl.gov. These reports reached the following conclusions.

- The analytical results for intermediate groundwater samples showed concentrations (<80 µg/L) of HE within the area defined by wells R-25, (CdV)-16-1(i), and CdV-16-2(i)r. In CdV-16-1(i) and R-25, RDX exceeded the EPA Region 6 tap water screening limit of 0.61 µg/L (EPA 2003, 093662). Recent results for RDX and TNT for area-monitoring wells are summarized in Figures 3.2-2 and 3.2-3, respectively. Based on these results, Figure 3.2.4 depicts the assumed area of intermediate and regional groundwater contamination addressed by this CME.
- For regional groundwater samples, analytical results from R-25 showed RDX and TNT concentrations exceeding the EPA Region 6 tap water screening limits (EPA 2003, 093662). The results from other wells located to the east of (downgradient of) R-25 showed that RDX was detected once in R-19 during 2000 but at a concentration less than the tap water screening limit. RDX was recently detected in well R-18 at very low levels (<1 µg/L).
- The wells evaluated in these reports include downgradient regional groundwater wells CdV-R-15-3, CdV-R-37-2, R-17, R-18, R-19, R-25, and R-27; downgradient intermediate wells/BHs CdV-16-1(i), CdV-16-2(i)r, CdV-16-3(i); and upgradient well R-26. At least 18 of 26 well screens provided reliable and representative data for RDX, which does not degrade easily in the environment.
- Hydrologic evaluations of wells in the monitoring network were also completed as part of the well screen evaluation (LANL 2007, 095787). The majority of the well screens provides reliable head (pressure) data.
- Based on a compilation of existing well data, it was determined that the average permeability of the intermediate and regional aquifers at TA-16 is approximately $3.2 \times 10^{-9}$ $cm^2$. Extreme local variability in permeability, however, is present, as demonstrated by collocated monitoring wells CdV-16-2(i) and CdV-16-2(i)r, the former of which was dry and was replaced by CdV-16-2(i)r.
- Intermediate groundwater is likely a groundwater mound recharge feature associated with Cañon de Valle, with hydraulic heads in existing wells [CdV-16-1(i), R-25 Screen 2, and CdV-16-2(i)r], indicating local groundwater-flow components both laterally (to the south) and to the east.

Presumably, local lateral flow occurs to the north also; however, no monitoring wells are located in sufficient proximity in that direction.

- The presence of productive fractures in both intermediate-zone well screens installed [CdV-16-1(i) and R-25 Screen 2] within the Bandelier Tuff of intermediate groundwater suggests a significant fracture density within this horizon. If this is the case, vertical groundwater and contaminant travel times through this zone may be relatively rapid.

## 3.3 Contaminant Characteristics and Environmental Fate

An important part of the site hydrogeological and contaminant transport CSM involves the chemical and physical properties of RDX and TNT and their behavior in intermediate and regional groundwater. These compounds are the COPCs for this CME. Specific properties include the potential for adsorption both on natural organic carbon and tuff and the potential for natural attenuation by hydrolysis or in situ bioremediation.

HE dissolved in groundwater partitions between a soluble and an adsorbed phase. Both tuff and sediment adsorb HE, although to varying degrees. On the basis of HE-contaminant adsorption studies done on clays (Myers 2003, 076188), it can be inferred that tuff has a relatively low adsorption capacity (on the order of 1 mL/g) for RDX and TNT. These constituents, however, will adsorb onto any organic carbon present in intermediate and regional groundwater, specifically the tuff and upper Puye Formation of the intermediate groundwater horizon and the Puye and Santa Fe Group of the regional groundwater horizon.

The potential for biodegradation is another chemical property important to the long-term environmental fate of HE. TNT degrades aerobically and anaerobically with reduction of the nitro groups, eventually leading to cleavage and assimilation or mineralization of a portion of the TNT carbon. Groundwater analytical data from regional groundwater indicate active TNT degradation, with breakdown products occasionally detected in regional groundwater wells.

The biodegradation of RDX also occurs aerobically and anaerobically (Card and Autenrieth 1998, 076873; Bradley and Dinicola 2005, 095588). Anaerobic degradation rates are typically greater than aerobic rates and may be significant at the relatively weak reducing conditions associated with manganese reduction. RDX and HMX can also degrade chemically through an inorganic pH hydrolysis reaction (Layton et al. 1987, 014703, p. 194).

## 3.4 Potential Exposure Pathways and Receptors

Regional groundwater from TA-16 flows toward a series of five municipal drinking water supply wells, the nearest of which is located approximately 3 mi east of TA-16. Drinking water is therefore a potential exposure pathway for site contaminants with potential receptors consisting of the public. Intermediate groundwater at TA-16 is likely a hydrological feature resulting from recharge of water into Cañon de Valle, and it ultimately flows into regional groundwater.

## 3.5 Conceptual Site Model Uncertainties

The current TA-16 CSM represents the results of several investigations, most recently, the intermediate and regional groundwater investigation (LANL 2006, 093798). Uncertainties, however, remain in several areas. These uncertainties and their effects on the CME are summarized as follows.

- Characterization activities have not yet bounded the vertical extent of subsurface contamination beneath the potential source areas (other than the 260 source area) located on the mesa. Future drilling activities (e.g., at the 90s Line Pond) may address this uncertainty and lead to additional remediation activities in these areas. This uncertainty does not affect the CME because these areas are not within the intermediate and regional groundwater horizons; however, these areas, if contaminated, may serve as contaminant sources for groundwater.

- The groundwater infiltration rates, travel times, and contaminant flux between the canyon bottoms and deeper groundwater systems, including the intermediate groundwater encountered at R-25, CdV-16-1(i), CdV-16-2(i)r, and the regional groundwater, are uncertain. This uncertainty has implications for modeling the long-term fate and transport of contaminants in regional groundwater, which is important for assessing the effects of the no-action and monitored natural attenuation (MNA) alternatives. The contaminant flux into regional groundwater from upper zones comprises the contaminant source term for the regional model and, as shown in Appendix C, the regional model is very sensitive to this source term, As discussed in Appendix C, some of this uncertainty can be mitigated through the use of contaminant data from area-monitoring wells and calibrating the source term to match the observed data.
- Detailed characterization of the lateral distribution of COPC concentrations within Cañon de Valle alluvium has not been completed. Of the estimated 7000 ft of suspected saturated alluvium downgradient of the 260 Outfall source area, monitoring wells are located along the first 4000 ft. In addition, alluvial groundwater and sediment characterization are incomplete in Cañon de Valle upgradient of the confluence of Cañon de Valle with Water Canyon. These areas are potential sources for deep groundwater contamination but are not addressed in this CME. The Canyons Team will sample the alluvial groundwater and sediment in these reaches as part of its investigation.
- Potential areas of enhanced vertical groundwater infiltration within the Cañon de Valle alluvium can be inferred from geophysics resistivity results. The permeability of the sediment and tuff or fractures that comprises these areas is not known. Moreover, the correlation between geophysics resistivity data and water content has not been verified by field sampling. The uncertainty in this horizon may affect the CME modeling by influencing the contaminant source term to the regional model, as described above.
- The permeability and other hydraulic characteristics of the intermediate-groundwater zone are uncertain. Pump tests have been conducted in CdV-16-1i and CdV-16-2(i)r; however, these wells and the pump tests were not designed to gather data to assess the feasibility of groundwater recovery in this zone. Related uncertainties include sustainable yield, radius of influence of a pumping well, and contaminant removal rates. Without these data, the feasibility of groundwater recovery in the intermediate zone cannot be fully determined.
- The HE concentration trends in intermediate and regional groundwater monitoring wells at the site [CdV-16-1(i), CdV-16-2(i)r, and R-25] are uncertain. Available data summarized in Figures 3.2-2 and 3.2-3 indicate a downward trend in HE levels in regional groundwater. However, the trend in intermediate groundwater shown in these figures is uncertain, primarily because the monitoring wells were installed relatively recently and the data are sparse. In regional groundwater, the levels appear to be trending toward the attainment of the media cleanup standards (MCSs) discussed in section 4.0. These uncertainties affect the CME primarily by influencing the remedial alternative cost-effectiveness analysis. In this analysis, higher concentration levels and either increasing or static trends tend to increase the cost-effectiveness of capital-intensive alternatives.

## 4.0 MEDIA CLEANUP STANDARDS AND REMEDIAL ACTION OBJECTIVES

### 4.1 Identification of ARARs for Intermediate and Regional Groundwater

Several regulatory agencies provide groundwater standards and screening limits that are potentially applicable or relevant and appropriate requirements (ARARs) for RDX and TNT. Under the Clean Water Act, EPA's maximum contaminant levels establish the highest allowable contaminant concentration levels for drinking water. In New Mexico, New Mexico Water Quality Control Commission (NMWQCC) regulation 20 New Mexico Administrative Code (NMAC) §6.2.3103, Parts A and B for potable groundwater, also establish contaminant concentration levels for drinking water. Neither of these sets of regulations, however, sets standards for RDX and TNT.

These contaminants are listed in tap water screening limits promulgated by EPA Region 6 (EPA 2005, 091002), in which tap water screening limits represent a lifetime cancer risk of $10^{-6}$. Current NMWQCC regulations set the acceptable lifetime cancer risk at $10^{-5}$. On this basis, EPA tap water screening limits at a cancer risk of $10^{-5}$ are proposed as an ARAR for intermediate and regional groundwater.

While NMWQCC regulations do not specifically list RDX and TNT as regulated contaminants, they define when remediation of groundwater is complete, including the requirement for a minimum of eight consecutive quarters of compliance with groundwater standards at compliance sampling stations approved by the NMED Secretary (20 NMAC §6.2.3103).

On the basis of the foregoing, the proposed site ARARs consist of Consent Order cleanup levels, EPA Region 6 tap water screening limits (EPA 2005, 091002), and NMWQCC regulations 20 NMAC §6.2.3103.

### 4.2 Identification of Media Cleanup Standards

EPA Region 6 tap water screening limits for a $10^{-6}$ risk level for RDX and TNT are 0.61 and 2.2 µg/L, respectively. At a $10^{-5}$ risk level, which is the level set by the Consent Order the respective limits for RDX and TNT become 6.1 and 22.2 µg/L. These limits are proposed as MCSs for intermediate and regional groundwater.

### 4.3 Monitoring Points

According to NMWQCC regulations, groundwater abatement shall not be considered complete until eight consecutive quarters of compliance are attained at compliance sampling stations (monitoring points) approved by the NMED Secretary (20 NMAC §6.2.3103). Existing groundwater-monitoring wells in intermediate and regional groundwater are proposed as groundwater-monitoring points pending NMED selection of a cleanup remedy. These wells are proposed to include R-25 (and its replacement wells), CdV-16-1(i), and CdV-16-2(i)r. The historical data for these locations will enable a determination of remediation progress with respect to past trends. Downgradient wells (e.g. R-18, CdV-R-15-3, CdV-R-37-2 and new wells to be drilled in 2008) will also be monitored to ensure that remedies are working effectively and that unexpected off-site migration is not occurring. Progress in attaining the remediation objective of eight consecutive quarters of MCS compliance will also be determined at each monitoring point.

### 4.4 Compliance Time Frame

The compliance time frame (CTF) establishes the length of time required to attain the MCSs. Pending NMED selection of a cleanup remedy, a specific CTF is not proposed for intermediate and regional groundwater. Site conditions, including the magnitude and extent of contamination and potential risks, do not warrant the imposition of an urgent, set time frame in which the remediation objectives and MCSs must be attained. Rather, the time required to meet these targets will be used as an evaluation factor for remedial alternatives, recognizing that those alternatives that require less time to meet the remediation objectives and MCSs may be preferable.

## 5.0 SELECTION OF REMEDIATION TECHNOLOGIES AND SCREENING

### 5.1 Sources for Technology Information

The process of selecting and evaluating corrective measure alternatives (Figure 1.3-1) begins with identifying and reviewing all remediation technologies, both standard and innovative, that have potential for use in the remediation of intermediate and regional groundwater. These technologies include in situ and ex situ treatment technologies for RDX and TNT. Favorable technologies are combined into remediation alternatives in section 6.0.

Based on a literature review (Card and Autenrieth 1998, 076873), the following DOE and U.S. Department of Defense (DoD) facilities contain sites with subsurface RDX contamination:

- Bangor Naval Submarine Base—Bangor, Washington
- BWXT Pantex and SAIC 2006—Amarillo, Texas
- Cornhusker (Army Ammunition Plant [AAP])—Grand Island, Nebraska
- Holston AAP—Kingsport, Tennessee
- Iowa AAP—Middletown, Iowa
- Joliet AAP—Joliet, Illinois
- Kansas AAP—Parsons, Kansas
- Lonestar AAP—Texarkana, Texas
- Los Alamos National Laboratory—Los Alamos, New Mexico
- Louisiana AAP—Shreveport, Louisiana
- Milan AAP—Milan Tennessee
- Savanna Army Depot—Savanna, Illinois
- U.S. Army—Umatilla, Oregon
- U.S. Navy—Crane, Indiana
- U.S. Navy—Hawthorne, Nevada
- U.S. Navy—McAlster, Oklahoma
- U.S. Navy—Yorktown, Virginia

Summary reports of remediation activities at these sites comprise the sources for candidate HE remediation technologies. These sources were identified through a literature review, a review of the recently completed CMS at the Pantex site in Amarillo, Texas (BWXT Pantex and SAIC 2006, 096990), and through remediation technology databases (DOE, DoD, and EPA), including the following:

- Superfund Innovative Technology Evaluation (SITE), online: Http://www.epa.gov/ORD/SITE
- Federal Remediation Technologies Roundtable (FRTR): Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, online: http://www.frtr.gov/matrix2/top_page.html
- Remediation and Characterization Innovative Technologies (Reach IT), online: http://www.epareachit.org
- Hazardous Waste Cleanup Information (CLU-IN), online: http://clu-in.org
- Ground-water Remediation Technologies Analysis Center (GWRTAC), online: http://www.gwrtac.org/Default.htm
- Strategic Environmental Research and Development Program (SERDP), online: http://serdp.org/general
- Center for Public Environmental Oversight (CPEO): Technology Tree, online: http://www.cpeo.org/tree.html
- Environmental Security Technology Certification Program, online: http://www.estcp.org/

In addition, Laboratory personnel have participated in DOE's Innovative Treatment and Remediation Demonstration (ITRD) Program's HE Advisory Group, whose goals were the identification and testing of potentially cost-saving remediation technologies for HE environmental contamination with a focus on the unique problems associated with DOE HE-processing facilities such as the Laboratory and Pantex.

Because of Pantex's participation in the ITRD and the similarity of site contaminants, the Pantex CMS provides an important source for technology identification and field treatability studies. Despite the similarities, differences in the sites are significant. These differences include the relatively higher concentrations of RDX at Pantex (up to 2 mg/L of RDX in Pantex perched groundwater vs. up to 75 µg/L in intermediate and regional groundwater at TA-16) and the disposition of the perched groundwater at Pantex as a high concentration source area rather than as a relatively low concentration downgradient plume. More specifically, aggressive source remediation technologies may be more cost-effective at Pantex. A similar situation is present at Umatilla where the maximum RDX concentration is 6800 µg/L.

## 5.2 Identification of Technologies

Technologies for groundwater remediation of RDX and TNT may be broadly classified as either in situ (in place) or ex situ (removed from place). In situ technologies do not require removal (pumping) of groundwater; rather, groundwater is treated within the aquifer. In contrast, ex situ technologies for groundwater involve pumping groundwater, its treatment, and its eventual disposal. This disposal may involve reinjection into the aquifer, discharge to surface water, use for irrigation, or use for municipal or industrial supply. Table 5.2-1 presents the list of ex situ and in situ technologies that were screened for this CME. This screening analysis incorporates both a review of the literature and a review of the status of remediation at RDX sites across the nation.

Groundwater recovery and treatment are proven standard remediation technologies. The advantages of groundwater recovery include hydraulic control of the contaminant plume and the use of relatively simple treatment technologies, such as granulated activated carbon (GAC). The primary disadvantage of groundwater recovery and treatment is that without enhancing the rate of degradation of adsorbed phase contaminant, the rate of cleanup can be slow, leading to long and expensive remediation times. This has spurred the development of in situ technologies such as bioremediation to enhance in situ degradation rates and the development of in situ permeable reactive barriers that if strategically placed can also control plume migration without the relatively higher cost of ex situ groundwater recovery and treatment. Finally, research into MNA has been conducted as an alternative to expensive and invasive remediation technologies.

## 5.3 Criteria for Screening of Technologies

Candidate remediation technologies were rated qualitatively with respect to several criteria specified in the Consent Order as follows:

- Ability to attain the MCSs
- Maturity of the technology
- Cost
- Feasibility given site conditions

## 5.4 Screening of Technologies

Candidate technologies are presented in Table 5.4-1, along with the screening evaluations. The evaluation of screening factors is summarized in this table through a plus (+) and minus (–) system to indicate whether the technology meets or does not meet the requirements of a particular factor. In the evaluation, "feasibility given site conditions" is weighted more heavily than other factors because feasibility assesses whether the technology is applicable at the site from a practical standpoint. Advancement of a technology to the next stage of the CME process (development and evaluation of corrective measure alternatives) is also indicated by this table. A more complete description of the evaluation of each technology is presented in the following sections.

## 5.5 Ex Situ Technologies for Groundwater Recovery and Treatment

Groundwater recovery and treatment are proven technologies for remediating groundwater contaminated with a variety of contaminants, including HE (Card and Autenrieth 1998, 076873; Pantex Plant 2003, 079784). Additional information is contained in FRTR online: http://www.frtr.gov/matrix2/top_page.html. A groundwater recovery and treatment system for HE contamination has been operating at Pantex since 1995. This system consists of 52 recovery wells. The system is designed to remove HE contamination using activated carbon adsorption. Other contaminants include heavy metals. The system treats approximately 7.5 million gal./month. At the U.S. Army's Umatilla Chemical Depot, a groundwater recovery system for HE has been active since January 1997. Three recovery wells pump approximately 1300 gal./min of contaminated groundwater to two parallel treatment lines, each containing two tanks with 20,000 lb of GAC (EPA 2002, 097388). These systems have succeeded in containing the groundwater plumes, meeting the required cleanup levels, and removing contaminant mass.

An important distinction between TA-16 and sites such as Pantex and Umatilla is in the differences in maximum contaminant concentrations. The maximum detected RDX concentration in either intermediate or regional groundwater at TA-16 is approximately 75 µg/L detected in R-25 regional groundwater, whereas the maximum concentrations at Pantex and Umatilla are approximately 2000 µg/L and 7000 µg/L, respectively. These substantially higher groundwater RDX concentrations, coupled with the disposition of area sensitive receptors, can affect the cost-effectiveness evaluation.

An ex situ groundwater recovery and treatment system generally uses a series of groundwater-recovery wells and an above-ground treatment system to treat the extracted groundwater to the appropriate levels. Once treated, the groundwater must be disposed of. Technologies for these different components of the system are screened separately below.

### 5.5.1 Groundwater Recovery Using Vertical Recovery Wells

By definition, ex situ groundwater recovery and treatment involve removal of groundwater, which requires a network of groundwater recovery wells and pumps. This network of recovery wells serves to hydraulically control the groundwater plume at its downgradient edge and to decrease the contaminant mass of the plume by pumping, which eventually remediates the groundwater. Because the volume of contaminated water within an aquifer can be large and the pumping rates of groundwater recovery are limited by the practical considerations of aquifer permeability and economics, the remedial progress using groundwater recovery wells can be slow. As discussed above, this has been the impetus for the development of in situ technologies.

Recovery wells and pumping have been used at the HE sites described above; however, the depth to water has generally been shallower than at TA-16, where the depths to intermediate and regional groundwater are approximately 800 and 1200 ft bgs, respectively, with most of this depth consisting of tuff. This depth also precludes alternatives to vertical recovery wells, such as recovery trenches or horizontal wells. Vertical recovery wells to this depth at the Laboratory are expensive (at least $300,000 each), which necessitates optimizing the design of the recovery well network so that the number of recovery wells is minimized.

#### Ability to Attain the MCSs

While this technology is not a treatment technology that directly treats groundwater, recovery wells remove contaminated groundwater and induce the flow of clean groundwater into the plume, thereby causing the dilution of the plume and a reduction in contaminant concentrations. Their effectiveness at accomplishing this has been demonstrated at several sites, including Pantex and Umatilla. For this reason, it is rated favorably with respect to this criterion.

#### Maturity of the Technology

Vertical groundwater recovery wells have been extensively used at numerous contaminated groundwater sites nationwide and are rated favorably for this criterion.

#### Cost

Other alternatives to vertical recovery wells, such as recovery trenches or horizontal wells, are not practical at the site primarily because the depth to water makes these technologies prohibitively expensive to install. While vertical wells are less expensive relative to these alternative technologies, the cost per well at TA-16 is high (at least $300,000). This warrants an unfavorable rating for this criterion.

#### Feasibility Given Site Conditions

Based on available permeability data for intermediate and regional groundwater, groundwater recovery using vertical wells appears to be feasible; however, as discussed in section 3.5, pump tests have not been conducted at the site to further investigate their feasibility given the extreme heterogeneity apparently present in intermediate and regional groundwater. This heterogeneity is exemplified by the contrasting permeabilities in CdV-16-2(i) and CdV-16-2(i)r (LANL 2006, 093798), which are located within 50 m of each other. Such conditions may adversely affect the flow rate and capture zone of groundwater recovery wells. Despite these concerns, groundwater recovery is rated favorably at this stage and will be evaluated in greater detail in section 6.

### 5.5.2 Granulated Activated Carbon Treatment of Water

Treatment of RDX-contaminated groundwater with GAC in conjunction with groundwater recovery and treatment has been used successfully at DoD HE-processing sites and at several HE groundwater contamination sites (Card and Autenrieth 1998, 076873; Pantex Plant 2003, 079784) (FRTR online: http://www.frtr.gov/matrix2/top_page.html). The Pantex site has been using GAC to successfully treat HE-contaminated groundwater since 1995 (BWXT Pantex and SAIC 2006, 096990). GAC's high capacity to adsorb RDX and the simplicity of the technology make it attractive for use in RDX groundwater treatment plants. The HE is not destroyed by GAC but rather is adsorbed and requires further treatment. Spent GAC derived from explosives processing wastewater is a hazardous waste and is typically thermally regenerated or disposed of in a landfill.

The main disadvantages of GAC are its high price and its disposal or regeneration costs (Card and Autenrieth 1998, 076873). The cost for regeneration, which is the preferred method of treatment because the adsorbed HE is destroyed by incineration, is approximately $2/lb (Pietz 2007, 097602). A second potential disadvantage is the possibility that conditioning the water may be necessary to avoid clogging the GAC adsorber beds, which incurs additional expense for water treatment equipment and chemicals.

#### Ability to Attain the MCSs

The technology is capable of attaining the MCSs, as demonstrated by the successful use of GAC at numerous groundwater cleanup sites, including the Pantex and Umatilla sites, where the RDX cleanup levels are 7.74 µg/L and 2.1 µg/L, respectively. For this reason, the technology is rated favorably.

#### Maturity of the Technology

The technology is mature and is rated favorably. Applications in the literature have been cited at least as early as 1990 for HE remediation.

#### Cost

Groundwater treatment by GAC is a standard technology against which innovative technologies are often compared. Costs for groundwater treatment using GAC range from $1.20 to $6.30 per thousand gallons treated (FRTR online: http://www.frtr.gov/matrix2/top_page.html). Assuming a 500 gal./min system and a 95% operational efficiency, yearly costs can range from $300,000 to $1,500,000. Alternative technologies, such as ultraviolet (UV)/photooxidation and phytoremediation, have been developed because of these relatively high GAC costs. In addition, groundwater treatment using GAC may be prone to fouling, which requires water conditioning measures. For these reasons, GAC's relative cost over other alternatives is unfavorable. However, treatability testing of GAC and competing technologies, such as UV photooxidation, are recommended to more accurately estimate treatment costs. Such tests are often performed by the respective treatment technology vendors. If performed, these tests may indicate that GAC is the most cost-effective technology given the site conditions, including groundwater flow rate and contaminant concentrations.

### Feasibility Given Site Conditions

Use of GAC for groundwater treatment at TA-16 is feasible. The site uncertainties discussed in section 3.5 do not affect the screening of this technology; however, a treatability test using GAC and site groundwater is recommended prior to the final design of a GAC system.

## 5.5.3 Ultraviolet/Photooxidation Treatment of Water

An alternative to carbon adsorption for groundwater recovery and treatment, UV photooxidation treats groundwater by the destruction of HE rather than by adsorption. The technology has been used successfully on a production scale at numerous groundwater remediation sites for various contaminants (EPA 1997, 097390). Treatment of explosives and their degradation products in groundwater using the UV photooxidation process has been evaluated at production and bench scales and is a promising technology because of its potential for reducing the long-term operational costs associated with carbon adsorption (Card and Autenrieth 1998, 076873).

A Calgon UV/peroxide ($H_2O_2$), system was used to treat groundwater at the former Nebraska Ordnance Plant in Mead, Nebraska. Site groundwater contained 28 µg/L RDX, the primary ordnance compound used at the site. The 30-kW system used at the site consisted of six 5-kW lamps, each mounted horizontally above one another in separate 6-in. reactor chambers. The groundwater flowed in series in a serpentine pattern to each reactor chamber. The field study was performed at a flow rate of 310 L/min (approximately 80 gal./min), pH of 7.0, $H_2O_2$ dose of 10 mg/L, and UV dose of 0.53 $kWh/m^3$. The RDX concentration was reduced by more than 82%. The total operating cost for the system was estimated to be $\$0.02/m^3$ ($0.08 per thousand gallons) of water treated, which includes the costs of power, lamp replacement, and $H_2O_2$ (EPA 1998, 097275). Other production scale applications include Aberdeen Proving Grounds.

The use of UV with an oxidant was chosen over carbon adsorption for the remediation of RDX in groundwater at the Bangor Naval Submarine Base (Card and Autenrieth 1998, 076873). A treatability study involving UV photooxidation and GAC was stipulated in the record of decision for the former Nebraska Ordnance Plant (EPA 1997, 097390); however, the results are currently not available. The Pantex CMS (BWXT Pantex and SAIC 2006, 096990) cites UV photooxidation as a potentially favorable technology but does not complete a detailed evaluation with respect to GAC.

A bench-scale treatability study using UV to treat TNT-contaminated water was completed (EPA 1998, 097275) and showed that TNT can be treated using UV with a titanium dioxide catalyst. No field-scale studies on UV treatment of TNT-contaminated water were available in the literature.

### Ability to Attain the MCSs

Based on the literature, the technology is able to attain the MCS for RDX; however, no operational data for TNT were available. The RDX concentration in the field test cited above was similar to the RDX concentrations found in regional and intermediate groundwater. Based on the available data, the technology will attain the MCSs and is rated favorably; however, a treatability study should be performed using site groundwater to determine its ability to attain the MCS for TNT, if groundwater recovery and treatment are recommended as the preferred remedial alternatives.

### Maturity of the Technology

The technology has been used in production settings for various contaminants, including several forms of HE with the exception of TNT. The technology is mature; however, a treatabilty study will be required to determine its effectiveness for TNT.

### Cost

Use of UV photooxidation rather than GAC adsorption may lead to operational cost savings over GAC of at least a factor of 10. In this preliminary technology screening, the technology is rated favorably for this criterion; however, its effectiveness for treating TNT is not known, and a treatability test is recommended to determine this. In addition, the treatabilty test will determine the costs of UV treatment, including electrical costs and $H_2O_2$ demand.

### Feasibility Given Site Conditions

The technology has been used for groundwater treatment of HE and would be feasible at TA-16, assuming it can be used to treat TNT, which will be determined by a treatability test if groundwater recovery is selected as the preferred remedial alternative. Its rating is favorable for this criterion. The site uncertainties discussed in section 3.5 do not affect the screening of this technology; however, a treatability test using UV and site groundwater is recommended prior to the final design of a UV system or for the comparison of GAC and UV treatment options.

## 5.5.4 Fluidized Bed Anaerobic Treatment of Water

Alternatives to GAC, such as UV photooxidation and phytormediation, offer the possibility of lower treatment costs for HE. Fluidized bed anaerobic treatment (Maloney and Heine 2005, 097283) is another such technology and has been developed as a pretreatment step for pinkwater prior to aerobic treatment in a conventional wastewater plant. Without such a pretreatment step, HE is not digestible in a conventional wastewater plant. The technology is based on anaerobic bacteria that attack dissolved explosives such as TNT and RDX at the nitro groups, converting them to amino groups, which can be aerobically treated. In a demonstration of the technology at McAlester Army Ammunition Plant in Oklahoma, the bacteria are cultivated on GAC contained in a fluidized bed (Maloney and Heine 2005, 097283). Favorable conditions for anaerobic bacteria are maintained through control of temperature, pH, and nutrients. Fuel-grade ethanol is used as the substrate to maintain the bacterial population.

The pilot reactor consists of a fluidized bed of activated carbon granules in a cylindrical tank with a column approximately 4.5 ft in diameter and an overall height of 22 ft. The bed of GAC occupies approximately 11 ft. Water recirculates through the column continuously at approximately 220 gal./min to keep the GAC fluidized, and pinkwater for treatment is pumped into the recirculation line at approximately 8 gal./min. The TNT concentrations during the pilot demonstration test ranged up to 80 mg/L and averaged approximately 40 mg/L. RDX concentrations were less than 6 mg/L.

The system was designed to be operated at 95°F to provide favorable conditions for the anaerobic bacteria. Gas produced as a byproduct of anaerobic degradation is collected at the top of the column and sent to a flare to burn off the methane. It could also be vented to the atmosphere. Nutrients and cosubstrate (electron donors) are also fed into the recirculation line. The nutrient solution consists of nitrogen, phosphorus, and several trace nutrients and minerals. The results of the pilot test showed a reduction of HE to levels below 100 μg/L in 94% of samples.

### Ability to Attain the MCSs

The technology was developed to treat pinkwater from HE processing, which contains relatively high concentrations (6 to 80 mg/L) of HE. The results showed treatment to levels below 100 µg/L, which is greater than the MCS. The capability to achieve the MCS concentration has not been demonstrated. In addition, the demonstration used a much lower flow rate than would be used in the groundwater recovery and treatment system. For these reasons, the technology is rated unfavorably for this criterion.

### Maturity of the Technology

The technology is in the pilot-scale stage and is not mature; it is rated unfavorably for this criterion.

### Cost

The pilot test demonstrated that for relatively high-concentration pinkwater, the technology is capable of lowering treatment costs compared with GAC. However, this has not been demonstrated for the lower HE concentrations expected in intermediate and regional groundwater, nor has the cost been determined for the much larger flow rates expected at TA-16. For these reasons, the technology is rated unfavorably for cost.

### Feasibility Given Site Conditions

The technology is a pretreatment step prior to aerobic treatment in a conventional wastewater treatment plant. Although TA-16 is served by a plant for sanitary waste, the plant does not have sufficient capacity to handle the large volumes of groundwater (up to 500 gal./min). For these reasons, the technology is not feasible at this time. The site uncertainties discussed in section 3.5 do not affect the screening of this technology.

## 5.5.5 Constructed Wetlands Phytoremediation Treatment of Water

Phytoremediation depends on plants to partially or substantially remediate contaminants of concern in groundwater. The plants remove, transfer, stabilize, or destroy contaminants through biological, chemical, and physical processes. The processes are mediated by plants and their roots and include degradation, recovery through accumulation in the plant (e.g., roots, shoots, and leaves), metabolism of contaminants, and immobilization of contaminants at the interface between roots and soil (EPA 2006, 097389).

The applicability and feasibility of phytoremediation must be considered on a site-specific basis. When selecting a phytoremediation method, it is important to ensure that unwanted transfer of contaminants to other media does not occur, thereby demanding a thorough understanding of the processes involved. Phytoremediation also requires an understanding of the plants that are selected and what needs to be done to ensure plant growth.

Deep groundwater applications of phytoremediation require that the contaminated water be pumped out of the subsurface using recovery wells, followed by a phytoremediation treatment system. It is important that the rate of groundwater flow into the phytoremediation area be equal to the rate of water uptake by the plants to prevent migration past the vegetation (EPA 2006, 097389).

The primary advantage of employing phytoremediation processes is the potential for substantial cost savings relative to the cost of more traditional technologies. Public acceptance of phytoremediation is generally greater, primarily because it is perceived as being more environmentally friendly and "low-tech" relative to more active remedial methods (EPA 2006, 097389). However, phytoremediation processes typically require a longer period of time to attain remediation goals due to the dependence on plant growth rates. An additional disadvantage is that plant species or varieties of one species may vary widely in their response to a contaminant and its concentration. Therefore, application of phytoremediation always requires site-specific studies prior to implementation.

A field study was designed and operated for the Milan Army Ammunition Plant near Milan, Tennessee (ESTCP 1999, 097271). The study was initiated in 1996 to determine the feasibility of treating contaminated groundwater with constructed wetlands. Two types of constructed wetlands were used at the site: (1) a lagoon system with submergent plants and (2) a subsurface flow gravel-bed wetland with emergent plants. Both systems were operated at 5 gal./min. The lagoon wetland was operated through September 1997, and the gravel-bed wetland was continuously operated until summer 1998. The goals of the field demonstration were to reduce

- TNT concentrations to less than 2 µg/L, and
- other total nitrobodies (including RDX and HMX) to concentrations less than 50 µg/L.

The design hydraulic retention time was 10 d through the lagoon system and 9.1 d through the gravel-bed system. Influent and effluent water samples were collected every 2 wk from each wetland system. Sampling of water at interior locations in the wetlands was performed at 2-month intervals.

The gravel-bed wetland met both of the field-demonstration objectives, with the exception of low-level explosives that were released during the cold winter months. The concentrations of TNT were reduced to 2 µg/L in the gravel-bed wetlands during the entire demonstration. Complete removal of TNT was observed during warmer months in the lagoon wetland system, and removal was less complete in the colder temperatures during the winter months. The gravel-bed wetland proved to be efficient at removing RDX from the contaminated groundwater during the warmer summer months; less efficient removal was observed during the colder winter months. The lagoon wetland did not remove RDX from the groundwater for the entire duration of the field demonstration.

### Ability to Attain the MCSs

Based on the above discussion, it was determined that a gravel-based phytoremediation system appears capable of achieving the MCS for TNT (22.2 µg/L) for a flow rate of 5 gal./min; however, there were no demonstrations in the literature that used a flow rate of up to 500 gal./min, which is the anticipated maximum groundwater recovery system flow rate. In addition, the technology does not appear capable of meeting the RDX MCS (6.1 µg/L). For these reasons, phytoremediation is rated unfavorably.

### Maturity of the Technology

Based on the results of the literature search, the technology has been tested at a field scale at only one site using a limited range of HE concentrations and flow rates. In particular, the flow rate was much lower than was expected at TA-16. For these reasons, this technology is innovative and not mature; its rating is unfavorable for this criterion.

### Cost

Phytoremediation has the potential for cost savings over other forms of treatment for HE-contaminated water because it destroys HE rather than transfers HE to another medium such as GAC, which then requires treatment or disposal. However, the capital costs to install such a system for 200 gal./min was estimated to be $3.5 million (ESTCP 1999, 097271) in 1998 dollars. Total 30-yr lifetime costs were estimated to be $1.78 per thousand gallons of treated water, which is competitive to GAC ($1.20 to $6.30 per thousand gallons). The installation costs are considerably higher than the likely capital costs for a GAC system, although operational costs as discussed above may be lower. Implementation at TA-16 may require up to 15 acres of constructed wetlands for a 500 gal./min flow rate. Based on these considerations, the technology is rated unfavorably with respect to cost.

#### Feasibility Given Site Conditions

The relatively low MCSs and the relatively large flow rate of groundwater requiring treatment would necessitate a large constructed wetland that would likely not be feasible. Based on the pilot-scale testing summarized above, winter weather conditions would adversely affect its operation. Moreover, significant ecological and National Environmental Policy Act (NEPA)-permitting concerns attend its construction and operation, particularly in Cañon de Valle. For these reasons, the technology is rated unfavorably. The site uncertainties discussed in section 3.5 do not affect the screening of this technology.

### 5.5.6 Use of Treated Water for Industrial or Municipal Supply

This technology involves use of treated groundwater from a groundwater treatment plant for industrial or municipal supply. Rather than inject the treated groundwater (in situ flushing) or discharge it to the surface (surface-water discharge under an NPDES permit), this technology provides treated groundwater for either industrial or municipal water supply use. In essence, the groundwater recovery wells become municipal drinking water supply wells. Typically, groundwater is treated to meet drinking water standards and is piped from the treatment plant to the end user. For municipal supply, piping of sufficient capacity must be installed from the treatment system location. In addition, adequate redundant treatment must be used to ensure that applicable drinking water standards have been met.

#### Ability to Attain the MCSs

As a method for disposal of treated water, this technology does not involve treatment of water to the MCSs and so the criterion is not applicable.

#### Maturity of the Technology

Treated groundwater from groundwater remediation system has been used extensively across the nation for municipal supply (American Water Works Association 1990, 080125). In New Mexico, NMED has approved of such a system, which is currently operating on a municipal well in Santa Fe (NMED 1997, 097176) since 1998. For these reasons, the technology is mature and is rated favorably for this criterion.

#### Cost

Industrial or municipal use of treated water is potentially the most expensive method of disposing of treated water because of the capital expense of required infrastructure modifications, such as installation of water mains. Currently, no such water mains are present at TA-16. On the positive side, use of treated water for municipal or industrial supply has the potential for significant cost savings if the value of water is considered. Primarily because of the lack of existing distribution main in the area, this technology is rated unfavorably for this criterion.

### Feasibility Given Site Conditions

Several potential problems arise concerning the feasibility of this technology. Water rights must be obtained for the use of water for municipal and industrial supply, although it may be possible to transfer existing Los Alamos County water rights to recovery wells at TA-16. With respect to industrial use, currently the Laboratory does not have sufficient local demand at TA-16 to use the estimated 200 to 500 gal./min of treated groundwater from a groundwater treatment system. To use this volume of water for municipal supply would necessitate the construction of a drinking water main from TA-16 into Los Alamos. For these reasons, the feasibility of this technology is rated unfavorably.

The site uncertainties discussed in section 3.5 affect the screening of this technology indirectly because the final groundwater flow rate for a groundwater recovery and treatment system is uncertain until a pump test is performed.

## 5.5.7 Injection of Treated Water

Injection of treated groundwater using injection wells is a technology used for disposing either treated or untreated wastewater. For this CME, the technology is considered a means of disposing treated groundwater from a groundwater recovery and treatment system. In this application, treated groundwater would be returned to intermediate or regional groundwater through a series of injection wells located upgradient of the recovery wells. This introduction of clean groundwater serves to flush out contaminants from the aquifer (Roote 1998, 097201) and is sometimes referred to as in situ flushing. In addition, bioremediation stimulants can be added to the injection wells, although these stimulants may cause biofouling of injection wells.

Potential difficulties with the technology consist primarily of injection well fouling, either caused by sediment, precipitated minerals, or biofouling. Filtration and conditioning of the treated water prior to injection are sometimes necessary to alleviate these problems. These measures can add considerable expense to operations and maintenance (O&M). Common methods of water conditioning include pH adjustment or chemical sequestration. Filters are typically used for sediment removal.

In New Mexico, injection wells must be permitted through a groundwater discharge permit. These permits are routinely issued by NMED for groundwater treatment systems, and the permitting process is not onerous. Permits must be renewed every 5 yr. Monthly sampling of the treatment system and discharge is typically required under the permit. Unlike an NPDES surface water discharge permit that generally requires a full suite of laboratory analyses of the effluent, groundwater discharge permits generally focus on the specific contaminant analytical suite, which reduces the sampling and laboratory costs.

### Ability to Attain the MCSs

Injection can help attain the MCSs within the aquifer; the injection of clean water directly into the contaminated aquifer displaces contaminated groundwater with clean groundwater. The displaced contaminated groundwater is captured by the downgradient groundwater recovery wells. This flushing action afforded by injection is more direct than in canyon discharge, where the discharged clean water must percolate through approximately 1000 ft of overburden before reaching intermediate or regional groundwater, by which point the infiltrated water may be contaminated by residual HE within the canyon. While canyon flushing may serve to flush the overburden, the rate of cleanup of intermediate and regional groundwater may be slower. Moreover, although canyon discharge may be better at flushing the overburden, downgradient-recovery wells, which are screened across a deeper horizon, may not be effective in hydraulically controlling contamination mobilized in overburden.

For this criterion, the technology is rated favorably with respect to other technologies.

#### Maturity of the Technology

Injection wells have been frequently used to dispose of water from a groundwater treatment system; the technology is rated favorably for this criterion.

#### Cost

Drilling and operational expenses comprise the major costs for injection wells. Preventative water conditioning and filtration can alleviate much of the expense associated with injection well cleaning and redevelopment. The primary alternatives to groundwater injection are surface water discharge and industrial/municipal use of the treated water. From the cost standpoint alone, injection wells are favorable for these alternatives. Surface-water discharge, while avoiding drilling expense, will require an NPDES permit and monthly effluent sampling and analyses for several analyte suites, which are more expensive over the long-term than the more focused sampling and analysis required under a groundwater discharge permit.

In addition, surface-water discharge may require significant expenses to mitigate ecosystem impacts, including construction of multiple outfalls to control the discharge volumes and the construction of erosion control measures. Industrial or municipal use of the treated water will require a new infrastructure in the form of distribution piping. For these reasons, although injection wells are expensive, they are rated favorably over the other technologies for this criterion.

#### Feasibility Given Site Conditions

Based on available site permeability data, injection wells are feasible for the disposal of treated groundwater from a groundwater-recovery system. However, because of site uncertainties (section 3.5), the final feasibility should be determined by conducting a pump test, which yields important data on site permeability. Despite this data uncertainty, the technology is rated favorably.

### 5.5.8 Canyon Discharge of Treated Water

An alternative technology to injection is surface-water discharge. This technology is a variant of in situ flushing and uses surface-water discharge of treated water to flush a contaminated aquifer by infiltration (Roote 1998, 097201). As applied to TA-16, treated groundwater would be discharged into Cañon de Valle, where it would infiltrate into the alluvial, intermediate, and regional groundwater systems, thereby serving to flush contaminants from these zones. Hydraulic capture of the infiltrated water would be achieved by the intermediate and regional groundwater recovery systems, creating a circulatory flow of water across both shallow and deeper horizons of the site. In situ flushing by canyon discharge would be implemented by installation of an NPDES-permitted outfall in Cañon de Valle. Up to 500 gal./min of treated groundwater from the intermediate and regional groundwater recovery and treatment system would be discharged.

#### Ability to Attain the MCSs

In situ flushing by surface discharge has the potential of achieving MCSs in intermediate and regional groundwater but would not be as effective as direct injection. Moreover, canyon discharge may actually mobilize additional contaminant mass, potentially leading to higher concentrations of contaminants in the intermediate and regional systems or in the downgradient alluvial system. Such a diffuse infiltration of contaminants would render the downgradient recovery well network less effective at controlling downgradient migration. For this criterion, canyon discharge is rated unfavorably.

#### Maturity of the Technology

As with in situ flushing by injection, the technology is mature and is rated favorably.

#### Cost

Discharge of treated water at the surface rather than injection avoids potential problems with injection well fouling but incurs other costs, such as NEPA permitting, NPDES permitting, and NPDES outfall monthly sampling. Over the lifetime of the project, the latter costs are significant.

In addition, a preferred remediation alternative has already been identified for the shallow Cañon de Valle system CMS (LANL 2003, 085531), obviating the need for the additional remediation offered by surface discharge and flushing. For this criterion, the technology is rated unfavorably.

#### Feasibility Given Site Conditions

Installation of an outfall discharge system into Cañon de Valle would require several permits, including NEPA and NPDES permits. Discharge of up to 500 gal./min of water may severely perturb the Cañon de Valle ecosystem, including extending the perennial reach of the stream and increasing the potential for erosion. Discharge of a large flow rate of water would likely overwhelm the alluvial remediation systems to be installed as part of the shallow system CMI (LANL 2007, 096003). Finally, the increased surface water flow may mobilize contaminants within the shallow and deeper horizons, making their capture by an intermediate or regional groundwater recovery well network difficult. For these reasons, the technology is rated unfavorably.

The site uncertainties discussed in section 3.5 indirectly affect the screening of this technology because the final groundwater flow rate is dependent on the results of a pump test.

## 5.6 In Situ Technologies

### 5.6.1 Nanoscale Zero-Valent Iron Permeable Reactive Barrier

Nanoscale zero-valent iron (ZVI) is a variant of the granular ZVI typically used in permeable reactive barriers (PRBs) (Gavaskar et al. 2005, 097195), which have been in use for approximately 10 yr. Results from a full-scale ZVI PRB system for HE for a site in Nebraska (Johnson et al. 2004, 095627) indicate that ZVI efficiently destroys TNT through a process of reductive denitrification. Numerous laboratory-scale studies have shown that ZVI effectively treats RDX in water (Singh et al. 1999, 095715; Comfort 2005, 095718; Wanaratna et al. 2006, 095714).

ZVI is a strong reducing agent that is capable of remediating chlorinated organic chemicals and HE contaminants. The granular ZVI used in permeable barrier applications typically consists of iron particles ranging from −8 to + 50 mesh. The finer nanoscale ZVI particles are much more reactive than granular ZVI and have the potential to quickly react with contaminants. In addition, nanoscale ZVI can also be injected as an emulsion, enabling its use in injection wells. These injection wells can be configured to create a reactive zone analogous to a PRB. At TA-16, such a PRB could be used as a downgradient treatment barrier to prevent plume migration.

The technology has been investigated on a bench-scale and has been shown to rapidly degrade RDX (Schaefer et al. 2007, 097640). Its capability to treat TNT was not studied; however, based on field-scale implementation of granular ZVI, TNT degradation can be assumed. Based on the results of the literature search, no field studies of nanoscale ZVI have been conducted.

### Ability to Attain the MCSs

Although the literature search showed no field applications of nanoscale ZVI for RDX and TNT, laboratory tests have shown its effectiveness for RDX. TNT testing was not conducted. Granular ZVI has been shown to be effective for TNT, and so nanoscale effectiveness for TNT can safely be assumed. For this technology, screening the technology is rated favorably.

### Maturity of the Technology

Although granular ZVI has been used for various groundwater contaminants, its use for HE has been limited to a few sites. Nanoscale ZVI has not been implemented on a field scale. For these reasons, the technology is rated unfavorably for maturity.

### Cost

The use of in situ remediation technologies, such as nanoscale ZVI, offers potential cost savings over groundwater recovery and treatment because contaminants are destroyed in situ. Expensive groundwater treatment equipment and water disposal systems are not required. Implementation of the nanoscale ZVI would consist of the installation of a series of injection wells spanning the HE plume in intermediate and regional groundwater. The number of these wells would have to be determined from an injection test conducted in a pilot injection well. However, given the assumed size of the plume (see Figure 3.2-4), the number of injection wells would likely be cost-prohibitive given a per-well drilling cost of at least $300,000. For these reasons, the technology is rated unfavorably with respect to cost.

### Feasibility Given Site Conditions

Because of the depth and expense of drilling to intermediate and regional groundwater and the large assumed plume dimensions (see Figure 3.2-4), the feasibility of in situ reaction zone technologies that use injection wells is questionable. Based on Figure 3.2-4, an in situ technology deployed as a “cutoff wall” on the downgradient edge of the plume would have to be approximately 0.5 mi wide. Generally, each injection well has a limited radius of influence for its reactive components, potentially requiring a large number of wells even under conditions of favorable permeability and homogeneity. As discussed in section 3.5, this does not appear to be the case at least for intermediate groundwater, although this is uncertain. As discussed in section 3.5, a pump test would help to address this uncertainty.

In addition to the assumed size of the groundwater plume, the intermediate zone is essentially a groundwater mound with strong vertical and locally radial gradients. This potential for both vertical and radial “pancake” flow is not well suited for any kind of in situ technology deployed as a linear cutoff wall transverse to the direction of groundwater flow to prevent downgradient plume migration. Furthermore, injection of reactive agents in and of itself may exacerbate the peripheral flow pattern even further, resulting in even less flux through a downgradient reaction zone or PRB. This configuration is hydrologically very different from an aquifer where the flow field is primarily horizontal and unidirectional—a more favorable setting for a PRB or reaction zone technology. The advantage of groundwater recovery in this hydrogeological setting, as opposed to reaction zone technologies, is that groundwater pumping depresses the heads around the recovery wells, inducing groundwater capture by the recovery wells.

In regional groundwater, the groundwater flow vectors are likely to be more unidirectional, though strong vertical gradients are apparently present. Aside from these vertical gradients, the problem of plume size and the associated large number of injection wells remains.

For these reasons, nanoscale iron is rated unfavorably with respect to feasibility.

### 5.6.2 Bioremediation by Edible Oil Emulsion Permeable Reactive Barrier

In situ bioremediation of HE has been studied under both aerobic and anaerobic conditions, with anaerobic conditions generally yielding higher degradation rates (Wani et al. 2002, 097588). To stimulate anaerobic conditions, a carbon source such as lactic acid or edible oils can be added. In addition, nitrogen injection may be feasible for vadose-zone contamination (BWXT Pantex and SAIC 2006, 096990, pp. 5-10). Injection of edible oils to stimulate anaerobic bioremediation has been used to remediate chlorinated organic groundwater plumes and may have applicability remediating HE groundwater contaminants (Wani et al. 2002, 097588; BWXT Pantex and SAIC 2006, 096990; ESTCP 2006, 097272). The technology functions by using emulsified oil as a hydrocarbon source to stimulate the populations of indigenous microbes, some of which may be capable of degrading HE. Acetate has also been used in a similar manner (Wani and Davis 2003, 097270). Laboratory and field-scale results of HE degradation tests using edible oils are promising.

Implementation of this technology typically involves installation of injection wells and injection of a water-oil emulsion. The injection wells can be configured to span the groundwater or can be used in a PRB formation in which a battery of injection wells creates a reaction zone through which groundwater flows and the contaminants are broken down by bioremediation.

Successful application of the technology requires a sufficient population of contaminant-degrading microbes in the aquifer. No studies have been completed in intermediate and regional groundwater regarding microbial populations of HE degraders. RDX and TNT breakdown products have been detected in Cañon de Valle alluvial groundwater and in intermediate and regional groundwater, indicating that biodegradation is occurring. However, a recent study of RDX biodegradation (Bradley and Dinicola 2005, 095588) suggests that the biodegradation pathway for RDX may proceed to completion without substantial accumulations of intermediate degradation products.

Cañon de Valle is a riparian environment with several wetlands, and as a result, the concentration of total organic carbon (TOC) in alluvial groundwater is relatively high compared with TOC concentrations in intermediate and regional groundwater (LANL 2003, 077965). The potential for biodegradation generally increases with increasing TOC concentrations.

Potential problems with edible-oil emulsion injection include biological fouling of the injection wells. Unfortunately, the nutrient-rich conditions created within an injection well often favor rapid microbial growth and biofilm formation, which can lead to clogging the well screen. Several methods of injection well rehabilitation have been used successfully (GeoSyntec Consultants 2005, 097197), including use of hypochlorite.

A pilot-scale implementation of this technology is currently being conducted at Pantex, the preliminary results of which are summarized in the recent Pantex CMS for perched groundwater (BWXT Pantex and SAIC 2006, 096990, pp. 5-10). A total of 13 monitoring and injection wells were installed, and a reaction zone was established by injecting an amendment consisting of 50% salad-grade soybean oil, 4% sodium lactate, buffering agents, and other proprietary surfactants. A total volume of 163,500 gal. of solution containing 7800 gal. of the amendment was injected into six injection wells during December 2005. As of the June 2006 Pantex CMS, final degradation results are not available. Preliminary observations included a decrease in the capacity of the injection wells with time.

### Ability to Attain the MCSs

Both laboratory and field tests suggest that the technology is promising for HE remediation. The technology is rated favorably for this criterion.

### Maturity of the Technology

Results of the literature search indicate that the technology first appeared in the literature circa 1998. Although several laboratory-scale systems have been implemented, few pilot- or field-scale tests have been conducted, and the technology is rated unfavorably in this regard.

### Cost

The use of in situ remediation technologies, such as bioremediation by edible oil injection, offers potential cost savings over groundwater recovery and treatment because contaminants are destroyed in situ. As with nanoscale ZVI, expensive groundwater treatment equipment and water disposal systems are not required. However, cost-effective implementation at TA-16 is problematic given the large assumed area of the intermediate and regional groundwater plumes (see Figure 3.2-4) and the expense of installing injection wells. The number of injection wells is likely to adversely affect any cost advantage of in situ treatment. For these reasons, it is rated unfavorably for this criterion.

### Feasibility Given Site Conditions

This technology may be implemented either as a series of injection wells that span the area of the groundwater plume or as a PRB through which groundwater flows. Given the relatively large area of the plume in intermediate and regional groundwater (approximately 0.6 $mi^2$), a PRB configuration is more practical than dispersed injection wells. Hydrogeological conditions in the intermediate and regional groundwater zones, however, do not appear favorable for a PRB configuration for the following reasons. (1) The apparent heterogeneity of conductivity within intermediate and regional groundwater indicates extreme variability in local groundwater flow rate and direction, although as discussed in section 3.5, permeability is uncertain. (2) The required depths of injection wells (600 to 1500 ft) and the 0.25-mi width of the groundwater plume would require numerous groundwater injection wells, which may be of limited use because of fouling potential.

Moreover, as discussed in detail in the above discussion of nanoscale ZVI feasibility, the hydrogeology of intermediate groundwater is not well suited for the installation of any in situ technology deployed as a linear downgradient cutoff wall. Finally, for this technology, the presence of groundwater microbial populations and their capability of degrading HE is not known.

For these reasons, the feasibility of the technology is rated unfavorably.

## 5.6.3 Oxidation by Permanganate Injection

Injection of potassium permanganate has been used to destroy contaminants by oxidizing them in situ. The technology is particularly useful in remediation of relatively high-concentration contaminant source areas that are slow to respond to groundwater pumping because of sorbed-phase contamination. In addition to permanganate, other oxidizers, such as $H_2O_2$ and Fenton's reagent, have been used in situ. A typical application involves installation of a series of injection wells and periodic injection of a potassium permanganate solution. Disadvantages of the technology include the safety concerns associated with permanganate and the fact that injection of a high manganese compound will likely violate the NMWQCC standard for manganese of 200 µg/L (20 NMAC §6.2.3103).

A treatability test of this technology for RDX in groundwater was conducted at the Pantex Plant (BWXT Pantex and SAIC 2006, 096990).The results showed that RDX can be oxidized using permanganate, but use of an oxidizer will not work to remediate hexavalent chromium, which is a co-contaminant along with RDX at Pantex. For this reason, a field pilot test using permanganate was not performed.

#### Ability to Attain the MCSs

Oxidation with permanganate is a very robust treatment technology, and its ability to attain the MCSs is rated favorably.

#### Maturity of the Technology

In situ permanganate has been used successfully to remediate organic contaminants at several sites; its use for HE has been field tested on a pilot scale at Pantex. The maturity of the technology is favorable.

#### Cost

With its ability to destroy contaminants in situ, the technology has the potential for cost savings when compared with ex situ techniques such as groundwater recovery. In addition, permanganate can destroy sorbed phase contaminants, which are typically not mobile under groundwater-pumping conditions. Deployment of this technology at the site, however, would be very expensive for the reason discussed above for other in situ technologies: the number of injection wells would be large and cost-prohibitive. For these reasons, its cost is rated unfavorably.

#### Feasibility Given Site Conditions

The feasibility of this technology is doubtful for the same reasons cited for other in situ technologies that must rely on injection wells. These reasons include the size of the HE plume in intermediate and regional groundwater (0.6 mi$^2$), the disposition of the intermediate groundwater as a groundwater mound with radial and vertical gradients, and the difficult and expensive drilling conditions. In summary, permanganate injection is not feasible given the large number of injection wells that would be required. Finally, the New Mexico groundwater standard for manganese would likely be violated with permanganate injection. For these reasons, the technology is not rated favorably.

### 5.6.4 In Situ Sodium Dithionite Reduction Permeable Reactive Barrier

Sodium dithionite has been used for the in situ reduction of inorganic contaminants, such as hexavalent chromium (EPA 2000, 097256). As a reducing agent, sodium dithionite remedial applications typically involve a series of injection wells configured to produce an in situ reaction zone. The chemistry involves reduction of iron to produce a reducing agent suitable as an electron donor for contaminant reduction.

An in situ pilot test study using sodium dithionite is being conducted at the Pantex Plant. The pilot test, which began in February 2005, entailed the installation of an in situ PRB using sodium dithionite to provide source control for a portion of the southeast perched-groundwater plume. The PRB, the length and width of which were 60 and 40 ft, respectively, was formed by the injection of 165,000 gal. of dithionite solution into two injection wells over the course of 7 d. Reaction progress was determined by the withdrawal of 175,000 gal. of fluid. The results indicated the complete treatment of RDX from initial concentrations of up to 440 µg/L to nondetections. Concentrations of some metals, such as arsenic and cadmium, increased as a result of treatment, with several metals exceeding allowable limits. Evaluation of the results is ongoing and will be used to determine the feasibility of a full-scale implementation at Pantex.

#### Ability to Attain the MCSs

The technology appears to be able to attain the MCSs based on the Pantex pilot test. RDX concentrations were reduced to nondetectable levels.

#### Maturity of the Technology

The literature review suggests that this technology has been used primarily for hexavalent chromium treatment where it has shown promise; nevertheless, for HE treatment, the technology is not mature and is rated unfavorably.

#### Cost

With its ability to destroy HE in situ, the technology has a very good potential for cost savings, particularly with respect to groundwater recovery and treatment; however, its deployment at TA-16 would likely require the installation of a prohibitively large number if injection wells. For this reason, it is rated unfavorably.

#### Feasibility Given Site Conditions

Application of this technology to intermediate groundwater suffers from the same potential problems as the other in situ technologies discussed in this CME. The relatively large dilute HE plume in intermediate groundwater, the likelihood of extreme local variations in permeability, the expense of installing injection wells, and the characteristics of the intermediate zone as a groundwater mound all negatively affect its feasibility. Although perched groundwater at Pantex also exhibits some of the flow characteristics of a groundwater mound, leading to a less-than-ideal setting for PRB/reaction zone technologies, the much higher HE concentrations warrant the consideration of aggressive source control measures.

An additional concern with this technology is the reduction, dissolution, and possible mobilization of naturally occurring heavy metals, which was observed at Pantex where certain metals became elevated above standards.

In regional groundwater, although the groundwater flow field may be more linear, the HE plume in regional groundwater is even more dilute than in intermediate groundwater, and HE concentrations have been less than the MCSs for several recent sampling rounds (LANL 2007, 095787).

### 5.6.5 Monitored Natural Attenuation

Natural attenuation is defined as dilution, dispersion, volatilization, adsorption, biodegradation, and abiotic reactions such as hydrolysis (Layton et al. 1987, 014703, p. 194) that reduce contaminant concentrations in site groundwater or soil over time. MNA is a site- remediation alternative in which the progress of natural attenuation is monitored by periodic testing. Its use has been prompted by the observation that sites such as petroleum hydrocarbon contamination sites often clean themselves over a period of a few years, principally by natural biodegradation. In contrast with petroleum hydrocarbons, however, natural attenuation of HE compounds is not as well documented (Pennington et al. 1999, 097268). It is generally thought to be slow because of the recalcitrance of HE organic compounds such as RDX and HMX to biodegradation, except under strongly anaerobic conditions (Bradley and Dinicola 2005, 095588). Nevertheless, RDX and TNT breakdown products have been detected in intermediate and regional groundwater (LANL 2006, 093798) and have been detected in the shallow alluvial system of Cañon de Valle (LANL 2003, 077965). Moreover, the current decreasing trends in RDX contamination in regional groundwater in R-25 (see Figure 3.2-2) indicate the MNA may be occurring at TA-16.

In addition, MNA is particularly appropriate where major contaminant sources have been removed (EPA 2004, 097694) At TA-16, these sources include the 260 Outfall drainage channel soils, which were removed during the IM (LANL 2002, 073706).

EPA (EPA 1999, 097386) has identified the following three lines of evidence to support MNA at groundwater sites:

- Historical groundwater and/or soil chemistry data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time at appropriate monitoring or sampling points
- Hydrogeologic and geochemical data that can be used to demonstrate indirectly the type(s) of natural attenuation processes active at the site and the rate at which such processes will reduce contaminant concentrations to required levels
- Data from field or microcosm studies (conducted in or with actual contaminated site media) that directly demonstrate the occurrence of a particular natural attenuation process at the site and its ability to degrade the contaminants of concern

Given the relatively slow rate of HE degradation in the environment, characterization of site hydrogeology plays a critical role in the evaluation of MNA. Important factors consist of groundwater flow rate and direction, lateral and vertical extent of contamination, hydraulic conductivity and recharge rate, and the nature of subsurface hydrogeology. Attenuation processes must be demonstrated to occur faster than groundwater flow can carry contaminants to potential receptors (Pennington et al. 1999, 097268).

Implementation of the technology includes additional monitoring well installation, a program of sampling and laboratory analyses designed to quantify the presence of degradation products or other indicators, statistical analysis of data trends, and a series of laboratory experiments using the site aquifer material and groundwater to further characterize site-attenuation processes. These experiments may help to develop an understanding of the adsorption, immobilization, and degradation processes that will affect the rate of contaminant attenuation.

Natural attenuation could potentially reduce the cost of remediation for a site, relative to remediation techniques requiring a large engineering effort. There is a reduced potential of human and environmental exposure to contaminants with the natural attenuation remedial alternative (Pennington et al. 1999, 097268; BWXT Pantex and SAIC 2006, 096990, section 7). Natural attenuation is limited by the rate of the attenuation processes and therefore requires an extended period of time to achieve cleanup goals. It is often difficult to obtain regulatory and community acceptance of natural attenuation as a remediation alternative. Another disadvantage of natural attenuation is that it is difficult to quantify and demonstrate attenuation processes that occur in the aquifer system.

A field demonstration of the application of MNA was initiated at the Louisiana Army Ammunition Plant in northwest Louisiana (ESTCP 1999, 097282). The plant was used for loading, assembling, and packing munitions. Wastes from the plant were disposed of in unlined lagoons, resulting in the eventual contamination of groundwater with TNT and RDX. Detected concentrations of the two compounds were as high as 24,000 µg/L. The regulatory and cleanup objectives for the field study were as follows:

- Demonstrate that natural attenuation of explosives can be determined through appropriate site monitoring
- Develop guidance for selection of MNA as a remediation alternative
- Develop guidance for establishing a site-monitoring plan and points of compliance
- Gain regulatory acceptance for use of MNA as an alternative for remediation of explosives

The concentration and mass of the plume were monitored in 11 monitoring wells and 51 cone penetrometry penetrations (to a depth of 40 m). The monitoring wells were sampled using micropurge sampling techniques. At the conclusion of the 2-yr test period, it was observed that the contaminant mass had decreased from 52 to 50 metric tons for TNT and from 78 to 68 metric tons for RDX in 9 of the 11 monitoring wells.

An evaluation of the use of MNA for the Pantex site was conducted as part of CME activities (BWXT Pantex and SAIC 2006, 096990). This evaluation indicated that MNA is a viable remedial alternative for RDX contamination and was based on a treatability study in which RDX degradation products were detected in groundwater. As a consequence, MNA was included as part of the preferred remedial alternative for groundwater.

### Ability to Attain the MCSs

The results of the literature search indicate that natural attenuation is capable of reducing RDX and TNT concentrations in groundwater, although the rate of degradation is slow. Based on recent groundwater concentration data (LANL 2007, 095787), it was noted that natural attenuation appears to be active in decreasing RDX concentrations in regional groundwater at monitoring well R-25. RDX concentrations for the past several sampling events have been less than the MCSs. These recent data indicate that MNA can attain the MCSs, at least in regional groundwater. It is likely that this decreasing trend in RDX at least partially reflects the fact that HE in regional groundwater may have been introduced during drilling.

### Maturity of the Technology

MNA has been used at numerous sites for petroleum hydrocarbons and other contaminants and has generally been accepted by regulatory agencies as a viable remediation alternative where justified. HE sites where MNA has been demonstrated include Pantex and the Louisiana AAP. Therefore, its maturity is rated favorably.

### Cost

Because it does not involve expensive groundwater treatment technology, MNA is relatively inexpensive, warranting a favorable rating for this criterion. Potential expenses include long-term monitoring and sampling, analysis of concentration trends, and research into site-attenuation mechanisms.

### Feasibility Given Site Conditions

MNA appears to be feasible for intermediate and regional groundwater. Additional monitoring wells in the intermediate and regional groundwater will likely be required to monitor contaminant concentrations in these zones (LANL 2007, 095787). In addition, laboratory bioremediation testing similar to that performed for an HE site in Bangor, Washington (Bradley and Dinicola 2005, 095588), could be performed to assess the potential for bioremediation of HE in several compartments of the CSM, including Cañon de Valle alluvial soil, as well as intermediate and regional zone aquifer materials. Such experiments may help to explain the discrepancy between the current site HE inventory based on media HE concentrations (LANL 2006, 093798) and the estimates of the mass of released HE.

Difficulties in feasibility are related to monitoring well installation, such as drilling conditions, depth to water, and site logistics, which preclude monitoring wells in certain areas.

## 5.7 Summary of Technology Screening

The technology screening exercise identified candidate technologies that have been developed in association with other HE sites. These candidate technologies were screened against several criteria including feasibility with respect to site conditions. The constraints posed by site conditions favored ex situ groundwater recovery and treatment and eliminated all in situ technologies except for MNA. These site conditions include the depth of intermediate and regional groundwater, apparent heterogeneity of intermediate groundwater permeability, the hydrogeology of intermediate groundwater, and the assumed large area of the intermediate and regional groundwater plumes. Site uncertainties discussed in section 3.5 affected the screening, primarily the uncertainty in intermediate groundwater permeability. However, this uncertainty was overwhelmed by the practical problems with the feasibility of in situ technologies caused by (1) the large area of the plume and (2) the expense of drilling the injection wells necessary for the deployment of these technologies.

Although deemed favorable, groundwater recovery and treatment also are affected by the uncertainties in permeability, though uncertainties are less sensitive than in situ technologies that rely on the injection of reactive agents. As discussed in section 6, these uncertainties become more important in the conceptual design and cost estimating for groundwater recovery and treatment, specifically with regard to the groundwater flow rate and the number of recovery and injection wells.

# 6.0 DEVELOPMENT AND EVALUATION OF CORRECTIVE MEASURE ALTERNATIVES

## 6.1 Assembly of Remediation Technologies into Corrective Measure Alternatives

The identification and screening of remediation technologies identified potentially applicable technologies that are capable of attaining MCSs and remedial objectives for intermediate and regional groundwater. This screening process favored ex situ groundwater recovery and treatment and its associated technologies and in situ MNA. Other technologies, although promising for other sites, were judged not feasible for TA-16 intermediate and regional groundwater.

In this section, these technologies are assembled into corrective measure alternatives and associated conceptual designs and are subjected to a detailed evaluation. Depending on the site conditions, corrective measure alternatives may consist of one or more technologies. Moreover, the alternatives are not mutually exclusive. A combination of one or more alternatives may be recommended along the lines of the Pantex perched-groundwater CMS (BWXT Pantex and SAIC 2006, 096990, section 7), in which the preferred alternative combined several technologies.

Table 6.1-1 presents the following candidate corrective measure alternatives for intermediate and regional groundwater:

- Groundwater recovery from a series of recovery wells, treatment using either GAC or UV photooxidation, with discharge of treated water to a series of upgradient injection wells; implementation in intermediate or regional groundwater or both simultaneously
- Natural attenuation in intermediate and regional groundwater
- No action

## 6.2 Criteria for Evaluation of Corrective Measure Alternatives

Corrective measure alternatives are compared and contrasted using the following evaluation criteria established in the Consent Order.

- *Technical Practicability.* Practicability addresses the overall suitability of the corrective action option for containment or remediation of the contaminants in the subject medium to protect human health and the environment.
- *Effectiveness.* Effectiveness assesses the ability of the corrective measure to mitigate the measured or potential impact of contamination in a medium under the current and projected site conditions. The assessment also includes the anticipated duration for the technology to attain regulatory compliance. In general, all corrective measures described in section 6.1 will have the ability to mitigate the impacts of contamination at the site, but not all remedial options will be equally effective in achieving the desired cleanup goals to the degree and within the same time frame as other options. Each remedy is evaluated for both short- and long-term effectiveness.
- *Implementability.* Implementability characterizes the degree of difficulty involved during the installation, construction, and operation of the corrective measure. Operation and maintenance of the alternative are addressed in this section.
- *Human Health and Ecological Protectiveness.* This factor evaluates the short-term (remedy installation-related) and long-term (remedy operation-related) hazards to human health and the environment of implementing the corrective measure. The assessment evaluates whether the technology will create a hazard or increase existing hazards and address the possible methods of hazard reduction.
- *Cost.* This factor discusses the anticipated cost of implementing the corrective measure, including the cost-effectiveness given site conditions. The costs are divided into (1) capital costs associated with constructing, installing, pilot testing, evaluating, permitting, and reporting the effectiveness of the alternative; and (2) continuing costs associated with operating, maintaining, monitoring, testing, and reporting on the use and effectiveness of the technology. Costs are accurate to within 15% and are placed on a net present value (NPV) basis using a reasonable discount factor (4.5%). In addition, an annual rate of inflation of 3% is assumed over the 30-yr lifetime of the remediation system.

## 6.3 Evaluation of Alternatives

### 6.3.1 Intermediate Groundwater Recovery and Treatment with Injection of Treated Groundwater (Alternative I)

This alternative consists of the phased design and installation of a groundwater recovery and treatment system with an in situ flushing system composed of upgradient injection wells. This alternative incorporates a phased approach because several important design parameters are uncertain, and a pump test is required to determine important aquifer parameters and to ultimately ascertain whether a full-scale system is feasible. Following completion of the pump test, the final feasibility of groundwater recovery will be assessed to determine whether full-scale design and installation are warranted. The pump test would be conducted in a new well to be installed near existing well CdV-16-2(i)r.

In this alternative, groundwater recovery wells are used to extract contaminated groundwater from the intermediate groundwater zone. The recovered groundwater is treated and returned to the intermediate zone to flush this zone, with the recovery well network designed to capture the contaminated groundwater displaced by this injection. A conceptual design for this alternative is shown in Figure 6.3-1. In the conceptual design, four recovery wells are used to extract groundwater, three of which are located in Cañon de Valle; the fourth is located on the mesa near existing monitoring well CdV-16-2(i)r. The recovery wells are screened across the intermediate zone, including Bandelier Tuff and unconsolidated Puye Formation horizons. The arrangement of the recovery wells is intended to capture intermediate zone groundwater contamination within the area shown in Figure 3.2-4 to the extent practical given site logistics.

Three of the recovery wells are placed in Cañon de Valle to intercept productive fractures within the Bandelier Tuff portion of the intermediate zone. Of two monitoring wells completed within this zone, both intercepted productive fractures (LANL 2006, 093798), suggesting a significant fracture density is present within the Bandelier Tuff. In addition, as a recharge feature associated with Cañon de Valle, the saturated thickness of the intermediate zone is likely to be greatest within the canyon rather than on the mesa, a conclusion supported by water-level measurements in CdV-16-1(i) and R-25.

The recovery wells are equipped with submersible pumps, and plumbing and electrical conduits are installed to each wellhead. The four wells in Cañon de Valle each have their own head tanks, which are located in the canyon near the MDA P canyon access road. This head tank is installed in a small shed. Water from the head tank is pumped to a second head tank within the main treatment compound located as shown in Figure 6.3-1. This treatment system consists of the unit operations shown in Figure 6.3-2, including (1) addition of a scale-prevention chemical such as polyphosphate or pH adjustment to condition the water, (2) bag filtration to remove suspended solids, and (3) GAC adsorption treatment. Treatment by UV photooxidation is a viable option; however, treatability studies on site groundwater need to be performed to determine which of these treatment technologies is superior. To implement in situ flushing within the intermediate zone, treated water is discharged to four upgradient injection wells screened across the intermediate zone.

The influence of this system on intermediate-groundwater hydraulic heads was modeled using a two-dimensional groundwater model. This model uses site-specific parameters along with several simplifying assumptions (Appendix C3), including homogeneous isotropic permeabilities. Several groundwater recovery rates are also used. The model results for a total groundwater flow rate of 500 gal./min are shown in Figure 6.3-3. The area of influence of this system appears to span the assumed plume area (Figure 3.2-4) within the constraints of site logistics. An important feature of the results is the absence of a significant capture zone downgradient of the recovery wells due to the relatively steep groundwater gradient present at the site.

### Technical Practicability

Groundwater recovery and treatment with injection are standard methods for the control and remediation of groundwater contamination; their application is generally straightforward. The unique hydrogeology of the site, however, presents several problems with respect to technical practicability, such as the following.

- The intermediate zone is apparently highly heterogeneous with respect to permeability, with the potential for markedly varying permeability over relatively small distances. Evidence for this observation rests with the markedly different intermediate zone (Puye Formation) permeabiltiies at CdV-16-2(i) and CdV-16-2(i)r, which are essentially collocated on the mesa at TA-16 (LANL 2006, 093798). Such conditions indicate that installing productive recovery or injection wells may involve trial and error, an expensive process.
- Saturation within the intermediate zone may not be sustainable under optimal pumping conditions, even with upgradient injection.

A pump test conducted in intermediate groundwater will address these issues, including sustainable yield and contaminant concentration trends.

### Effectiveness

The effectiveness of this alternative in attaining the MCSs and remedial objectives is questionable given the uncertainties with respect to site heterogeneities. The presence of significant heterogeneities may require an increase in the number of recovery or injection wells, which would decrease the cost-effectiveness. The sustainable pumping rate in the intermediate zone is also not known; the intermediate zone may be prone to local drying out, even with upgradient injection of treated groundwater. Drying out of recovery wells would severely affect cost-effectiveness.

Finally, the behavior of groundwater concentrations under natural and pumping conditions is not known. These concentrations are currently 20–50 µg/L of RDX, but the database is sparse because the wells were recently installed, precluding an assessment of their long-term trends. Although exceeding the MCS, these levels may not persist and may not warrant aggressive remedial action at this time. In contrast, the RDX concentrations at Pantex and Umatilla are as high as 2000 and 7000 µg/L, respectively.

### Implementability

With regard to implementability, a primary issue concerns drill rig and other equipment access into Cañon de Valle or other downgradient locations for the installation of recovery wells and recovery equipment. Based on a recent reconnaissance conducted within the canyon, it was determined that access to the proposed recovery well locations is possible but not without some tree removal.

In addition, NEPA-permitting issues regarding wetlands and the presence of a threatened and endangered species (Mexican spotted owl) may also pose implementability problems. The wetlands-permitting process is depicted in the flow chart in Figure 6.3-4. Finally, F-listed chlorinated organic solvents have been sporadically detected in intermediate and regional groundwater (LANL 2006, 093798), which may require a contained-in determination from NMED.

### Human Health and Ecological Protectiveness

Once installed, this alternative will not adversely affect human health and the local ecology. As described in the implementability section above, however, installation of the recovery wells and related utilities in Cañon de Valle may have a short-term ecological impact, and it may be difficult to obtain a permit under NEPA.

### Cost

The estimated capital cost for this alternative is $3,852,000. The estimated 30-yr O&M NPV cost is $13,738,000, for a total lifetime NPV cost of $17,590,000. These costs assume groundwater treatment using GAC.

## 6.3.2 Regional Groundwater Recovery and Treatment with Injection of Treated Groundwater (Alternative II)

In this alternative, regional groundwater is recovered through a series of recovery wells, treated and injected upgradient to help flush contaminants from the regional aquifer. The alternative is similar to Alternative I for intermediate groundwater, except the recovery and injection wells are screened across regional rather than intermediate groundwater. Otherwise, the conceptual design is the same (Figures 6.3-2, and 6.3-3). This alternative also locates three recovery wells in Cañon de Valle in an attempt to place these wells as far downgradient as is practical.

The alternative consists of installing four recovery wells and four injection wells, as well as a groundwater treatment system consisting of GAC adsorption. A pump test is also recommended for this alternative to determine the effective radius of influence and the expected groundwater flow rate. In addition, both GAC and UV photooxidation treatability studies should be performed on groundwater from the pump test. Completion of a pump test will require the installation of a recovery well near R-25, which will serve as the observation well in regional groundwater.

In the conceptual design, a maximum groundwater flow rate of 500 gal./min was assumed. Aquifer parameters identical to the intermediate groundwater parameters are assumed, including gradient and permeability.

### Technical Practicability

Because existing municipal production wells pump from regional groundwater, deployment of this alternative for regional groundwater may not encounter the same issues of practicability as its counterpart in intermediate groundwater, namely, heterogeneity and the possible limited sustained pumping rates. However, a pump test is recommended to determine important design parameters and the final feasibility.

### Effectiveness

Currently, regional groundwater concentrations of RDX and TNT in monitoring well R-25 are less than the MCSs (Figures 6.3-2 and 6.3-3). Although the data do not yet show the required eight consecutive quarters of compliance, the downward trend of the data indicates that natural attenuation is occurring, and attainment of this goal may be imminent. Therefore, installation and operation of this alternative may not be justified.

Moreover, the hydrogeologic relationship between intermediate and regional groundwater may preclude elevated localized concentrations of contaminants in regional groundwater that would justify this alternative. Available evidence suggests that although a head difference exists between intermediate and regional groundwater, the vertical recharge is indirect. One indicator is the presence of an unsaturated zone between intermediate and regional groundwater in R-25. The anisotropy between vertical and horizontal permeability also suggests that flow from the intermediate zone occurs primarily horizontally. In addition, because a groundwater mound is associated with Cañon de Valle recharge, this horizontal flow may occur along the perimeter of the intermediate zone. Therefore, infiltration of intermediate groundwater contaminants into regional groundwater is diffuse and widespread along the edges of intermediate groundwater, leading to significant dilution within regional groundwater.

#### Implementability

Implementation challenges with this alternative are similar to those of the intermediate groundwater recovery alternative, namely, potentially heavy equipment and drill rig access difficulties in Cañon de Valle, the potential for a contained-in determination for trace levels of F-listed solvents, and NEPA issues associated with the presence of wetlands and a threatened and endangered species (Mexican spotted owl).

#### Human Health and Ecological Protectiveness

Implementation of this alternative would not adversely affect human health or the local ecology, with the exception of a short-term potential impact that construction may pose for Cañon de Valle wetlands and the Mexican spotted owl.

#### Cost

The estimated capital cost for this alternative is $3,871,000. The estimated 30-yr O&M NPV cost is $15,079,000 for a total lifetime NPV cost of $18,950,000. These costs assume groundwater treatment using GAC.

### 6.3.3 Intermediate and Regional Groundwater Recovery with Injection of Treated Groundwater (Alternative III)

This alternative combines Alternatives I and II but entails the installation of eight recovery wells and injection wells, four in each groundwater zone. These wells are installed in the locations shown in Figure 6.3-1, with each location containing both an intermediate and regional well. The combined flow rate is estimated to be approximately 1000 gal./min. Pump tests in both the intermediate and regional wells are required to further assess important design parameters and feasibility. Water from the pump tests will be used for treatability testing to select either GAC or UV photooxidation treatment.

#### Technical Practicability

The evaluation of this factor is similar to the evaluations for Alternatives I and II, with the exception that the treatment plant is larger (double the capacity). This increased capacity, however, will not pose additional practicability problems.

**Effectiveness**

The evaluation of this factor is similar to the evaluations for Alternatives I and II; the alternative is of questionable effectiveness in intermediate and regional groundwater because of hydrogeological concerns in intermediate groundwater and the low level of contaminants in regional groundwater.

**Implementability**

Implementability problems for this alternative are similar to Alternatives I and II, with the added concern that the installation of six recovery wells in Cañon de Valle may pose additional logistical challenges.

**Human Health and Ecological Protectiveness**

Implementation and operation of this alternative do not pose human health or ecological hazards.

**Cost**

The estimated capital cost for this alternative is $6,095,000. The estimated 30-yr O&M NPV cost is $18,838,000 for a total lifetime NPV cost of $24,933,000. These costs assume groundwater treatment using GAC.

### 6.3.4 Intermediate and Regional Groundwater Monitored Natural Attenuation (Alternative IV)

As discussed in Section 5.6.5, MNA is defined as dilution, dispersion, volatilization, adsorption, biodegradation, and abiotic reactions such as hydrolysis that reduce contaminant concentrations in site groundwater or soil over time. The MNA alternative for intermediate groundwater consists of additional monitoring well installation; comprehensive monitoring, sampling, and reporting; and further investigating aquifer contaminant attenuation mechanisms. To determine the effectiveness of MNA, contaminant trends in intermediate-zone wells [R-25, CdV-16-1(i), CdV-16-2(i)r] and downgradient monitoring wells (R-18, CdV-R-15-3 and CdV-R-37-2) will continue to be assessed. Indication of increasing trends in these wells, particularly the downgradient wells, will prompt a reevaluation of this alternative, potentially leading to more aggressive remediation.

Independent of this CME, the Laboratory has recommended improvements to the monitoring well network (LANL 2007, 095787) that will facilitate the implementation of intermediate groundwater MNA, including drilling and completing CdV-16-3(i) in regional groundwater and replacing the intermediate-zone screens also in R-25 (LANL 2007, 095787). Additional well drilling and well screen rehabilitation will also be proposed based on a notice of disapproval (NOD) (NMED 2007, 097874). The costs of this additional drilling are not included in the remedy costs analyzed in this report, since it will be completed regardless of what remedy is selected.

Semiannual monitoring and sampling of intermediate-groundwater wells will continue along with laboratory analyses for important MNA parameters, including TNT and RDX reductive byproducts (A-DNTs, mononitroso-RDX, dinitroso-RDX, and trinitroso-RDX), ferrous iron, nitrate, sulfate, and manganese. In addition, hydraulic heads in Cañon de Valle alluvial monitoring wells and intermediate-groundwater wells will be recorded and analyzed with respect to precipitation events to understand more thoroughly the recharge dynamics of intermediate groundwater. This is important to assess the contribution of dilution to MNA. Annual reports will be prepared summarizing the progress of MNA.

Several additional natural attenuation mechanisms will be investigated as part of this alternative. The sorption potential of RDX and TNT on aquifer materials has not been investigated. Laboratory sorption studies will be conducted on aquifer materials within the CSM, including Cañon de Valle alluvial sediments, Bandelier Tuff, and Puye Formation components of intermediate groundwater, and Puye Formation, and Santa Fe Group components of regional groundwater.

In addition, the biodegradation potential of these materials and the potential for hydrolysis will also be investigated. Recent experimental data on RDX biodegradation in natural environments (Bradley and Dinicola 2005, 095588) indicate that significant RDX degradation can occur under relatively mild reducing conditions if a sufficient population of RDX-degrading microbes is present. Moreover, active bioremediation of RDX may not necessarily imply elevated concentrations of RDX degradation products. The potential for hydrolysis degradation of RDX will also be investigated.

Semiannual monitoring and sampling of intermediate-zone wells and downgradient monitoring wells will be conducted. Currently, downgradient monitoring wells do not show HE contamination above standards as reported in the periodic monitoring reports for the watershed aggregates. If this changes, the MNA evaluation may be discontinued and more aggressive remediation pursued.

The MNA alternative can be implemented through the existing sitewide monitoring and sampling program with additional activities, with the cost of the MNA alternative representing the incremental costs.

### Technical Practicability

This alternative is practical from a technical standpoint; the site condition that affects its feasibility is the difficult terrain that may preclude installation of additional monitoring wells, if needed. Independent of this CME, the Laboratory has proposed installing a monitoring well at existing borehole CdV-16-3(i) and reconditioning a select number of groundwater screens in multiple-completion monitoring wells (LANL 2007, 095787). The recent NOD (NMED 2007, 097874) to which the Laboratory will respond on September 30, 2007, will result in the installation of additional monitoring wells or the reconditioning of additional well screens beyond those currently proposed.

### Effectiveness

Guidance on MNA implementation from EPA (1999, 097386) provides three criteria that support the selection of MNA for a site. These criteria consist of (1) historical data that indicate a decreasing trend in contaminant mass, (2) geochemical or hydrological evidence that support active attenuation, and (3) field or microcosm studies using actual media that demonstrate active attenuation. In addition, MNA at a site is usually successful only if major contaminant sources have been removed.

Historical data for RDX in R-25 indicate a decrease in RDX concentrations in regional groundwater (Figure 3.2-2). Because of the relatively recent installation of CdV-16-1(i) and CdV-16-2(i)r, an extensive historical database has not been accumulated for intermediate groundwater. Existing data from the past 2 yr indicate that contaminant concentrations are relatively stable at 20–50 µg/L for RDX (Figure 3.2-2). For TNT, intermediate groundwater results have consistently been below detection limits in CdV-16-1(i) and CdV-16-2(i)r but have been inconsistent in the R-25 intermediate-groundwater level (Figure 3.2-3). TNT concentrations in regional groundwater in R-25, however, have shown decreasing trends. The data therefore indicate active attenuation in regional groundwater but are inconclusive for intermediate groundwater. As noted earlier, some of this decrease in RDX concentration in the regional aquifer may be due to dilution of RDX that was introduced into the regional aquifer during drilling.

Products of HE degradation have been detected in intermediate and regional groundwater (LANL 2006, 093798), indicating that attenuation by degradation is occurring; however, field or microcosm testing of HE degradation has not been completed.

An important criterion for the justification of MNA is whether the apparent rate of attenuation is greater than the rate at which contaminants are transported by groundwater to area municipal wells. Available data indicate that contaminants have not reached downgradient monitoring wells CdV-R-37-2 and CdV-R-15-3 or municipal supply wells (LANL 2006, 093798), although trace levels (<1 µg/L) of RDX have been detected at R-18 (LANL 2006, 093798). These data indicate that attenuation rates exceed the rate of groundwater transport.

With the removal of the 260 Outfall soils as part of the IM (LANL 2002, 073706) and the removal of other potential sources at TA-16 as described in section 2.2, the significant sources for intermediate and regional groundwater have been removed. In addition, the implementation of several remediation activities in the shallow alluvial system (LANL 2007, 096003) will further remediate residual sources for intermediate and regional groundwater contamination.

#### Implementability

The MNA alternative does not present significant implementability problems. The additional well installation and well screen rehabilitation are straightforward without logistical difficulties. No permits are associated with this alternative.

#### Human Health and Ecological Protectiveness

For this alternative, protectiveness of human health is ensured through a series of safeguards. These safeguards consist of periodic monitoring of intermediate-zone wells and regional groundwater downgradient monitoring wells to determine whether contaminant increases warrant more aggressive action. The three monitoring wells proposed for this alternative (R-18, CdV-R-15-3, and CdV-R-37-2) are located in downgradient locations, of which the easternmost well is approximately 2 mi from the nearest municipal well. The modeling results presented in Appendix C4 indicate that under very conservative assumptions, travel times to municipal wells are on the order of dozens to hundreds of years.

#### Cost

The estimated 30-yr O&M NPV cost is $3,522,000 for this alternative. Drilling costs for new wells, both those currently proposed and those that may be proposed in the Laboratory's response to NMED's NOD (NMED 2007, 097874) are not included in these costs because such wells would be installed regardless of what cleanup remedy is selected.

### 6.3.5 No Action (Alternative V)

In this CME, the no-action alternative consists of the existing baseline activity against which the other alternatives are compared. This baseline activity consists of the current, sitewide, monitoring and sampling program (Appendix F). Under this program, all intermediate groundwater monitoring wells are sampled semiannually for a standard list of contaminants, including HE.

This alternative may be justified if adequate protection of human health is offered by the existing sitewide program. The no-action alternative as embodied in the current sitewide program offers the same monitoring safeguards as MNA without features such as laboratory testing. For this CME, the cost for the no-action alternative is zero because this program will continue regardless of which alternative is selected.

### Technical Practicability

Because the no-action alternative consists of the currently ongoing, sitewide, monitoring and sampling program, it is technically practical.

### Effectiveness

The existing monitoring and sampling program uses the same monitoring wells as the MNA alternative. Moreover, the Laboratory has independently proposed improvement to the existing monitoring wells, as described in the discussion of the MNA alternative in section 6.3.4. Because the no-action alternative uses the same monitoring well network as the MNA alternative, its effectiveness would be the same.

### Implementability

Because the no-action alternative consists of ongoing monitoring and sampling activities, no problems are associated with implementability.

### Human Health and Ecological Protectiveness

The no-action alternative is equivalent to the status quo, which is the current, sitewide, monitoring and sampling program. Performance of this program poses no human health or ecological hazards. Groundwater modeling (Appendix C) conducted for the no-action alternative suggests that travel times to municipal wells are on the order of dozens to hundreds of years, even under very conservative assumptions. Because this alternative uses the same system of intermediate-zone wells and downgradient monitoring wells as the MNA alternative, its protectiveness should be similar. However, without laboratory testing and other focused MNA procedures to additionally investigate attenuation mechanisms, this alternative does not elucidate the mechanisms of natural attenuation or their relative importance.

### Cost

The cost for the no-action alternative is the portion of the existing sitewide groundwater monitoring and sampling program as applied to the TA-16 monitoring wells. This 30-yr NPV cost is estimated to be $2,455,000.

## 6.4 Summary of Alternative Cost Evaluations

Table 6.4-1 provides a summary of the remediation alternative cost evaluations. Alternatives I and II, groundwater recovery in intermediate and regional groundwater, respectively, are similar in costs because the assumed groundwater flow rate for each aquifer is the same. The difference between these costs resides in the deeper drilling depth. All total NPV costs represent a 30-yr lifetime with a 5% discount factor.

## 7.0 DESCRIPTION AND JUSTIFICATION OF THE PREFERRED ALTERNATIVES

### 7.1 Intermediate Groundwater

Based on the evaluation of remedial alternatives presented in section 6, a single alternative is not recommended for intermediate groundwater; rather, a combination of Alternatives I and IV implemented on a phased schedule with several embedded decision points is recommended.

The final feasibility of intermediate groundwater recovery and treatment (Alternative I) cannot be addressed without performing a pump test in the intermediate zone. The results of the pump test will determine the sustainable groundwater flow rate and contaminant concentrations, as well as the radius of influence of the pumping well. Water from the pump test will be used in treatability studies to determine whether GAC or UV photooxidation is preferred. Installation of a 6-in.-diameter recovery well near existing well CdV-16-2(i)r is recommended. A report will be prepared summarizing the pump test results. In addition, during the time required for the performance of these tasks, additional contaminant data from intermediate groundwater will have been collected, enabling an assessment of trends. This assessment may also elucidate the final feasibility and cost-effectiveness of groundwater recovery.

Alternative IV, MNA in intermediate and regional groundwater, will be implemented concurrently. Groundwater contaminant and MNA parameter data will be obtained from both existing wells and a new well to be installed at CdV-16-3(i). Data collected from these wells will establish contaminant trends, which are not available at this time because of a lack of historical data. Aquifer material testing for HE adsorption, hydrolysis, and biodegradation will be initiated. The groundwater monitoring program should be integrated with respect to alluvial, intermediate, and regional groundwater zones to understand the hydrogeology among these zones more fully. This has important implications for natural attenuation mechanisms, as well as potentially affecting the remediation efforts in the Cañon de Valle alluvial system that are currently underway.

The CMI plan will present the plans and design drawings for the implementation of these alternatives.

### 7.2 Regional Groundwater

Given the low levels of RDX and TNT in regional groundwater—levels that are currently less than the MCSs—recovery and treatment of regional groundwater are not recommended at this time. Instead, the MNA alternative will be implemented in regional as well as intermediate groundwater. The MNA program as described in section 6.3.4 will be implemented using site intermediate and regional groundwater wells [CdV-16-1(i), CdV-16-2(i)r, and R-25] and several downgradient monitoring wells (R-18, CdV-R-15-3, and CdV-R-37-2) in regional groundwater, which all are anticipated to serve as ongoing monitoring wells. The wells located between TA-16 and the municipal supply wells do not show significant HE contamination (9>0.1 MCSs). In addition. groundwater modeling results with very conservative assumptions support travel times to the municipal wells of dozens to hundreds of years. However, if contamination is detected at levels greater than the MCSs, more aggressive remediation alternatives may be warranted. An assessment of the progress of MNA in regional groundwater will be included in the periodic monitoring reports for the Water Valle watershed.

The CMI plan will present a more complete description of the plans for MNA implementation in regional groundwater.

### 7.3 Schedule

The Consent Order establishes a schedule of CME and follow-on CMI activities. This schedule is presented in Table 7.3-1 and in Appendix E.

### 7.4 Public Involvement

A public involvement plan for the CME is presented in Appendix D. This plan lists the objectives, methods for communicating with the public, and key contacts.

## 8.0 REFERENCES AND MAP DATA SOURCES

### 8.1 Text References

*The following list includes all documents cited in the main body of this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.*

*Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.*

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## 8.2 Map Data Sources

Data sources for all figures are provided below, unless otherwise indicated on the figures themselves.

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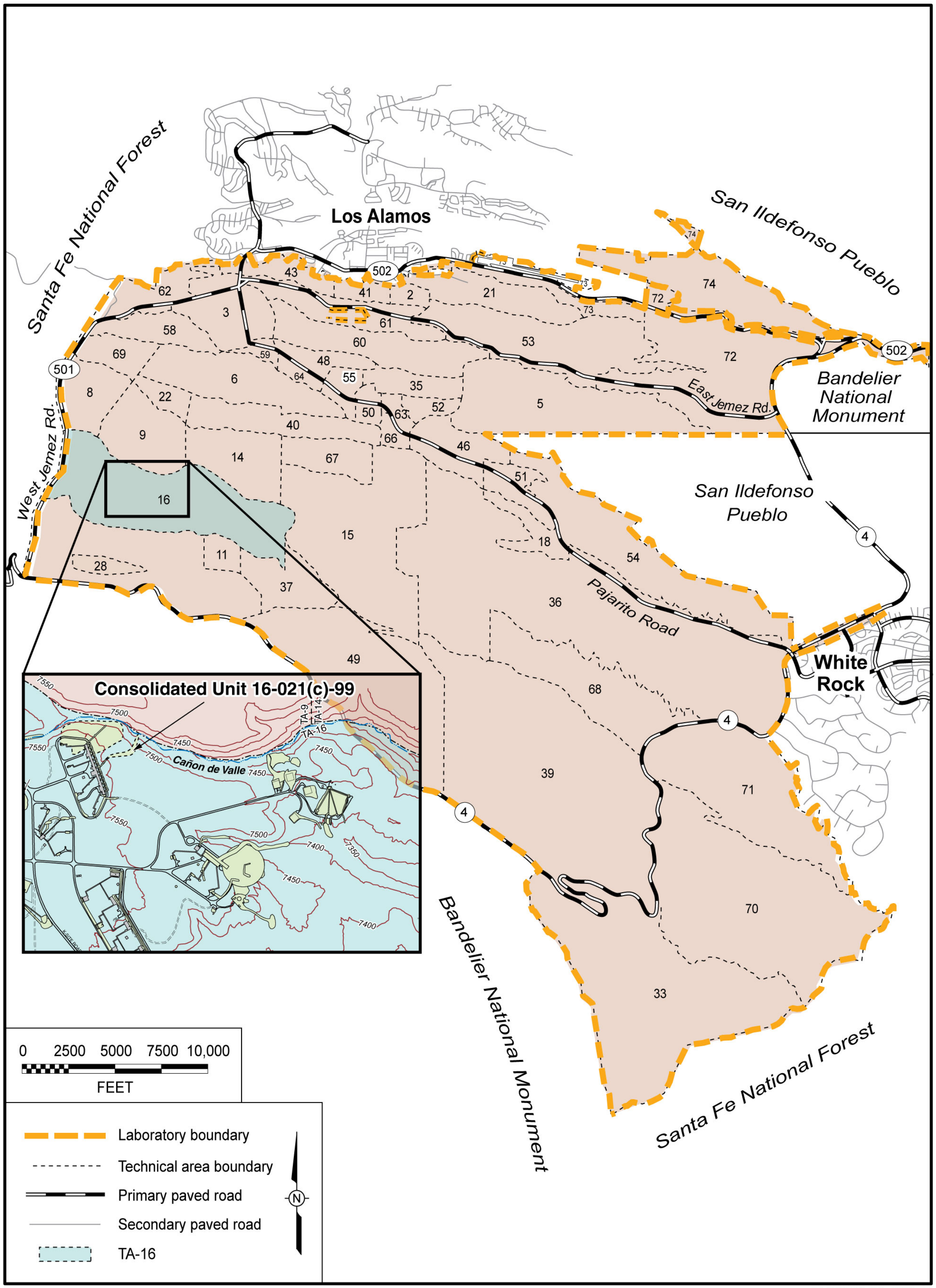

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**Figure 1.2-1** Location of TA-16 with respect to Laboratory technical areas and surrounding landholdings; Consolidated Unit 16-021(c)-99 is also shown.

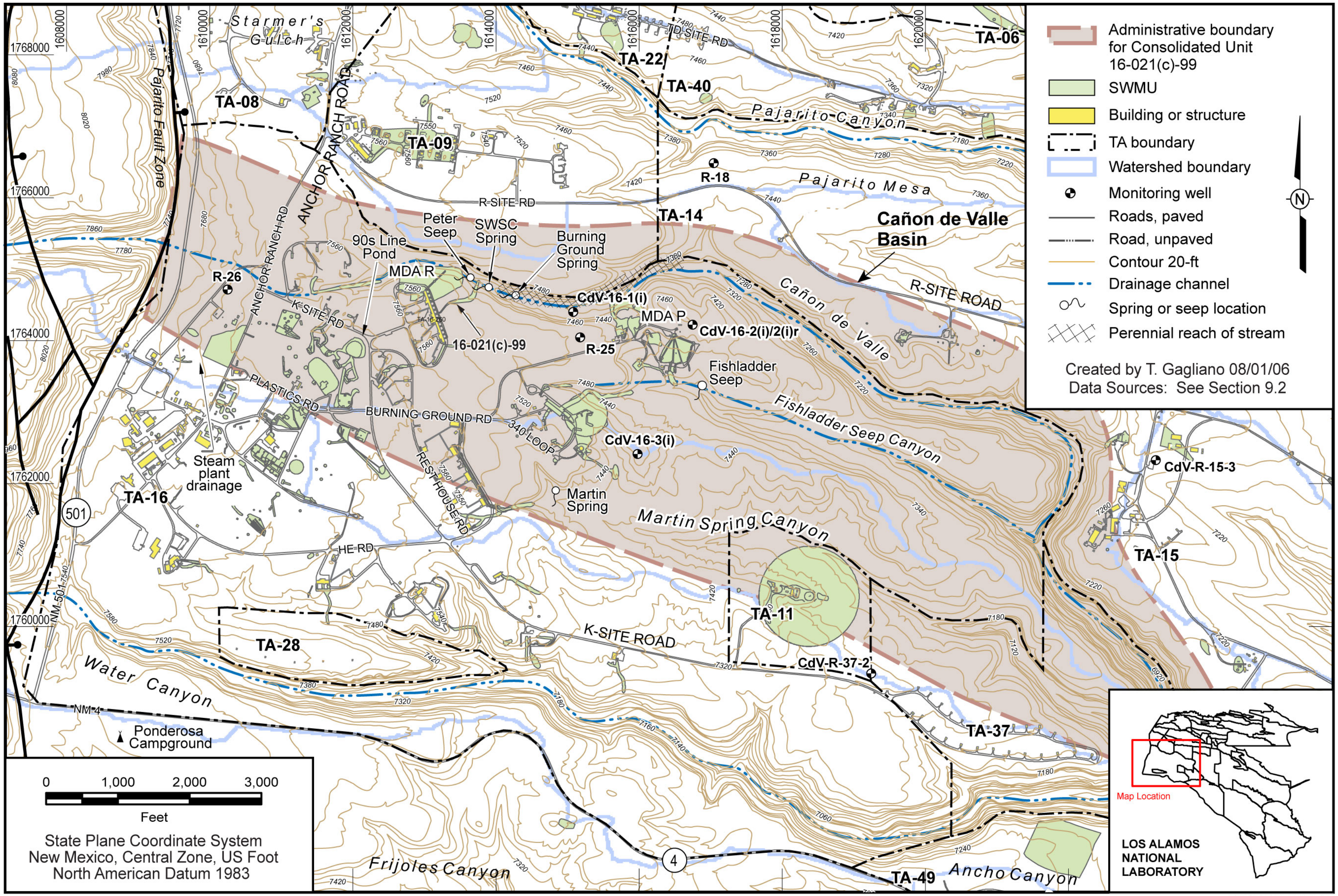

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Figure 1.2-2 Administrative boundaries for Consolidated Unit 16-021(c)-99 activities

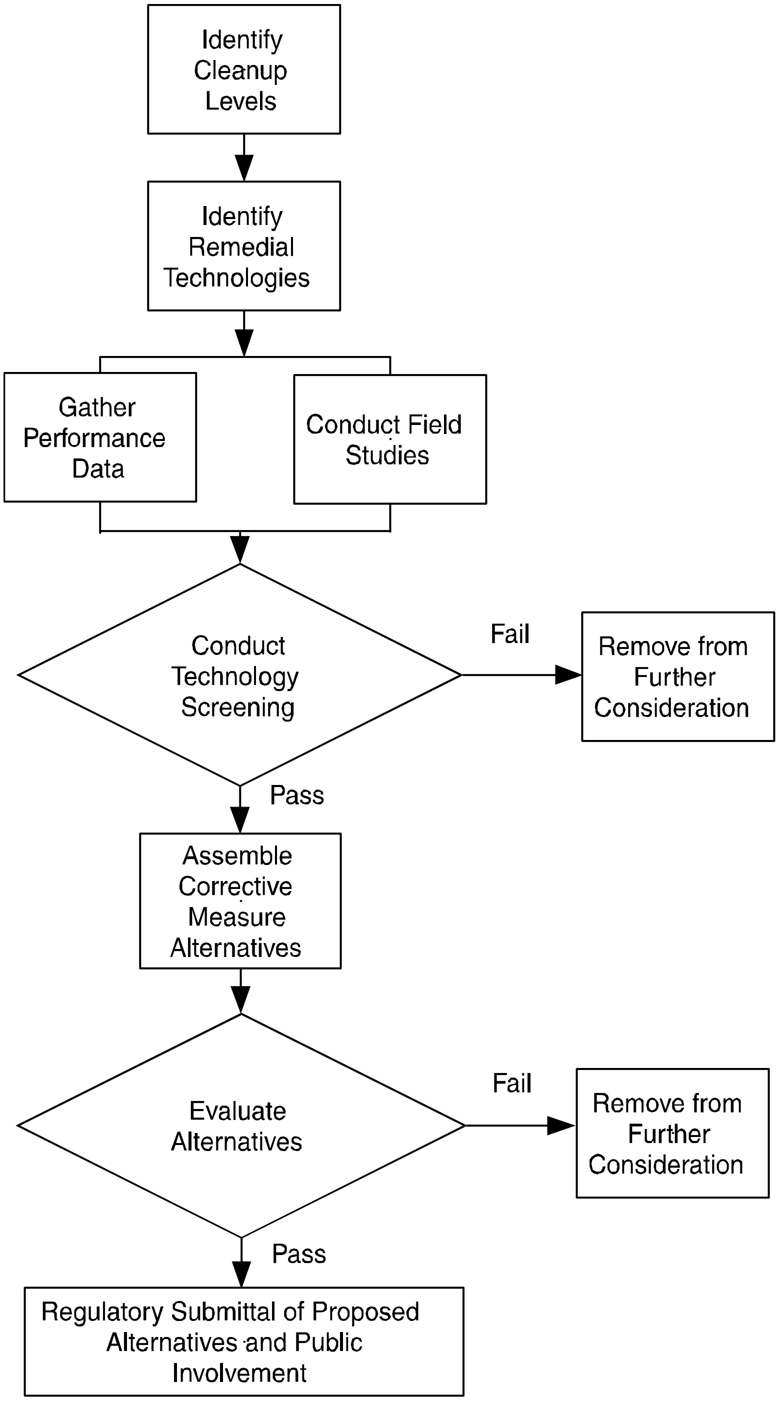

**Figure 1-3.1 Flow chart of the CME process**

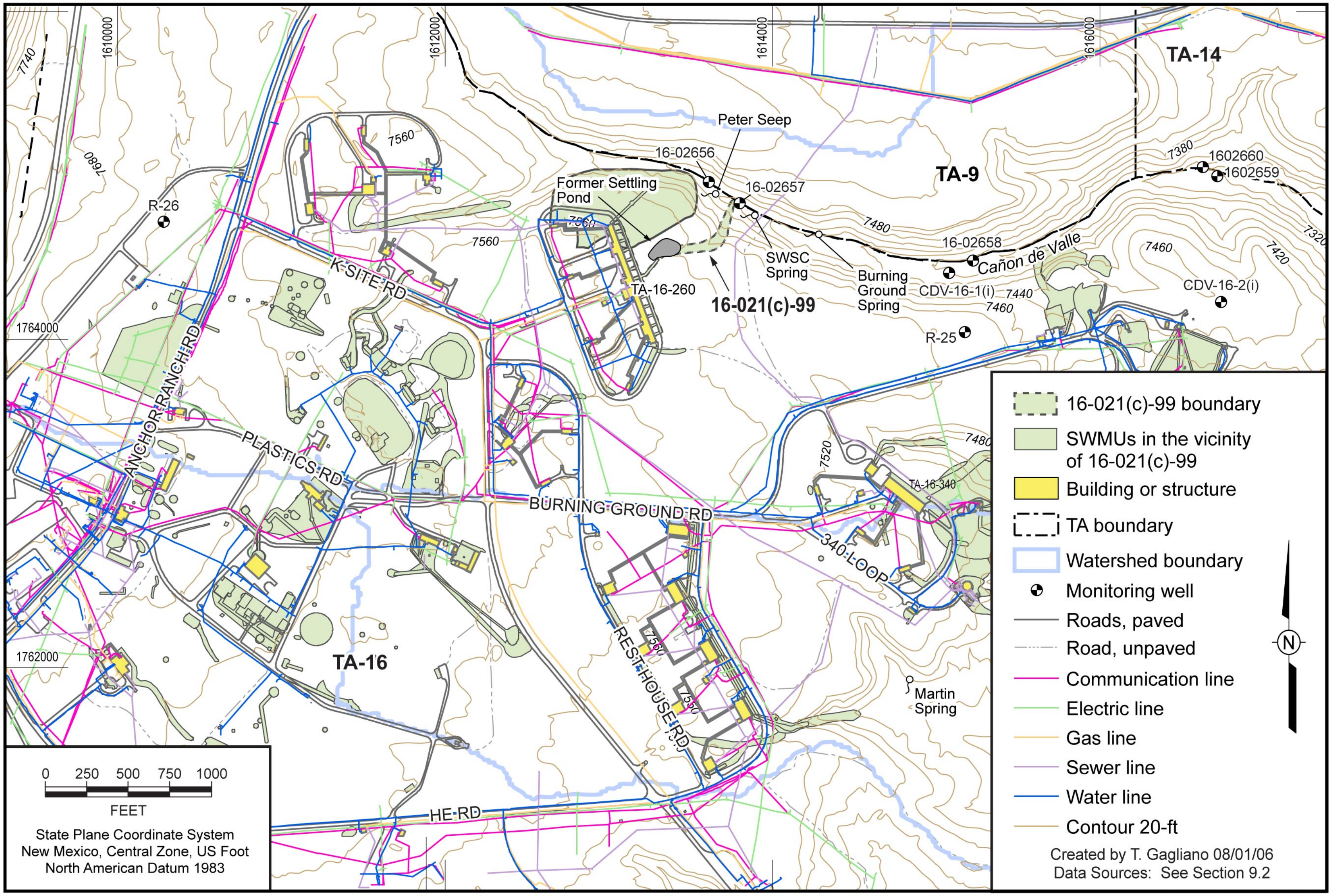

Figure 2.1-1 Location of Consolidated Unit 16-021(c)-99 and associated features

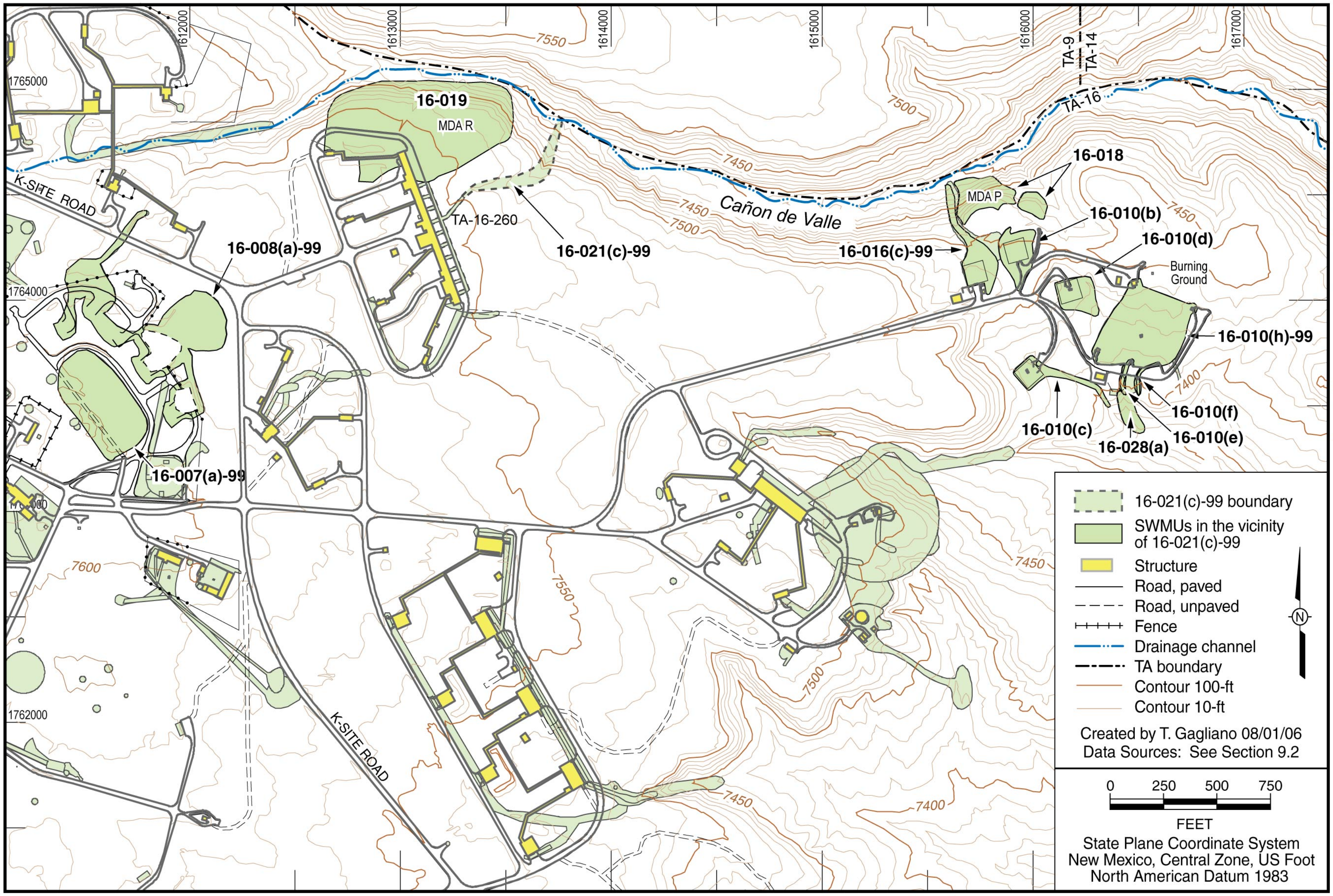

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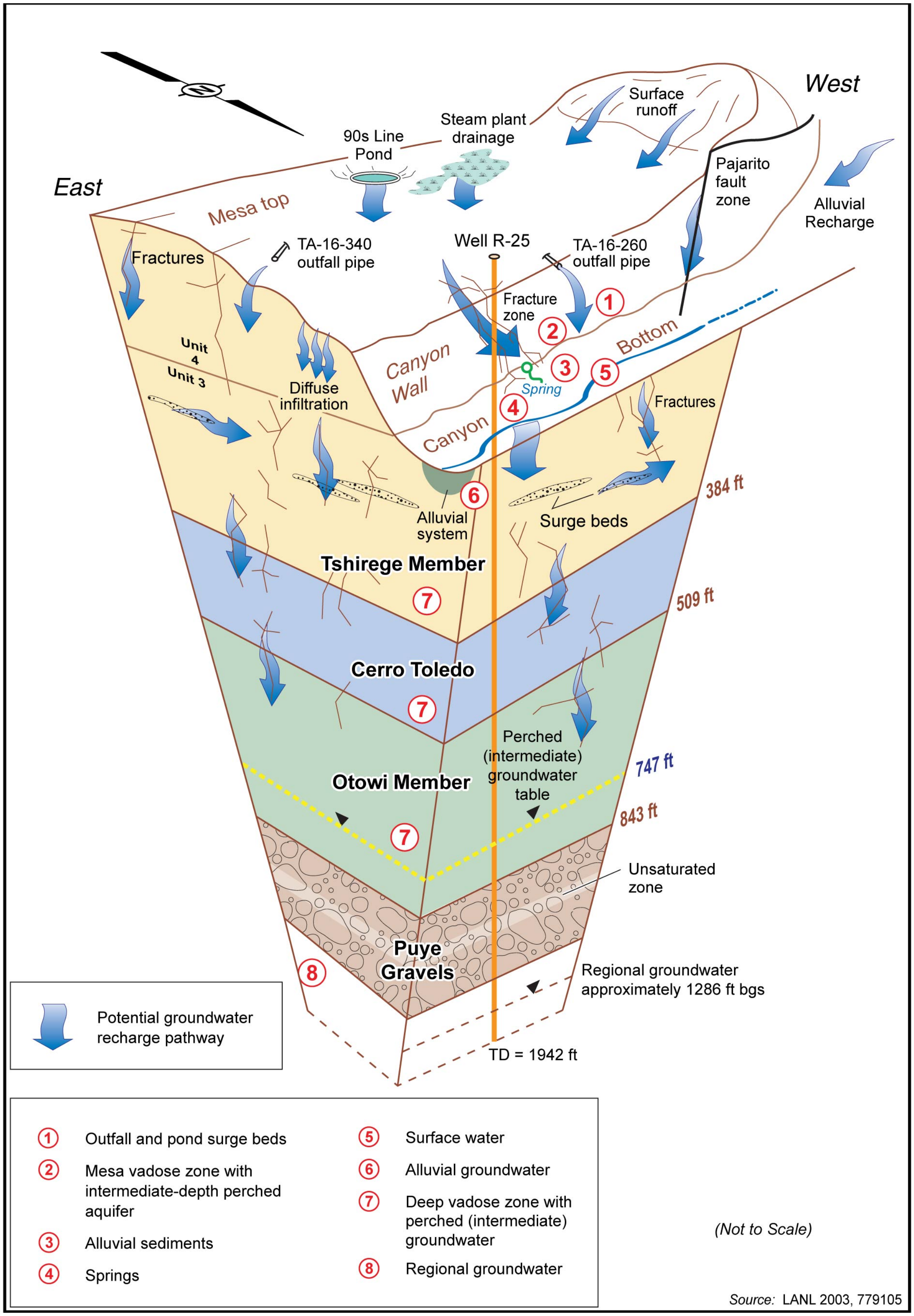
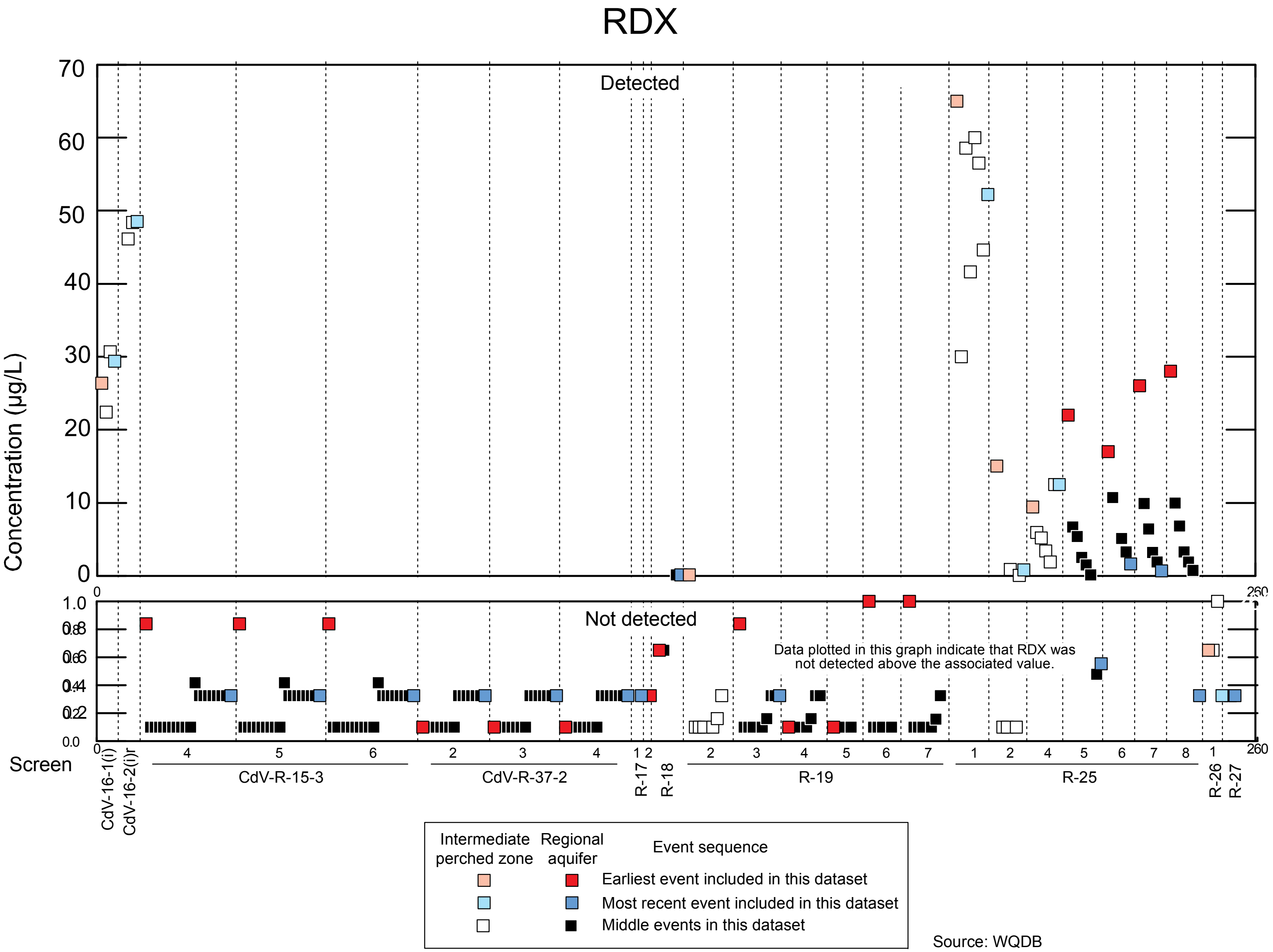
**Figure 2.2-1** **Major SWMUs in the vicinity of Consolidated Unit 16-021(c)-99**



*Source:* LANL 2003, 779105

**Figure 3.2-1 Conceptual site model of hydrogeology and contaminant transport for TA-16 and Consolidated Unit 16-021(c)-99**



Source: WQDB

**Figure 3.2-2 RDX concentrations in intermediate and regional groundwater monitoring wells**

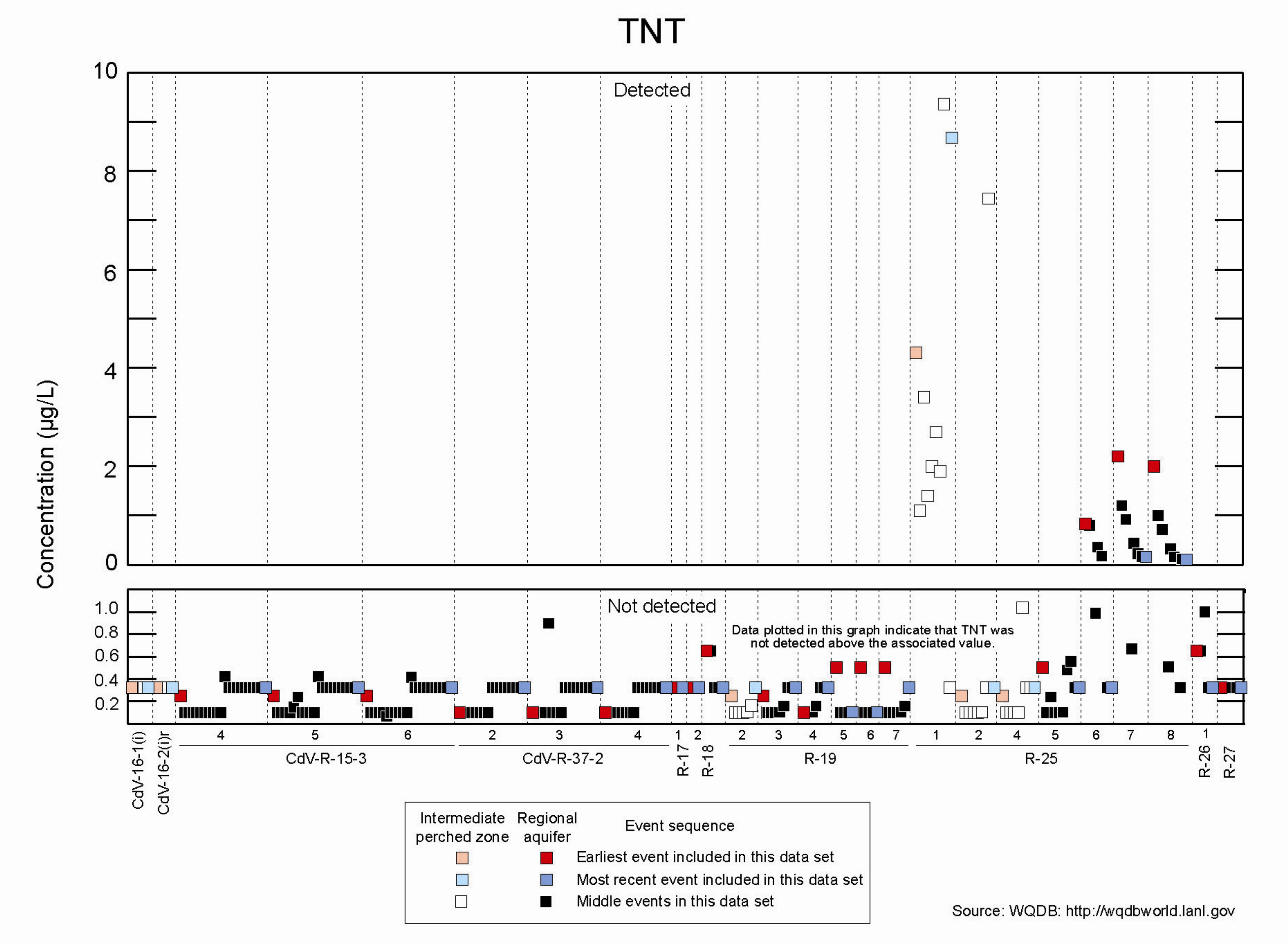


Figure 3.2-3 TNT concentrations in water-quality samples

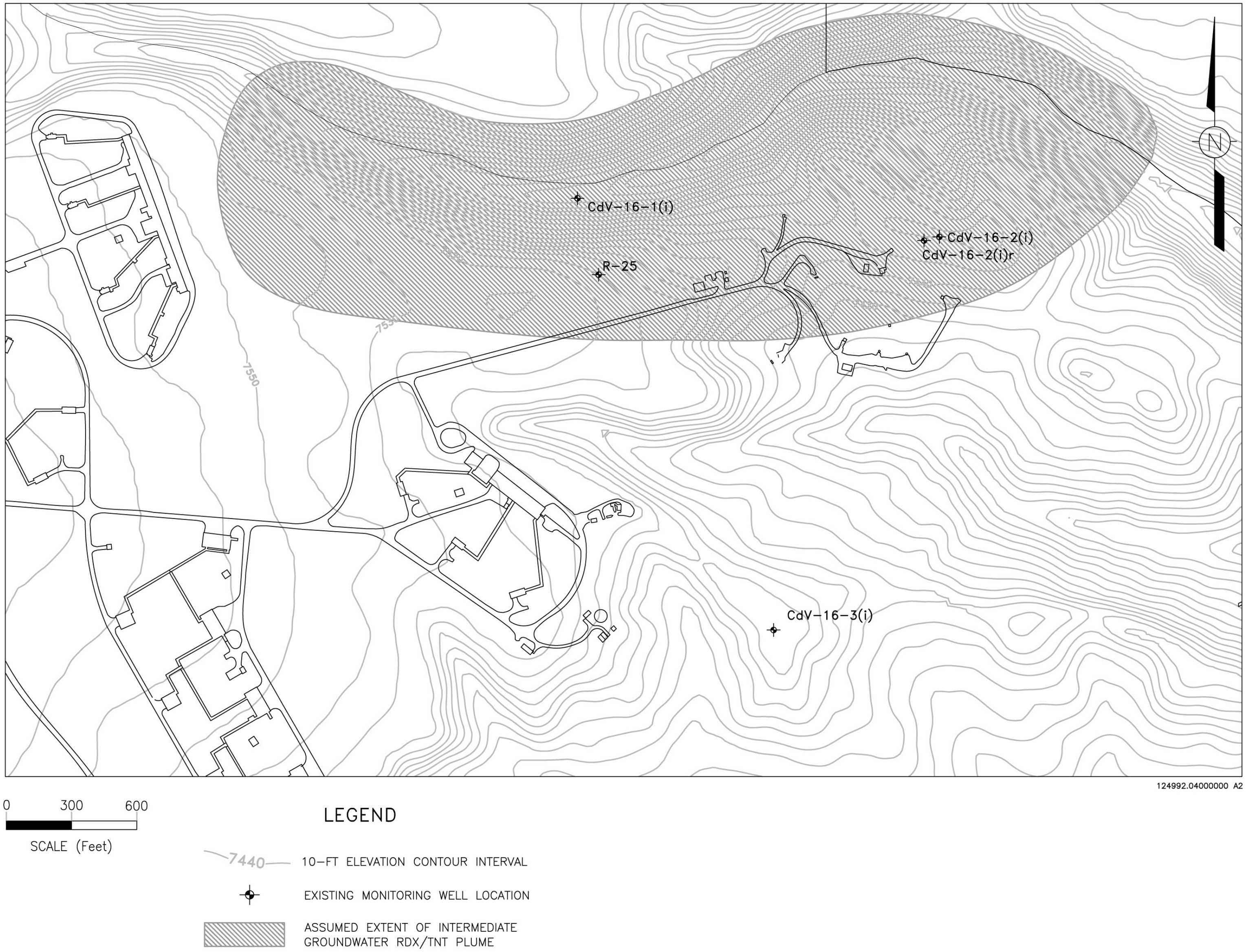


**Figure 3.2-4** Area of groundwater contamination in intermediate and regional groundwater addressed in this CME

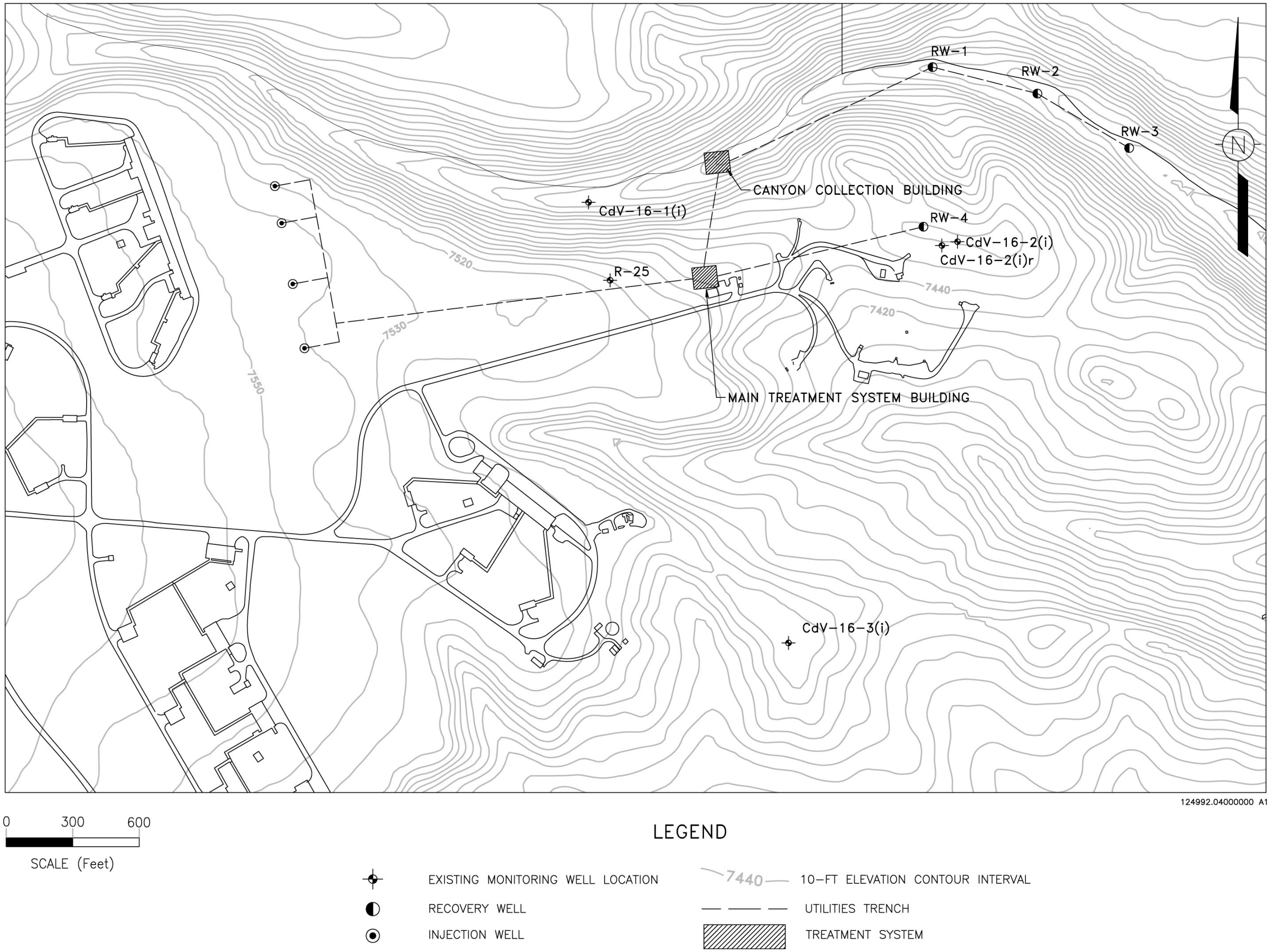


Figure 6.3-1 Conceptual design for an intermediate and regional groundwater recovery and injection system

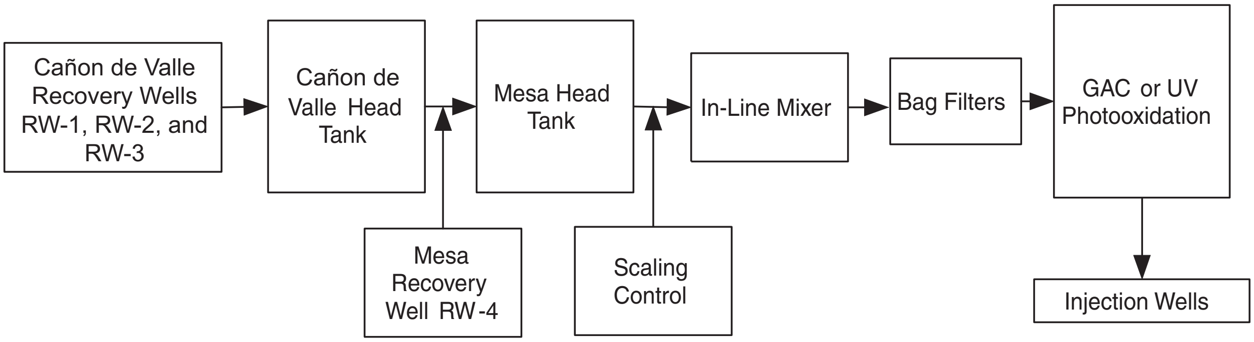


**Figure 6.3-2** **Process flow diagram for intermediate and regional groundwater treatment system**

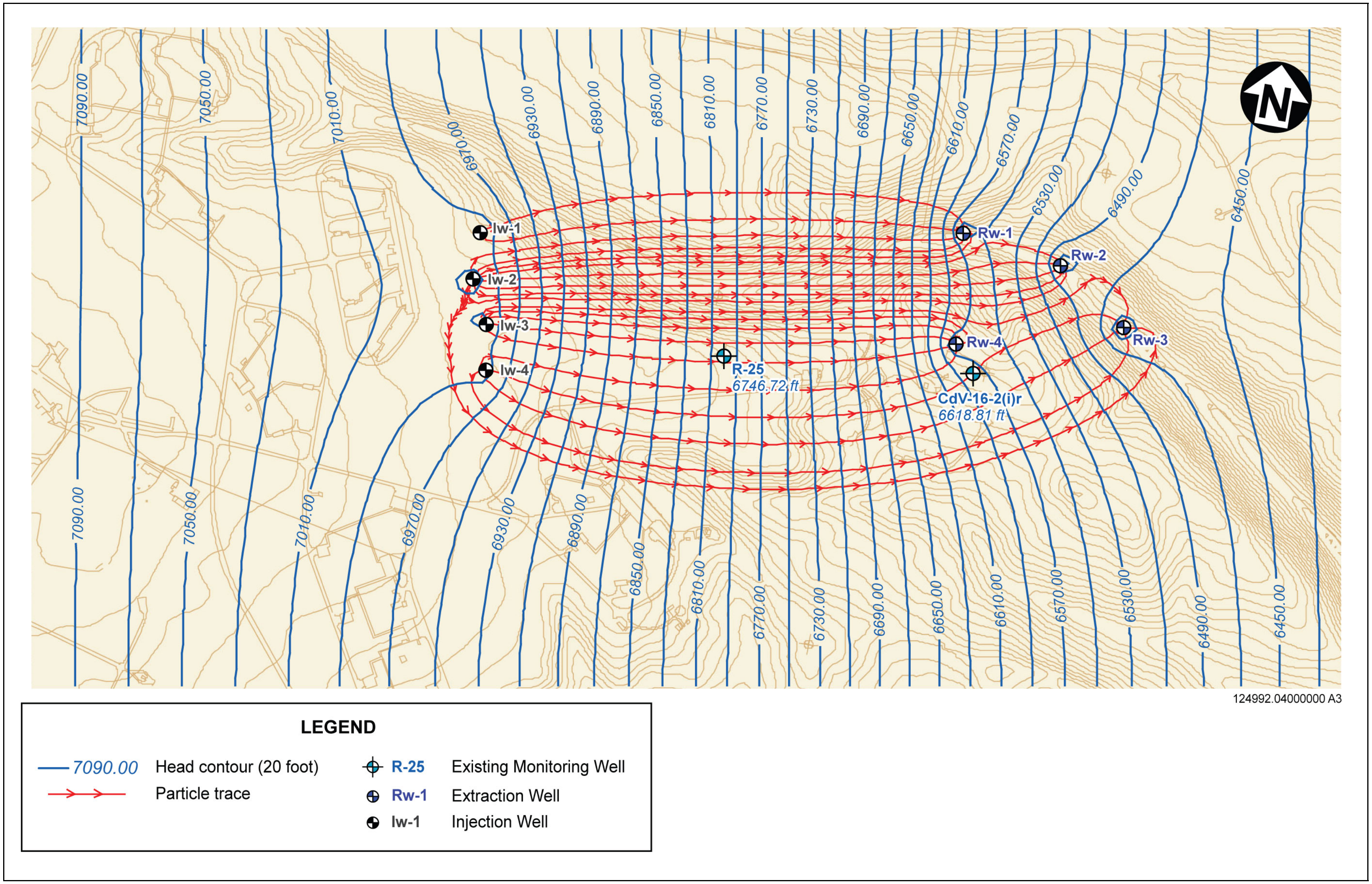


Figure 6.3-3 Influence of recovery and injection on intermediate groundwater heads at 500 gal./min

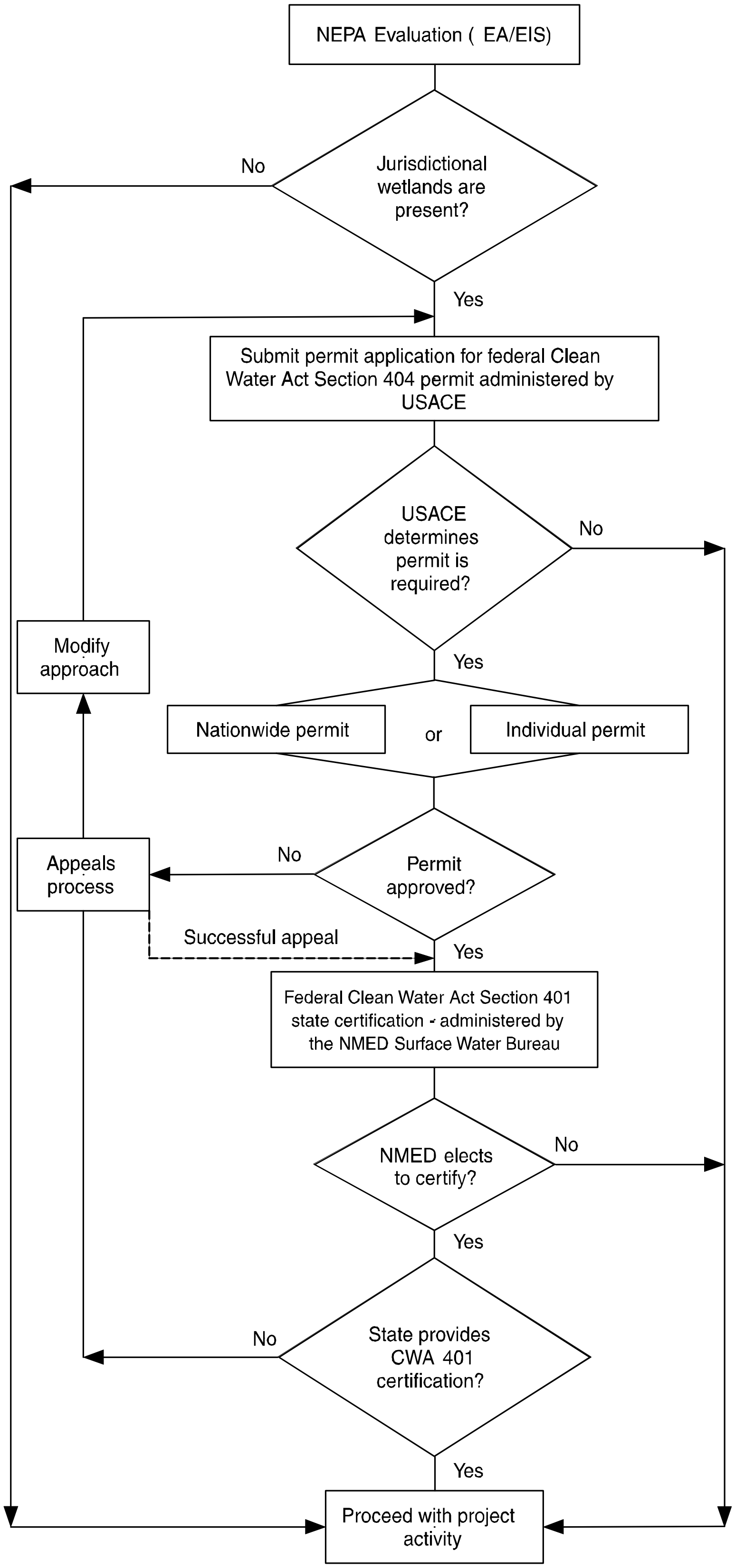


**Figure 6.3-4 Flow chart of wetlands-permitting process**

## Table 2.4-1
## Chronology of Laboratory Environmental Activities at Consolidated Unit 16-021(c)-99

| Date | Activity (Reference) | Summary of Activity |
|---|---|---|
| 1990 | RFA (LANL 1990, 007512) | RFA initial site assessment is completed. Previous studies are summarized and document extensive contamination in TA-16-260 sump water. |
| July 1993 | Phase I RFI Work Plan—Site Characterization Plan (LANL 1993, 020948) | "RFI Work Plan for Operable Unit 1082" is issued. Plan addresses Phase I sampling at Consolidated Unit 16-021(c). |
| May 1994 | First addendum to Phase I RFI Work Plan (LANL 1994, 039440) | "RFI Work Plan for Operable Unit 1082, Addendum 1" is issued. Plan approved by NMED in January 1995. |
| April 1995–November 1995 | Phase I RFI Site Characterization | Phase I RFI is implemented, including Phase I investigation of Consolidated Unit 16-021(c)-99. |
| 1995–1996 | Interim action—Best Management Practices (LANL 1996, 053838) | Sandbag dam and diversion pipe are installed upgradient of the former HE pond; sandbag dam is located east of the parking lot behind TA-16-260; geotextile fabric matting is placed in former HE pond area; eight hay bale check dams are placed within the SWMU drainage between the rock dam and the 15-ft-high cliff. |
| September 1996 | Phase I RFI Report (LANL 1996, 055077) | Phase I RFI report is issued. Data show widespread HE contamination at Consolidated Unit 16-021(c)-99, extending from the 260 Outfall discharge point down to the sediment and waters of Cañon de Valle. Report is approved by NMED in March 1998. |
| September 1996 | Phase II RFI Work Plan part of (LANL 1996, 055077) | Phase II RFI work plan is included in Phase I RFI report. Report approved by NMED in March 1998. |
| November 1, 1996–December 23, 1996; May 1997–November 9, 1997 | Phase II RFI Site Characterization | Phase II RFI is implemented at Consolidated Unit 16-021(c)-99. |
| September 1998 | Phase II RFI Report (LANL 1998, 059891) | Phase II RFI report is issued. Data confirm widespread HE contamination extending from the 260 Outfall discharge point down to the sediment and waters of Cañon de Valle and show deeper subsurface contamination. Up to 1% total HE is detected in surge bed at a depth of 17 ft. Report documents risk to human health and the environment. Report approved by NMED in September 1999. |
| September 30, 1998 | CMS Plan (LANL 1998, 062413) | CMS plan is issued. Alternatives are evaluated. Report includes Phase III RFI sampling plan and describes ongoing hydrogeologic investigations for the site. Report approved by NMED in September 1999. |
| October 1998–March 2002 | Phase III RFI Site Characterization | Continued monitoring and sampling are used to characterize the temporal and spatial variability of site contamination; components of the site hydrogeologic system are undergoing continued evaluation. |
| October 1998–November 2003 | CMS—ongoing evaluation of alternatives | CMS is initiated. Series of soil and water corrective measures technologies are evaluated. Investigation of components of the site hydrogeologic system continues. |

## Table 2.4-1 (continued)

| Date | Activity (Reference) | Summary of Activity |
|---|---|---|
| September 30, 1999 | Addendum to CMS Plan (LANL 1999, 064873) | Addendum to CMS plan is issued. Addendum expands investigations to include deeper perched and regional groundwater potentially impacted by releases from Consolidated Unit 16-021(c)-99. |
| November 1999 | IM Plan—abatement of potential risks at the source area (LANL 2000, 064355)( | IM plan is issued. Plan specifies removal of the highly contaminated soil and tuff identified in the 260 Outfall drainage channel. Plan approved by NMED in April 2002. |
| November 12, 1999–November 18, 2000 | Abatement of ongoing risks is initiated | TA-16-260 IM begins. Activities are interrupted by Cerro Grande fire. Initial stage of project completed in November 2000. |
| January 7, 2000 | Contained-in determination (NMED 2000, 064730) | NMED memo of contained-in determination sent to the Laboratory (J. Brown) and DOE-ER (T. Taylor). |
| April 4, 2000 | Designation of area of contamination (NMED 2000, 070649) | NMED designates Consolidated Unit 16-021(c)-99 an area of contamination. Purpose of designation is to allow material from entire drainage area to be excavated, processed, and segregated without invoking RCRA land disposal restrictions. Excavated material considered potentially hazardous waste is staged in covered piles within area-of-contamination boundary. |
| June 5, 2000 | In situ blending authorization (NMED 2000, 067094) | NMED authorizes in situ blending in memo sent to the Laboratory and DOE. To ensure worker health and safety during the IM and after, settling pond soil is robotically blended in situ with clean or low HE concentration material to reduce maximum concentration of settling pond sediment to below-reactive limit. |
| August 4, 2001–October 13, 2001 | Abatement of ongoing risks is completed | Remobilization and removal of isolated areas containing more than 100 mg/kg of RDX are completed. Waste disposal stage of project is completed. |
| July 2002 | 260 Outfall IM report (LANL 2002, 073706) | IM results are presented in IM report. Report approved by NMED in January 2003. |
| March 2003 | Revision 1 to CMS Plan Addendum—evaluation of alternatives (LANL 2003, 075986) | Addendum to CMS plan updated. Investigation into deeper perched and regional groundwater and deeper vadose zone potentially impacted by releases from Consolidated Unit 16-021(c)-99 is expanded further. Plan approved by NMED in March 2003. |
| September 2003 | “Phase III RFI Report for Solid Waste Management Unit 16-021-(c)-99,” ((LANL 2003, 077965) | Report focuses on investigations into the surface water, alluvial groundwater, canyon sediment, and springs in Cañon de Valle and Martin Spring Canyon. Report includes analysis of data generated since Phase II RFI report (post-1998) and baseline risk assessments using a comprehensive database of both pre- and post-1998 data and emphasizes greater understanding of site hydrogeology and contaminant behavior. Report presents human health baseline risk assessments for source area and selected reaches of Cañon de Valle and Martin Spring Canyon. In addition, a baseline ecological risk assessment is performed for that reach of Cañon de Valle. |

### Table 2.4-1 (continued)

| Date | Activity (Reference) | Summary of Activity |
|---|---|---|
| November 2003 | CMS report for alluvial system corrective measures evaluated/selected (LANL 2003, 085531) | CMS report for Consolidated Unit 16-021(c)-99 alluvial system. Report is a companion document to Phase III RFI report and relies heavily on the understanding of site hydrogeology and contaminant behavior outlined in that document. Report evaluates potential remedial technologies for each media and proposes appropriate technologies. |
| May 2006 | NMED request for public comment, alluvial system statement of basis | NMED issues request for public comment for selection of permeable reactive barriers as the preferred alternative the alluvial system. |
| August 2006 | "Investigation Report for Intermediate and Regional Groundwater, Consolidated Unit 16-021(c)-99" (LANL 2006, 093798) | Investigation report for the nature and extent of Consolidated Unit 16-021(c)-99 impacts to intermediate and regional groundwater |
| April 2007 | Evaluation of the suitability of wells near TA-16 for Monitoring Contaminant releases from Consolidated Unit 16-021(c)-99 | Documents conditions of wells and well screens and evaluates locations of wells for monitoring releases and migration to groundwater from Consolidated Unit 16-021(c)-99; NOD received August 15, 2007 |
| May 2007 | Corrective measures implementation plan, Consolidated Unit 16-021(c)-99 | Presents engineering designs and specifications for CMI remedy for near-surface system associated with Consolidated Unit 16-021(c)-99; NMED approves document August 2007. |
| August 2007 (this document) | "Corrective Measures Evaluation Report, Intermediate and Regional Groundwater, Consolidated Unit 16-021(c)-99" | Presents cleanup alternatives for groundwater contamination associated with Consolidated Unit 16-021(c)-99 |

## Table 5.2-1
## Technologies for Remediation of RDX and TNT in Groundwater

| **Ex Situ Technologies for Groundwater Recovery and Treatment** |
|---|
| Groundwater recovery using vertical recovery wells |
| GAC adsorption treatment of water |
| UV/photooxidation treatment of water |
| Fluidized bed anaerobic treatment of water |
| Constructed wetlands phytoremediation treatment of water |
| Use of treated water for industrial or municipal supply |
| Injection of treated water |
| Canyon discharge of treated water |
| **In Situ Remediation Technologies** |
| Nanoscale ZVI permeable reactive barrier |
| Bioremediation by edible oil emulsion permeable reactive barrier |
| Oxidation by permanganate injection |
| Sodium dithionite reduction permeable reactive barrier |
| Monitored natural attenuation |

## Table 5.4-1
## Screening of Technologies for Remediation of RDX and TNT in Groundwater

| | Ability to Attain the MCSs | Maturity of the Technology | Cost | Feasibility Given Site Conditions | Retained for Further Evaluation |
|---|---|---|---|---|---|
| *Ex Situ Remediation Technologies* | | | | | |
| Groundwater recovery using vertical recovery wells | +[a] | + | –[b] | + | Yes |
| GAC adsorption treatment of water | + | + | - | + | Yes |
| UV/photooxidation treatment of water | + | + | + | + | Yes |
| Fluidized bed anaerobic treatment of water | – | – | – | – | No |
| Constructed wetlands phytoremediation treatment of water | – | – | – | – | No |
| Use of treated water for industrial or municipal supply | n/a[c] | + | – | – | No |
| Injection of treated water | + | + | + | + | Yes |
| Canyon discharge of treated water | – | + | – | – | No |
| *In Situ Remediation Technologies* | | | | | |
| Nanoscale ZVI permeable reactive barrier | + | – | – | – | No |
| Bioremediation by edible oil emulsion permeable reactive barrier | + | – | – | – | No |
| Oxidation by permanganate injection | + | + | – | – | No |
| Sodium dithionite reduction permeable reactive barrier | + | – | – | – | No |
| Monitored natural attenuation | + | + | + | + | Yes |

[a] + = Favorable.

[b] – = Unfavorable.

[c] n/a = Not applicable.

## Table 6.1-1
## Alternatives for Remediation of RDX and TNT in Groundwater

| Alternative Number | Description |
|---|---|
| I | Intermediate-groundwater recovery and treatment with GAC treatment of recovered groundwater and injection of treated groundwater |
| II | Alternative I, except deployed in regional groundwater alone |
| III | Alternative I, except deployed in both intermediate and regional groundwater |
| IV | Monitored natural attenuation in intermediate and regional groundwater |
| V | No action |

## Table 6.4-1
## Summary of Costs for Remediation Alternatives at Consolidated Unit 16-021(c)-99

| Alternative Number | Description | Capital Costs | 30-Yr O&M Costs (NPV) | Total Cost (NPV) |
|---|---|---|---|---|
| I | Intermediate groundwater recovery and treatment, with granular activated carbon treatment of recovered groundwater and upgradient injection of treated groundwater | \$3,852,000 | \$13,738,000 | \$17,590,000 |
| II | Alternative I, except deployed in regional groundwater alone | \$3,871,000 | \$15,079,000 | \$18,950,000 |
| III | Alternative I, except deployed in both intermediate and regional groundwater | \$6,095,000 | \$18,838,000 | \$24,933,000 |
| IV | Monitored natural attenuation in intermediate and regional groundwater | \$287,000 | \$3,522,000 | \$3,809,000 |
| V | No action | n/a* | \$2,455,000 | \$2,455,000 |

*n/a = Not applicable.

## Table 7.3-1
## Consent Order Schedule for CME/CMI Activities

| Activity | Schedule |
|---|---|
| CME report | August 31, 2007 |
| Draft SB issued by NMED | 90 d after submittal of CME Report |
| Public comment period (SB) | 60 d |
| Final SB issued by NMED | April 21, 2008 |
| Submit CMI plan to NMED | November 2008 |
| NMED approves CMI plan | 120 d after submittal of CMI plan to NMED |
| CMI implementation | April 2009 |

# Appendix A

*Acronyms, Glossary, and Metric Conversion Table*

## A-1.0 LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AAP | Army Ammunition Plant |
| A-DNT | amino-dinitrotoluene |
| ARAR | applicable or relevant and appropriate requirement |
| bgs | below ground surface |
| BH | borehole |
| CME | corrective measures evaluation |
| CMI | corrective measures implementation |
| CMS | corrective measures study |
| COPC | chemical of potential concern |
| CSM | conceptual site model |
| CTF | compliance time frame |
| DoD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| EP | Environmental Programs |
| EPA | U.S. Environmental Protection Agency |
| ER | environmental restoration |
| ERSS | Environment and Remediation Support Services |
| GAC | granular activated carbon |
| $H_2O_2$ | peroxide |
| HE | high explosive(s) |
| HI | hazard index |
| HMX | 1,3,5,7-tetranitro-1,3,5,7-tetrazocine |
| IM | interim measure |
| ITRD | Innovative Treatment Remediation Demonstration |
| LANL | Los Alamos National Laboratory |
| MCS | media cleanup standard |
| MDA | material disposal area |
| MNA | monitored natural attenuation |
| O&M | operations and maintenance |
| NEPA | National Environmental Policy Act |
| NMAC | New Mexico Administrative Code |
| NMED | New Mexico Environment Department |
| NMSA | New Mexico Statutes Annotated |
| NMWQCC | New Mexico Water Quality Control Commission |
| NOD | notice of disapproval |
| NPDES | National Pollutant Discharge Elimination System |
| NPV | net present value |
| PRB | permeable reactive barrier |
| RCRA | Resource Conservation and Recovery Act |
| RDX | hexahydro-1,3,5-trinitro-1,3,5-triazine |
| RFA | RCRA facility assessment |
| RFI | RCRA facility investigation |
| RPF | Records Processing Facility |
| SB | statement of basis |

| | |
|---|---|
| SWMU | solid waste management unit |
| SWSC | Sanitary Wastewater System Consolidation |
| TA | technical area |
| TNB | 1,3,5-trinitrobenzene |
| TNT | 2,4,6-trinitrotoluene |
| TOC | total organic carbon |
| UV | ultraviolet |
| VOC | volatile organic compound |
| wt% | weight percent |
| ZVI | zero-valent iron |

## A-2.0 GLOSSARY

**absorption**—The penetration of substances into the bulk of a solid or liquid.

**adsorption**—The surface retention of solid, liquid, or gas molecules, atoms, or ions by a solid or a liquid.

**alluvial**—Relating to geologic deposits or features formed by running water.

**alluvium**—Clay, silt, sand, and gravel transported by water and deposited on streambeds, flood plains, and alluvial fans.

**analysis**—Includes physical analysis, chemical analysis, and knowledge-of-process determinations. (Laboratory Hazardous Waste Facility Permit)

**aquifer**—Body of permeable geologic material whose saturated portion is capable of readily yielding groundwater to wells.

**area of concern (AOC)**—Areas at the Laboratory that might warrant further investigation for releases based on past facility waste-management activities.

**background level**—Naturally occurring concentrations (levels) of an inorganic chemical and naturally occurring radionuclides in soil, sediment, and tuff.

**barrier**—Any material or structure that prevents or substantially delays movement of solid-, liquid-, or gaseous-phase chemicals in environmental media.

**baseline risk assessment** (also known as risk assessment)—A site-specific analysis of the potential adverse effects of hazardous constituents that are released from a site in the absence of any control or mitigation actions. A baseline risk assessment consists of four steps: data collection and analysis, exposure assessment, toxicity assessment, and risk characterization.

**bentonite**—A clay composed of the mineral montmorillonite and variable amounts of magnesium and iron, formed over time by the alteration of volcanic ash. As bentonite can *adsorb* large quantities of water and expand to several times its normal volume, it is a common additive to drilling mud.

**chemical**—Any naturally occurring or man-made substance characterized by a definite molecular composition, including molecules that contain radionuclides.

**chemical analysis**—Process used to measure one or more attributes of a sample in a clearly defined, controlled, systematic manner. Often requires treating a sample chemically or physically before measurement.

**chemical of potential concern (COPC)**—A chemical, detected at a site, that has the potential to adversely affect human receptors due to its concentration, distribution, and mechanism of toxicity. A COPC remains a concern until exposure pathways and receptors are evaluated in a site-specific human health risk assessment.

**cleanup levels**—Media-specific contaminant concentration levels that must be met by a selected corrective action. Cleanup levels are established by using criteria such as protection of human health and the environment; compliance with regulatory requirements; reduction of toxicity, mobility, or volume through treatment; long- and short-term effectiveness; implementability; cost; and public acceptance.

**Code of Federal Regulation (CFR)**—A codification of all regulations developed by federal government agencies and finalized by publication in the Federal Register.

**conceptual hydrogeologic model**—Mathematical approximation of the occurrence, movement, and quality of groundwater in a given area and the relationship of that groundwater to the surface water, soil water, and geologic framework in that area.

**confluence**—Place where two or more streams meet; the point where a tributary meets the main stream.

**contaminant**—Any chemical (including radionuclides) present in environmental media or on structural debris.

**corrective action**—Action to rectify conditions adverse to human health or the environment.

**corrective measures implementation (CMI) plan**—A detailed plan and specifications to implement the approved remedy at the facility. It is the third step of the corrective-action process. It includes design, construction, maintenance, and monitoring of the chosen remedy.

**corrective measures study (CME)**—A formal process to identify and evaluate remedy alternatives for releases at the facility (55 Federal Register 30798).

**dilution attenuation factor**—Ratio of contaminant concentration in soil leachate to the concentration in groundwater at the receptor point and is used to account for dilution of soil leachate in an aquifer.

**discharge**—Accidental or intentional spilling, leaking, pumping, pouring, emitting, emptying, or dumping of hazardous waste into or on any land or water. (RCRA, 40 CFR 260.10)

**disposal**—The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters. (40 CFR Part 260.10)

**DOE**—See US Department of Energy

**ecological screening level (ESL)**—An organism's exposure-response threshold for a given chemical constituent. The concentration of a substance in a particular medium corresponds to a hazard quotient (HQ) of 1.0 for a given organism below which no risk is indicated.

**effluent**—Liquid discharged as a waste, such as contaminated water from a factory or the outflow from a sewage works; water discharged from a storm sewer or from land after irrigation.

**environmental assessment (EA)**—A report that identifies potentially significant environmental impacts from any federally approved or federally funded project that may change the physical environment. If an EA shows significant impact, an environmental impact statement (EIS) is required.

**environmental impact statement (EIS)**—Detailed report, required by federal law, on the significant environmental impacts that proposed major federal projects would have on the environment.

**EPA**—See US Environmental Protection Agency

**ephemeral**—Said of a stream or spring that flows only during and immediately after periods of rainfall or snowmelt.

**evapotranspiration**—The combined discharge of water from the earth's surface to the atmosphere by evaporation from lakes, streams, and soil surfaces, and by transpiration from plants.

**exposure pathway**—Mode by which a receptor may be exposed to contaminants in environmental media (e.g., drinking water, ingesting food, or inhaling dust).

**fault**—A fracture, or zone of fractures, in rock along which there has been vertical or horizontal movement; adjacent rock layers or bodies are displaced.

**Federal Register**—The official daily publication for Rules, Proposed Rules, and Notices of federal agencies and organizations, as well as Executive Orders and other Presidential Documents.

**flood plain**—The portion of a river valley that is built of overbank sediment deposited when the river floods.

**geohydrology**—The science that applies hydrologic methods to the understanding of geologic phenomena.

**groundwater**—Water in a subsurface saturated zone; water beneath the regional *water table*.

**Hazardous and Solid Waste Amendments (HSWA)**—The Hazardous and Solid Waste Amendments of 1984 (Public Law No. 98-616, 98 Stat. 3221), which amended the Resource Conservation and Recovery Act of 1976, 42 U.S.C. § 6901 et seq.

**hazardous constituent**—Those constituents listed in Appendix VIII to 40 CFR Part 261.

**hazardous waste**—Any solid waste is generally a hazardous waste if it

- is not excluded from regulation as a hazardous waste,
- is listed in the regulations as a hazardous waste,
- exhibits any of the defined characteristics of hazardous waste (ignitability, corrosivity, reactivity, or toxicity), or
- is a mixture o*f* solid waste and hazardous waste.

See 40 CFR 261.3 for a complete definition of hazardous waste.

**HSWA module**—Module VIII of the Laboratory's Hazardous Waste Facility Permit. This permit allows the Laboratory to operate as a treatment, storage, and disposal facility.

**hydraulic conductivity**—The rate at which water moves through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

**hydraulic gradient**—The rate of change of hydraulic head per unit of distance in the direction of groundwater flow.

**hydraulic head**—Elevation of the water table or potentiometric surface as measured in a well.

**Hydrogeologic Workplan**—The document that describes activities planned by the Laboratory to characterize the hydrologic setting beneath the Laboratory and to enhance the Laboratory's groundwater monitoring program.

**hydrogeology**—The science that applies geologic methods to the understanding of hydrologic phenomena.

**hypothesis**—A proposition stated as a basis for further investigation.

**industrial-use scenario**—Industrial use is the scenario in which current Laboratory operations continue. Any necessary remediation involves cleanup to standards designed to ensure a safe and healthy work environment for Laboratory workers.

**infiltration**—Entry of water into the ground.

**injection well**—A well into which fluids are injected (40 CFR 260.10). It should be noted that the ER Project is not using this term in its RCRA context (i.e., the injection of hazardous-waste liquid into the well under specific, approved conditions) but for adding water and/or tracers to the saturated zone during well tests of hydrologic behavior.

**interim measure**—Short-term actions taken to respond to immediate threats to human health or to prevent damage or contaminant migration to the environment.

**interflow**—A runoff process that involves lateral subsurface flow in the soil zone.

**intermittent stream**—A stream that flows only in certain reaches due to losing and gaining characteristics of the channel bed.

**land disposal restrictions (LDR)**—Requirements in 40 CFR 268 that specify treatment standards that are protective of human health and the environment when hazardous waste is land disposed.

**leachate**—Any liquid, including any suspended components in the liquid that has percolated through or drained from hazardous waste (40 CFR 260.10).

**leaching**—The separation or dissolving out of soluble constituents of a solid material by the natural action of percolating water or by chemicals.

**medium** (environmental)—Any media capable of absorbing or transporting constituents. Examples of media include tuffs, soils and sediments derived from these tuffs, surface water, soil water, groundwater, air, structural surfaces, and debris.

**medium** (geological)—The solid part of the hydrogeological system; may be unsaturated or saturated.

**migration**—The movement of inorganic and organic species through unsaturated or saturated materials.

**migration pathway**—A route (e.g., a stream or subsurface flow path) that controls the potential movement of contaminants to environmental receptors (plants, animals, humans).

**mixed waste**—Waste that contains both hazardous waste (as defined by RCRA) and radioactive waste (as defined by the Atomic Energy Act [AEA] and its amendments).

**model**—A mathematical approximation of a physical, biological, or social system.

**monitoring well**—A well or borehole drilled for the purpose of yielding groundwater samples for analysis.

**National Pollutant Discharge Elimination System (NPDES)**—The national program for both issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits and imposing requirements under Sections 307, 318, 402, and 405 of the Clean Water Act.

**operable unit (OU)**—At the Laboratory, one of 24 areas originally established for administering the ER Project. Set up as groups of potential release sites, the OUs were aggregated based on geographic proximity for the purpose of planning and conducting RCRA facility assessments and RCRA facility investigations. As the project matured, it became apparent that 24 were too many to allow efficient communication and to ensure consistency in approach. Therefore, in 1994, the 24 OUs were reduced to six administrative “field units.”

**outfall**—The vent or end of a drain, pipe, sewer, ditch, or other conduit that carries wastewater, sewage, storm runoff or other effluent into a stream.

**perched groundwater**—Groundwater that lies above the regional water table and is separated from it by one or more unsaturated zones.

**percolation**—Gravity flow of soil water through the pore spaces in soil or rock below the ground surface.

**perennial stream**—A stream or reach that flows continuously throughout the year.

**piezometer**—A tightly cased well drilled for the purpose of measuring hydraulic head or water level at a discrete depth; ideally only open at the bottom but usually constructed with a very short screen interval.

**piezometric surface**—The surface that represents the static head in an aquifer: applies to both confined and unconfined aquifers (also called potentiometric surface).

**polychlorinated biphenyls (PCBs)**—Any chemical substance that is limited to the biphenyl molecule that has been chlorinated to varying degrees or any combination of substances which contains such substances. PCBs are colorless, odorless compounds that are chemically, electrically, and thermally stable and have proven to be toxic to both humans and animals.

**porosity**—The ratio of the volume of interstices in a soil or rock sample to its total volume expressed as a percentage or as a fraction.

**preliminary remediation goal (PRG)**—Acceptable exposure levels, protective of human health and the environment, that are used as a risk-based tool for evaluating remedial alternatives.

**RCRA facility investigation (RFI)**—The investigation that determines if a release has occurred and the nature and extent of the contamination at a hazardous waste facility. The RFI is generally equivalent to the remedial investigation portion of the Comprehensive Environment Response, Compensation, and Liability Act (CERCLA) process.

**receptor**—A person, plant, animal, or geographical location that is exposed to a chemical or physical agent released to the environment by human activities**.**

**recharge**—The process by which water is added to the zone of saturation, either directly from the overlying unsaturated zone or indirectly by way of another material in the saturated zone.

**regional aquifer**—Geologic material(s) or unit(s) of regional extent whose saturated portion yields significant quantities of water to wells, contains the regional zone of saturation, and is characterized by the regional water table or potentiometric surface.

**regulatory standard**—Media-specific contaminant concentration levels of potential concern that are mandated by federal or state legislation or regulation (e.g., the Safe Drinking Water Act, New Mexico Water Quality Control Commission regulations).

**release**—Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of hazardous waste or hazardous constituents into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles that contain any hazardous wastes or hazardous constituents).

**remediation**—The process of reducing the concentration of a contaminant (or contaminants) in air, water, or soil media to a level that poses an acceptable risk to human health and the environment; the act of restoring a contaminated area to a usable condition based on specified standards.

**residential-use scenario**—The standards for residential use are the most stringent of the three current- and future-use scenarios being considered by the ER Project and is the level of cleanup the EPA is currently specifying for SWMUs located off the Laboratory site and for those released for non-Laboratory use.

**Resource Conservation and Recovery Act (RCRA)**—The Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976. (40 CFR 270.2)

**retardation**—The act or process that reduces the rate of movement of a chemical substance in water relative to the average velocity of the water. The movement of chemical substances in water can be retarded by adsorption and precipitation reactions, and by diffusion into the pore water of the rock matrix.

**risk assessment**—See *baseline risk assessment.*

**risk characterization**—The summarization and integration of the results of toxicity and exposure assessments into quantitative and qualitative expressions of risk. The major assumptions, scientific judgments, and sources of uncertainty related to the assessment are also presented.

**screening action level (SAL)**—Medium-specific concentration level for a chemical derived using conservative criteria below for which it is generally assumed that there is no potential for unacceptable risk to human health. The derivation of a SAL is based on conservative exposure and land-use assumptions. However, if an applicable regulatory standard exists that is less than the value derived by risk-based computations, it will be used for the SAL.

**screening assessment**—A process designed to determine whether contamination detected in a particular medium at a site may present a potentially unacceptable human-health and /or ecological risk. The assessment utilizes screening levels that are either human-health or ecologically based concentrations derived by using chemical-specific toxicity information and standardized exposure assumptions below which no additional actions are generally warranted.

**sediment**—(1) A mass of fragmented inorganic solid that comes from the weathering of rock and is carried or dropped by air, water, gravity, or ice; or a mass that is accumulated by any other natural agent and that forms in layers on the earth's surface such as sand, gravel, silt, mud, fill, or loess. (2) A solid material that is not in solution and either is distributed through the liquid or has settled out of the liquid.

**site characterization**—Defining the pathways and methods of migration of the hazardous waste or constituents, including the media affected, the extent, direction and speed of the contaminants, complicating factors influencing movement, concentration profiles, etc. (US Environmental Protection Agency, May 1994. "RCRA Corrective Action Plan, Final," Publication EPA-520/R-94/004, Office of Solid Waste and Emergency Response, Washington, DC)

**site conceptual model**—A qualitative or quantitative description of sources of contamination, environmental transport pathways for contamination, and biota that may be impacted by contamination (called receptors) and whose relationships describe qualitatively or quantitatively the release of contamination from the sources, the movement of contamination along the pathways to the exposure points, and the uptake of contaminant by the receptors.

**soil gas**—Those gaseous elements and compounds that occur in the void spaces in unsaturated rock or soil. Such gases can move through or leave the rock or soil, depending on changes in pressure.

**soil water**—Water in the unsaturated zone, regardless of whether it occurs in soil or rock.

**solid waste**—Any garbage; refuse; sludge from a waste treatment plant, water-supply treatment plant, or air-pollution-control facility; and other discarded material including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations and from community activities.

**solid waste management unit (SWMU)**—Any discernible unit at which solid wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous waste. Such units include any area at a facility at which solid wastes have been routinely and systematically released. This definition includes regulated units (i.e., landfills, surface impoundments, waste piles, and land treatment units) but does not include passive leakage or one-time spills from production areas and units in which wastes have not been managed (e.g., product-storage areas).

**spring**—The site where groundwater discharges to the ground surface.

**stakeholder**—As used in this document, stakeholder refers to any party or agency, whether inside or outside the Laboratory, interested in or affected by Environmental Restoration Project issues and activities.

**technical area (TA)**—The Laboratory established technical areas as administrative units for all its operations. There are currently 49 active TAs spread over approximately 40 square miles.

**tracer**—A substance, usually a radioactive isotope, added to a sample to determine the efficiency (chemical or physical losses) of the chemical extraction, reaction, or analysis. The tracer is assumed to behave in the same manner as that of the target radionuclides. Recovery guidelines for tracer results are 30% to 110% under the current contract laboratory statement of work and will be 40% to 105% under the new statement of work. Correction of the analytical results for the tracer recovery is performed for each sample. The concentration of the tracer added needs to be sufficient to result in a maximum of 10% uncertainty at the 95% confidence level in the measured recovery.

**transmission loss**—Reduction in surface water flow by seepage into the channel bed.

**transmissivity**—A measure of the rate at which water is transmitted through a cross section of aquifer having the dimensions unit width and total saturated thickness as height, under a unit hydraulic gradient; also hydraulic conductivity times aquifer thickness.

**transport or transportation**—The movement of a hazardous waste by air, rail, highway, or water. (40 CFR 260.10)

**treatment**—Any method, technique, or process, including elementary neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste; recover energy or material resources from the waste; or so as to render such waste nonhazardous or less hazardous; safer to transport, store, or dispose of; or amenable for recovery or storage; or reduced in volume.

**treatment, storage, and disposal (TSD) facility**—An interim status or permitted facility in which hazardous waste is treated, stored, or disposed.

**tuff**—A compacted deposit of volcanic ash and dust that contains rock and mineral fragments accumulated during an eruption.

**underflow**—Groundwater flow beneath the bed of a non-flowing stream; such water is often perched in the channel alluvium atop the bedrock surface.

**unsaturated zone**—The zone between the land surface and the regional water table and between perched zones of saturation. Generally, fluid pressure in this zone is less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure.

**US Department of Energy (DOE)**—Federal agency that sponsors energy research and regulates nuclear materials for weapons production.

**US Environmental Protection Agency (EPA)**—Federal agency responsible for enforcing environmental laws. While state regulatory agencies may be authorized to administer some of this responsibility, the EPA retains oversight authority to ensure protection of human health and the environment.

**vadose zone**—The unsaturated zone. Portion of the subsurface above the regional water table in which pores are not fully saturated.

**water balance**—The relationship between water input (precipitation) and output (runoff, evapotranspiration, and recharge) in a hydrological system; the partitioning of precipitation among these components of the hydrological cycle.

**water content**—(Also gravimetric moisture content) The amount of water in an unsaturated medium, expressed as the ratio of the weight of water in a sample to the weight of the oven-dried sample; often expressed as a percent.

**water table**—The top of the regional saturated zone; the piezometric surface associated with an unconfined aquifer.

## A-3.0 METRIC TO US CUSTOMARY UNIT CONVERSION TABLE

| Multiply SI (Metric) Unit | by | To Obtain US Customary Unit |
|---|---|---|
| kilometers (km) | 0.622 | miles (mi) |
| kilometers (km) | 3281 | feet (ft) |
| meters (m) | 3.281 | feet (ft) |
| meters (m) | 39.37 | inches (in.) |
| centimeters (cm) | 0.03281 | feet (ft) |
| centimeters (cm) | 0.394 | inches (in.) |
| millimeters (mm) | 0.0394 | inches (in.) |
| micrometers or microns (µm) | 0.0000394 | inches (in.) |
| square kilometers ($km^2$) | 0.3861 | square miles ($mi^2$) |
| hectares (ha) | 2.5 | acres |
| square meters ($m^2$) | 10.764 | square feet ($ft^2$) |
| cubic meters ($m^3$) | 35.31 | cubic feet ($ft^3$) |
| kilograms (kg) | 2.2046 | pounds (lb) |
| grams (g) | 0.0353 | ounces (oz) |
| grams per cubic centimeter ($g/cm^3$) | 62.422 | pounds per cubic foot ($lb/ft^3$) |
| milligrams per kilogram (mg/kg) | 1 | parts per million (ppm) |
| micrograms per gram (µg/g) | 1 | parts per million (ppm) |
| liters (L) | 0.26 | gallons (gal.) |
| milligrams per liter (mg/L) | 1 | parts per million (ppm) |
| degrees Celsius (°C) | 9/5 + 32 | degrees Fahrenheit (°F) |

# Appendix B

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*Corrective Measures Alternatives Cost Estimates*

# Appendix B
# Table of Contents

# Table B-1
# Summary of Alternative Costs

| Alternative Number | Description | Capital Costs | 30 Year O&M Costs (NPV) | Total Cost (NPV) |
|---|---|---|---|---|
| I | Intermediate groundwater recovery and treatment, with granular activated carbon treatment of recovered groundwater and upgradient injection of treated groundwater | $ 3,852,000 | $ 13,738,000 | $ 17,590,000 |
| II | Alternative I, except deployed in regional groundwater alone | $ 3,871,000 | $ 15,079,000 | $ 18,950,000 |
| III | Alternative I, except deployed in both intermediate and regional groundwater | $ 6,095,000 | $ 18,838,000 | $ 24,933,000 |
| IV | Monitored natural attenuation in intermediate and regional groundwater | $ 287,000 | $ 3,522,000 | $ 3,809,000 |
| V | No-action | n/a | $ 2,455,000 | $ 2,455,000 |

| | |
|---|---|
| n/a | Not applicable |
| NPV | Net present value |
| O&M | Operations and Maintenance |

# Table B-2
## Unit Labor Costs for Corrective Measure Alternative Cost Estimates

| Labor Category | Loaded Rate, $/h |
|---|---|
| LANL Project Manager | 300 |
| LANL Health & Safety Supervisor | 200 |
| LANL Senior Scientist | 300 |
| LANL Laboratory Scientist | 200 |
| LANL NEPA Specialist | 200 |
| Program Manager | 200 |
| Project Manager | 130 |
| Senior Engineer | 110 |
| Project Engineer | 85 |
| Senior Scientist | 125 |
| Junior Engineer | 75 |
| Junior Scientist | 75 |
| Permitting Specialist | 80 |
| Draftsman | 80 |
| Word Processor | 55 |
| Quality Assurance | 75 |
| Administrative Assistant | 45 |
| Cost/Schedule Engineer | 55 |
| | |
| Field Supervisor | 70 |
| Field Engineer | 75 |
| Field Equipment Operator | 50 |
| Field Driver | 45 |
| Field Technician | 45 |
| Field Laborer | 35 |
| Field Craft Labor | 50 |
| Field Electrician | 65 |
| Field Equipment Operator - PT | 25 |
| Field Driver - PT | 22.5 |
| Field Technician - PT | 22.5 |
| Field Laborer - PT | 17.5 |
| Field Craft Labor - PT | 25 |
| Field Electrician - PT | 32.5 |

| | |
|---|---|
| LANL | Los Alamos National Laboratory |
| PT | Premium time |

# Table B-3
# Major Unit Costs for Corrective Measure Alternative Cost Estimates

## Equipment

| Item | Description | Rate, $/Month | Source |
|---|---|---|---|
| Excavator | Case 9040 | 4600 | Hertz |
| Grader | | 4100 | Hertz |
| Dozer | | 4250 | |
| Backhoe | JD410 | 4152 | Hertz |
| Dump truck | 30 ton, off road | 7200 | Hertz |
| Pickup | utility | 400 | Hertz |
| Generator | 30 kw | 650 | Hertz |
| Vibrating compactor | plate type | 275 | Hertz |
| Portolet | | 71 | NM Chemical |
| HDPE fusion machine | | 1200 | Crowe |
| Submersible pump rental, 6 in. | 25–75 gal./min @ 1000 ft TDH | 2500 | Estimated |
| 2 vessels | 2 500 lb units | 1250 | Tigg Corporation |
| Frac tank rental for pump test | 4 20,000 gal. frac tanks | 4000 | estimated |
| Fuel, oil, & maintenance | fuel, oil, & maintenance | 4000 | estimated |

## Materials

| Description | UOM | Unit Cost, $/UOM | Source |
|---|---|---|---|
| Peastone | ton | 24 | LaFarge |
| Backfill, engineered | ton | 15 | LaFarge |
| GAC | lb | 2 | Calgon |
| GAC disposal, small quantity | drum | 500 | Rin.em |
| 4-in. HDPE, SDR 11 | ft | 2.5 | Integrity Fusion Products |
| 6-in. HDPE, SDR 11 | ft | 3.5 | |
| 4-in. threaded pipe, galvanized Sch 40 | ft | 6.5 | Pioneer Pipe |
| Bulk GAC change/disposal | lb | 2 | Calgon |

| Well Installation | UOM | Unit Cost, $/UOM | Source |
|---|---|---|---|
| to 20 ft | ft | 250 | WDC |
| Drill to total depth—direct mud rotary | ft | 72 | WDC |
| Silt trap with welded end cap | ft | 36 | WDC |
| 6-in. LCS Casing—0.307 wall | ft | 36 | WDC |
| Vertical Mill Slot Screen | ft | 64 | WDC |
| Furnish & install centralizers | ea | 27 | WDC |

# Table B-3
# Major Unit Costs for Corrective Measure Alternative Cost Estimates

| | | | |
|---|---|---|---|
| Furnish & install rounded gravel filter pack | ft | 20 | WDC |
| Furnish & install barrier bentonite/s& | ft | 20 | WDC |
| Furnish & install annular seal | ft | 20 | WDC |
| Furnish & install above grade well protection | ea | 1200 | WDC |
| Mobilization/Demobilization—e a rig - pump | ea | 1400 | WDC |
| Swab & bail only | h | 185 | WDC |
| Per diem | d | 220 | WDC |
| Standby | h | 210 | WDC |

# Table B-3
# Major Unit Costs for Corrective Measure Alternative Cost Estimates

## Analytical

| Method | Description | Cost, $ | Source |
|---|---|---|---|
| LANL full suite analytical | HE soil/water | 2000 | LANL |

## Soil Disposal

| Item | UOM | Unit Cost, $/UOM | Source |
|---|---|---|---|
| Nonhazardous | ton | 52 | MDA P |

## Energy

| Item | UOM | Unit Cost | Source |
|---|---|---|---|
| Electric power | kwh | 0.12 | estimated |
| Subgrade 2-in. conduit, 3 conductors, installed | ft | 10 | Means |

## Groundwater Treatment System (300 gal./min)

| Item | UOM | Unit Cost | Source |
|---|---|---|---|
| Water piping | lump | 45000 | PNM SFGS + 50% |
| Concrete foundation | lump | 30000 | PNM SFGS + 50% |
| Sump pump | lump | 10000 | PNM SFGS + 50% |
| Bag filter, install, piping | lump | 10000 | PNM SFGS + 50% |
| Eye wash | lump | 3000 | PNM SFGS + 50% |
| Transformer pad & service | lump | 8000 | PNM SFGS + 50% |
| Building electrical | lump | 60000 | PNM SFGS + 50% |
| Lightening protection | lump | 7500 | PNM SFGS + 50% |
| Building (32 ft x 32 ft), split block, metal roof | lump | 170000 | PNM SFGS + 50% |
| Site prep, grading | lump | 10000 | PNM SFGS + 50% |
| 6-in. gravel base course | lump | 14000 | PNM SFGS + 50% |
| Chemical injection system | lump | 9000 | PNM SFGS + 50% |
| 10,000 lb carbon vessels | ea | 39000 | Tigg Corporation |
| Carbon vessels install, piping | lump | 5000 | PNM SFGS + 50% |
| 4000 gal. head tank, poly | lump | 7000 | estimated |
| Transfer pumps, 10 hp duplex | set | 5000 | Gould Pump |
| Aluminum vault enclosure doors 4 ft x 4 ft | ea | 3500 | Bilco |

| | |
|---|---|
| GAC | Granular activated carbon |
| HDPE | High-density polyethylene |
| LANL | Los Alamos National Laboratory |
| SFGS | Santa Fe Generating Station |
| TDH | Total dynamic head |

# Table B-3
## Major Unit Costs for Corrective Measure Alternative Cost Estimates

| | |
|---|---|
| UOM | Unit of Measure |

# Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

**Assumptions**

1. Recovery/injection system consists of 4 recovery & 4 injection wells.
2. Recovery & injection wells are 1200 ft in total depth.
3. A 48-h (24-h pump/24-h recovery) test will be performed on one recovery well prior to the final design.
4. Pump test flow rate is 50 gal./min, with frac tank containment, GAC treatment, & dust suppression recycle of treated water.
6. Clearing & grubbing for unimproved road installation will be require in Cañon de Valle & on the mesa.
7. Treatment system building is 32 ft x 32 ft & will be constructed near MDA P.
8. Treatment system consists of water conditioning with polyphosphate, GAC & bag filters
9. GAC vessels consist of two 10,000-lb vessels in series.
10. All subgrade piping is heat welded HDPE without secondary containment.
11. Head tank enclosed in a 144-ft$^2$ shed is installed in Cañon de Valle for the three canyon wells.
12. All wellheads are installed in 4 ft x 4 ft aluminum & concrete subgrade vaults
13. Installation will require 6 month to complete.
14. All labor is local & does not incur travel costs, except for drilling.
15. Four GAC changeout per yr will be completed.
16. GAC provided by vendor, who also h&les disposal/regeneration.
17. A groundwater discharge permit will be required.
18. Monthly sampling consists of influent/effluent samples & between GAC beds.
19. Analytical for O&M & semiannual sampling consists of the full LANL suite (HE, VOCs, SVOCs, metals, inorganics).
20. Treatment plant operations labor requires a full time technician and a full time field engineer.
21. Under Phase IV O&M, semiannual sampling of five monitoring wells & four recovery wells is included.
22. The discount rate for the NPV calculation is 4.5%.
23. A yearly inflation rate of 3% applies over the 30 year lifetime of the project.
24. NMGRT is 5.8125%.
25. Subcontractors are priced with a 10% markup.
26. Decommissioning and demolition costs are not included.

**Phase I RW-4 Installation & Pump Test (yr 1)** **$ 442,750**

**Task 1 Project Plans** **$ 57,630**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 57,630** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 20 | $ 2,600 | |
| Senior Engineer | 110 | 80 | $ 8,800 | |
| Project Engineer | 85 | 120 | $ 10,200 | |
| Senior Scientist | 125 | 16 | $ 2,000 | |
| Permitting Specialist | 80 | 8 | $ 640 | |
| Draftsman | 80 | 40 | $ 3,200 | |
| Word Processor | 55 | 40 | $ 2,200 | |
| Quality Assurance | 75 | 2 | $ 150 | |
| Administrative Assistant | 45 | 40 | $ 1,800 | |

| | Rate | Hours | Subtotal |
|---|---|---|---|
| Cost/Schedule Engineer | 55 | 8 | $ 440 |

**Task 2 Safety Plan** $ 17,880

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 17,880** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 4 | $ 520 | |
| Senior Engineer | 110 | 40 | $ 4,400 | |
| Project Engineer | 85 | 40 | $ 3,400 | |
| Junior Engineer | 75 | 40 | $ 3,000 | |
| Draftsman | 80 | 4 | $ 320 | |
| Word Processor | 55 | 8 | $ 440 | |
| Administrative Assistant | 45 | 40 | $ 1,800 | |

**Task 3 Readiness Review** $ 8,160

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 |
| Project Manager | 130 | 8 | $ 1,040 |
| Senior Engineer | 110 | 16 | $ 1,760 |
| Project Engineer | 85 | 16 | $ 1,360 |

**Task 4 RW-4 Installation** $ 247,701

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 39,640** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 | |
| LANL Health & Safety Supervisor | 200 | 4 | $ 800 | |
| Project Manager | 130 | 40 | $ 5,200 | |
| Junior Scientist | 75 | 160 | $ 12,000 | |
| Senior Engineer | 110 | 160 | $ 17,600 | |
| Quality Assurance | 75 | 16 | $ 1,200 | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | |

| **Drilling Subcontractor** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 207,361** | (incl 10% markup) |
|---|---|---|---|---|---|---|

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Mobilization/ Demobilization - ea rig - ARCH | ea | 6400 | 1 | $ 6,400 | | |
| Drill & Install 16 in. conductor to 20 ft | ft | 250 | 20 | $ 5,000 | | |
| Drill to total depth - direct mud rotary | ft | 72 | 1200 | $ 86,400 | | |
| Silt trap with welded end cap | ft | 36 | 10 | $ 360 | | |
| 6-in. LCS Casing—0.307 wall | ft | 36 | 800 | $ 28,800 | | |
| Vertical Mill Slot Screen | ft | 64 | 400 | $ 25,600 | | |
| Furnish & install centralizers | ea | 27 | 150 | $ 4,050 | | |
| Furnish & install rounded gravel filter pack | ft | 20 | 400 | $ 8,000 | | |
| Furnish & install barrier bentonite/sand | ft | 20 | 5 | $ 100 | | |
| Furnish & install annular seal | ft | 20 | 800 | $ 16,000 | | |
| Furnish & install above grade well protection | ea | 1200 | 1 | $ 1,200 | | |
| Mobilization/Demobilization—ea rig - pump | ea | 1400 | 1 | $ 1,400 | | |
| Swab & bail only | h | 185 | 20 | $ 3,700 | | |
| per diem | d | 220 | 3 | $ 660 | | |
| Standby | h | 210 | 4 | $ 840 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 700** | |
| Pickup | mo | 400 | 0.5 | $ 200 | | |
| Misc | | | | $ 500 | | |
| **Task 5 Pump Test** | | | | | | **$ 78,519** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 21,070** | |
| LANL Project Manager | | 300 | 16 | $ 4,800 | | |
| LANL Health & Safety Supervisor | | 200 | 2 | $ 400 | | |
| Project Manager | | 130 | 8 | $ 1,040 | | |
| Project Engineer | | 85 | 40 | $ 3,400 | | |
| Senior Scientist | | 125 | 40 | $ 5,000 | | |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Junior Scientist | | 75 | 80 | $ 6,000 | | |
| Permitting Specialist | | 80 | 4 | $ 320 | | |
| Cost/Schedule Engineer | | 55 | 2 | $ 110 | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 7,860** | |
| Field Technician | | 45 | 80 | $ 3,600 | | |
| Field Craft Labor | | 50 | 40 | $ 2,000 | | |
| Field Electrician | | 65 | 24 | $ 1,560 | | |
| Field Technician - PT | | 22.5 | 20 | $ 450 | | |
| Field Craft Labor - PT | | 25 | 10 | $ 250 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 10,439** | (incl 10% markup) |
| Submersible pump rental | mo | 2500 | 1 | $ 2,500 | | |
| Frac tank rental for pump test | mo | 4000 | 1 | $ 4,000 | | |
| Carbon vessels for pump test, 2 vessels | mo | 1740 | 1 | $ 1,740 | | |
| Pickup | mo | 400 | 1 | $ 400 | | |
| Generator | wk | 350 | 1 | $ 350 | | |
| Misc | | | | $ 500 | | |
| **Materials** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 12,000** | |
| GAC Disposal | lb | 500 | 5 | $ 2,500 | | |
| 4-in. threaded pipe, galvanized Sch 40 | ft | 1000 | 6.5 | $ 6,500 | | |
| Data logger with pressure transducers | wk | 2500 | 1 | $ 2,500 | | |
| Misc | | | | $ 500 | | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 27,150** | |
| LANL full suite analytical | ea | 2000 | 10 | $ 20,000 | | |
| Drill rig & crew (set & pull pump) | lump | 6500 | 1 | $ 7,150 | (incl 10% markup) | |
| **Task 6 Field Summary Report** | | | | | | **$ 32,860** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 32,860** | |
| LANL Project Manager | | 300 | 16 | $ 4,800 | | |
| Project Manager | | 130 | 8 | $ 1,040 | | |
| Senior Scientist | | 125 | 80 | $ 10,000 | | |

| | | | |
|---|---|---|---|
| Junior Engineer | 75 | 160 | $ 12,000 |
| Draftsman | 80 | 40 | $ 3,200 |
| Word Processor | 55 | 24 | $ 1,320 |
| | | | |
| Quality Assurance | 75 | 4 | $ 300 |
| Administrative Assistant | 45 | 2 | $ 90 |
| Cost/Schedule Engineer | 55 | 2 | $ 110 |

**Phase II Final Design & Permitting (yr 2)** **$ 320,380**

**Task 1 Final Design** **$ 254,400**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 |
| LANL Health & Safety Supervisor | 200 | 16 | $ 3,200 |
| Project Manager | 130 | 160 | $ 20,800 |
| Senior Engineer | 110 | 480 | $ 52,800 |
| Project Engineer | 85 | 480 | $ 40,800 |
| Junior Engineer | 75 | 480 | $ 36,000 |
| LANL NEPA Specialist | 200 | 80 | $ 16,000 |
| Permitting Specialist | 80 | 160 | $ 12,800 |
| Draftsman | 80 | 320 | $ 25,600 |
| Word Processor | 55 | 160 | $ 8,800 |
| | | | |
| Quality Assurance | 75 | 80 | $ 6,000 |
| Administrative Assistant | 45 | 120 | $ 5,400 |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 |

**Task 2 Final Design Cost Estimate** **$ 44,780**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 |
| Senior Engineer | 110 | 160 | $ 17,600 |
| Project Engineer | 85 | 160 | $ 13,600 |
| Junior Engineer | 75 | 80 | $ 6,000 |
| | | | |
| Quality Assurance | 75 | 16 | $ 1,200 |

| | | | |
|---|---|---|---|
| Administrative Assistant | 45 | 4 | $ 180 |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 |

**Task 3 Project Administration** **$ 21,200**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| LANL Project Manager | 300 | 40 | $ 12,000 |
| Project Manager | 130 | 40 | $ 5,200 |
| Administrative Assistant | 45 | 40 | $ 1,800 |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 |

**Phase III Installation (yr 3)** **$ 2,876,978**

**Task 1 Installation Plan** **$ 52,620**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 52,620** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 40 | $ 12,000 | |
| Program Manager | 200 | 4 | $ 800 | |
| Project Manager | 130 | 8 | $ 1,040 | |
| Senior Engineer | 110 | 160 | $ 17,600 | |
| Project Engineer | 85 | 160 | $ 13,600 | |
| Draftsman | 80 | 40 | $ 3,200 | |
| Word Processor | 55 | 16 | $ 880 | |
| Quality Assurance | 75 | 8 | $ 600 | |
| Administrative Assistant | 45 | 40 | $ 1,800 | |
| Cost/Schedule Engineer | 55 | 20 | $ 1,100 | |

**Task 2 Safety Plan** **$ 11,040**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 11,040** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 8 | $ 1,040 | |
| Senior Engineer | 110 | 8 | $ 880 | |
| Project Engineer | 85 | 16 | $ 1,360 | |
| Junior Engineer | 75 | 40 | $ 3,000 | |
| Draftsman | 80 | 4 | $ 320 | |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | |
|---|---|---|---|---|
| Word Processor | 55 | 8 | $ 440 | |

**Task 3 Training** **$ 8,700**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 5,220** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 4 | $ 1,200 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 2 | $ 260 | |
| Senior Engineer | 110 | 8 | $ 880 | |
| Project Engineer | 85 | 8 | $ 680 | |
| Junior Engineer | 75 | 8 | $ 600 | |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 3,480** |
|---|---|---|---|---|
| Field Supervisor | 70 | 8 | $ 560 | |
| Field Engineer | 75 | 8 | $ 600 | |
| Field Equipment Operator | 50 | 8 | $ 400 | |
| Field Driver | 45 | 8 | $ 360 | |
| Field Technician | 45 | 8 | $ 360 | |
| Field Laborer | 35 | 8 | $ 280 | |
| Field Craft Labor | 50 | 8 | $ 400 | |
| Field Electrician | 65 | 8 | $ 520 | |

**Task 4 Readiness Review** **$ 6,400**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 6,400** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 8 | $ 1,040 | |
| Project Engineer | 85 | 16 | $ 1,360 | |

**Task 5 Road Installation (Mesa & Cañon de Valle)** **$ 90,114**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 37,200** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 40 | $ 5,200 | |
| Senior Engineer | 110 | 40 | $ 4,400 | |
| Project Engineer | 85 | 160 | $ 13,600 | |
| Junior Engineer | 75 | 80 | $ 6,000 | |
| Administrative Assistant | 45 | 40 | $ 1,800 | |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Cost/Schedule Engineer | | 55 | 40 | $ 2,200 | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 41,025** | |
| Field Supervisor | | 70 | 120 | $ 8,400 | | |
| Field Engineer | | 75 | 120 | $ 9,000 | | |
| Field Equipment Operator | | 50 | 120 | $ 6,000 | | |
| Field Driver | | 45 | 120 | $ 5,400 | | |
| Field Technician | | 45 | 120 | $ 5,400 | | |
| Field Laborer | | 35 | 120 | $ 4,200 | | |
| Field Equipment Operator - PT | | 25 | 30 | $ 750 | | |
| Field Driver - PT | | 22.5 | 30 | $ 675 | | |
| Field Technician - PT | | 22.5 | 30 | $ 675 | | |
| Field Laborer - PT | | 17.5 | 30 | $ 525 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 11,889** | |
| Backhoe | mo | 4152 | 0.75 | $ 3,114 | | |
| Grader | mo | 4100 | 0.75 | $ 3,075 | | |
| Pickup | mo | 400 | 0.75 | $ 300 | | |
| Dump truck | mo | 7200 | 0.75 | $ 5,400 | | |
| **Task 6 Recovery/Injection Well Installation** | | | | | | **$ 1,440,038** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 60,440** | |
| LANL Project Manager | | 300 | 40 | $ 12,000 | | |
| LANL Health & Safety Supervisor | | 200 | 40 | $ 8,000 | | |
| Project Manager | | 130 | 80 | $ 10,400 | | |
| Junior Scientist | | 75 | 320 | $ 24,000 | | |
| Senior Engineer | | 110 | 40 | $ 4,400 | | |
| Quality Assurance | | 75 | 16 | $ 1,200 | | |
| Cost/Schedule Engineer | | 55 | 8 | $ 440 | | |
| **Drilling Subcontractor** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 1,379,598** | (incl 10% markup) |
| Mobilization/ Demobilization - ea rig - ARCH | ea | 6400 | 1 | $ 6,400 | | |
| Drill & install 16 in. conductor to 20 ft | ft | 250 | 140 | $ 35,000 | | |
| Drill to total depth: direct mud rotary | ft | 72 | 8400 | $ 604,800 | | |

# Table B-4
# Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | |
|---|---|---|---|---|
| Silt trap with welded end cap | ft | 36 | 70 | $ 2,520 |
| 6-in. LCS Casing—0.307 wall | ft | 36 | 5600 | $ 201,600 |
| Vertical mill slot screen | ft | 64 | 2800 | $ 179,200 |
| Furnish & install centralizers | ea | 27 | 280 | $ 7,560 |
| Furnish & install rounded gravel filter pack | ft | 20 | 2800 | $ 56,000 |
| Furnish & install barrier bentonite/sand | ft | 20 | 35 | $ 700 |
| Furnish & install annular seal | ft | 20 | 5600 | $ 112,000 |
| Furnish & install above grade well protection | ea | 1200 | 7 | $ 8,400 |
| Mobilization/ Demobilization: ea rig - pump | ea | 1400 | 2 | $ 2,800 |
| Swab & bail only | h | 185 | 40 | $ 7,400 |
| per diem | day | 220 | 40 | $ 8,800 |
| Set pumps & piping | h | 210 | 80 | $ 16,800 |
| Standby | h | 210 | 20 | $ 4,200 |

**Task 7 Subsurface Installation** **$ 460,613**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 91,200** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 | |
| LANL Health & Safety Supervisor | 200 | 40 | $ 8,000 | |
| Project Manager | 130 | 80 | $ 10,400 | |
| Senior Engineer | 110 | 160 | $ 17,600 | |
| Project Engineer | 85 | 160 | $ 13,600 | |
| Junior Engineer | 75 | 80 | $ 6,000 | |
| Administrative Assistant | 45 | 160 | $ 7,200 | |
| Cost/Schedule Engineer | 55 | 80 | $ 4,400 | |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 213,200** |
|---|---|---|---|---|
| Field Supervisor | 70 | 480 | $ 33,600 | |
| Field Engineer | 75 | 480 | $ 36,000 | |
| Field Equipment Operator | 50 | 480 | $ 24,000 | |
| Field Driver | 45 | 480 | $ 21,600 | |

# Table B-4

## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Field Technician | | 45 | 480 | $ 21,600 | | |
| Field Laborer | | 35 | 480 | $ 16,800 | | |
| Field Craft Labor | | 50 | 480 | $ 24,000 | | |
| Field Electrician | | 65 | 320 | $ 20,800 | | |
| Field Equipment Operator - PT | | 25 | 120 | $ 3,000 | | |
| Field Driver - PT | | 22.5 | 120 | $ 2,700 | | |
| Field Technician - PT | | 22.5 | 120 | $ 2,700 | | |
| Field Laborer - PT | | 17.5 | 120 | $ 2,100 | | |
| Field Craft Labor - PT | | 25 | 120 | $ 3,000 | | |
| Field Electrician - PT | | 32.5 | 40 | $ 1,300 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 156,213** | (incl 10% markup) |
| Backhoe | mo | 4152 | 3 | $ 12,456 | | |
| Backhoe | mo | 4152 | 3 | $ 12,456 | | |
| Pickup | mo | 400 | 3 | $ 1,200 | | |
| Dump truck | mo | 7200 | 3 | $ 21,600 | | |
| Generator | mo | 350 | 3 | $ 1,050 | | |
| Compactor | mo | 550 | 3 | $ 1,650 | | |
| HDPE fusion machine | mo | 1200 | 3 | $ 3,600 | | |
| FOM | mo | 4000 | 3 | $ 12,000 | | |
| Submersible pump | ea | 15000 | 4 | $ 60,000 | | |
| Pump variable frequency drive | ea | 4000 | 4 | $ 16,000 | | |
| **Materials** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 186,340** | (incl 10% markup) |
| 4-in. HDPE, SDR 11 | ft | 2.5 | 15000 | $ 37,500 | | |
| 4-in. threaded pipe, galvanized Sch 40 | ft | 6.5 | 3600 | $ 23,400 | | |
| 4-in. fittings | well | 1000 | 4 | $ 4,000 | | |
| 6-in. HDPE, SDR 11 | ft | 3.5 | 1000 | $ 3,500 | | |
| Aluminum vault enclosure doors 4x4 | ea | 3500 | 8 | $ 28,000 | | |
| Recovery well vaults, precast, 4x4x4 | ea | 1500 | 8 | $ 12,000 | | |
| Backfill, engineered | ton | 15 | 400 | $ 6,000 | | |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | |
|---|---|---|---|---|
| Subgrade 2 in. conduit, 3 conductors, installed | ft | 10 | 5500 | $ 55,000 |

**Task 8 Subcontractor Treatment System Building & Equipment Installation $ 608,850**

| **Treatment System** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 518,650** | (incl 10% markup) |
|---|---|---|---|---|---|---|
| Water piping | lump | 45000 | 1 | $ 45,000 | | |
| Concrete foundation | lump | 30000 | 1 | $ 30,000 | | |
| Sump pump | lump | 10000 | 1 | $ 10,000 | | |
| Bag filter, install, piping | lump | 10000 | 1 | $ 10,000 | | |
| Eye wash | lump | 3000 | 1 | $ 3,000 | | |
| Transformer pad & service | lump | 8000 | 1 | $ 8,000 | | |
| Building electrical | lump | 60000 | 1 | $ 60,000 | | |
| Lightening protection | lump | 7500 | 1 | $ 7,500 | | |
| Building (32 ft x 32 ft), split block, metal roof | lump | 170000 | 1 | $ 170,000 | | |
| Site prep, grading | lump | 10000 | 1 | $ 10,000 | | |
| 6-in. gravel base course | lump | 14000 | 1 | $ 14,000 | | |
| Chemical injection system | lump | 9000 | 1 | $ 9,000 | | |
| 10,000 lb carbon vessels | ea | 39000 | 2 | $ 78,000 | | |
| Carbon vessels install, piping | lump | 5000 | 1 | $ 5,000 | | |
| 4000 gal. head tank, poly | lump | 7000 | 1 | $ 7,000 | | |
| Transfer pumps, 10 hp duplex operation | set | 5000 | 1 | $ 5,000 | | |

| **Cañon de Valle Head Tank & Shed** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 90,200** | (incl 10% markup) |
|---|---|---|---|---|---|---|
| Site prep, grading | lump | 5000 | 1 | $ 5,000 | | |
| 6-in. gravel base course | lump | 8000 | 1 | $ 8,000 | | |
| Concrete foundation | lump | 12000 | 1 | $ 12,000 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Building, split block, metal roof | lump | 25000 | 1 | $ 25,000 | | |
| 4000 gal. head tank, poly | lump | 7000 | 1 | $ 7,000 | | |
| Transfer pumps, 10 hp duplex operation | set | 5000 | 1 | $ 5,000 | | |
| Electrical | lump | 15000 | 1 | $ 15,000 | | |
| Transformer pad & service | lump | 5000 | 1 | $ 5,000 | | |
| **Task 9 Site Restoration** | | | | | | **$ 31,063** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 6,250** | |
| LANL Project Manager | | 300 | 4 | $ 1,200 | | |
| Project Manager | | 130 | 10 | $ 1,300 | | |
| Junior Engineer | | 75 | 50 | $ 3,750 | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 15,875** | |
| Field Supervisor | | 70 | 50 | $ 3,500 | | |
| Field Equipment Operator | | 50 | 50 | $ 2,500 | | |
| Field Driver | | 45 | 50 | $ 2,250 | | |
| Field Technician | | 45 | 50 | $ 2,250 | | |
| Field Laborer | | 35 | 50 | $ 1,750 | | |
| Field Craft Labor | | 50 | 50 | $ 2,500 | | |
| Field Equipment Operator - PT | | 25 | 10 | $ 250 | | |
| Field Driver - PT | | 22.5 | 10 | $ 225 | | |
| Field Technician - PT | | 22.5 | 10 | $ 225 | | |
| Field Laborer - PT | | 17.5 | 10 | $ 175 | | |
| Field Craft Labor - PT | | 25 | 10 | $ 250 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 3,938** | |
| Backhoe | mo | 4152 | 0.25 | $ 1,038 | | |
| Dump Truck | mo | 7200 | 0.25 | $ 1,800 | | |
| Truck | mo | 400 | 0.25 | $ 100 | | |
| Fuel, oil, & maintenance | mo | 4000 | 0.25 | $ 1,000 | | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 5,000** | |
| Reseed & stabilize materials | lump | 5000 | 1 | $ 5,000 | | |
| **Task 10 Waste Management** | | | | | | **$ 21,280** |

# Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 9,280** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 4 | $ 1,200 | |
| LANL Health & Safety Supervisor | 200 | 4 | $ 800 | |
| Project Manager | 130 | 4 | $ 520 | |
| Project Engineer | 85 | 40 | $ 3,400 | |
| Junior Engineer | 75 | 40 | $ 3,000 | |
| Administrative Assistant | 45 | 8 | $ 360 | |

| **Soil Disposal** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 10,400** |
|---|---|---|---|---|---|
| Contaminated soil disposal | ton | 52 | 200 | $ 10,400 | |

| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 1,600** |
|---|---|---|---|---|---|
| Soil analytical | ea | 160 | 10 | $ 1,600 | |

**Task 11 Demobilization** **$ 15,540**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 8,000** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 4 | $ 1,200 | |
| LANL Health & Safety Supervisor | 200 | 2 | $ 400 | |
| Project Manager | 130 | 8 | $ 1,040 | |
| Senior Engineer | 110 | 16 | $ 1,760 | |
| Project Engineer | 85 | 16 | $ 1,360 | |
| Administrative Assistant | 45 | 40 | $ 1,800 | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 7,540** |
|---|---|---|---|---|
| Field Supervisor | 70 | 16 | $ 1,120 | |
| Field Engineer | 75 | 16 | $ 1,200 | |
| Field Equipment Operator | 50 | 16 | $ 800 | |
| Field Driver | 45 | 16 | $ 720 | |
| Field Technician | 45 | 16 | $ 720 | |
| Field Laborer | 35 | 16 | $ 560 | |
| Field Craft Labor | 50 | 16 | $ 800 | |
| Field Electrician | 65 | 16 | $ 1,040 | |
| Field Equipment Operator - PT | 25 | 4 | $ 100 | |
| Field Driver - PT | 22.5 | 4 | $ 90 | |
| Field Technician - PT | 22.5 | 4 | $ 90 | |
| Field Laborer - PT | 17.5 | 4 | $ 70 | |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Field Craft Labor - PT | | 25 | 4 | $ | 100 | | | | |
| Field Electrician - PT | | 32.5 | 4 | $ | 130 | | | | |
| | | | | | | | | | |
| **Task 12 Asbuilts** | | | | | | | | **$** | **25,440** |
| | | | | | | | | | |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **25,440** | | |
| LANL Project Manager | | 300 | 8 | $ | 2,400 | | | | |
| Project Manager | | 130 | 8 | $ | 1,040 | | | | |
| Senior Engineer | | 110 | 80 | $ | 8,800 | | | | |
| Project Engineer | | 85 | 80 | $ | 6,800 | | | | |
| Draftsman | | 80 | 80 | $ | 6,400 | | | | |
| | | | | | | | | | |
| **Task 13 First Month Operation** | | | | | | | | **$** | **78,480** |
| | | | | | | | | | |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **26,880** | | |
| LANL Project Manager | | 300 | 16 | $ | 4,800 | | | | |
| LANL Health & Safety Supervisor | | 200 | 8 | $ | 1,600 | | | | |
| Project Manager | | 130 | 8 | $ | 1,040 | | | | |
| Senior Engineer | | 110 | 80 | $ | 8,800 | | | | |
| Project Engineer | | 85 | 120 | $ | 10,200 | | | | |
| Cost/Schedule Engineer | | 55 | 8 | $ | 440 | | | | |
| | | | | | | | | | |
| **Field Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **23,600** | | |
| Field Engineer | | 75 | 80 | $ | 6,000 | | | | |
| Field Technician | | 45 | 200 | $ | 9,000 | | | | |
| Field Laborer | | 35 | 200 | $ | 7,000 | | | | |
| Field Technician - PT | | 22.5 | 40 | $ | 900 | | | | |
| Field Laborer - PT | | 17.5 | 40 | $ | 700 | | | | |
| | | | | | | | | | |
| **Other** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **28,000** | | |
| LANL full suite analytical | ea | 2000 | 14 | $ | 28,000 | | | | |
| | | | | | | | | | |
| **Task 14 Project Administration** | | | | | | | | **$** | **26,800** |
| | | | | | | | | | |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **26,800** | | |
| LANL Project Manager | | 300 | 40 | $ | 12,000 | | | | |
| Program Manager | | 200 | 8 | $ | 1,600 | | | | |
| Project Manager | | 130 | 40 | $ | 5,200 | | | | |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | |
|---|---|---|---|---|
| Administrative Assistant | 45 | 80 | $ | 3,600 |
| Cost/Schedule Engineer | 55 | 80 | $ | 4,400 |

**Phase IV Operations & Maintenance yr 4-33, per yr** **$ 459,700**

**Task 1 yrly Operations & Maintenance & Reporting** **$ 459,700**

| **Office Labor** | **Rate** | **Hours** | | **Subtotal** | **$** | **55,100** |
|---|---|---|---|---|---|---|
| LANL Project Manager | 300 | 96 | $ | 28,800 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ | 1,600 | | |
| Project Manager | 130 | 48 | $ | 6,240 | | |
| Senior Engineer | 110 | 48 | $ | 5,280 | | |
| Project Engineer | 85 | 96 | $ | 8,160 | | |
| Word Processor | 55 | 4 | $ | 220 | | |
| Administrative Assistant | 45 | 48 | $ | 2,160 | | |
| Cost/Schedule Engineer | 55 | 48 | $ | 2,640 | | |

| **Field Labor** | **Rate** | **Hours** | | **Subtotal** | **$** | **149,760** |
|---|---|---|---|---|---|---|
| Field Engineer | 75 | 1248 | $ | 93,600 | | |
| Field Technician | 45 | 1248 | $ | 56,160 | | |

| **Other** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **254,840** |
|---|---|---|---|---|---|---|---|
| LANL full suite analytical | ea | 2000 | 24 | $ | 48,000 | | |
| Bag filters | ea | 3.5 | 240 | $ | 840 | | |
| Polyphosphate | drum | 500 | 36 | $ | 18,000 | | |
| Carbon change, with disposal | lb | 2 | 40000 | $ | 80,000 | | |
| Electrical | kwh | 0.12 | 900000 | $ | 108,000 | | |

**Phase IV Monitoring, Sampling & Reporting (per yr, yrs 4-33)** **$ 93,700**

**Task 1 Safety Plan (existing)**

**Task 2 Field Sampling** **$ 93,700**

| **Office Labor** | **Rate** | **Hours** | | **Subtotal** | **$** | **34,400** |
|---|---|---|---|---|---|---|
| LANL Project Manager | 300 | 16 | $ | 4,800 | | |
| Project Manager | 130 | 24 | $ | 3,120 | | |
| Senior Engineer | 110 | 80 | $ | 8,800 | | |
| Senior Scientist | 125 | 16 | $ | 2,000 | | |
| Junior Scientist | 75 | 160 | $ | 12,000 | | |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | | | |
|---|---|---|---|---|---|
| Draftsman | | 80 | 24 | $ 1,920 | |
| Word Processor | | 55 | 24 | $ 1,320 | |
| Cost/Schedule Engineer | | 55 | 8 | $ 440 | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 18,400** |
| Field Supervisor | | 70 | 160 | $ 11,200 | |
| Field Technician | | 45 | 160 | $ 7,200 | |
| **Equipment** | | **Rate** | **mo** | **Subtotal** | **$ 900** |
| Truck | | 400 | 1 | $ 400 | |
| Field Analytical Equipment | | 500 | 1 | $ 500 | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 40,000** |
| LANL full suite analytical | ea | 2000 | 20 | $ 40,000 | |

**Summary**

| **Phase** | **Subtotal** | **NMGRT** | **Total** |
|---|---|---|---|
| Phase I RW-4 Installation & Pump Test (yr 1) | $ 442,750 | $ 25,735 | $ 468,485 |
| Phase II Final Design & permitting (yr 2) | $ 320,380 | $ 18,622 | $ 339,002 |
| Phase III Installation (yr 3) | $ 2,876,978 | $ 167,224 | $ 3,044,203 |
| Phase IV O&M yr 4-33, per yr | $ 459,700 | $ 26,720 | $ 486,420 |
| Phase V Monitoring, Sampling & Reporting, per yr | $ 93,700 | $ 5,446 | $ 99,146 |

| | |
|---|---|
| **Capital Installation Cost** | **$ 3,851,689** |
| **30 yr O&M Costs (NPV)** | **$ 13,738,202** |
| **Total Cost (NPV)** | **$ 17,589,892** |

**30 yr NPV Calculation**

Discount Rate = 4.50%

| **yr** | **Incurred Cost** | **Divisor** | **Subtotal** |
|---|---|---|---|
| 1 | $ 585,566 | 1.045 | $ 560,351 |
| 2 | $ 603,133 | 1.092025 | $ 552,307 |
| 3 | $ 621,227 | 1.141166125 | $ 544,379 |
| 4 | $ 639,864 | 1.192518601 | $ 536,565 |
| 5 | $ 659,060 | 1.246181938 | $ 528,863 |
| 6 | $ 678,832 | 1.302260125 | $ 521,272 |
| 7 | $ 699,197 | 1.36086183 | $ 513,790 |
| 8 | $ 720,173 | 1.422100613 | $ 506,415 |

## Table B-4
## Alternative I Intermediate Groundwater Recovery with Injection of Treated Water

| | | | |
|---|---|---|---|
| 9 | $ 741,778 | 1.48609514 | $ 499,146 |
| 10 | $ 764,031 | 1.552969422 | $ 491,981 |
| 11 | $ 786,952 | 1.622853046 | $ 484,919 |
| 12 | $ 810,561 | 1.695881433 | $ 477,958 |
| 13 | $ 834,878 | 1.772196097 | $ 471,098 |
| 14 | $ 859,924 | 1.851944922 | $ 464,336 |
| 15 | $ 885,722 | 1.935282443 | $ 457,670 |
| 16 | $ 912,293 | 2.022370153 | $ 451,101 |
| 17 | $ 939,662 | 2.11337681 | $ 444,626 |
| 18 | $ 967,852 | 2.208478766 | $ 438,244 |
| 19 | $ 996,888 | 2.307860311 | $ 431,953 |
| 20 | $ 1,026,794 | 2.411714025 | $ 425,753 |
| 21 | $ 1,057,598 | 2.520241156 | $ 419,642 |
| 22 | $ 1,089,326 | 2.633652008 | $ 413,618 |
| 23 | $ 1,122,006 | 2.752166348 | $ 407,681 |
| 24 | $ 1,155,666 | 2.876013834 | $ 401,829 |
| 25 | $ 1,190,336 | 3.005434457 | $ 396,061 |
| 26 | $ 1,226,046 | 3.140679007 | $ 390,376 |
| 27 | $ 1,262,827 | 3.282009562 | $ 384,773 |
| 28 | $ 1,300,712 | 3.429699993 | $ 379,250 |
| 29 | $ 1,339,734 | 3.584036492 | $ 373,806 |
| 30 | $ 1,379,926 | 3.745318135 | $ 368,440 |
| | | | $ 13,738,202 |

| | |
|---|---|
| FOM | Fuel, oil and maintenance |
| GAC | Granular activated carbon |
| HDPE | High-density polyethylene |
| HE | High explosives |
| LANL | Los Alamos National |
| MDA | Material disposal area |
| NMGRT | New Mexioco Gross Reciepts Tax |
| NPV | Net present value |
| O&M | Operations & Maintenance |
| PNM | Public Service Company of New Mexico |
| PT | Premium time (overtime) |
| SVOC | Semivolatile organic compound |
| TDH | Total dynamic head |
| UOM | Unit of Measure |
| VOC | Volatile organic compound |

# Table B-5
# Alternative II Regional Groundwater Recovery with Injection of Treated Water

**Assumptions**

1. Recovery/injection system consists of 4 recovery & 4 injection wells.
2. Recovery & injection wells are 1300 ft in total depth, with 100 ft of screen.
3. A 48-h (24-h pump/24-h recovery) test will be performed on one recovery well prior to the final design.
4. Pump test flow rate is 50 gal./min, with frac tank containment, GAC treatment, & dust suppression recycle of treated water.
5. Treatment system building is 32 ft x 32 ft & will be constructed near MDA P.
6. Clearing & grubbing for unimproved road installation will be require in Cañon de Valle & on the mesa.
7. Treatment system consists of water conditioning with polyphosphate, GAC & bag filters
8. GAC vessels consist of two 10,000-lb vessels in series.
9. All subgrade piping is heat welded HDPE without secondary containment.
10. Head tank enclosed in a 144 square ft shed is installed in Cañon de Valle for the 3 canyon wells.
11. All wellheads are installed in 4 ft x 4 ft aluminum & concrete subgrade vaults
12. Installation will require 6 months to complete.
13. All labor is local & does not incur travel costs, except for drilling.
14. Four GAC changeouts per yr (both vessels) will be completed.
15. GAC provided by vendor, who also h&les disposal/regeneration.
16. A groundwater discharge permit will be required.
17. Monthly sampling consists of influent/effluent samples & between GAC beds.
18. Analytical for O&M & semiannual sampling consists of the full LANL suite (HE, VOCs, SVOCs, metals, inorganics).
19. Treatment plant operations labor requires a full time technician and a full time field engineer.
20. Under Phase IV O&M, semiannual sampling of five monitoring wells & four recovery wells is included.
21. The discount rate for the NPV calculation is 4.5%.
22. A yearly inflation rate of 3% applies over the 30 year lifetime of the project.
23. NMGRT is 5.8125%.
24. Subcontractors are priced with a 10% markup.
25. Decommissioning and demolition costs are not included.

**Phase I RW-4 Installation & Pump Test (yr 1) $ 444,026**

**Task 1 Project Plans $ 57,630**

| Office Labor | Rate | Hours | Subtotal | $ 57,630 |
|---|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 20 | $ 2,600 | |
| Senior Engineer | 110 | 80 | $ 8,800 | |
| Project Engineer | 85 | 120 | $ 10,200 | |
| Senior Scientist | 125 | 16 | $ 2,000 | |
| Permitting Specialist | 80 | 8 | $ 640 | |
| Draftsman | 80 | 40 | $ 3,200 | |
| Word Processor | 55 | 40 | $ 2,200 | |
| Quality Assurance | 75 | 2 | $ 150 | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | |
|---|---|---|---|---|---|
| Administrative Assistant | 45 | 40 | $ 1,800 | | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | | |
| | | | | | |
| **Task 2 Safety Plan** | | | | | **$ 17,880** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 17,880** | |
| Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 4 | $ 520 | | |
| Senior Engineer | 110 | 40 | $ 4,400 | | |
| Project Engineer | 85 | 40 | $ 3,400 | | |
| Junior Engineer | 75 | 40 | $ 3,000 | | |
| Draftsman | 80 | 4 | $ 320 | | |
| Word Processor | 55 | 8 | $ 440 | | |
| Administrative Assistant | 45 | 40 | $ 1,800 | | |
| | | | | | |
| **Task 3 Readiness Review** | | | | | **$ 8,160** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | | |
| LANL Project Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 8 | $ 1,040 | | |
| Senior Engineer | 110 | 16 | $ 1,760 | | |
| Project Engineer | 85 | 16 | $ 1,360 | | |
| | | | | | |
| **Task 4 RW-4 Installation** | | | | | **$ 248,977** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 39,640** | |
| LANL Project | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 4 | $ 800 | | |
| Project Manager | 130 | 40 | $ 5,200 | | |
| Junior Scientist | 75 | 160 | $ 12,000 | | |
| Senior Engineer | 110 | 160 | $ 17,600 | | |
| Quality Assurance | 75 | 16 | $ 1,200 | | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Drilling Subcontractor** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 208,637** | (incl 10% markup) | |
| Mobilization/ Demobilization—ea rig - ARCH | EA | 6400 | 1 | $ 6,400 | | | |
| Drill & install 16-in. conductor to 20 ft | ft | 250 | 20 | $ 5,000 | | | |
| Drill to total depth—direct mud rotary | ft | 72 | 1300 | $ 93,600 | | | |
| Silt trap with welded end cap | ft | 36 | 10 | $ 360 | | | |
| 6-in. LCS Casing—0.307 wall | ft | 36 | 1200 | $ 43,200 | | | |
| Vertical mill slot screen | ft | 64 | 100 | $ 6,400 | | | |
| Furnish & install centralizers | ea | 27 | 30 | $ 810 | | | |
| Furnish & install rounded gravel filter pack | ft | 20 | 100 | $ 2,000 | | | |
| Furnish & install barrier bentonite/sand | ft | 20 | 5 | $ 100 | | | |
| Furnish & install annular seal | ft | 20 | 1200 | $ 24,000 | | | |
| above grade well protection | ea | 1200 | 1 | $ 1,200 | | | |
| Mobilization/ Demobilization: ea rig - pump | ea | 1400 | 1 | $ 1,400 | | | |
| Swab & bail only | h | 185 | 20 | $ 3,700 | | | |
| per diem | d | 220 | 3 | $ 660 | | | |
| Standby | h | 210 | 4 | $ 840 | | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 700** | | |
| Pickup | month | 400 | 0.5 | $ 200 | | | |
| Misc | | | | $ 500 | | | |
| **Task 5 Pump Test** | | | | | | | **$ 78,519** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 21,070** | | |
| Manager | | 300 | 16 | $ 4,800 | | | |

## Table B-5

## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LANL Health & Safety Supervisor | | 200 | 2 | $ | 400 | | | |
| Project Manager | | 130 | 8 | $ | 1,040 | | | |
| Project Engineer | | 85 | 40 | $ | 3,400 | | | |
| Senior Scientist | | 125 | 40 | $ | 5,000 | | | |
| Junior Scientist | | 75 | 80 | $ | 6,000 | | | |
| permitting Specialist | | 80 | 4 | $ | 320 | | | |
| Cost/Schedule Engineer | | 55 | 2 | $ | 110 | | | |
| | | | | | | | | |
| **Field Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **7,860** | |
| Field Technician | | 45 | 80 | $ | 3,600 | | | |
| Field Craft Labor | | 50 | 40 | $ | 2,000 | | | |
| Field Electrician | | 65 | 24 | $ | 1,560 | | | |
| Field Technician - PT | | 22.5 | 20 | $ | 450 | | | |
| Field Craft Labor - PT | | 25 | 10 | $ | 250 | | | |
| | | | | | | | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **10,439** | (incl 10% markup) |
| Submersible pump rental | month | 2500 | 1 | $ | 2,500 | | | |
| Frac tank rental for pump test | month | 4000 | 1 | $ | 4,000 | | | |
| Carbon vessels for pump test, 2 vessels | month | 1740 | 1 | $ | 1,740 | | | |
| Pickup | month | 400 | 1 | $ | 400 | | | |
| Generator | week | 350 | 1 | $ | 350 | | | |
| Misc | | | | $ | 500 | | | |
| | | | | | | | | |
| **Materials** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **12,000** | |
| GAC Disposal | lb | 500 | 5 | $ | 2,500 | | | |
| 4-inch threaded pipe, galvanized Sch 40 | ft | 1000 | 6.5 | $ | 6,500 | | | |
| Data logger with pressure transducers | week | 2500 | 1 | $ | 2,500 | | | |
| Misc | | | | $ | 500 | | | |
| | | | | | | | | |
| **Other** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **27,150** | |
| LANL full suite analytical | ea | 2000 | 10 | $ | 20,000 | | | |
| Drill rig & crew (set & pull pump) | lump | 6500 | 1 | $ | 7,150 | (incl 10% markup) | | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

**Task 6 Field Summary Report** $ 32,860

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 32,860** |
|---|---|---|---|---|
| Manager | 300 | 16 | $ 4,800 | |
| Project Manager | 130 | 8 | $ 1,040 | |
| Senior Scientist | 125 | 80 | $ 10,000 | |
| Junior Engineer | 75 | 160 | $ 12,000 | |
| Draftsman | 80 | 40 | $ 3,200 | |
| Word Processor | 55 | 24 | $ 1,320 | |
| Quality Assurance | 75 | 4 | $ 300 | |
| Administrative Assistant | 45 | 2 | $ 90 | |
| Cost/Schedule Engineer | 55 | 2 | $ 110 | |

**Phase II Final Design & permitting (yr 2)** $ 320,380

**Task 1 Final Design** $ 254,400

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| Manager | 300 | 80 | $ 24,000 |
| LANL Health & Safety Supervisor | 200 | 16 | $ 3,200 |
| Project Manager | 130 | 160 | $ 20,800 |
| Senior Engineer | 110 | 480 | $ 52,800 |
| Project Engineer | 85 | 480 | $ 40,800 |
| Junior Engineer | 75 | 480 | $ 36,000 |
| LANL NEPA Specialist | 200 | 80 | $ 16,000 |
| Permitting Specialist | 80 | 160 | $ 12,800 |
| Draftsman | 80 | 320 | $ 25,600 |
| Word Processor | 55 | 160 | $ 8,800 |
| Quality Assurance | 75 | 80 | $ 6,000 |
| Administrative Assistant | 45 | 120 | $ 5,400 |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 |

**Task 2 Final Design Cost Estimate** $ 44,780

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| LANL Project | 300 | 8 | $ 2,400 |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | | |
| Senior Engineer | 110 | 160 | $ 17,600 | | | |
| Project Engineer | 85 | 160 | $ 13,600 | | | |
| Junior Engineer | 75 | 80 | $ 6,000 | | | |
| Quality Assurance | 75 | 16 | $ 1,200 | | | |
| Administrative Assistant | 45 | 4 | $ 180 | | | |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 | | | |
| **Task 3 Project Administration** | | | | | **$ 21,200** | |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | | | |
| LANL Project | 300 | 40 | $ 12,000 | | | |
| Project Manager | 130 | 40 | $ 5,200 | | | |
| Administrative Assistant | 45 | 40 | $ 1,800 | | | |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 | | | |
| **Phase III Installation (yr 3)** | | | | | | **$ 2,894,221** |
| **Task 1 Installation Plan** | | | | | **$ 52,620** | |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 52,620** | | |
| Manager | 300 | 40 | $ 12,000 | | | |
| Program Manager | 200 | 4 | $ 800 | | | |
| Project Manager | 130 | 8 | $ 1,040 | | | |
| Senior Engineer | 110 | 160 | $ 17,600 | | | |
| Project Engineer | 85 | 160 | $ 13,600 | | | |
| Draftsman | 80 | 40 | $ 3,200 | | | |
| Word Processor | 55 | 16 | $ 880 | | | |
| Quality Assurance | 75 | 8 | $ 600 | | | |
| Administrative Assistant | 45 | 40 | $ 1,800 | | | |
| Cost/Schedule Engineer | 55 | 20 | $ 1,100 | | | |
| **Task 2 Safety Plan** | | | | | **$ 11,040** | |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 11,040** | | |
| Manager | 300 | 8 | $ 2,400 | | | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | |
|---|---|---|---|---|---|
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 8 | $ 1,040 | | |
| Senior Engineer | 110 | 8 | $ 880 | | |
| Project Engineer | 85 | 16 | $ 1,360 | | |
| Junior Engineer | 75 | 40 | $ 3,000 | | |
| Draftsman | 80 | 4 | $ 320 | | |
| Word Processor | 55 | 8 | $ 440 | | |
| **Task 3 Training** | | | | | **$ 8,700** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 5,220** | |
| Manager | 300 | 4 | $ 1,200 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 2 | $ 260 | | |
| Senior Engineer | 110 | 8 | $ 880 | | |
| Project Engineer | 85 | 8 | $ 680 | | |
| Junior Engineer | 75 | 8 | $ 600 | | |
| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 3,480** | |
| Field Supervisor | 70 | 8 | $ 560 | | |
| Field Engineer | 75 | 8 | $ 600 | | |
| Field Equipment Operator | 50 | 8 | $ 400 | | |
| Field Driver | 45 | 8 | $ 360 | | |
| Field Technician | 45 | 8 | $ 360 | | |
| Field Laborer | 35 | 8 | $ 280 | | |
| Field Craft Labor | 50 | 8 | $ 400 | | |
| Field Electrician | 65 | 8 | $ 520 | | |
| **Task 4 Readiness Review** | | | | | **$ 6,400** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 6,400** | |
| Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 8 | $ 1,040 | | |
| Project Engineer | 85 | 16 | $ 1,360 | | |
| **Task 5 Road Installation (Mesa & Cañon de Valle)** | | | | | **$ 90,114** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 37,200** | |
| Manager | 300 | 8 | $ 2,400 | | |

# Table B-5

## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| LANL Health & Safety Supervisor | | 200 | 8 | $ | 1,600 | | | |
| Project Manager | | 130 | 40 | $ | 5,200 | | | |
| Senior Engineer | | 110 | 40 | $ | 4,400 | | | |
| Project Engineer | | 85 | 160 | $ | 13,600 | | | |
| Junior Engineer | | 75 | 80 | $ | 6,000 | | | |
| Administrative Assistant | | 45 | 40 | $ | 1,800 | | | |
| Cost/Schedule Engineer | | 55 | 40 | $ | 2,200 | | | |
| **Field Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **41,025** | |
| Field Supervisor | | 70 | 120 | $ | 8,400 | | | |
| Field Engineer | | 75 | 120 | $ | 9,000 | | | |
| Field Equipment Operator | | 50 | 120 | $ | 6,000 | | | |
| Field Driver | | 45 | 120 | $ | 5,400 | | | |
| Field Technician | | 45 | 120 | $ | 5,400 | | | |
| Field Laborer | | 35 | 120 | $ | 4,200 | | | |
| Field Equipment Operator - PT | | 25 | 30 | $ | 750 | | | |
| Field Driver - PT | | 22.5 | 30 | $ | 675 | | | |
| Field Technician - PT | | 22.5 | 30 | $ | 675 | | | |
| Field Laborer - PT | | 17.5 | 30 | $ | 525 | | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **11,889** | |
| Backhoe | month | 4152 | 0.75 | $ | 3,114 | | | |
| Grader | month | 4100 | 0.75 | $ | 3,075 | | | |
| Pickup | month | 400 | 0.75 | $ | 300 | | | |
| Dump truck | month | 7200 | 0.75 | $ | 5,400 | | | |
| **Task 6 Recovery/Injection Well Installation** | | | | | | | | **$ 1,467,681** |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **60,440** | |
| Manager | | 300 | 40 | $ | 12,000 | | | |
| LANL Health & Safety Supervisor | | 200 | 40 | $ | 8,000 | | | |
| Project Manager | | 130 | 80 | $ | 10,400 | | | |
| Junior Scientist | | 75 | 320 | $ | 24,000 | | | |
| Senior Engineer | | 110 | 40 | $ | 4,400 | | | |
| Quality Assurance | | 75 | 16 | $ | 1,200 | | | |
| Cost/Schedule Engineer | | 55 | 8 | $ | 440 | | | |

# Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| **Drilling Subcontractor** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 1,407,241** | (incl 10% markup) |
|---|---|---|---|---|---|---|
| Mobilization/ Demobilization—ea rig - ARCH | ea | 6400 | 1 | $ 6,400 | | |
| Drill & install 16-in. conductor to 20 ft | ft | 250 | 140 | $ 35,000 | | |
| Drill to total depth—direct mud rotary | ft | 72 | 9100 | $ 655,200 | | |
| Silt trap with welded end cap | ft | 36 | 70 | $ 2,520 | | |
| 6-in. LCS Casing—0.307 wall | ft | 36 | 8400 | $ 302,400 | | |
| Vertical mill slot screen | ft | 64 | 700 | $ 44,800 | | |
| Furnish & install centralizers | ea | 27 | 70 | $ 1,890 | | |
| Furnish & install rounded gravel filter pack | ft | 20 | 700 | $ 14,000 | | |
| Furnish & install barrier bentonite/sand | ft | 20 | 35 | $ 700 | | |
| Furnish & install annular seal | ft | 20 | 8400 | $ 168,000 | | |
| above grade well protection | ea | 1200 | 7 | $ 8,400 | | |
| Mobilization/ Demobilization—ea rig - pump | ea | 1400 | 2 | $ 2,800 | | |
| Swab & bail only | h | 185 | 40 | $ 7,400 | | |
| per diem | d | 220 | 40 | $ 8,800 | | |
| Set pumps & piping | h | 210 | 80 | $ 16,800 | | |
| Standby | h | 210 | 20 | $ 4,200 | | |

**Task 7 Subsurface Installation** **$ 450,213**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 91,200** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 | |
| LANL Health & Safety Supervisor | 200 | 40 | $ 8,000 | |
| Project Manager | 130 | 80 | $ 10,400 | |
| Senior Engineer | 110 | 160 | $ 17,600 | |

# Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Project Engineer | | 85 | 160 | $ 13,600 | | |
| Junior Engineer | | 75 | 80 | $ 6,000 | | |
| Administrative Assistant | | 45 | 160 | $ 7,200 | | |
| Cost/Schedule Engineer | | 55 | 80 | $ 4,400 | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 202,800** | |
| Field Supervisor | | 70 | 480 | $ 33,600 | | |
| Field Engineer | | 75 | 480 | $ 36,000 | | |
| Field Equipment Operator | | 50 | 480 | $ 24,000 | | |
| Field Driver | | 45 | 480 | $ 21,600 | | |
| Field Technician | | 45 | 480 | $ 21,600 | | |
| Field Laborer | | 35 | 480 | $ 16,800 | | |
| Field Craft Labor | | 50 | 480 | $ 24,000 | | |
| Field Electrician | | 65 | 160 | $ 10,400 | | |
| Field Equipment Operator - PT | | 25 | 120 | $ 3,000 | | |
| Field Driver - PT | | 22.5 | 120 | $ 2,700 | | |
| Field Technician - PT | | 22.5 | 120 | $ 2,700 | | |
| Field Laborer - PT | | 17.5 | 120 | $ 2,100 | | |
| Field Craft Labor - PT | | 25 | 120 | $ 3,000 | | |
| Field Electrician - PT | | 32.5 | 40 | $ 1,300 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 156,213** | (incl 10% markup) |
| Backhoe | month | 4152 | 3 | $ 12,456 | | |
| Backhoe | month | 4152 | 3 | $ 12,456 | | |
| Pickup | month | 400 | 3 | $ 1,200 | | |
| Dump truck | month | 7200 | 3 | $ 21,600 | | |
| Generator | month | 350 | 3 | $ 1,050 | | |
| Compactor | month | 550 | 3 | $ 1,650 | | |
| HDPE fusion machine | month | 1200 | 3 | $ 3,600 | | |
| FOM | month | 4000 | 3 | $ 12,000 | | |
| Submersible pump | ea | 15000 | 4 | $ 60,000 | | |
| Pump variable frequency drive | ea | 4000 | 4 | $ 16,000 | | |
| **Materials** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 188,485** | (incl 10% markup) |
| 4-inch HDPE, SDR 11 | ft | 2.5 | 15000 | $ 37,500 | | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | |
|---|---|---|---|---|---|
| 4-inch threaded pipe, galvanized Sch 40 | ft | 6.5 | 3900 | $ | 25,350 |
| 4-inch fittings | well | 1000 | 4 | $ | 4,000 |
| 6-inch HDPE, SDR 11 | ft | 3.5 | 1000 | $ | 3,500 |
| Aluminum vault enclosure doors 4x4 | ea | 3500 | 8 | $ | 28,000 |
| Recovery well vaults, precast, 4x4x4 | ea | 1500 | 8 | $ | 12,000 |
| Backfill, engineered | ton | 15 | 400 | $ | 6,000 |
| conduit, 3 conductors, | ft | 10 | 5500 | $ | 55,000 |

**Task 8 Subcontractor Treatment System Building & Equipment** **$ 608,850**

| **Treatment System** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **518,650** | (incl 10% markup) |
|---|---|---|---|---|---|---|---|---|
| Water piping | lump | 45000 | 1 | $ | 45,000 | | | |
| Concrete foundation | lump | 30000 | 1 | $ | 30,000 | | | |
| Sump pump | lump | 10000 | 1 | $ | 10,000 | | | |
| Bag filter, install, piping | lump | 10000 | 1 | $ | 10,000 | | | |
| Eye wash | lump | 3000 | 1 | $ | 3,000 | | | |
| Transformer pad & service | lump | 8000 | 1 | $ | 8,000 | | | |
| Building electrical | lump | 60000 | 1 | $ | 60,000 | | | |
| Lightening protection | lump | 7500 | 1 | $ | 7,500 | | | |
| Building (32 ft x 32 ft), split block, metal roof | lump | 170000 | 1 | $ | 170,000 | | | |
| Site prep, grading | lump | 10000 | 1 | $ | 10,000 | | | |
| 6-in. gravel base course | lump | 14000 | 1 | $ | 14,000 | | | |
| Chemical injection system | lump | 9000 | 1 | $ | 9,000 | | | |
| 10,000 lb carbon vessels | ea | 39000 | 2 | $ | 78,000 | | | |
| Carbon vessels install, piping | lump | 5000 | 1 | $ | 5,000 | | | |
| 4000 gal. head tank, poly | lump | 7000 | 1 | $ | 7,000 | | | |

# Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Transfer pumps, 10 hp duplex operation | set | 5000 | 1 | $ 5,000 | | |

| **Cañon de Valle Head Tank & Shed** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 90,200** | (incl 10% markup) |
|---|---|---|---|---|---|---|
| Site prep, grading | lump | 5000 | 1 | $ 5,000 | | |
| 6-inch gravel base course | lump | 8000 | 1 | $ 8,000 | | |
| Concrete foundation | lump | 12000 | 1 | $ 12,000 | | |
| Building, split block, metal roof | lump | 25000 | 1 | $ 25,000 | | |
| 4000 gallon head tank, poly | lump | 7000 | 1 | $ 7,000 | | |
| Transfer pumps, 10 hp duplex operation | set | 5000 | 1 | $ 5,000 | | |
| Electrical | lump | 15000 | 1 | $ 15,000 | | |
| Transformer pad & service | lump | 5000 | 1 | $ 5,000 | | |

**Task 9 Site Restoration** **$ 31,063**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 6,250** |
|---|---|---|---|---|
| Manager | 300 | 4 | $ 1,200 | |
| Project Manager | 130 | 10 | $ 1,300 | |
| Junior Engineer | 75 | 50 | $ 3,750 | |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 15,875** |
|---|---|---|---|---|
| Field Supervisor | 70 | 50 | $ 3,500 | |
| Field Equipment Operator | 50 | 50 | $ 2,500 | |
| Field Driver | 45 | 50 | $ 2,250 | |
| Field Technician | 45 | 50 | $ 2,250 | |
| Field Laborer | 35 | 50 | $ 1,750 | |
| Field Craft Labor | 50 | 50 | $ 2,500 | |
| Field Equipment Operator - PT | 25 | 10 | $ 250 | |
| Field Driver - PT | 22.5 | 10 | $ 225 | |
| Field Technician - PT | 22.5 | 10 | $ 225 | |
| Field Laborer - PT | 17.5 | 10 | $ 175 | |
| Field Craft Labor - PT | 25 | 10 | $ 250 | |

| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 3,938** |
|---|---|---|---|---|---|

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Backhoe | month | 4152 | 0.25 | $ 1,038 | | |
| Dump Truck | month | 7200 | 0.25 | $ 1,800 | | |
| Truck | month | 400 | 0.25 | $ 100 | | |
| FOM | month | 4000 | 0.25 | $ 1,000 | | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 5,000** | |
| Reseed & stabilize materials | lump | 5000 | 1 | $ 5,000 | | |
| **Task 10 Waste Management** | | | | | | **$ 21,280** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 9,280** | |
| LANL Project Manager | | 300 | 4 | $ 1,200 | | |
| LANL Health & Safety Supervisor | | 200 | 4 | $ 800 | | |
| Project Manager | | 130 | 4 | $ 520 | | |
| Project Engineer | | 85 | 40 | $ 3,400 | | |
| Junior Engineer | | 75 | 40 | $ 3,000 | | |
| Administrative Assistant | | 45 | 8 | $ 360 | | |
| **Soil Disposal** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 10,400** | |
| Contaminated soil disposal | ton | 52 | 200 | $ 10,400 | | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 1,600** | |
| Soil analytical | ea | 160 | 10 | $ 1,600 | | |
| **Task 11 Demobilization** | | | | | | **$ 15,540** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 8,000** | |
| Manager | | 300 | 4 | $ 1,200 | | |
| LANL Health & Safety Supervisor | | 200 | 2 | $ 400 | | |
| Project Manager | | 130 | 8 | $ 1,040 | | |
| Senior Engineer | | 110 | 16 | $ 1,760 | | |
| Project Engineer | | 85 | 16 | $ 1,360 | | |
| Administrative Assistant | | 45 | 40 | $ 1,800 | | |
| Cost/Schedule Engineer | | 55 | 8 | $ 440 | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 7,540** | |
| Field Supervisor | | 70 | 16 | $ 1,120 | | |
| Field Engineer | | 75 | 16 | $ 1,200 | | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Field Equipment Operator | 50 | 16 | $ | 800 | | | | |
| Field Driver | 45 | 16 | $ | 720 | | | | |
| Field Technician | 45 | 16 | $ | 720 | | | | |
| Field Laborer | 35 | 16 | $ | 560 | | | | |
| Field Craft Labor | 50 | 16 | $ | 800 | | | | |
| Field Electrician | 65 | 16 | $ | 1,040 | | | | |
| Field Equipment Operator - PT | 25 | 4 | $ | 100 | | | | |
| Field Driver - PT | 22.5 | 4 | $ | 90 | | | | |
| Field Technician - PT | 22.5 | 4 | $ | 90 | | | | |
| Field Laborer - PT | 17.5 | 4 | $ | 70 | | | | |
| Field Craft Labor - PT | 25 | 4 | $ | 100 | | | | |
| Field Electrician - PT | 32.5 | 4 | $ | 130 | | | | |
| **Task 12 Asbuilts** | | | | | | | **$** | **25,440** |
| **Office Labor** | **Rate** | **Hours** | | **Subtotal** | **$** | **25,440** | | |
| LANL Project Manager | 300 | 8 | $ | 2,400 | | | | |
| Project Manager | 130 | 8 | $ | 1,040 | | | | |
| Senior Engineer | 110 | 80 | $ | 8,800 | | | | |
| Project Engineer | 85 | 80 | $ | 6,800 | | | | |
| Draftsman | 80 | 80 | $ | 6,400 | | | | |
| **Task 13 First Month Operation** | | | | | | | **$** | **78,480** |
| **Office Labor** | **Rate** | **Hours** | | **Subtotal** | **$** | **26,880** | | |
| Manager | 300 | 16 | $ | 4,800 | | | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ | 1,600 | | | | |
| Project Manager | 130 | 8 | $ | 1,040 | | | | |
| Senior Engineer | 110 | 80 | $ | 8,800 | | | | |
| Project Engineer | 85 | 120 | $ | 10,200 | | | | |
| Cost/Schedule Engineer | 55 | 8 | $ | 440 | | | | |
| **Field Labor** | **Rate** | **Hours** | | **Subtotal** | **$** | **23,600** | | |
| Field Engineer | 75 | 80 | $ | 6,000 | | | | |
| Field Technician | 45 | 200 | $ | 9,000 | | | | |
| Field Laborer | 35 | 200 | $ | 7,000 | | | | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Field Technician - PT | | 22.5 | 40 | $ 900 | | | |
| Field Laborer - PT | | 17.5 | 40 | $ 700 | | | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 28,000** | | |
| LANL full suite analytical | ea | 2000 | 14 | $ 28,000 | | | |
| **Task 14 Project Administration** | | | | | | **$ 26,800** | |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 26,800** | | |
| Manager | | 300 | 40 | $ 12,000 | | | |
| Program Manager | | 200 | 8 | $ 1,600 | | | |
| Project Manager | | 130 | 40 | $ 5,200 | | | |
| Administrative Assistant | | 45 | 80 | $ 3,600 | | | |
| Cost/Schedule Engineer | | 55 | 80 | $ 4,400 | | | |
| **Phase IV Operations & Maintenance yr 4-33, per yr** | | | | | | | **$ 513,700** |
| **Task 1 yrly Operations & Maintenance & Reporting** | | | | | | **$ 513,700** | |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 55,100** | | |
| Manager | | 300 | 96 | $ 28,800 | | | |
| LANL Health & Safety Supervisor | | 200 | 8 | $ 1,600 | | | |
| Project Manager | | 130 | 48 | $ 6,240 | | | |
| Senior Engineer | | 110 | 48 | $ 5,280 | | | |
| Project Engineer | | 85 | 96 | $ 8,160 | | | |
| Word Processor | | 55 | 4 | $ 220 | | | |
| Administrative Assistant | | 45 | 48 | $ 2,160 | | | |
| Cost/Schedule Engineer | | 55 | 48 | $ 2,640 | | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 149,760** | | |
| Field Engineer | | 75 | 1248 | $ 93,600 | | | |
| Field Technician | | 45 | 1248 | $ 56,160 | | | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 308,840** | | |
| LANL full suite analytical | ea | 2000 | 24 | $ 48,000 | | | |
| bag filters | ea | 3.5 | 240 | $ 840 | | | |
| polyphosphate | drum | 500 | 36 | $ 18,000 | | | |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | | | | |
|---|---|---|---|---|
| Carbon change, with disposal | lb | 2 | 40000 | $ 80,000 |
| Electrical | kwh | 0.12 | 1.35E+06 | $ 162,000 |

**Phase IV Monitoring, Sampling & Reporting (per yr, yrs 4-33) $ 93,700**

**Task 1 Safety Plan (existing)**

**Task 2 Field Sampling $ 93,700**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 34,400** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 16 | $ 4,800 | |
| Project Manager | 130 | 24 | $ 3,120 | |
| Senior Engineer | 110 | 80 | $ 8,800 | |
| Senior Scientist | 125 | 16 | $ 2,000 | |
| Junior Scientist | 75 | 160 | $ 12,000 | |
| Draftsman | 80 | 24 | $ 1,920 | |
| Word Processor | 55 | 24 | $ 1,320 | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 18,400** |
|---|---|---|---|---|
| Field Supervisor | 70 | 160 | $ 11,200 | |
| Field Technician | 45 | 160 | $ 7,200 | |

| **Equipment** | **Rate** | **Month** | **Subtotal** | **$ 900** |
|---|---|---|---|---|
| Truck | 400 | 1 | $ 400 | |
| Field Analytical Equipment | 500 | 1 | $ 500 | |

| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 40,000** |
|---|---|---|---|---|---|
| LANL full suite analytical | ea | 2000 | 20 | $ 40,000 | |

**Summary**

| **Phase** | **Subtotal** | **NMGRT** | **Total** |
|---|---|---|---|
| Phase I RW-4 Installation & Pump Test (yr 1) | $ 444,026 | $ 25,809 | $ 469,835 |
| Phase II Final Design & permitting (yr 2) | $ 320,380 | $ 18,622 | $ 339,002 |
| Phase III Installation (yr 3) | $ 2,894,221 | $ 168,227 | $ 3,062,448 |
| Phase IV O&M yr 4-33, per yr | $ 513,700 | $ 29,859 | $ 543,559 |
| Phase V Monitoring, Sampling & Reporting, per yr | $ 93,700 | $ 5,446 | $ 99,146 |

## Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | |
|---|---|
| **Capital Installation Cost** | **$ 3,871,285** |
| **30 yr O&M Costs (NPV)** | **$ 15,078,757** |
| | |
| **Total Cost (NPV)** | **$ 18,950,042** |

**30 yr NPV Calculation**

Discount Rate = 4.50%

| yr | Incurred Cost | Divisor | Subtotal |
|---|---|---|---|
| 1 | $ 642,705 | 1.045 | $ 615,029 |
| 2 | $ 661,986 | 1.092025 | $ 606,201 |
| 3 | $ 681,846 | 1.141166125 | $ 597,499 |
| 4 | $ 702,301 | 1.192518601 | $ 588,923 |
| 5 | $ 723,370 | 1.246181938 | $ 580,469 |
| 6 | $ 745,071 | 1.302260125 | $ 572,137 |
| 7 | $ 767,424 | 1.36086183 | $ 563,925 |
| 8 | $ 790,446 | 1.422100613 | $ 555,830 |
| 9 | $ 814,160 | 1.48609514 | $ 547,852 |
| 10 | $ 838,584 | 1.552969422 | $ 539,988 |
| 11 | $ 863,742 | 1.622853046 | $ 532,237 |
| 12 | $ 889,654 | 1.695881433 | $ 524,597 |
| 13 | $ 916,344 | 1.772196097 | $ 517,067 |
| 14 | $ 943,834 | 1.851944922 | $ 509,645 |
| 15 | $ 972,149 | 1.935282443 | $ 502,329 |
| 16 | $ 1,001,314 | 2.022370153 | $ 495,119 |
| 17 | $ 1,031,353 | 2.11337681 | $ 488,012 |
| 18 | $ 1,062,294 | 2.208478766 | $ 481,007 |
| 19 | $ 1,094,162 | 2.307860311 | $ 474,103 |
| 20 | $ 1,126,987 | 2.411714025 | $ 467,297 |
| 21 | $ 1,160,797 | 2.520241156 | $ 460,590 |
| 22 | $ 1,195,621 | 2.633652008 | $ 453,978 |
| 23 | $ 1,231,489 | 2.752166348 | $ 447,462 |
| 24 | $ 1,268,434 | 2.876013834 | $ 441,039 |
| 25 | $ 1,306,487 | 3.005434457 | $ 434,708 |
| 26 | $ 1,345,682 | 3.140679007 | $ 428,468 |
| 27 | $ 1,386,052 | 3.282009562 | $ 422,318 |
| 28 | $ 1,427,634 | 3.429699993 | $ 416,256 |
| 29 | $ 1,470,463 | 3.584036492 | $ 410,281 |
| 30 | $ 1,514,577 | 3.745318135 | $ 404,392 |
| | | | |
| | | | $ 15,078,757 |

| | |
|---|---|
| FOM | Fuel, oil and maintenance |
| GAC | Granular |
| HDPE | High-density polyethylene |
| HE | High explosives |
| LANL | Los Alamos National |
| MDA | Material disposal area |
| NMGRT | New Mexioco Gross Reciepts Tax |

# Table B-5
## Alternative II Regional Groundwater Recovery with Injection of Treated Water

| | |
|---|---|
| NPV | Net present value |
| O&M | Operations & Maintenance |
| PNM | Public Service Company of New Mexico |
| PT | Premium time (overtime) |
| SVOC | Semivolatile organic compound |
| TDH | Total dynamic head |
| UOM | Unit of Measure |
| VOC | Volatile organic compound |

# Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

**Assumptions**

1. Recovery/injection system consists of 8 recovery & 8 injection wells (4 of ea in ea zone).
2. Intermediate recovery & injection wells are 1200 ft in total depth (400 ft of screen).
3. Regional recovery & injection wells are 1300 ft in total depth (100 ft of screen).
4. A 48-h (24-h pump/24-h recovery) test will be performed on one recovery well in ea zone prior to the final design.
5. Pump test flow rate is 50 gal./min, with frac tank containment, GAC treatment, & dust suppression recycle of treated water.
6. Groundwater treatment system baseline flowrate is 300 gal./min from ea zone, with a maximum flowrate of 700 gal./min
7. Treatment system building is 50 ft H 50 ft & will be constructed near MDA P.
8. Clearing & grubbing for unimproved road installation will be require in Cañon de Valle & on the mesa.
9. Treatment system consists of water conditioning with polyphosphate, GAC & bag filters
10. GAC vessels consist of four 10,000-lb vessels.
11. All subgrade piping is heat welded HDPE without secondary containment.
12. Head tank enclosed in a 400-ft2 shed is installed in Cañon de Valle for the three canyon wells.
13. All wellheads are installed in 4 ft H 4 ft aluminum & concrete subgrade vaults
14. Installation will require 8 months to complete.
15. All labor is local & does not incur travel costs, except for drilling.
16. Six GAC changeouts per yr will be completed.
17. GAC provided by vendor, who also h&les disposal/regeneration.
18. A groundwater discharge permit will be required.
19. Monthly sampling consists of influent/effluent samples & between GAC beds.
20. Analytical for O&M & semiannual sampling consists of the full LANL suite (HE, VOCs, SVOCs, metals, inorganics).
21. Treatment plant operations labor requires a full time technician and a full time field engineer.
22. Under Phase IV O&M, semiannual sampling of five monitoring wells & four recovery wells is included.
23. The discount rate for the NPV calculation is 4.5%.
24. A yearly inflation rate of 3% applies over the 30 year lifetime of the project.
25. NMGRT is 5.8125%.
26. Subcontractors are priced with a 10% markup.
27. Decommissioning and demolition costs are not included.

**Phase I RW-4 Installation & Pump Test (yr 1)** **$ 706,607**

**Task 1 Project Plans** **$ 63,390**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 63,390** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | |
| Project Manager | 130 | 20 | $ 2,600 | |
| Senior Engineer | 110 | 80 | $ 8,800 | |
| Project Engineer | 85 | 120 | $ 10,200 | |
| Senior Scientist | 125 | 16 | $ 2,000 | |
| Permitting Specialist | 80 | 80 | $ 6,400 | |
| Draftsman | 80 | 40 | $ 3,200 | |
| Word Processor | 55 | 40 | $ 2,200 | |

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | | | | | |
|---|---|---|---|---|---|
| Quality Assurance | 75 | 2 | $ 150 | | |
| Administrative Assistant | 45 | 40 | $ 1,800 | | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | | |
| **Task 2 Safety Plan** | | | | | **$ 17,880** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 17,880** | |
| LANL Project Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 4 | $ 520 | | |
| Senior Engineer | 110 | 40 | $ 4,400 | | |
| Project Engineer | 85 | 40 | $ 3,400 | | |
| Junior Engineer | 75 | 40 | $ 3,000 | | |
| Draftsman | 80 | 4 | $ 320 | | |
| Word Processor | 55 | 8 | $ 440 | | |
| Administrative Assistant | 45 | 40 | $ 1,800 | | |
| **Task 3 Readiness Review** | | | | | **$ 8,160** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | | |
| LANL Project Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 8 | $ 1,040 | | |
| Senior Engineer | 110 | 16 | $ 1,760 | | |
| Project Engineer | 85 | 16 | $ 1,360 | | |
| **Task 4 RW-4-I & RW4-R Installation** | | | | | **$ 447,758** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 39,640** | |
| LANL Project Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 4 | $ 800 | | |
| Project Manager | 130 | 40 | $ 5,200 | | |
| Junior Scientist | 75 | 160 | $ 12,000 | | |
| Senior Engineer | 110 | 160 | $ 17,600 | | |
| Quality Assurance | 75 | 16 | $ 1,200 | | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | | |

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| **Drilling Subcontractor** | **UOM** | **Rate** | **Qty** | **Subtotal** | | | |
|---|---|---|---|---|---|---|---|
| | | | | | **$ 407,418** | | (incl 10% markup) |
| Mobilization/ Demobilization—ea rig - ARCH | ea | 6400 | 1 | $ 6,400 | | | |
| Drill & install 16-in. conductor to 20 ft | ft | 250 | 40 | $ 10,000 | | | |
| Drill to total depth—direct mud rotary | ft | 72 | 2500 | $ 180,000 | | | |
| Silt trap with welded end cap | ft | 36 | 20 | $ 720 | | | |
| 6-in. LCS Casing—0.307 wall | ft | 36 | 2000 | $ 72,000 | | | |
| Vertical mill slot screen | ft | 64 | 500 | $ 32,000 | | | |
| Furnish & install centralizers | ea | 27 | 180 | $ 4,860 | | | |
| Furnish & install rounded gravel filter pack | ft | 20 | 500 | $ 10,000 | | | |
| Furnish & install barrier bentonite/sand | ft | 20 | 10 | $ 200 | | | |
| Furnish & install annular seal | ft | 20 | 2000 | $ 40,000 | | | |
| Furnish & install above grade well protection | ea | 1200 | 2 | $ 2,400 | | | |
| Mobilization/ Demobilization—ea rig - pump | ea | 1400 | 1 | $ 1,400 | | | |
| Swab & bail only | h | 185 | 40 | $ 7,400 | | | |
| per diem | d | 220 | 6 | $ 1,320 | | | |
| Standby | h | 210 | 8 | $ 1,680 | | | |
| | | | | | | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 700** | | |
| Pickup | mo | 400 | 0.5 | $ 200 | | | |
| Misc | | | | $ 500 | | | |
| | | | | | | | |
| **Task 5 Pump Test** | | | | | | **$ 133,559** | |
| | | | | | | | |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 31,420** | | |
| LANL Project Manager | | 300 | 16 | $ 4,800 | | | |

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | | | |
|---|---|---|---|
| LANL Health & Safety Supervisor | 200 | 2 | $ 400 |
| Project Manager | 130 | 8 | $ 1,040 |
| Project Engineer | 85 | 60 | $ 5,100 |
| Senior Scientist | 125 | 80 | $ 10,000 |
| Junior Scientist | 75 | 120 | $ 9,000 |
| Permitting Specialist | 80 | 8 | $ 640 |
| Cost/Schedule Engineer | 55 | 8 | $ 440 |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 13,400** |
|---|---|---|---|---|
| Field Technician | 45 | 120 | $ 5,400 | |
| Field Craft Labor | 50 | 80 | $ 4,000 | |
| Field Electrician | 65 | 40 | $ 2,600 | |
| Field Technician - PT | 22.5 | 40 | $ 900 | |
| Field Craft Labor - PT | 25 | 20 | $ 500 | |

| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 10,439** | (incl 10% markup) |
|---|---|---|---|---|---|---|
| Submersible pump rental | mo | 2500 | 1 | $ 2,500 | | |
| Frac tank rental for pump test | mo | 4000 | 1 | $ 4,000 | | |
| Carbon vessels for pump test, 2 vessels | mo | 1740 | 1 | $ 1,740 | | |
| Pickup | mo | 400 | 1 | $ 400 | | |
| Generator | wk | 350 | 1 | $ 350 | | |
| Misc | | | | $ 500 | | |

| **Materials** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 24,000** |
|---|---|---|---|---|---|
| GAC Disposal | lb | 500 | 10 | $ 5,000 | |
| 4-in. threaded pipe, galvanized Sch 40 | ft | 2000 | 6.5 | $ 13,000 | |
| Data logger with pressure transducers | wk | 2500 | 2 | $ 5,000 | |
| Misc | | | | $ 1,000 | |

| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 54,300** |
|---|---|---|---|---|---|
| LANL full suite analytical | ea | 2000 | 20 | $ 40,000 | |
| Drill rig & crew (set & pull pump) | lump | 6500 | 2 | $ 14,300 | (incl 10% markup) |

**Task 6 Field Summary Report** **$ 35,860**

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 35,860** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 16 | $ 4,800 | |
| Project Manager | 130 | 12 | $ 1,560 | |
| Senior Scientist | 125 | 80 | $ 10,000 | |
| Junior Engineer | 75 | 160 | $ 12,000 | |
| Draftsman | 80 | 60 | $ 4,800 | |
| Word Processor | 55 | 40 | $ 2,200 | |
| Quality Assurance | 75 | 4 | $ 300 | |
| Administrative Assistant | 45 | 2 | $ 90 | |
| Cost/Schedule Engineer | 55 | 2 | $ 110 | |

**Phase II Final Design & permitting (yr 2) $ 333,880**

**Task 1 Final Design $ 260,800**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 |
| LANL Health & Safety Supervisor | 200 | 16 | $ 3,200 |
| Project Manager | 130 | 160 | $ 20,800 |
| Senior Engineer | 110 | 480 | $ 52,800 |
| Project Engineer | 85 | 480 | $ 40,800 |
| Junior Engineer | 75 | 480 | $ 36,000 |
| LANL NEPA Specialist | 200 | 80 | $ 16,000 |
| Permitting Specialist | 80 | 160 | $ 12,800 |
| Draftsman | 80 | 400 | $ 32,000 |
| Word Processor | 55 | 160 | $ 8,800 |
| Quality Assurance | 75 | 80 | $ 6,000 |
| Administrative Assistant | 45 | 120 | $ 5,400 |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 |

**Task 2 Final Design Cost Estimate $ 50,780**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** |
|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 |

## Table B-6

## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | | | |
|---|---|---|---|
| Senior Engineer | 110 | 160 | $ 17,600 |
| Project Engineer | 85 | 160 | $ 13,600 |
| Junior Engineer | 75 | 160 | $ 12,000 |
| Quality Assurance | 75 | 16 | $ 1,200 |
| Administrative Assistant | 45 | 4 | $ 180 |
| Cost/Schedule Engineer | 55 | 40 | $ 2,200 |

**Task 3 Project Administration** **$ 22,300**

| Office Labor | Rate | Hours | Subtotal |
|---|---|---|---|
| LANL Project Manager | 300 | 40 | $ 12,000 |
| Project Manager | 130 | 40 | $ 5,200 |
| Administrative Assistant | 45 | 40 | $ 1,800 |
| Cost/Schedule Engineer | 55 | 60 | $ 3,300 |

**Phase III Installation (yr 3)** **$ 4,719,698**

**Task 1 Installation Plan** **$ 52,620**

| Office Labor | Rate | Hours | Subtotal | $ 52,620 |
|---|---|---|---|---|
| LANL Project Manager | 300 | 40 | $ 12,000 | |
| Program Manager | 200 | 4 | $ 800 | |
| Project Manager | 130 | 8 | $ 1,040 | |
| Senior Engineer | 110 | 160 | $ 17,600 | |
| Project Engineer | 85 | 160 | $ 13,600 | |
| Draftsman | 80 | 40 | $ 3,200 | |
| Word Processor | 55 | 16 | $ 880 | |
| Quality Assurance | 75 | 8 | $ 600 | |
| Administrative Assistant | 45 | 40 | $ 1,800 | |
| Cost/Schedule Engineer | 55 | 20 | $ 1,100 | |

**Task 2 Safety Plan** **$ 11,040**

| Office Labor | Rate | Hours | Subtotal | $ 11,040 |
|---|---|---|---|---|
| LANL Project Manager | 300 | 8 | $ 2,400 | |

# Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | | | | | |
|---|---|---|---|---|---|
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 8 | $ 1,040 | | |
| Senior Engineer | 110 | 8 | $ 880 | | |
| Project Engineer | 85 | 16 | $ 1,360 | | |
| Junior Engineer | 75 | 40 | $ 3,000 | | |
| Draftsman | 80 | 4 | $ 320 | | |
| Word Processor | 55 | 8 | $ 440 | | |
| **Task 3 Training** | | | | | **$ 8,700** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 5,220** | |
| LANL Project Manager | 300 | 4 | $ 1,200 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 2 | $ 260 | | |
| Senior Engineer | 110 | 8 | $ 880 | | |
| Project Engineer | 85 | 8 | $ 680 | | |
| Junior Engineer | 75 | 8 | $ 600 | | |
| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 3,480** | |
| Field Supervisor | 70 | 8 | $ 560 | | |
| Field Engineer | 75 | 8 | $ 600 | | |
| Field Equipment Operator | 50 | 8 | $ 400 | | |
| Field Driver | 45 | 8 | $ 360 | | |
| Field Technician | 45 | 8 | $ 360 | | |
| Field Laborer | 35 | 8 | $ 280 | | |
| Field Craft Labor | 50 | 8 | $ 400 | | |
| Field Electrician | 65 | 8 | $ 520 | | |
| **Task 4 Readiness Review** | | | | | **$ 6,400** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 6,400** | |
| LANL Project Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 8 | $ 1,600 | | |
| Project Manager | 130 | 8 | $ 1,040 | | |
| Project Engineer | 85 | 16 | $ 1,360 | | |
| **Task 5 Road Installation (Mesa & Cañon de Valle)** | | | | | **$ 104,103** |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 50,000** | |
| LANL Project Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 40 | $ 8,000 | | |

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | | | | | | |
|---|---|---|---|---|---|---|
| Project Manager | | 130 | 40 | $ 5,200 | | |
| Senior Engineer | | 110 | 160 | $ 17,600 | | |
| Project Engineer | | 85 | 80 | $ 6,800 | | |
| Junior Engineer | | 75 | 80 | $ 6,000 | | |
| Administrative Assistant | | 45 | 40 | $ 1,800 | | |
| Cost/Schedule Engineer | | 55 | 40 | $ 2,200 | | |
| | | | | | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 41,025** | |
| Field Supervisor | | 70 | 120 | $ 8,400 | | |
| Field Engineer | | 75 | 120 | $ 9,000 | | |
| Field Equipment Operator | | 50 | 120 | $ 6,000 | | |
| Field Driver | | 45 | 120 | $ 5,400 | | |
| Field Technician | | 45 | 120 | $ 5,400 | | |
| Field Laborer | | 35 | 120 | $ 4,200 | | |
| Field Equipment Operator - PT | | 25 | 30 | $ 750 | | |
| Field Driver - PT | | 22.5 | 30 | $ 675 | | |
| Field Technician - PT | | 22.5 | 30 | $ 675 | | |
| Field Laborer - PT | | 17.5 | 30 | $ 525 | | |
| | | | | | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 13,078** | (incl 10% markup) |
| Backhoe | mo | 4152 | 0.75 | $ 3,114 | | |
| Grader | mo | 4100 | 0.75 | $ 3,075 | | |
| Pickup | mo | 400 | 0.75 | $ 300 | | |
| Dump truck | mo | 7200 | 0.75 | $ 5,400 | | |
| | | | | | | |
| **Task 6 Recovery/Injection Well Installation** | | | | | | **$ 2,847,559** |
| | | | | | | |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 70,840** | |
| LANL Project Manager | | 300 | 60 | $ 18,000 | | |
| LANL Health & Safety Supervisor | | 200 | 40 | $ 8,000 | | |
| Project Manager | | 130 | 80 | $ 10,400 | | |
| Junior Scientist | | 75 | 320 | $ 24,000 | | |
| Senior Engineer | | 110 | 80 | $ 8,800 | | |
| Quality Assurance | | 75 | 16 | $ 1,200 | | |
| Cost/Schedule Engineer | | 55 | 8 | $ 440 | | |
| | | | | | | |
| **Drilling Subcontractor** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 2,776,719** | (incl 10% markup) |

# Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | | | | |
|---|---|---|---|---|
| Mobilization/ Demobilization—each rig - ARCH | ea | 6400 | 1 | $ 6,400 |
| Drill & install 16-in. conductor to 20 ft | ft | 250 | 280 | $ 70,000 |
| Drill to total depth—direct mud rotary | ft | 72 | 17500 | $ 1,260,000 |
| Silt trap with welded end cap | ft | 36 | 140 | $ 5,040 |
| 6-in. LCS Casing—0.307 wall | ft | 36 | 14000 | $ 504,000 |
| Vertical mill slot screen | ft | 64 | 3500 | $ 224,000 |
| Furnish & install centralizers | ea | 27 | 350 | $ 9,450 |
| Furnish & install rounded gravel filter pack | ft | 20 | 3500 | $ 70,000 |
| Furnish & install barrier bentonite/sand | ft | 20 | 70 | $ 1,400 |
| Furnish & install annular seal | ft | 20 | 14000 | $ 280,000 |
| Furnish & install above grade well protection | ea | 1200 | 14 | $ 16,800 |
| Mobilization/ Demobilization—each rig - pump | ea | 1400 | 2 | $ 2,800 |
| Swab & bail only | hr | 185 | 80 | $ 14,800 |
| per diem | day | 220 | 80 | $ 17,600 |
| Set pumps & piping | hr | 210 | 160 | $ 33,600 |
| Standby | hr | 210 | 40 | $ 8,400 |

**Task 7 Subsurface Installation** **$ 617,913**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 101,200** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 100 | $ 30,000 | |
| LANL Health & Safety Supervisor | 200 | 60 | $ 12,000 | |
| Project Manager | 130 | 80 | $ 10,400 | |
| Senior Engineer | 110 | 160 | $ 17,600 | |
| Project Engineer | 85 | 160 | $ 13,600 | |
| Junior Engineer | 75 | 80 | $ 6,000 | |

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | | | | |
|---|---|---|---|---|
| Administrative Assistant | 45 | 160 | $ 7,200 | |
| Cost/Schedule Engineer | 55 | 80 | $ 4,400 | |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 276,900** |
|---|---|---|---|---|
| Field Supervisor | 70 | 640 | $ 44,800 | |
| Field Engineer | 75 | 640 | $ 48,000 | |
| Field Equipment Operator | 50 | 640 | $ 32,000 | |
| Field Driver | 45 | 640 | $ 28,800 | |
| Field Technician | 45 | 640 | $ 28,800 | |
| Field Laborer | 35 | 640 | $ 22,400 | |
| Field Craft Labor | 50 | 640 | $ 32,000 | |
| Field Electrician | 65 | 320 | $ 20,800 | |
| Field Equipment Operator - PT | 25 | 160 | $ 4,000 | |
| Field Driver - PT | 22.5 | 160 | $ 3,600 | |
| Field Technician - PT | 22.5 | 160 | $ 3,600 | |
| Field Laborer - PT | 17.5 | 160 | $ 2,800 | |
| Field Craft Labor - PT | 25 | 160 | $ 4,000 | |
| Field Electrician - PT | 32.5 | 40 | $ 1,300 | |

| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 239,813** | (incl 10% markup) |
|---|---|---|---|---|---|---|
| Backhoe | mo | 4152 | 3 | $ 12,456 | | |
| Backhoe | mo | 4152 | 3 | $ 12,456 | | |
| Pickup | mo | 400 | 3 | $ 1,200 | | |
| Dump truck | mo | 7200 | 3 | $ 21,600 | | |
| Generator | mo | 350 | 3 | $ 1,050 | | |
| Compactor | mo | 550 | 3 | $ 1,650 | | |
| HDPE fusion machine | mo | 1200 | 3 | $ 3,600 | | |
| FOM | mo | 4000 | 3 | $ 12,000 | | |
| Submersible pump | ea | 15000 | 8 | $ 120,000 | | |
| Pump variable frequency drive | ea | 4000 | 8 | $ 32,000 | | |

| **Materials** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 348,425** | (incl 10% markup) |
|---|---|---|---|---|---|---|
| 4-in. HDPE, SDR 11 | ft | 2.5 | 30000 | $ 75,000 | | |
| 4-in. threaded pipe, galvanized Sch 40 | ft | 6.5 | 7500 | $ 48,750 | | |
| 4-in. fittings | well | 1000 | 7 | $ 7,000 | | |

| | | | | | |
|---|---|---|---|---|---|
| 8-in. HDPE, SDR 11 | ft | 4 | 1000 | $ | 4,000 |
| Aluminum vault enclosure doors 4x4 | ea | 3500 | 14 | $ | 49,000 |
| Recovery well vaults, precast, 4x4x4 | ea | 1500 | 14 | $ | 21,000 |
| Backfill, engineered | ton | 15 | 800 | $ | 12,000 |
| conduit, 3-in. conductors, | ft | 10 | 10000 | $ | 100,000 |

**Task 8 Subcontractor Treatment System Building & Equipment Installation $ 847,000**

| Treatment System | UOM | Rate | Qty | | Subtotal | $ | 738,100 | (incl 10% markup) |
|---|---|---|---|---|---|---|---|---|
| Water piping | lump | 60000 | 1 | $ | 60,000 | | | |
| Concrete foundation | lump | 40000 | 1 | $ | 40,000 | | | |
| Sump pump | lump | 10000 | 1 | $ | 10,000 | | | |
| Bag filter, install, piping | lump | 15000 | 1 | $ | 15,000 | | | |
| Eye wash | lump | 3000 | 1 | $ | 3,000 | | | |
| Transformer pad & service | lump | 8000 | 1 | $ | 8,000 | | | |
| Building electrical | lump | 75000 | 1 | $ | 75,000 | | | |
| Lightening protection | lump | 10000 | 1 | $ | 10,000 | | | |
| Building (50 ft x 50 ft), split block, metal roof | lump | 225000 | 1 | $ | 225,000 | | | |
| Site prep, grading | lump | 12000 | 1 | $ | 12,000 | | | |
| 6-in. gravel base course | lump | 18000 | 1 | $ | 18,000 | | | |
| Chemical injection system | lump | 12000 | 1 | $ | 12,000 | | | |
| 10,000 lb carbon vessels | ea | 39000 | 4 | $ | 156,000 | | | |
| Carbon vessels install, piping | lump | 12000 | 1 | $ | 12,000 | | | |
| 4000 gal. head tank, poly | lump | 7000 | 1 | $ | 7,000 | | | |
| Transfer pumps, 15 hp duplex operation | set | 8000 | 1 | $ | 8,000 | | | |

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| Cañon de Valle Head Tank & Shed | UOM | Rate | Qty | Subtotal | $ 108,900 | (incl 10% markup) |
|---|---|---|---|---|---|---|
| Site prep, grading | lump | 6000 | 1 | $ 6,000 | | |
| 6-inch gravel base course | lump | 9000 | 1 | $ 9,000 | | |
| Concrete foundation | lump | 14000 | 1 | $ 14,000 | | |
| Building, split block, metal roof | lump | 35000 | 1 | $ 35,000 | | |
| 4000 gallon head tank, poly | lump | 7000 | 1 | $ 7,000 | | |
| Transfer pumps, 15 hp duplex operation | set | 8000 | 1 | $ 8,000 | | |
| Electrical | lump | 15000 | 1 | $ 15,000 | | |
| Transformer pad & service | lump | 5000 | 1 | $ 5,000 | | |

**Task 9 Site Restoration** **$ 31,063**

| Office Labor | Rate | Hours | Subtotal | $ 6,250 |
|---|---|---|---|---|
| LANL Project Manager | 300 | 4 | $ 1,200 | |
| Project Manager | 130 | 10 | $ 1,300 | |
| Junior Engineer | 75 | 50 | $ 3,750 | |

| Field Labor | Rate | Hours | Subtotal | $ 15,875 |
|---|---|---|---|---|
| Field Supervisor | 70 | 50 | $ 3,500 | |
| Field Equipment Operator | 50 | 50 | $ 2,500 | |
| Field Driver | 45 | 50 | $ 2,250 | |
| Field Technician | 45 | 50 | $ 2,250 | |
| Field Laborer | 35 | 50 | $ 1,750 | |
| Field Craft Labor | 50 | 50 | $ 2,500 | |
| Field Equipment Operator - PT | 25 | 10 | $ 250 | |
| Field Driver - PT | 22.5 | 10 | $ 225 | |
| Field Technician - PT | 22.5 | 10 | $ 225 | |
| Field Laborer - PT | 17.5 | 10 | $ 175 | |
| Field Craft Labor - PT | 25 | 10 | $ 250 | |

| Equipment | UOM | Rate | Qty | Subtotal | $ 3,938 |
|---|---|---|---|---|---|
| Backhoe | mo | 4152 | 0.25 | $ 1,038 | |
| Dump Truck | mo | 7200 | 0.25 | $ 1,800 | |
| Truck | mo | 400 | 0.25 | $ 100 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| FOM | mo | 4000 | 0.25 | $ | 1,000 | | | | |
| **Other** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **5,000** | | |
| Reseed & stabilize materials | lump | 5000 | 1 | $ | 5,000 | | | | |
| **Task 10 Waste Management** | | | | | | | | **$** | **21,280** |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **9,280** | | |
| LANL Project Manager | | 300 | 4 | $ | 1,200 | | | | |
| LANL Health & Safety Supervisor | | 200 | 4 | $ | 800 | | | | |
| Project Manager | | 130 | 4 | $ | 520 | | | | |
| Project Engineer | | 85 | 40 | $ | 3,400 | | | | |
| Junior Engineer | | 75 | 40 | $ | 3,000 | | | | |
| Administrative Assistant | | 45 | 8 | $ | 360 | | | | |
| **Soil Disposal** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **10,400** | | |
| Contaminated soil disposal | ton | 52 | 200 | $ | 10,400 | | | | |
| **Other** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **1,600** | | |
| Soil analytical | ea | 160 | 10 | $ | 1,600 | | | | |
| **Task 11 Demobilization** | | | | | | | | **$** | **15,540** |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **8,000** | | |
| LANL Project Manager | | 300 | 4 | $ | 1,200 | | | | |
| LANL Health & Safety Supervisor | | 200 | 2 | $ | 400 | | | | |
| Project Manager | | 130 | 8 | $ | 1,040 | | | | |
| Senior Engineer | | 110 | 16 | $ | 1,760 | | | | |
| Project Engineer | | 85 | 16 | $ | 1,360 | | | | |
| Administrative Assistant | | 45 | 40 | $ | 1,800 | | | | |
| Cost/Schedule Engineer | | 55 | 8 | $ | 440 | | | | |
| **Field Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **7,540** | | |
| Field Supervisor | | 70 | 16 | $ | 1,120 | | | | |
| Field Engineer | | 75 | 16 | $ | 1,200 | | | | |
| Field Equipment Operator | | 50 | 16 | $ | 800 | | | | |
| Field Driver | | 45 | 16 | $ | 720 | | | | |
| Field Technician | | 45 | 16 | $ | 720 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Field Laborer | | 35 | 16 | $ | 560 | | | | |
| Field Craft Labor | | 50 | 16 | $ | 800 | | | | |
| Field Electrician | | 65 | 16 | $ | 1,040 | | | | |
| Field Equipment Operator - PT | | 25 | 4 | $ | 100 | | | | |
| Field Driver - PT | | 22.5 | 4 | $ | 90 | | | | |
| Field Technician - PT | | 22.5 | 4 | $ | 90 | | | | |
| Field Laborer - PT | | 17.5 | 4 | $ | 70 | | | | |
| Field Craft Labor - PT | | 25 | 4 | $ | 100 | | | | |
| Field Electrician - PT | | 32.5 | 4 | $ | 130 | | | | |
| **Task 12 Asbuilts** | | | | | | | | **$** | **38,160** |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **38,160** | | |
| LANL Project Manager | | 300 | 12 | $ | 3,600 | | | | |
| Project Manager | | 130 | 12 | $ | 1,560 | | | | |
| Senior Engineer | | 110 | 120 | $ | 13,200 | | | | |
| Project Engineer | | 85 | 120 | $ | 10,200 | | | | |
| Draftsman | | 80 | 120 | $ | 9,600 | | | | |
| **Task 13 First Month Operation** | | | | | | | | **$** | **90,480** |
| **Office Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **26,880** | | |
| LANL Project Manager | | 300 | 16 | $ | 4,800 | | | | |
| LANL Health & Safety Supervisor | | 200 | 8 | $ | 1,600 | | | | |
| Project Manager | | 130 | 8 | $ | 1,040 | | | | |
| Senior Engineer | | 110 | 80 | $ | 8,800 | | | | |
| Project Engineer | | 85 | 120 | $ | 10,200 | | | | |
| Cost/Schedule Engineer | | 55 | 8 | $ | 440 | | | | |
| **Field Labor** | | **Rate** | **Hours** | | **Subtotal** | **$** | **23,600** | | |
| Field Engineer | | 75 | 80 | $ | 6,000 | | | | |
| Field Technician | | 45 | 200 | $ | 9,000 | | | | |
| Field Laborer | | 35 | 200 | $ | 7,000 | | | | |
| Field Technician - PT | | 22.5 | 40 | $ | 900 | | | | |
| Field Laborer - PT | | 17.5 | 40 | $ | 700 | | | | |
| **Other** | **UOM** | **Rate** | **Qty** | | **Subtotal** | **$** | **40,000** | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LANL full suite analytical | ea | 2000 | 20 | $ 40,000 | | | |
| **Task 14 Project Administration** | | | | | | **$ 27,840** | |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 27,840** | | |
| LANL Project Manager | | 300 | 40 | $ 12,000 | | | |
| Program Manager | | 200 | 8 | $ 1,600 | | | |
| Project Manager | | 130 | 48 | $ 6,240 | | | |
| Administrative Assistant | | 45 | 80 | $ 3,600 | | | |
| Cost/Schedule Engineer | | 55 | 80 | $ 4,400 | | | |
| **Phase IV Operations & Maintenance yr 4-33, per yr** | | | | | | | **$ 621,140** |
| **Task 1 yrly Operations & Maintenance & Reporting** | | | | | | **$ 621,140** | |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 28,700** | | |
| LANL Project Manager | | 300 | 8 | $ 2,400 | | | |
| LANL Health & Safety Supervisor | | 200 | 8 | $ 1,600 | | | |
| Project Manager | | 130 | 48 | $ 6,240 | | | |
| Senior Engineer | | 110 | 48 | $ 5,280 | | | |
| Project Engineer | | 85 | 96 | $ 8,160 | | | |
| Word Processor | | 55 | 4 | $ 220 | | | |
| Administrative Assistant | | 45 | 48 | $ 2,160 | | | |
| Cost/Schedule Engineer | | 55 | 48 | $ 2,640 | | | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 249,600** | | |
| Field Engineer | | 75 | 2080 | $ 156,000 | | | |
| Field Technician | | 45 | 2080 | $ 93,600 | | | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 342,840** | | |
| LANL full suite analytical | ea | 2000 | 48 | $ 96,000 | | | |
| bag filters | ea | 3.5 | 240 | $ 840 | | | |
| polyphosphate | drum | 500 | 36 | $ 18,000 | | | |
| Carbon change, with disposal | lb | 2 | 60000 | $ 120,000 | | | |
| Electrical | kwh | 0.12 | 900000 | $ 108,000 | | | |
| **Phase IV Monitoring, Sampling & Reporting (per yr, yrs 4-33)** | | | | | | | **$ 137,700** |

# Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

**Task 1 Safety Plan (existing)**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Task 2 Field Sampling** | | | | | | **$ 137,700** |

| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 58,400** |
|---|---|---|---|---|---|
| LANL Project Manager | | 300 | 96 | $ 28,800 | |
| Project Manager | | 130 | 24 | $ 3,120 | |
| Senior Engineer | | 110 | 80 | $ 8,800 | |
| Senior Scientist | | 125 | 16 | $ 2,000 | |
| Junior Scientist | | 75 | 160 | $ 12,000 | |
| Draftsman | | 80 | 24 | $ 1,920 | |
| Word Processor | | 55 | 24 | $ 1,320 | |
| Cost/Schedule Engineer | | 55 | 8 | $ 440 | |
| **Field Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 18,400** |
| Field Supervisor | | 70 | 160 | $ 11,200 | |
| Field Technician | | 45 | 160 | $ 7,200 | |
| **Equipment** | | **Rate** | **mo** | **Subtotal** | **$ 900** |
| Truck | | 400 | 1 | $ 400 | |
| Field Analytical Equipment | | 500 | 1 | $ 500 | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 60,000** |
| LANL full suite analytical | ea | 2000 | 30 | $ 60,000 | |

**Summary**

| **Phase** | **Subtotal** | **NMGRT** | **Total** |
|---|---|---|---|
| Phase I RW-4 Installation & Pump Test (yr 1) | $ 706,607 | $ 41,072 | $ 747,679 |
| Phase II Final Design & permitting (yr 2) | $ 333,880 | $ 19,407 | $ 353,287 |
| Phase III Installation (yr 3) | $ 4,719,698 | $ 274,332 | $ 4,994,031 |
| Phase IV O&M yr 4-33, per yr | $ 621,140 | $ 36,104 | $ 657,244 |
| Phase V Monitoring, Sampling & Reporting, per yr | $ 137,700 | $ 8,004 | $ 145,704 |
| **Capital Installation Cost** | | | **$ 6,094,996** |
| **30 yr O&M Costs (NPV)** | | | **$ 18,838,268** |
| | | | |
| **Total Cost (NPV)** | | | **$ 24,933,264** |

# Table B-6

## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

**30 yr NPV Calculation**

Discount Rate = 4.50%

| yr | Incurred Cost | Divisor | Subtotal |
|---|---|---|---|
| 1 | $ 802,948 | 1.045 | $ 768,371 |
| 2 | $ 827,036 | 1.092025 | $ 757,342 |
| 3 | $ 851,847 | 1.141166125 | $ 746,471 |
| 4 | $ 877,402 | 1.192518601 | $ 735,756 |
| 5 | $ 903,725 | 1.246181938 | $ 725,195 |
| 6 | $ 930,836 | 1.302260125 | $ 714,785 |
| 7 | $ 958,761 | 1.36086183 | $ 704,525 |
| 8 | $ 987,524 | 1.422100613 | $ 694,412 |
| 9 | $ 1,017,150 | 1.48609514 | $ 684,445 |
| 10 | $ 1,047,664 | 1.552969422 | $ 674,620 |
| 11 | $ 1,079,094 | 1.622853046 | $ 664,937 |
| 12 | $ 1,111,467 | 1.695881433 | $ 655,392 |
| 13 | $ 1,144,811 | 1.772196097 | $ 645,985 |
| 14 | $ 1,179,156 | 1.851944922 | $ 636,712 |
| 15 | $ 1,214,530 | 1.935282443 | $ 627,573 |
| 16 | $ 1,250,966 | 2.022370153 | $ 618,564 |
| 17 | $ 1,288,495 | 2.11337681 | $ 609,685 |
| 18 | $ 1,327,150 | 2.208478766 | $ 600,934 |
| 19 | $ 1,366,964 | 2.307860311 | $ 592,308 |
| 20 | $ 1,407,973 | 2.411714025 | $ 583,806 |
| 21 | $ 1,450,213 | 2.520241156 | $ 575,426 |
| 22 | $ 1,493,719 | 2.633652008 | $ 567,166 |
| 23 | $ 1,538,531 | 2.752166348 | $ 559,025 |
| 24 | $ 1,584,687 | 2.876013834 | $ 551,001 |
| 25 | $ 1,632,227 | 3.005434457 | $ 543,092 |
| 26 | $ 1,681,194 | 3.140679007 | $ 535,296 |
| 27 | $ 1,731,630 | 3.282009562 | $ 527,613 |
| 28 | $ 1,783,579 | 3.429699993 | $ 520,039 |
| 29 | $ 1,837,086 | 3.584036492 | $ 512,575 |
| 30 | $ 1,892,199 | 3.745318135 | $ 505,217 |
|  |  |  | $ 18,838,268 |

| | |
|---|---|
| FOM | Fuel, oil and maintenance |
| GAC | Granular activated carbon |
| HDPE | High-density polyethylene |
| HE | High explosives |
| LANL | Los Alamos National |
| MDA | Material disposal area |
| NMGRT | New Mexioco Gross Reciepts Tax |
| NPV | Net present value |
| O&M | Operations & Maintenance |
| PNM | Public Service Company of New Mexico |
| PT | Premium time (overtime) |
| SVOC | Semivolatile organic compound |
| TDH | Total dynamic head |

## Table B-6
## Alternative III Intermediate and Regional Groundwater Recovery with Injection of Treated Water

| | |
|---|---|
| UOM | Unit of Measure |
| VOC | Volatile organic compound |

# Table B-7
# Alternative IV Intermediate and Regional Groundwater Monitored Natural Attenuation

**Assumptions**

1. Phase I MNA laboratory testing will be performed at LANL.
2. MNA lab testing consists of sorption tests & bioremediation testing on 3 media.
3. Cañon de Valle sediment samples will be collected; other media have already been collected.
4. MNA sampling consists of LANL full suite (HE, VOCs, SVOCs, metals & inorganics), & field parameters.
5. Monitoring wells consist of R-25, CdV-16-1(i), CdV-16-2(i)r, CdV-R-15-3, R-18, & CdV-R-37-2.
6. MNA reporting includes statistical trend analysis of the data to determine contaminant trends.
7. The discount rate for the NPV calculation is 4.5%.
8. A yearly inflation rate of 3% applies over the 30 year lifetime of the project.
9. NMGRT is 5.8125%.

| | | | | | |
|---|---|---|---|---|---|
| **Phase I Laboratory MNA Testing (yr 1)** | | | | | **$ 271,200** |
| **Task 1 Develop Experimental Plan** | | | | **$ 62,840** | |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 62,840** | |
| LANL Project Manager | 300 | 40 | $ 12,000 | | |
| LANL Senior Scientist | 300 | 40 | $ 12,000 | | |
| LANL Laboratory Scientist | 200 | 80 | $ 16,000 | | |
| Project Manager | 130 | 40 | $ 5,200 | | |
| Senior Engineer | 110 | 40 | $ 4,400 | | |
| Senior Scientist | 125 | 40 | $ 5,000 | | |
| Draftsman | 80 | 40 | $ 3,200 | | |
| Word Processor | 55 | 40 | $ 2,200 | | |
| Quality Assurance | 75 | 8 | $ 600 | | |
| Administrative Assistant | 45 | 40 | $ 1,800 | | |
| Cost/Schedule Engineer | 55 | 8 | $ 440 | | |
| **Task 2 Safety Plan** | | | | **$ 11,040** | |
| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 11,040** | |
| LANL Project Manager | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supervisor | 200 | 4 | $ 800 | | |
| Project Manager | 130 | 4 | $ 520 | | |
| Senior Engineer | 110 | 16 | $ 1,760 | | |
| Junior Engineer | 75 | 40 | $ 3,000 | | |
| Draftsman | 80 | 4 | $ 320 | | |
| Word Processor | 55 | 8 | $ 440 | | |
| Administrative Assistant | 45 | 40 | $ 1,800 | | |

## Table B-7
## Alternative IV Intermediate and Regional Groundwater Monitored Natural Attenuation

| **Task 3 Readiness Review** | | | | | | **$ 4,080** |
|---|---|---|---|---|---|---|
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | | |
| LANL Project Manager | | 300 | 4 | $ 1,200 | | |
| LANL Health & Safety Supervisor | | 200 | 4 | $ 800 | | |
| Project Manager | | 130 | 4 | $ 520 | | |
| Senior Engineer | | 110 | 8 | $ 880 | | |
| Project Engineer | | 85 | 8 | $ 680 | | |
| | | | | | | |
| **Task 4 Sediment Sample Collection** | | | | | | **$ 8,280** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 8,280** | |
| LANL Project Manager | | 300 | 8 | $ 2,400 | | |
| LANL Health & Safety Supe | | 200 | 4 | $ 800 | | |
| Project Manager | | 130 | 16 | $ 2,080 | | |
| Junior Scientist | | 75 | 40 | $ 3,000 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 600** | |
| Pickup | mo | 400 | 0.25 | $ 100 | | |
| Misc | | | | $ 500 | | |
| | | | | | | |
| **Task 6 MNA Laboratory Testing** | | | | | | **$ 141,500** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 136,000** | |
| LANL Project Manager | | 300 | 80 | $ 24,000 | | |
| LANL Senior Scientist | | 300 | 160 | $ 48,000 | | |
| LANL Laboratory Scientist | | 200 | 320 | $ 64,000 | | |
| **Equipment** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 5,500** | |
| Laboratory equipment | lump | 5000 | 1 | $ 5,000 | | |
| Misc | | | | $ 500 | | |
| | | | | | | |
| **Task 7 MNA Laboratory Testing Summary Report** | | | | | | **$ 43,460** |
| **Office Labor** | | **Rate** | **Hours** | **Subtotal** | **$ 43,460** | |
| LANL Project Manager | | 300 | 16 | $ 4,800 | | |
| LANL Senior Scientist | | 300 | 40 | $ 12,000 | | |

## Table B-7
## Alternative IV Intermediate and Regional Groundwater Monitored Natural Attenuation

| | | | |
|---|---|---|---|
| LANL Laboratory Scientist | 200 | 80 | $ 16,000 |
| Project Manager | 130 | 8 | $ 1,040 |
| Senior Scientist | 125 | 40 | $ 5,000 |
| Draftsman | 80 | 24 | $ 1,920 |
| Word Processor | 55 | 40 | $ 2,200 |
| Quality Assurance | 75 | 4 | $ 300 |
| Administrative Assistant | 45 | 2 | $ 90 |
| Cost/Schedule Engineer | 55 | 2 | $ 110 |

**Phase II 30 yr MNA Monitoring Sampling & Reporting, per yr** **$ 141,880**

**Task 1 Safety Plan (existing)**

**Task 2 MNA Field Sampling** **$ 141,880**

| **Office Labor** | **Rate** | **Hours** | **Subtotal** | **$ 90,080** |
|---|---|---|---|---|
| LANL Project Manager | 300 | 80 | $ 24,000 | |
| Project Manager | 130 | 80 | $ 10,400 | |
| Senior Scientist | 125 | 160 | $ 20,000 | |
| Junior Scientist | 75 | 320 | $ 24,000 | |
| Draftsman | 80 | 80 | $ 6,400 | |
| Word Processor | 55 | 80 | $ 4,400 | |
| Cost/Schedule Engineer | 55 | 16 | $ 880 | |

| **Field Labor** | **Rate** | **Hours** | **Subtotal** | **$ 18,400** |
|---|---|---|---|---|
| Field Supervisor | 70 | 160 | $ 11,200 | |
| Field Technician | 45 | 160 | $ 7,200 | |

| **Equipment** | **Rate** | **mo** | **Subtotal** | **$ 1,400** |
|---|---|---|---|---|
| Pickup | 400 | 1 | $ 400 | |
| Field Analytical Equipment | 500 | 2 | $ 1,000 | |

| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 32,000** |
|---|---|---|---|---|---|
| LANL full suite | ea | 2000 | 16 | $ 32,000 | |

**Summary**

| **Phase** | **Subtotal** | **NMGRT** | **Total** |
|---|---|---|---|
| Phase I RW-4 Installation & Pump Test (yr 1) | $ 271,200 | $ 15,764 | $ 286,964 |
| Phase II 30 yr MNA Monitoring, Sampling & Reporting, per yr | $ 141,880 | $ 8,247 | $ 150,127 |

## Table B-7
## Alternative IV Intermediate and Regional Groundwater Monitored Natural Attenuation

| | |
|---|---|
| **Capital Installation Cost** | **$ 286,964** |
| **30 yr O&M Costs (NPV)** | **$ 3,522,183** |
| **Total Cost (NPV)** | **$ 3,809,147** |

**30 yr NPV Calculation**

Discount Rate = 4.50%

| yr | Incurred Cost | Divisor | Subtotal |
|---|---|---|---|
| 1 | $ 150,127 | 1.045 | $ 143,662 |
| 2 | $ 154,631 | 1.092025 | $ 141,600 |
| 3 | $ 159,269 | 1.1411661 | $ 139,567 |
| 4 | $ 164,048 | 1.1925186 | $ 137,564 |
| 5 | $ 168,969 | 1.2461819 | $ 135,589 |
| 6 | $ 174,038 | 1.3022601 | $ 133,643 |
| 7 | $ 179,259 | 1.3608618 | $ 131,725 |
| 8 | $ 184,637 | 1.4221006 | $ 129,834 |
| 9 | $ 190,176 | 1.4860951 | $ 127,970 |
| 10 | $ 195,881 | 1.5529694 | $ 126,133 |
| 11 | $ 201,758 | 1.622853 | $ 124,323 |
| 12 | $ 207,811 | 1.6958814 | $ 122,538 |
| 13 | $ 214,045 | 1.7721961 | $ 120,779 |
| 14 | $ 220,466 | 1.8519449 | $ 119,046 |
| 15 | $ 227,080 | 1.9352824 | $ 117,337 |
| 16 | $ 233,893 | 2.0223702 | $ 115,653 |
| 17 | $ 240,909 | 2.1133768 | $ 113,993 |
| 18 | $ 248,137 | 2.2084788 | $ 112,356 |
| 19 | $ 255,581 | 2.3078603 | $ 110,744 |
| 20 | $ 263,248 | 2.411714 | $ 109,154 |
| 21 | $ 271,146 | 2.5202412 | $ 107,587 |
| 22 | $ 279,280 | 2.633652 | $ 106,043 |
| 23 | $ 287,658 | 2.7521663 | $ 104,521 |
| 24 | $ 296,288 | 2.8760138 | $ 103,020 |
| 25 | $ 305,177 | 3.0054345 | $ 101,542 |
| 26 | $ 314,332 | 3.140679 | $ 100,084 |
| 27 | $ 323,762 | 3.2820096 | $ 98,648 |
| 28 | $ 333,475 | 3.4297 | $ 97,232 |
| 29 | $ 343,479 | 3.5840365 | $ 95,836 |
| 30 | $ 353,784 | 3.7453181 | $ 94,460 |
| | | | $ 3,522,183 |

| | |
|---|---|
| LANL | Los Alamos National |
| MNA | Monitored natural attenuation |
| NPV | Net present value |
| O&M | Operations & Maintenance |
| PT | Part-time |

# Table B-8
# Alternative V No-Action

**Assumptions**

1. No-Action consists of the current site semiannual monitoring & reporting program.
2. Monitoring wells consist of R-25, CdV-16-1(i), CdV-16-2(i)r, CdV-R-15-3, R-18, & CdV-R-37-2.
3. Three additional QA samples per round are assumed.
4. The discount rate for the NPV calculation is 4.5%.
5. A yearly inflation rate of 3% applies over the 30 year lifetime of the project.
6. NMGRT is 5.8125%.

**Phase II 30 yr Monitoring Sampling & Reporting, per yr** **$ 98,880**

**Task 1 Safety Plan (existing)**
**Task 2 Monitoring & Sampling** **$ 98,880**

| **Office Labor** | | **Rate** | **h** | **Subtotal** | **$ 46,080** |
|---|---|---|---|---|---|
| LANL Project Manager | | 300 | 40 | $ 12,000 | |
| Project Manager | | 130 | 80 | $ 10,400 | |
| Junior Scientist | | 75 | 160 | $ 12,000 | |
| Draftsman | | 80 | 80 | $ 6,400 | |
| Word Processor | | 55 | 80 | $ 4,400 | |
| Cost/Schedule Engineer | | 55 | 16 | $ 880 | |
| **Field Labor** | | **Rate** | **h** | **Subtotal** | **$ 18,400** |
| Field Supervisor | | 70 | 160 | $ 11,200 | |
| Field Technician | | 45 | 160 | $ 7,200 | |
| **Equipment** | | **Rate** | **mo** | **Subtotal** | **$ 2,400** |
| Pickup | | 400 | 1 | $ 400 | |
| Field Analytical Equipment | | 2000 | 1 | $ 2,000 | |
| **Other** | **UOM** | **Rate** | **Qty** | **Subtotal** | **$ 32,000** |
| LANL full suite analytical | ea | 2000 | 16 | $ 32,000 | |

**Summary**

| **Phase** | **Subtotal** | **NMGRT** | **Total** |
|---|---|---|---|
| 30 yr Monitoring, Sampling & Reporting, per yr | $ 98,880 | $ 5,747 | $ 104,627 |

**30 yr O&M Costs (NPV)** **$ 2,454,704**

**30 yr NPV Calculation**

Discount Rate = 4.50%

## Table B-8
## Alternative V No-Action

| yr | Incurred Cost | Divisor | Subtotal |
|---|---|---|---|
| 1 | $ 104,627 | 1.045 | $ 100,122 |
| 2 | $ 107,766 | 1.092025 | $ 98,685 |
| 3 | $ 110,999 | 1.141166 | $ 97,268 |
| 4 | $ 114,329 | 1.192519 | $ 95,872 |
| 5 | $ 117,759 | 1.246182 | $ 94,496 |
| 6 | $ 121,292 | 1.30226 | $ 93,139 |
| 7 | $ 124,931 | 1.360862 | $ 91,803 |
| 8 | $ 128,679 | 1.422101 | $ 90,485 |
| 9 | $ 132,539 | 1.486095 | $ 89,186 |
| 10 | $ 136,515 | 1.552969 | $ 87,906 |
| 11 | $ 140,610 | 1.622853 | $ 86,644 |
| 12 | $ 144,829 | 1.695881 | $ 85,400 |
| 13 | $ 149,174 | 1.772196 | $ 84,174 |
| 14 | $ 153,649 | 1.851945 | $ 82,966 |
| 15 | $ 158,258 | 1.935282 | $ 81,775 |
| 16 | $ 163,006 | 2.02237 | $ 80,602 |
| 17 | $ 167,896 | 2.113377 | $ 79,445 |
| 18 | $ 172,933 | 2.208479 | $ 78,304 |
| 19 | $ 178,121 | 2.30786 | $ 77,180 |
| 20 | $ 183,465 | 2.411714 | $ 76,072 |
| 21 | $ 188,969 | 2.520241 | $ 74,980 |
| 22 | $ 194,638 | 2.633652 | $ 73,904 |
| 23 | $ 200,477 | 2.752166 | $ 72,843 |
| 24 | $ 206,491 | 2.876014 | $ 71,798 |
| 25 | $ 212,686 | 3.005434 | $ 70,767 |
| 26 | $ 219,067 | 3.140679 | $ 69,751 |
| 27 | $ 225,639 | 3.28201 | $ 68,750 |
| 28 | $ 232,408 | 3.4297 | $ 67,763 |
| 29 | $ 239,380 | 3.584036 | $ 66,791 |
| 30 | $ 246,561 | 3.745318 | $ 65,832 |
| | | | $ 2,454,704 |

| | |
|---|---|
| LANL | Los Alamos National Laboratory |
| NPV | Net present value |
| O&M | Operations & Maintenance |

# Appendix C

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*Groundwater Modeling Reports*

## C-1.0 INTRODUCTION

Appendix C presents the results of several mathematical modeling studies that were conducted in support of the corrective measures evaluation. Appendix C1 estimates the mass of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) released at the 260 Outfall and the current environmental inventory of RDX mass at Technical Area (TA) 16. Estimates of mass released were calculated using historical data collected from the Los Alamos National Laboratory (the Laboratory) Archives concerning the mass of high explosives (HE) processed through building 260 and other buildings at TA-16. These estimates range from 15,000 to 64,000 kg over the approximate 45-yr operating history of the 260 Outfall. An estimate of the current environmental inventory of RDX mass used subsurface environmental data from wells and boreholes drilled by the Laboratory's Environmental Restoration Project. These estimates range from 2,000 to 30,000 kg.

Appendix C2 summarizes numerical modeling used to estimate RDX transport from the 260 Outfall through the vadose zone and into regional groundwater. Deterministic GoldSim models were developed and used to predict vadose-zone transport at the site. The model uses the 64,000-kg time-dependent RDX source (the most conservative estimate of released mass from Appendix C1), distributes that RDX within the Cañon de Valle alluvial system, and then simulates vadose-zone transport of RDX down to the top of the regional aquifer. Results are presented in the form of breakthrough curves which are then used as input to a regional groundwater model (Appendix C4).

Appendix C3 developed a groundwater model to support corrective measure alternative development and evaluation. The groundwater model was used to conduct a capture zone analysis for intermediate groundwater and to simulate the effects of groundwater recovery and injection on intermediate zone hydraulic heads. The resulting groundwater recovery and injection flow rates were used to produce a conceptual design of an intermediate-zone groundwater recovery and injection system.

Appendix C4 describes the development of regional groundwater flow and contaminant transport model and its use to predict future contaminant concentrations and contaminant transport times to area-monitoring wells and public supply wells under the monitored natural attenuation (MNA) and no-action remedial alternatives. A conceptual model is presented of the Laboratory's interpretation of basin-scale flow in the Los Alamos region. The groundwater model used a Monte Carlo modeling approach with probability distributions of important groundwater flow parameters. The two source terms for RDX introduction into regional groundwater consisted of (1) the RDX mass-release study and GoldSim modeling described in Appendixes C1 and C2, respectively and (2) a mass-release rate derived from observed RDX concentrations at monitoring well R-25. Source Term Two yielded model results that more closely matched the observed RDX data. Using Source Term Two, predicted concentration levels at area wells are approximately at or below the detection limit for RDX, with levels at the municipal wells predicted to be significantly below the RDX detection limit. Based on these results, it was determined that the existing RDX groundwater contamination at TA-16 does not pose an imminent threat under either an MNA or no-action alternative.

# *Appendix C1*

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## High Explosives Source Term

## C1-1.0 INTRODUCTION

Facilities at Technical Area (TA) 16 have been used for high explosives (HE) processing for weapons research and development since the 1940s. Early facilities included V-Site, the 30s Line, the 40s Line, the 90s Line, and others. These facilities were not designed for high levels of production and were hastily built to provide HE for the small number of nuclear weapons that were initially built at Los Alamos National Laboratory (LANL, or the Laboratory). The start of the Cold War with the Soviet Union initiated the construction of higher-capacity buildings for much greater levels of research and development than had been done previously. This building boom saw the construction of TA-16-260 (hereafter, building 260) and the 300 series buildings. According to the Facilities and Waste Operations database, MOADS, building 260 was constructed between September 21, 1949, and February 16, 1951, by R.E. McKee. The original building number designation was S-132.

The objective of this report is to document information relative to HE (and in particular, hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX]) releases at TA-16). RDX is the primary HE component of interest because of its (1) relatively high solubility, (2) potential mobility in the subsurface, (3) resistance to degradation, and (4) low Environmental Protection Agency health advisory limit because it is a suspected carcinogen. Because TA-16 is upstream from Los Alamos County public drinking water wells, there is concern that HE contamination may eventually reach these drinking water wells.

This report documents two studies that estimate RDX releases based upon two different data sets. The first study used primarily historical data collected from the Laboratory Archives concerning the amount of HE processed through building 260 and other buildings at TA-16. This study is discussed in sections C1-2.0 through C1-4.0, and the background data sets are included on a CD as part of Gard and Newman (2005, 093651, Appendix B). The second study used subsurface environmental data from wells and boreholes drilled by the Laboratory’s Environmental Restoration Project. These data give a clearer picture of concentration distributions of RDX in the environment. The study is discussed in section C1-5.0, and the environmental data are found in the respective investigation and well completion reports and in the Water Quality Database http://wqdbworld.lanl.gov.

## C1-2.0 BUILDING 260, RDX DISCHARGE ESTIMATES USING ARCHIVAL INFORMATION

No rigorous monitoring of discharge volumes or concentrations was performed while the outfall at building 260 was active from 1951 to 1996. Therefore, several different methods were used for the initial study to estimate the RDX discharged to the environment in order to compare the results.

### C1-2.1 Assumptions about RDX Discharge at Building 260

A major assumption that was made for initial source estimates based on archival information is that all water discharged from building 260 was contaminated with RDX at its solubility limit of 44 mg/L. This is the solubility limit of RDX at standard temperature as reported by Layton et al. (1987, 058925). This assumption provides a method to bound RDX concentrations, and it is very conservative. Data from sump water-sampling analyses at WX-3 building 302 in 1979 support the solubility-limit assumption because RDX analyses yielded a maximum concentration of 63 mg/L, a minimum of 16 mg/L, and an average of 32 mg/L. In addition, data from 1953 to 1954 for water samples from machining and casting operations were in the 25 to 36 ppm range (Gard and Newman 2005, 093651, p. 2, HE Source Term Data file pdf, Appendix B). Another reason that the solubility-limit assumption is reasonable is that while RDX compounds were being machined, machining and wash-down water would nearly always have been in contact with small pieces of RDX (with large exposed surface areas) in the sumps. This would have been true except immediately after the sumps were cleaned and until an RDX-containing part had been machined. Finally, there is not a consistently collected long-term data set to justify and defend using a lower concentration. However, there are weekly data for building 260 from 1972 where 1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)/RDX concentration ranges from 0 to 3.2 ppm with a 2.7 ppm average for July 1972 (Gard and Newman 2005, 093651, p. 3, HE Source Term Data file pdf, Appendix B). These data indicate that using the solubility limit is a conservative approach. A final fact that supports the solubility-limit assumption is that the water used for machining was heated to room temperature (tempered) to reduce thermally induced dimensional changes in the machined parts (Spencer, Attachment A). A final major assumption for the initial study was that all HE discharged was in solution.

### C1-2.2 Method 1 Discussion

The first discharge estimate is based on equation 1 and used both the assumed RDX solubility and the water flow-rate data that were collected while the National Pollutant Discharge Elimination System (NPDES) application program, which began in 1977, was monitored.

$$D = F * C * T \tag{1}$$

*Where*

D is the estimated mass of RDX discharged from the 260 Outfall (kg),

F is the NPDES average yearly flow rate for the years 1977 to 1989 (7,573,882 L/yr),

C is the concentration (4.4E-005 kg/L) (the solubility limit of RDX as discussed above), and

T is time (45 yr of releases).

These data yield an RDX source of 15,000 kg.

The best available data to constrain the average yearly flow came from a variety of sources. For 1977, the Section II Basic Discharge Descriptions (M.L. McCorkle, Attachment A) were used. For 1978 to 1989, the best available data are handwritten records of discharge data for building 260. These data have been entered into Excel, summarized by year, and the average annual flow rate was then calculated for use in equation 1 (Gard and Newman 2005, 093651, Worksheet NPDES_Flows 1977-1989, HE Source Term Calculations File .xls, Appendix B). It was assumed that the calculated average flow rate applied for the entire discharge period of 1951 to 1996. It was noted that the NPDES Discharge Monitoring Reports for the TA-16 outfalls were not used because they aggregate four different outfalls (based on the more detailed handwritten records for the individual outfalls) for reporting purposes. In addition, the flows used for the NPDES applications were not actual measured/totalized flows.

#### C1-2.2.1 Method 1 Uncertainties

Assuming that the solubility-limit assumption is reasonably representative, the predicted RDX discharge is possibly an overestimate for the 1977 to 1996 period because the NPDES flow data are conservative for the later years because they assume 24-h/d continuous discharge rather than for a single shift. The predicted RDX discharge is probably an underestimate for 1952 to 1957 because there were more machinists working during that period than during the 1977–1989 period on which the flow estimate is based. The NPDES data represent flow rates from building 260 when only one shift of machinists was working, and previously as many as three shifts/day with up to 14 machinists/shift were working (this is addressed in Method 4b). Another caveat is that prior to the NPDES measurements, the wash-down systems and methods generated more discharge water than was used during the NPDES measurements (Rivera, Attachment A). Before this modification, substantially more water was used for wash down. Another uncertainty is that the water leaving the sumps may have contained solid HE prior to 1962 when the sumps were modified to remove more particulates.

The average NPDES discharge for 1980, which is the last year there were 13 machinists, had the same average discharge as 1989 when there were eight machinists (Gard and Newman 2005, 093651, Worksheets Method4a_Noe, NPDES_Flows 1977-1989, HE Source Term Calculations File, Appendix B). This illustrates the difficulties associated with accurately estimating discharge flows based on manpower and NPDES flow measurements.

### C1-2.3 Method 2 Discussion

Another method for estimating RDX discharge was based on field data collected during the interim measure (IM) removal of HE contaminated soil from the building 260 Outfall Pond and drainage. The excavation made it possible to bound the mass of HE removed from the outfall pond area and thus provided an estimate (though incomplete) of the amount of HE discharged. In this approach, the source release was estimated using the following equation:

$$D = WP * MSR \tag{2}$$

*Where*

D is the mass of RDX discharged,

WP is the weight percent (wt%) of HE in the soil removed (2 wt%) (LANL 2002, 073706) and

MSR is the amount of soil removed (1,608,540 kg).

Using these values, equation 2 yields a discharge of approximately 32,000 kg of RDX. However, there are significant uncertainties and problems associated with this RDX estimate, as discussed below.

#### C1-2.3.1 Method 2 Uncertainties

HMX was the largest HE component in the soil removed during the IM. Thus, Method 2 provides a better estimate of HMX release than of RDX release. This observation is supported by the higher solubility of RDX relative to HMX (44 mg/L vs. ~5 mg/L) and by the fact that the majority of HE machined during the highest production period (1952–1957) at building 260 contained mostly RDX (Gard and Newman 2005, 093651, Worksheet 52_Inv_Summary, HE Source Term Calculations File, Appendix B). In other words, given the high solubility and approximately 40-yr transport period since the largest RDX releases, much of the 1950's era RDX was likely mobilized into the vadose zone or to Cañon de Valle. The dominance of HMX in the soils removed during the IM is also supported by Baytos (1972, 004953), which shows mostly HMX in soil samples taken from the pond and drainage ditches below building 260 from 1969 to 1971. For example, HMX/RDX ratios reported in Baytos (1972, 004953) range from 3 to 26, and 8 of the 13 analyses have values over 10. Another uncertainty related to Method 2 is that the 2 wt% HE assumption is a maximum bound, and the actual amount of HE removed could have been lower (LANL 2002, 073706). Therefore, because of these uncertainties and the dominance of HMX in the outfall area during the IM, the RDX release estimates of Methods 1, 3, and 4 have not been reduced using the implied 32,000-kg removal from Method 2.

### C1-2.4 Method 3 Discussion

Method 3 is based on statistical analysis of casting and machining data gleaned from the archived monthly progress reports from GMX-3 and WX-3 (former HE-processing groups at the Laboratory). The monthly progress reports were continually changing while programs, processes, weapons designs, and manufacturing processes changed. During this period, the HE-processing program moved from using mostly cast HE parts to mostly pressed HE parts and went from hand compilation of the report data to computer-generated reports. The lack of continual, consistent data sets made it impossible to use a single data set for calculating the RDX discharges. As the monthly reports were reviewed for this study, the inventory, casting, and machining data were entered into Excel spreadsheets. Much more data were collected than were used for the analysis. There were so many different data-reporting formats used during this time that the usefulness of any one data set was not known until all of the data were compiled (Gard and Newman 2005, 093651, Worksheet Discharge CalcMethod3, HE Source Term Calculations File, Appendix B).

There are two long-term data sets that were ultimately used to develop Method 3: (1) detailed casting data from 1952 to 1956 and less detailed casting data from 1958 to 1972, and (2) a machining data set from 1962 to 1980, with variable detail and some data gaps.

Beginning with the October 15, 1962, progress report, there are data for the number of operations performed per month for remote, inert, and operator-attended HE machining. Remote machining is machining done automatically and monitored through closed circuit television without an operator present in the bay. The plastic-bonded explosive (PBX) parts began to be remotely machined soon after two accidents: on February 24, 1959, in building 260 and on October 14, 1959, at the Burning Grounds. Inert parts were used for testing purposes, and most were made from barium compounds that were selected for their physical property similarity to HE materials without being explosive (Bazzell, Attachment A). The data for machining of inert parts show that cooling water was not required the entire time these parts were being machined. Operator-attended HE machining was performed on the cast types of HE such as Comp B, TNT, Baratol, etc., which are less sensitive than the PBX compounds.

There was less RDX used in the PBX materials, but the PBX compounds 9401, 9405, 9407, and 9010 are all RDX mixtures that were used extensively. A comment in the August 15, 1972, progress report states that in earlier batches of HMX, there was 8%–10 wt% RDX impurity, but for the past 4 yr, it had been running less than 1 wt%. HMX was noted in the inventory in 1954 (in very limited quantities) and doesn’t seem to have been used much until later in 1955. Because of the RDX impurity in HMX and because there were PBX compounds that contained RDX, all of the remote machining water has also been included in the source-term calculation (which is probably a conservative assumption).

Between January 15, 1964, and February 15, 1968, there are data for the number of pieces cast, number of operator-attended operations, number of remote operations, man-hours of operator-attended operations, man-hours of remote operations, man-hours of operator-attended setup, man-hours of remote setup, man-hours of inert machining, man-hours of inert setup, man-hours of tile machining, and man-hours of tile setup. These data are especially valuable because they provide information about hours spent machining and the hours spent on setup. In addition, the information about the number of parts machined, operations, parts cast, and the man-hours spent doing the work give a detailed picture of the processing done in building 260 during that time.

#### C1-2.4.1 Method 3 Calculations

The calculation of the RDX discharge from building 260 by Method 3 was done in three steps using the two long-term data sets mentioned earlier.

*Step 1 (1952–1963).* The first step was to calculate the RDX discharge from 1952 to 1963. During this period, the HE components for the early weapon designs, which used larger cast charges than later designs, were machined (Hatler, Attachment A). A majority of the RDX would have been discharged during the early 1950s when the high numbers of these large castings were being machined as shown in Figure C1-2.4-1. The peak of casting operations was March 1953 when over 12,800 pieces were cast with over 408,200 kg of HE in inventory (Gard and Newman 2005, 093651, Worksheet 52_Inv_Summary, HE Inventory and Castings .xls, Appendix B). There are two main reasons for the huge drop in numbers cast between 1956 and 1958: (1) much of the production was moved to Pantex, and (2) pressing techniques were developed to make smaller charges for new weapons designs (Hatler, Attachment A). These weapon-design changes are also documented in the on-line Pantex history, which describes a radical change in weapons design and how the Pantex plant was reconfigured to make the new designs. Its web site is http://www.pantex.com/ds/pxgena2b.htm.

To calculate RDX discharges from 1952 to 1963, detailed machining information from 1964 was used to calculate the mean machining time (man-hours) per operator-attended part (this was the first per part machining data available). The mean machining time (man-hours) plus 2 $\sigma$ (2 Standard Deviations) was then multiplied by the number of parts cast from 1952 to 1956. (The mean plus 2 $\sigma$ was used to be conservative.) This value was also multiplied by the interpolated annual casting data between 1956 and 1958 as shown in equation 3.

$$T_1 = MMT * NC \tag{3}$$

*Where*

$T_1$ is the man-hours of machining from February 1951 to October 1962,

MMT is the mean machining time/operator-attended part (man-hours) plus 2 $\sigma$, and

NC is the number of castings.

The uncertainties associated with this step are discussed in section C1-2.4.2. The value for 1951 was assumed to be 10/12 of the 1952 value because building 260 was completed in February 1951. This is a conservative number because startup problems likely prevented full production for a time after building completion.

*Step 2 (1963–1980).* From October 1962 to January 1964, the data reported in the monthly progress reports were constantly changing. There are data from October 1962 to October 1980 for the number of remote and operator-attended operations. The data set from January 15, 1964, to February 15, 1968, which is the most complete data set for the entire 45-yr period, has information on the man-hours required for each type of operation per month, which allows the calculation of the average man-hours per operation. The average man-hours per operation allows for the calculation of time spent machining for both operator-attended operations and remote operations from October 1962 to October 1980 using equation 4.

$$T_2 = NO * TPO \tag{4}$$

*Where*

$T_2$ is the man-hours of machining from October 1962 to October 1980,

NO is the number of operations/month, and

TPO is the mean time/operation plus 2 $\sigma$ (Mean time/operation plus 2 $\sigma$ was used to be conservative).

Because this data set includes setup time, inert machining setup, and machining time, it makes it possible to calculate the discharge without including time when water was not running through the sumps.

*Step 3 (1980–1996).* Extrapolation was used to calculate the HE discharges after the October 15, 1980, progress report because that was the last WX3 monthly report available in the Laboratory Archives. For the period from 1980 until the outfall was shut down in 1996, there are no machining data available, so the mean plus 2 $\sigma$ of the hours of machining per month as calculated above from 1970 to 1980 was used. This approach was used because the hours of machining were highly variable from 1970 to 1980. However, the regression line is basically flat with a –0.038 slope for a linear regression of the hourly machining data between February 15, 1970, and October 15, 1980. This method assumes a steady flow rate from 1980 to 1996.

$$T_3 = H_{\text{1970 to 1980 average}} * \text{NMonths}_{\text{1980 to1996}} \tag{5}$$

*Where*

$T_3$ is the extrapolated man-hours of machining from 1980 to 1996,

$H_{\text{1970 to 1980 average}}$ is the average man-hours per month of coolant type machining from 1970 to 1980, and

$\text{NMonths}_{\text{1980 to1996}}$ is the number of months from 1980 to 1996.

The total RDX discharge from all three steps was then determined using equation 6.

$$D = (T_1 + T_2 + T_3) * 11.4\ (\text{L/min}) * 60\ \text{min/h} * C \tag{6}$$

*Where*

D is total RDX discharge,

$T_1$ is the total hours of machining for the early castings,

$T_2$ is the total hours for the remote and operator attended operations from Step 2,

$T_3$ is the total machining hours from Step 3, and

C is the solubility limit of RDX.

Method 3 results are graphically displayed in Figure C1-2.4-2, and the total discharge is estimated as 52,000 kg of RDX.

### C1-2.4.2 Method 3 Uncertainties

The uncertainties for the combined steps associated with Method 3 are listed below followed by uncertainties for each step. None of the steps include any wash-down water for bay cleanup. Wash-down water was significant and is included in Method 4. Wash-down water was applied by hand from a ¾-in. hose to wash machinings off of and away from the machines and to force the machinings down the gutters into the sumps. The sumps allowed the machinings to settle out of the wash-down and coolant water, and then the water overflowed into the drain to the outfall. Flow rate from the wash-down hoses has not been determined, and the wash-down system was modified to reduce the amount of wash-down water used in later years. Wash-down water was also used to clean the machining bays on a weekly basis as a safety measure. Uncertainties related to the sump modifications discussed in section C1-2.2.1 would also apply to this method.

*Step 1.* This step assumed that the hours of machining were correlated with the number of castings during the period from 1952 to 1963 and that there was not much change in that correlation over time. However, the hours of machining time from 1951 to 1955 are too high an estimate because more than 3 times as many machinists than were working in 1952 would have been required in order to work the hours calculated by this method. Thus, this step may overestimate the RDX discharge from 1952 to 1963.

*Step 2.* This step assumes that the time per operation is constant for the period from 1962 to 1980. This is unlikely given the increasing efficiency of computer-controlled machine tools during this period. Another uncertainty is that before 1972, water was also used to keep the dust down while machining inert materials (Bazzell, Attachment A). Even though the dust abatement water was not running over HE parts, it was still running through the sumps where it would be exposed to solid HE. Because the [mean time/operation] multiplied by the [number of operations plus 2 $\sigma$] was used for this step, it is probably conservative. When the [mean time/operation] times the [number of operations plus 2 $\sigma$] was compared with the 1964 to 1968 data when there were actual hours of machining, the [mean time/operation] times the [number of operations plus 2 $\sigma$] calculation is always greater than the actual data and yields an extra 787 kg of RDX more than the actual data. The lack of data for the amount of wash-down water used is the shortcoming of this otherwise substantial data set.

*Step 3.* This step of Method 3 may be a closer estimate of the actual amount of RDX discharged from 1980 to 1996 because the estimate assumes a steady flow rate from 1980 to 1996. That estimated flow rate is lower than the reported NPDES flow rate because it was based on actual machining times and not three or four measurements per year. However, as HE research progressed, less RDX was used, and HMX was used more extensively. By the mid-1970s, triaminotrinitrobenzene (TATB) became available and was used extensively (Hatler, Attachment A). Because the actual RDX concentration in the machining water was probably lower than its solubility limit, the calculated RDX is likely to be a net overestimate for this period. Because there are no continual RDX concentration data for the discharge water, the higher values are used in order to be conservative, bearing in mind that the data from building 302 in 1979 mentioned in section C1-2.1 averaged 32 ppm RDX (Gard and Newman 2005, 093651, p. 1, HE Source Term Data file, Appendix B).

### C1-2.5 Method 4 Discussion

This method is based on interviews with current and former Laboratory employees, and it gives the most complete qualitative picture of actual operations. The method delineates how many shifts were worked, the approximate number of machinists per shift, and estimates of the flow rates and usage of wash-down water. There were no records found in the progress reports that describe three-shift machining and casting operations; however, there are retirees who recall those days. Building 260 production dropped from three shifts to two shifts in 1957 (Lujan, Attachment A; Marr, Attachment A). This agrees with the huge drop in the number of pieces cast during 1956 to 1958. Operations then dropped to a single shift with occasional overtime, as delineated in the February 15, 1969, progress report. During the early 1970s, there was Saturday overtime in building 260 for about 2 months of Saturdays per year (Bazzell, Attachment A). Overtime was ignored in the calculations because there was seldom a full crew working when all employees have 24 d of vacation and 18 d of sick leave per year.

### C1-2.5.1 Method 4 Calculations

Formulas were used in Excel (Gard and Newman 2005, 093651, Worksheet Method4a_Noe, HE Source Term Calculations File, Appendix B) to calculate the mass of discharged RDX per year using a compilation of information from these interviews. The totals for each year were then summed to give a total estimated RDX discharge.

$$D = \sum_{1996}^{1951} (((((N_{MS} * (F_{Lpm} * 60 * (T_P - T_s)) * S) + (WD_s * W_w * S)) * D_{PY}) + (F_{wd} * W_w * 51)) * C) \qquad (7)$$

*Where*

D = discharged RDX per year,

$N_{MS}$ is the number of machinists per shift,

$F_{lpm}$ is the coolant water flow (11.4 L/m) (Lujan Attachment A),

$T_P$ is the productive time per shift (hours),

$T_s$ is the setup time per shift (hours),

S is the number of shifts per day,

$WD_s$ is the wash downs per shift,

$W_w$ is the wash-down water per wash down (liters),

$D_{PY}$ is the days worked per year, and

$F_{wd}$ is the number of Friday weekly wash downs/year.

Approximately 37,000 kg of RDX was discharged using equation 7 if 50 gal. of water was used per wash down (Method 4a). The coolant water flow rate was 3 gal./min as estimated by Noe Lujan (Attachment A). Approximately 32,000 kg of RDX was discharged using equation 7 if 20 gal. of water was used per wash down (Method 4b), and the coolant water flow rate was 2 gal./min as estimated by W.A. Spencer in the 1976 letter to H. Ballance (Spencer, Attachment A) (Gard and Newman 2005, 093651, p. 4, HE Source Term Data file, Appendix B). (See also Gard and Newman 2005, 093651, Worksheet Method4a_20GalWashd, HE Source Term Calculations File, Appendix B.)

### C1-2.5.2 Method 4 Uncertainties

The greatest uncertainties with this method are in the amount of water used per wash down and the coolant water flow rates.

### C1-2.6 Method 5 Discussion

Method 5 is a composite of Method 3 and Method 4. This method utilizes the calculations from Methods 3 and 4 and uses the highest masses from each, yielding an estimated total RDX discharge of 65,000 kg (Gard and Newman 2005, 093651, Worksheet Composite3_4=5, HE Source Term Calculations File, Appendix B). Method 3 yields the higher RDX release for the years 1952–1956, and Method 4 yields the higher RDX release for the remaining years.

### C1-2.6.1 Method 5 Uncertainties

Like Method 3, Method 5 likely overestimates the number of hours spent machining castings during 1951–1956. Similarly, it does not account for wash-down water flows for those years. Likewise, Method 5 has the same uncertainties as Method 4 for the later period.

### C1-2.7 Summary of Method Results for Building 260

Total RDX discharge estimates for the five various methods are included in Table C1-2.7-1, and the annual time series are shown in Figure C1-2.7-1.

To test whether these estimates are reasonable (in other words, if the estimates are physically realistic given the amount of HE processed at TA-16), the estimates from Method 5 were compared with usage estimates based on actual inventory data. The minimum usage of RDX compounds was calculated for the 4 yr that inventory data were available by subtracting the ending inventory for each month from the previous month's inventory (see Appendix B of this report for more details). The estimated usage of RDX compounds, Comp B, RDX, and Cyclotol from February 1952 to April 1956 was between 738,992 kg and 1,298,677 kg. The total estimated 45-yr RDX discharge of 65,000 kg using Method 5 is between 5% and 8.8% of the minimum usage for 1952–1956. Thus, even the maximum estimate is physically realistic given the large inventories and extensive HE processing that occurred at the site. An important observation is that all of the five methods yield values that are within an order of magnitude of each other. The most conservative estimate is just over 4 times the least conservative estimate. This relatively narrow range using a variety of methods suggests that these may be reasonable upper bounds for RDX releases from building 260.

### C1-2.8 Building 260, Other Considerations

Water-sealed vacuum pumps were used at building 260 to generate a vacuum that was used to clamp the HE parts onto the machines during the machining process. The sealing water did not run through the sumps where the HE cuttings were accumulated, but it did combine with the flow from the sumps and runoff from the roof as it was discharged into the building 260 Outfall Pond, which then flowed into Cañon de Valle. This added water would have diluted the contaminated water from machining activities and increased HE transport away from building 260, into Cañon de Valle, and down into the vadose zone.

## C1-3.0 DISCUSSION OF RDX DISCHARGES AT OTHER TA-16 LOCATIONS

Additional source terms at TA-16 include discharges from grinding, inspection and casting operations, as well as other machining facilities. The limited data from these facilities are described below.

### C1-3.1 90s Line Facility

The 90s Line facility was built prior to building 260, and there was no mention of the facility in any progress report available between 1952 and 1980. It is assumed that there was only minor HE processing performed there after building 260 came online (Spencer, Attachment A). HE has been detected in the 90s Line area (e.g., 90s Line Pond), but the inventory and extent have not been determined. The total absence of records prevents an estimation of 90s Line releases.

### C1-3.2 300 Line Facilities—Buildings TA-16-301 and TA-16-303

Buildings TA-16-301 and 303 were used for sawing cast HE parts. Cast parts had risers, which formed where the molten material was poured into the mold. These were sawn off prior to machining or other use. Pieces of different shapes were also sawn from larger cylinders and slabs as needed. Sawing operations generated fine cuttings that were solubilized by coolant water, the same as during machining. Water from these facilities was discharged into Martin Canyon. The October 15, 1960, progress report discusses the addition of water control flow meters to HE sawing tables in 301 and 303 where the sawing of the cast HE parts was done.

#### C1-3.2.1 Buildings TA-16-301 and TA-16-303 Calculations

Because there were no historical data found for calculating the discharge from sawing, the sawing discharge could only be calculated using information gleaned from interviews. From 1951 to 1957, Noe Lujan (Lujan, Attachment A) estimates that three men spent one half day, 3 d/wk sawing the risers. The sawing operations in buildings 301 and 303 probably dropped substantially after 1957 when fewer parts were made and were shut down by the early 1980s with the increase in HE pressing. To be conservative, the discharge calculations assumed a 10-yr period of sawing activities at the 1951 to 1957 rate to account for the entire casting period.

$$D_s = H_{pd} * D_{pw} * W_{py} * Q * C \tag{8}$$

*Where*

$D_s$ is discharge from sawing operations in the 300s buildings,

$H_{pd}$ is hours per day (4),

$D_{pw}$ is days per week (3),

$W_{py}$ is weeks worked per year (51),

Q is liters per minute (11.4), and

C is concentration of RDX in water, assumed to be the solubility limit.

Approximately 563 kg of RDX was discharged according to this method.

#### C1-3.2.2 Buildings TA-16-301 and TA-16-303 Uncertainties

If solid HE materials were carried out of the 301 and 303 buildings in the discharged water prior to the 1962 sump modifications, this could have substantially increased the total HE discharged.

### C1-3.3 300 Line Facilities—Buildings TA-16-300 and TA-16-302

Buildings TA-16-300 and 302 were the locations used for casting HE into desired shapes. The casting operations used steam to heat the melting kettles as well as for cleaning the melting kettles and molds. The steam used for cleaning, condensing on the kettles and molds, as well as the wash-down water used to hose down the facilities after the processing activities would have generated some RDX discharge. However, the majority of water used in buildings 300 and 302 was pumped through the jackets of the molds to maintain the proper temperature of the molds before and during the pour of molten HE. This is to prevent the HE from setting up too quickly (Maes, Attachment A). None of this water came into contact with HE.

### C1-3.4 Building TA-16-340

Formulation operations in building 340 used large amounts of water. Some water was used in the formulation process for mixing HE with plastic-bonding materials that were dissolved in organic solvents (Hatler, Attachment A). The majority of the water was used by water-sealed vacuum pumps when the mixing process was finished. Nine or ten vacuum pumps that used 3 gal./min of sealing water were used to vacuum dry the mixture of HE, water, solvent, and plastic (Hatler, Attachment A). There could have been some RDX in the vacuum sealing water discharged, but it is very unlikely that much of the vacuum sealing water was contaminated with RDX. Other consumption of water was wash-down water used to hose down the facilities after the processing activities.

#### C1-3.4.1 Building TA-16-340 Calculations

The NPDES measured flow for 1994 for TA-16-340 was 46,587,469 L/yr.

### C1-3.5 Building TA-16-460

Analytical chemistry operations in TA-16-460 generated water from vacuum pumps and other processing activities. It is likely there was minimal RDX in the TA-16-460 waters.

#### C1-3.5.1 Building TA-16-460 Calculations

The NPDES average measured flow from 1977 to 1994 for TA-16-460 was 6,209,486 L/yr.

### C1-3.6 Building TA-16-400

Building TA-16-400 was used for washing trucks used for transporting HE to remove any HE residue that collected in or on the body and frame of the truck. There would have been RDX discharges from the water used to wash these trucks (McCorkle, Attachment A). This water ran through multiweir sumps and was discharged into Water Canyon.

#### C1-3.6.1 Building TA-16-400 Calculations

The NPDES average yearly flow from 1977 to 1994 for TA-16-400 was 458,436 L/yr. This would give a discharge of 900 kg of RDX for the 45-yr period if all of the trucks were contaminated with RDX at its solubility limit.

## C1-4.0 OTHER TA-16 RDX CONSIDERATIONS

Information about various buildings at TA-16 that were used for HE processing and storage was retrieved from the Laboratory on-line database, MOADS.

### C1-4.1 Other Historical Site Considerations

V-Site, 30s Line machining facilities as well as the old casting building would also have been points of discharge. However, the amounts discharged here are probably within the uncertainty of what was discharged from building 260 and the 300s buildings. If better release estimates are deemed necessary for these locations, retired Laboratory workers would provide the most useful data for these older facilities that lack good records. Those interviews should be held as soon as possible. Burning Ground facilities would have also discharged some RDX into Cañon de Valle from the Basket Washing Facilities.

## C1-5.0 BUILDING 260, RDX DISCHARGE ESTIMATES USING ENVIRONMENTAL DATA FROM WELLS AND BOREHOLES

### C1-5.1 Drivers for Well and Borehole Data Study

Prior efforts at estimating subsurface RDX inventories attributable to the 260 Outfall focused on estimating the amount of RDX that was discharged in solution from the outfall. As noted earlier, in section C1-2.0, during the early years of the Laboratory there were very sparse data collected related to the concentration of RDX in the discharged water. In addition, there were also no consistent measurements of water use, and for many years, there were no records related to the composition of the HE that was machined. These factors lead to the multiple models/estimates of the 260 Outfall RDX releases of earlier sections of this appendix. However, even though some of the estimates were thought to be conservative (i.e., likely to be overestimates of actual releases), it was difficult to check the accuracy or representativeness of the results. Thus, these estimates had substantial uncertainties and in effect had to be treated as bounding a possible range of RDX releases.

Because of uncertainties and lack of an effective way to examine the representativeness of the estimates, a complementary approach was developed that aids in evaluating the various RDX release estimates. A key aspect of this conceptual model for RDX transport is the understanding of where 260 Outfall-related RDX inventories are currently located. This information can provide a picture of how RDX has been distributed in the environment over time and also can be used to help guide future remediation options. Given the substantial amount of surface water, groundwater, vadose-zone sampling, and the current monitoring well network, it is possible to make bounding estimates about where the RDX inventory discharged from the 260 Outfall now resides. Therefore, the objective of this section is to use existing Resource Conservation and Recovery Act facility investigation (RFI) and Laboratory groundwater monitoring information to estimate the 260 Outfall-related RDX mass and its distribution in the subsurface environment. This approach is based primarily on recent field measurements instead of on the estimated variables from archival data discussed previously in this appendix. This approach/model can also be updated as sampling and drilling activities continue. An additional benefit of using current environmental data is that even if the exact inventory amount were known, it is still necessary to know how the RDX inventory is partitioned in the environment. Because the RDX was released over a nearly 50-yr span, variations in precipitation and outfall flow will have affected the current partitioning. For example, estimating the RDX inventory with environmental data addresses questions such as how much RDX is still in the mesa soil and the vadose zone or how much RDX has reached the perched and regional aquifers.

### C1-5.2 Distribution of RDX in the Environment

RDX in TA-16 occurs within seven different components of the hydrologic system. Here RDX inventories were estimated for each component. These components include the following:

1. Mesa soil in the 260 Outfall Pond and drainage area following the IM removal of contaminated soils
2. Mesa vadose zone (bedrock), directly below the outfall pond and drainage area

3. Mesa vadose zone encountered by the saturated zones feeding the Burning Ground and Sanitary Wastewater Systems Consolidation (SWSC) Springs (note that this component partially overlaps with component 2)
4. Alluvial sediments in the bottom of Cañon de Valle
5. Vadose zone in Cañon de Valle down to the top of the intermediate-perched zone
6. Intermediate-perched saturated zone
7. Regional aquifer

### C1-5.3 Inventory Estimate Methods

The following describes how the inventory estimates were determined for the seven components listed above. Ranges of values were typically used so that estimates capture uncertainties related to spatial or temporal variations in RDX concentrations, for example, or volumes of contaminated water in saturated zones. Because the input data were ranges, minimum and maximum values were determined for each component except for the shallow soils in the outfall pond area and the Cañon de Valle alluvial sediments. The estimates for these two components come from previous site-specific studies that each provided single estimates for these two inventories. Therefore, it was difficult to determine bounding values for these inventory estimates. These two exceptions are not viewed as critical because they are relatively low inventories that have been fairly well characterized.

#### C1-5.3.1 Mesa Soil in the 260 Outfall Pond and Drainage Area

This is the soil in the outfall pond and the surrounding area that was exposed to outfall water as it progressed from the outfall into Cañon de Valle. According to LANL (2002, 073706), the amount of RDX left in this soil after the IM removal is 650 kg.

#### C1-5.3.2 Mesa Vadose Zone (Bedrock), Directly Below the Outfall Pond and Drainage Area

This is primarily tuff located below the outfall pond and above the intermediate-perched zone. The ranges for maximum and minimum RDX concentrations were taken from analysis of the 16-06370 borehole, which was drilled in the outfall pond after the IM removal of contaminated soils. The minimum and maximum rock volumes between the bottom of the outfall pond and the perched-intermediate aquifer were constrained by borehole and soil sampling in the outfall pond and drainage area. Inventories were calculated by converting the vadose zone rock volumes to mass using local bulk density and then multiplying the resultant mass estimates by measured RDX concentrations (mg/kg) from the 16-06370 borehole core.

#### C1-5.3.3 Mesa Vadose Zone Encountered by the Saturated Zones Feeding Burning Ground and SWSC Springs

Spring flow and concentration data used to constrain the inventories were sampled in 1997 and reported in the 2003 RFI report for Solid Waste Management Unit (SWMU) 16-021(c)-99 (LANL 2003, 077965). Maximum and minimum RDX concentrations from the springs were multiplied by maximum and minimum flow rates to obtain maximum and minimum RDX releases on a yearly basis. A 100-yr release period was assumed to estimate the inventory. Note that this component partially overlaps with component 2, so there may be some minor double counting of inventory for the mesa.

### C1-5.3.4 Alluvial Sediments in the Bottom of Cañon de Valle

This inventory value was taken from an estimate reported in Reid et al. (2005, 093660) and is based on a geomorphic assessment of the canyon bottom sediment inventories.

### C1-5.3.5 Vadose Zone Below Cañon de Valle Down to the Top of the Intermediate Perched Zone

For this calculation, it was assumed that alluvial aquifer concentrations could be used to represent the underlying vadose-zone concentrations. This assumption was made even though no RDX was detected in the vadose zone in CdV-16-1(i) pore water; CdV-16-1(i) is the only borehole that samples the vadose zone below the alluvial aquifer. It is reasonable to use the alluvial aquifer concentrations because these waters will pass through the vadose zone before reaching the intermediate-perched zone. To calculate the inventories, maximum and minimum alluvial aquifer RDX concentrations were multiplied by the volume of water estimated to reside in the vadose zone below the perennial reach of the canyon. The aerial extent of the canyon vadose zone was constrained to be that below the alluvial aquifer footprint,which was constrained using alluvial aquifer borehole water-level data and high-resolution resistivity profiles in the canyon; see LANL (2003, 077965).

### C1-5.3.6 Intermediate-Perched Saturated Zone

For this component, minimum and maximum RDX concentrations from the intermediate-perched zone in CdV-16-1(i) and CdV-16-2(i) (WQDB, http://wqdbworld.lanl.gov) were used as the basis for the inventory calculations. RDX concentrations were converted to masses using estimated perched aquifer water volumes. The perched-aquifer volume was constrained by the measured thickness of the perched-intermediate zone observed in R-25, and the aerial extent of the contaminated water in the aquifer is constrained by the surrounding boreholes such as CdV-R-15-3 and CdV-R-37-2, which have had no detections of RDX.

### C1-5.3.7 Regional Aquifer

For the regional aquifer estimate, RDX concentrations from screens 5 through 8 in well R-25 (Longmire 2005, 088510) were used because they are the only observed regional aquifer detections of RDX. The concentrations were converted to inventory using the same method as that used for the intermediate-perched zone. The aerial extent of the RDX contamination in the regional aquifer was assumed to be the same as for the perched-intermediate zone, and the contaminated thickness was assumed to be twice the thickness of the regional aquifer penetrated by R-25. Thus, these volumes for the contaminated portion of the regional aquifer are not as well constrained as the other hydrologic components because so little information is available for the deep regional aquifer. However, concentrations in R-25 are decreasing with time: some RDX concentrations at the regional aquifer well screens are now below detection levels. Therefore, it is likely that even the minimum estimate overestimates the actual regional aquifer inventory.

## C1-5.4 Results and Discussion

The ranges for the estimated RDX inventories located within the seven hydrologic environments are shown in Table C1-5.4-1. In terms of distributions among the seven components, the vadose zone accessed by the springs, the shallow outfall pond area, and the alluvial sediments all have relatively minor inventories. For the other components, there are fairly large differences between the minimum and maximum estimated inventories. These ranges are reflective of the uncertainties in the parameters used in the calculations and also the spatial and/or temporal variability of RDX concentrations. The perched-intermediate aquifer and the regional aquifer apparently contain large proportions of the total inventory based on these estimation techniques. This result is consistent with the relatively wet conditions at TA-16 (especially when the outfall was in operation) and with the fact that most of the RDX was released during the 1950s (see sections C1-1.0 through C1-4.0), which means there has been about 50 yr for downward transport to occur. However, these estimates are based on little data extrapolated over a large volume, especially in the case of the regional aquifer estimate. In addition, it is not too surprising that the vadose zones below the TA-16-260 pond area and the canyon bottom may contain fairly large proportions of the RDX inventory, but again this estimate is based on sparse data. The maximum estimate of the total amount of RDX in the subsurface environment is within the range of RDX source release estimates based on archival information about water and RDX usage at TA-16 from the archival study. However, the minimum total inventory in Table C1-5.4-1 is much lower than the minimum source estimate in the archival study (Table C1-2.7-1). Although the minimum and maximum total inventory estimates in Table C1-5.4-1 span over an order of magnitude, they help bound the mass and location of RDX in the environment resulting from RDX machining activities at the 260 facility, especially with regards to a lower bound.

## C1-6.0 REFERENCES

*The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.*

*Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.*

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LANL (Los Alamos National Laboratory), July 2002. "Interim Measure Report for Potential Release Site 16-021(c)-99," Los Alamos National Laboratory document LA-UR-02-4229, Los Alamos, New Mexico. (LANL 2002, 073706)

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Reid, K.D., S.L. Reneau, B.D. Newman, and D.D. Hickmott, August 2005. "Barium and High Explosives in a Semiarid Alluvial System, Cañon de Valle, New Mexico," *Vadose Zone Journal,* Vol. 4, pp. 744-759. (Reid et al. 2005, 093660)

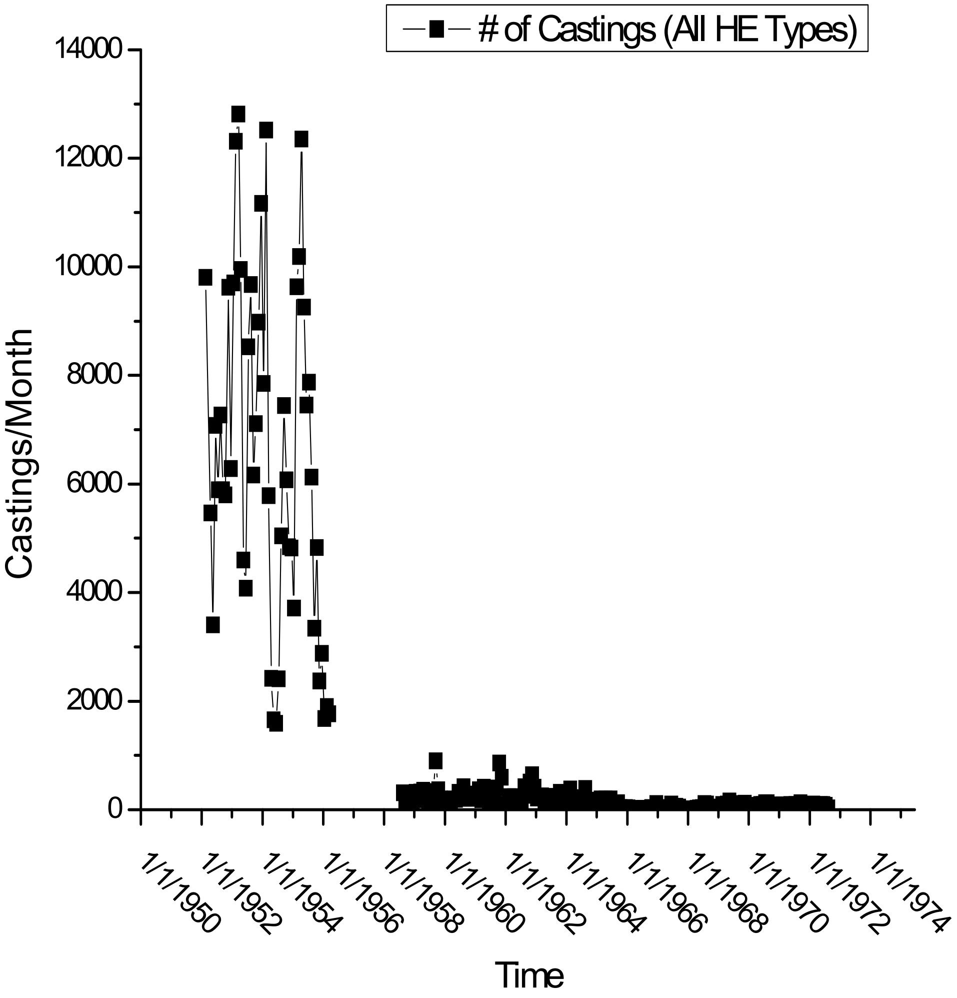

**Figure C1-2.4-1 Number of HE parts (all types of HE) cast per month. Gaps represent periods when no data were available.**

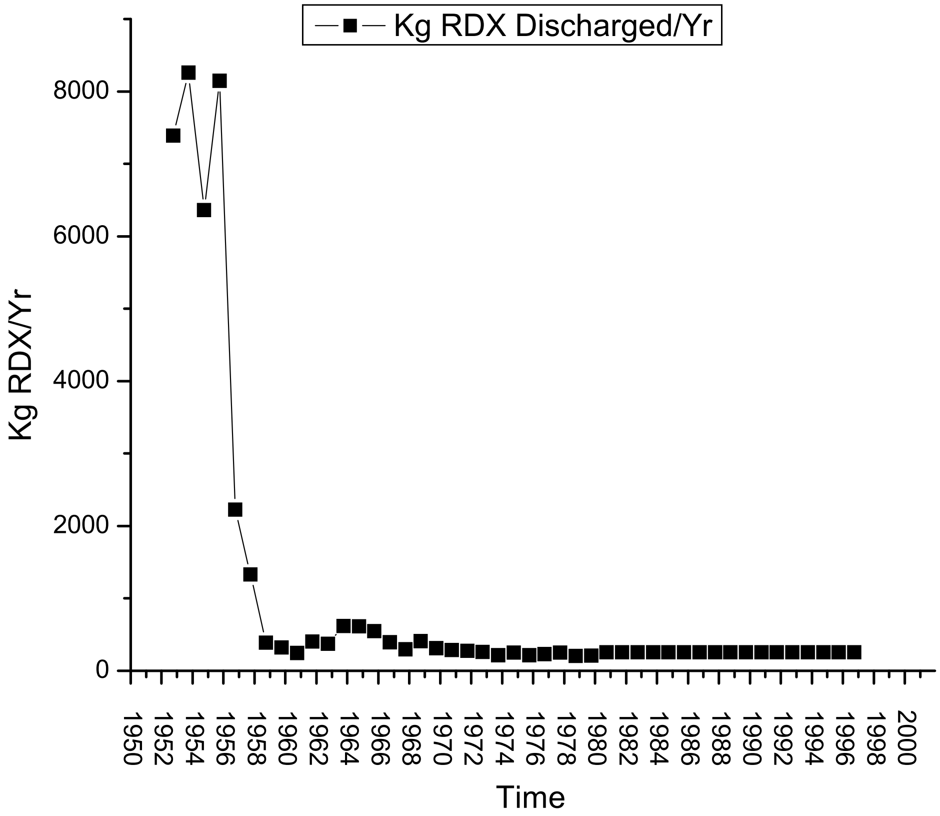

**Figure C1-2.4-2 Kilograms of RDX discharged using Method 3**

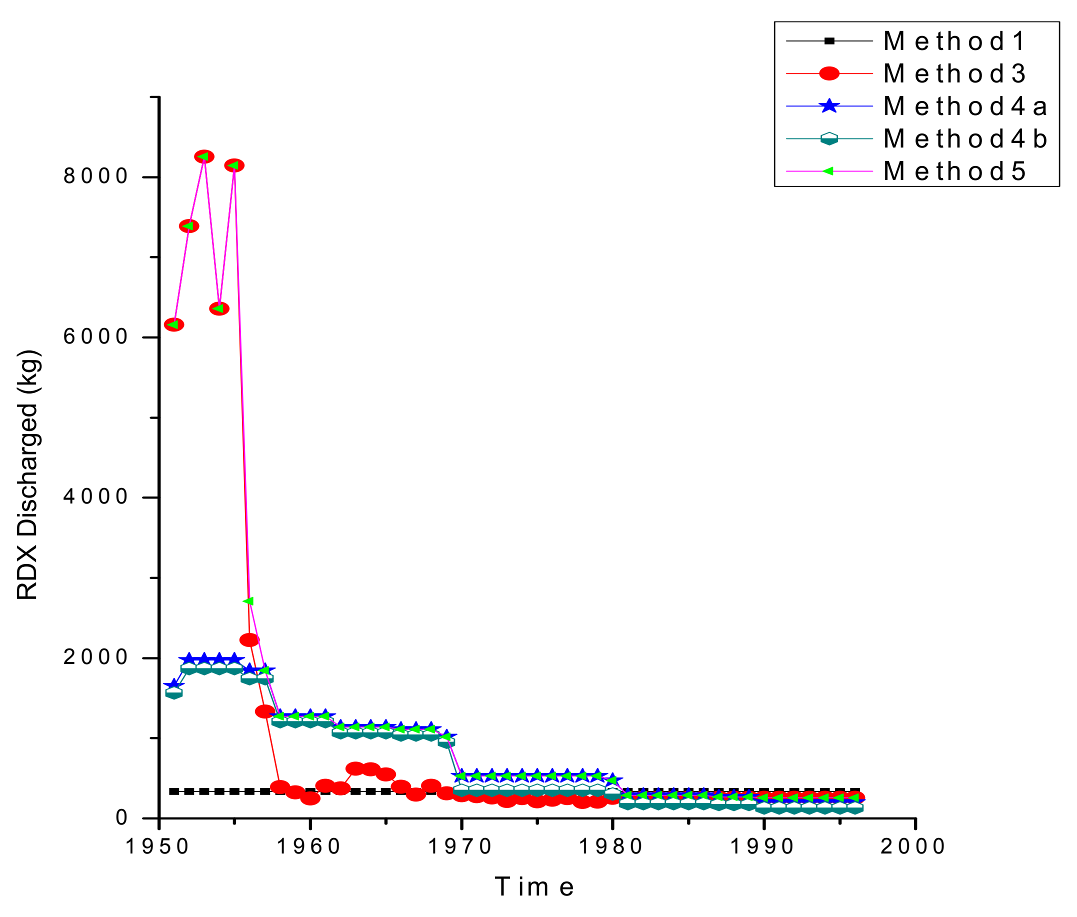

**Figure C1-2.7-1 Estimated RDX discharge with time from building 260 using four different methods**

## Table C1-2.7-1
## Estimates of RDX Release at Building 260

| Method # | Method Description | kg of Aqueous RDX Discharged in ~45 yr |
|---|---|---|
| 1 | Average NPDES outfall flow data from1 shift | 15,000 |
| 2 | IM report data | 32,000 |
| 3 | Progress report statistics | 52,000 |
| 4a | Interviews—# of machinists/shift—# shifts 50 gal. wash down | 37,000 |
| 4b | Interviews—# machinists/shift—# shifts 20 gal. wash down | 32,000 |
| 5 | Method 5—most conservative composite | 64,000 |

*Shifts mean how many 8-h rotations of facility staff per day.

## Table C1-5.4-1
## Estimated Minimum and Maximum RDX Near-Surface and Subsurface Inventories from the 260 Outfall by Hydrologic Component

| Location | Maximum Amount of RDX (kg) | Minimum Amount of RDX (kg) |
|---|---|---|
| SWSC & Burning Ground Springs | 482 | 3 |
| Outfall Pond Area after IM | 650 | 650 |
| Vadose Directly under Outfall Pond Area | 4311 | 234 |
| Alluvial Sediments | 5 | 5 |
| Vadose under Alluvial Aquifer | 12286 | 224 |
| Intermediate-Perched Zone 747–1132-ft Depth | 8109 | 697 |
| Regional Aquifer 1286–1942-ft Depth | 6053 | 135 |
| **Total** | 30524 | 1949 |

## ATTACHMENT A

Dewight Bazzell, 2003, personal communication, February 4, 2003

C. Courtright, 2003, personal communication, February 4, 2003

Machinists used water when machining to reduce dust when machining some inert materials.

L. Hatler, 2002–2005, multiple personal conversations

David Hayden, 2003

From 1990 to 1996 there were approximately six machinists working at building 260.

E. Hyde, 2003, personal communication, October 29, 2003

Noe Lujan (2003) worked at the Laboratory from 1953 until he retired in 1987. From 1953 to 1955, he worked as an expediter moving HE materials to and from the rest houses where HE was stored when it was going into building 260 to be processed or after it had been processed. From 1955 to 1959, he left 260 to work in Transportation and then returned to 260 where he retired as a supervisor in 1987. He was working in 260 and had just left the bay where the explosion occurred in February 1959. His father was killed in the accident at the Burning Grounds in October 1959.

Notes from Noe Lujan: February 4, 2003

1. Twelve to 13 machinists per shift plus 2 supervisors from 1953 to 1980 in building 260
2. Seven to eight machinists plus two supervisors from 1980 to 1987 in 260
3. Three shifts until 1957, two shifts until 1969, one shift until retired in 1987
4. The high-pressure water hoses (¾-in. hoses with city water pressure at 40 to 60 psi; Nuttall, Attachment A) used to wash down the bays while machining were quite powerful and would squirt 30 to 40 ft. Depending on the part being machined, the amount of machinings generated, and individual preferences, a machinist would wash down an average of two times per shift. This would entail hosing all of the machinings that were on the machine and on the floor into the sumps. This was done for safety and to reduce the mess around the work area.
5. These same high-pressure hoses were used during swing shift cleaning on Fridays. At this time every bay was given a complete wash down from the ceiling to the floor.

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Bob Marr, January 29, 2003

1. He worked at the Laboratory from 1957 until he retired in 1980 from building 260 as a supervisor.
2. Fourteen machinists on day shift and 12 machinists on evening shift plus 2 supervisors from 1957 to 1980
3. The detailed machining data found in the monthly progress reports after 1962 were collected after the accidents in order to better track activities in case of more explosions.
4. Marr confirmed the use of the high-pressure hoses for wash down and Friday swing shifts complete bay hose downs.

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M.L. McCorkle, May 5, 1977, "Review of National Pollutant Discharge Elimination System (NPDES) Permit Applications," Los Alamos Scientific Laboratory memorandum to L. Hilton

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J. Nuttall, 2003, personal communication, February 27, 2003

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Steve Rivera, the current supervisor in building 260, personal communication, February 5, 2003

> The wash-down hoses and system had been changed since the early days, and less water was now being used for wash down. Since the wash-down system has been changed, it will be very difficult to get the actual flows used for wash down. The use of flow meters on the current system would give a low-flow boundary.

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Bill Spencer, February 20, 2003

1. Started at the Laboratory October 1952; retired April 1984
2. Used tempered water for machining to prevent thermally induced dimensional changes in HE parts as they were being machined.
3. Shift schedules ~14 men on day shift and 12 on night shift from 1952 to 1957
4. ¼-in. tube running aerated water on most parts as coolant
5. ¾-in. hose used for hose down and clean up

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# *Appendix C2*

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## Unsaturated Zone Modeling

## C2-1.0 INTRODUCTION

This section discusses numerical modeling used to estimate RDX transport from the 260 Outfall through the vadose zone, especially from Cañon de Valle, and the ultimate breakthrough of RDX to the regional aquifer. The effluent from building 260 was routed to an outfall that discharged into the 260 Outfall Pond that then overflowed down into Cañon de Valle. The estimated RDX source from building 260 effluent was used as the Cañon de Valle source in the vadose-zone model. Specifically, the greatest source presented in Table C1-2.7-1 using the Method 5 source estimate was used, 64,000 kg RDX, so that the resulting simulated RDX breakthrough from the vadose zone would be conservative. This source is time dependent as depicted in Figure C1-2.7-1. In addition, this approach is also conservative because the HE is assumed to be released directly into the canyon bottom where infiltration rates are highest.

## C2-2.0 GOLDSIM MODEL SETUP

Deterministic GoldSim models were developed and used to predict vadose-zone transport at the site, as shown in Figure C2-2.0-1. The model uses the 64,000-kg time-dependent RDX source as input, distributes that RDX within the Cañon de Valle alluvial system, and then simulates vadose-zone transport of RDX down to the top of the regional aquifer. Breakthrough curves from two models were used to simulate two vadose-zone flow rates. These breakthrough curves are then used as input to a stochastic model of the regional aquifer to simulate RDX transport within the regional system away from the site and toward any production wells or the Laboratory boundary along the simulated transport pathways.

GoldSim uses a network model to mimic the transport pathways as shown in Figure C2-2.0-1. The modeler can assign pertinent properties to the different pathways that are connected in a network. The following is a list of the different RDX and hydrologic properties and components included in the GoldSim model (Figure C2-2.0-1). Also included are discussions of how the different model elements interact to simulate the pathways.

1. **Materials**—The materials box (Figure C2-2.0-1) assigns input parameters that describe the material properties for the rocks and RDX, as shown in Table C2-2.0-1.

2. **RDX Source Term**—(TimeSeries_RDX_260 in Figure C2-2.0-1) The RDX source is represented by a time-series element (Method 5, Figure C1-2.7-1) that calculates the annual mass of RDX released at the outfall and transfers that mass to the Cañon de Valle Alluvial element. RDX releases at the source are assumed to be zero following cessation of releases in 1996 for the duration of the runs. This source is input to the Cañon de Valle alluvial system.

3. **Cañon de Valle Alluvial System**—The alluvial materials in the perennial reach of Cañon de Valle were contaminated by HE dissolved in water draining from the 260 Outfall pond into Cañon de Valle. The Cañon de Valle alluvial region is modeled as a well-stirred reactor. In GoldSim, a well-stirred reactor is called a cell pathway, and it has a uniform concentration throughout its volume at a given time, as controlled by the time-dependent RDX source (Figure C2-2.0-1). The estimated thickness of the Cañon de Valle alluvial cell is 1.2 m based on alluvial well cores. The length of the cell is defined by the perennial reach of Cañon de Valle that extends from Peter Seep to the TA-14/15 boundary, which is 2956 m based on information from the Geographic Information System site database. The width of the alluvial system is assumed to be 19 m, based on the average of two geophysical transects. RDX output from this cell (the alluvial system) acts as the source to the Cañon de Valle vadose zone (Figure C2-2.0-1).

4. **Cañon de Valle Vadose Zone—**The contributing area of the Cañon de Valle vadose zone is assumed to lie directly beneath the Cañon de Valle alluvial system and therefore has the same area (2956 m × 19 m). It extends 171 m down to the regional aquifer. The vadose zone was modeled as a one-dimensional pipe. In GoldSim, a pipe provides a computationally efficient way of solving the advection-dispersion transport equation. The vadose-zone pipe is filled with tuff that has a porosity based on laboratory analyses of TA-16 tuff units, as defined in the materials box. Unlike the cell pathway, concentration can vary along the length of the pipe. In the simulations, the pipe is assumed to have a saturation of 100%. The initial choice of full saturation was based on the relatively large volume of water lost to subsurface flow in Cañon de Valle, particularly while the outfall was in operation. Measurements performed on core collected later from CdV-1(i) indicated that actual saturation is approximately 45%. RDX output as a function of time for this pathway is the desired model output. This output becomes input to the top of the regional aquifer as simulated with the FEHM flow and transport model (see Appendix C4) (Zyvoloski et al. 1996, 054421).

5. **Cañon de Valle Q**—This input parameter is the estimated volumetric flow rate through the Cañon de Valle system (CDV_Q in Figure C2-2.0-1). The flow rate continues through the alluvial material, through the vadose zone, and into the regional aquifer. Two values were used in the GoldSim simulations for CDV_Q. Note that both of the volumetric flow rates assumed here are far larger than the outfall volume for the 1977 to 1989 period of 7574 $m^3$/yr cited in the archival source discussion in section C1-2.2.

   a. The flow rate for the high Q deterministic model is 753,271 $m^3$/yr. This value is based on a bromide tracer test that was performed at the 260 Outfall Pond. In the test, bromide was transported a vertical distance of 30.48 m to SWSC Spring in about 6 months or 61 m/yr (LANL 2003, 077965). The bromide-based flow rate for the vadose-zone pathways is an extremely rapid one and likely represents fast-path type transport along preferential flow paths such as fractures. It therefore provides a very conservative estimate for transport at TA-16, particularly when this near-surface linear velocity is applied across the entire area of the alluvial aquifer system to yield a volumetric flow rate.

   b. The flow rate for the low Q deterministic model is 40,775 $m^3$/yr. This lower value is calculated based on an RDX linear transport velocity of 3.3 m/yr for RDX contamination in R-25 (547 ft in 50 yr). This velocity is similar to the darcy flux (0.9 m/yr) value estimated by Rogers et al. (1996, 055543) for a hole near MDA-P and by Dander (1998, 088743) (4.6 m/yr) for Mortandad Canyon. These flow rates were calculated assuming linear velocity (above values) multiplied by an average porosity of 0.22 (porosity for units Qbt3 and Qbt4) multiplied by area.

6. **Regional Aquifer—**The aquifer extends beneath the Pajarito Plateau and is the source of drinking water for Los Alamos County and the Laboratory. It is not modeled in this deterministic GoldSim model.

## C2-3.0 RESULTS AND DISCUSSION

The results for the GoldSim simulations are the two RDX breakthrough curves to the regional aquifer beneath Cañon de Valle shown in Figures C2-3.0-1 and C2-3.0-2, for the high and low Q cases, respectively, and the largest estimated discharge mass of 64,000 kg from the 260 Outfall. In these figures, the initial time corresponds to 1951 when operations at building 260 were started.

- For the high Q case, the GoldSim model predicts that peak breakthrough at the water table at a rate of approximately 6000 kg/yr RDX occurred after 7 yr in 1958 and that additional breakthrough essentially no longer occurs. For this calculation, the vadose zone is predicted to currently be RDX free.
- For the low Q case, the model predicts peak breakthrough of approximately 800 kg/yr will occur after 80 yr in 2031. These results show that currently RDX is arriving at the water table at a rate of approximately 400 kg/yr. This rate is predicted to rise until the peak occurs, and arrival at the water table will continue for approximately 300 yr or the year 2250. For this calculation, a substantial inventory of RDX is predicted to still reside in the vadose zone.

## C2-4.0 REFERENCES

*The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.*

*Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.*

Dander, D.C., October 1998. "Unsaturated Groundwater Flow beneath Upper Mortandad Canyon, Los Alamos, New Mexico," Los Alamos National Laboratory document LA-UR-98-4759, Los Alamos, New Mexico. (Dander 1998, 088743)

LANL (Los Alamos National Laboratory), September 2003. "Phase III RFI Report for Solid Waste Management Unit 16-021(c)-99," Los Alamos National Laboratory document LA-UR-03-5248, Los Alamos, New Mexico. (LANL 2003, 077965)

Rogers, D.B., B.M. Gallaher, and E.L. Vold, 1996. "Vadose Zone Infiltration Beneath the Pajarito Plateau at Los Alamos National Laboratory," The Jemez Mountains Region: New Mexico Geological Society Forty-Seventh Annual Field Conference, September 25-28, 1996, F. Goff, B.S. Kues, M.A. Rogers, L.D. McFadden, and J.N. Gardner (Eds.), pp. 413-420. (Rogers et al. 1996, 055543)

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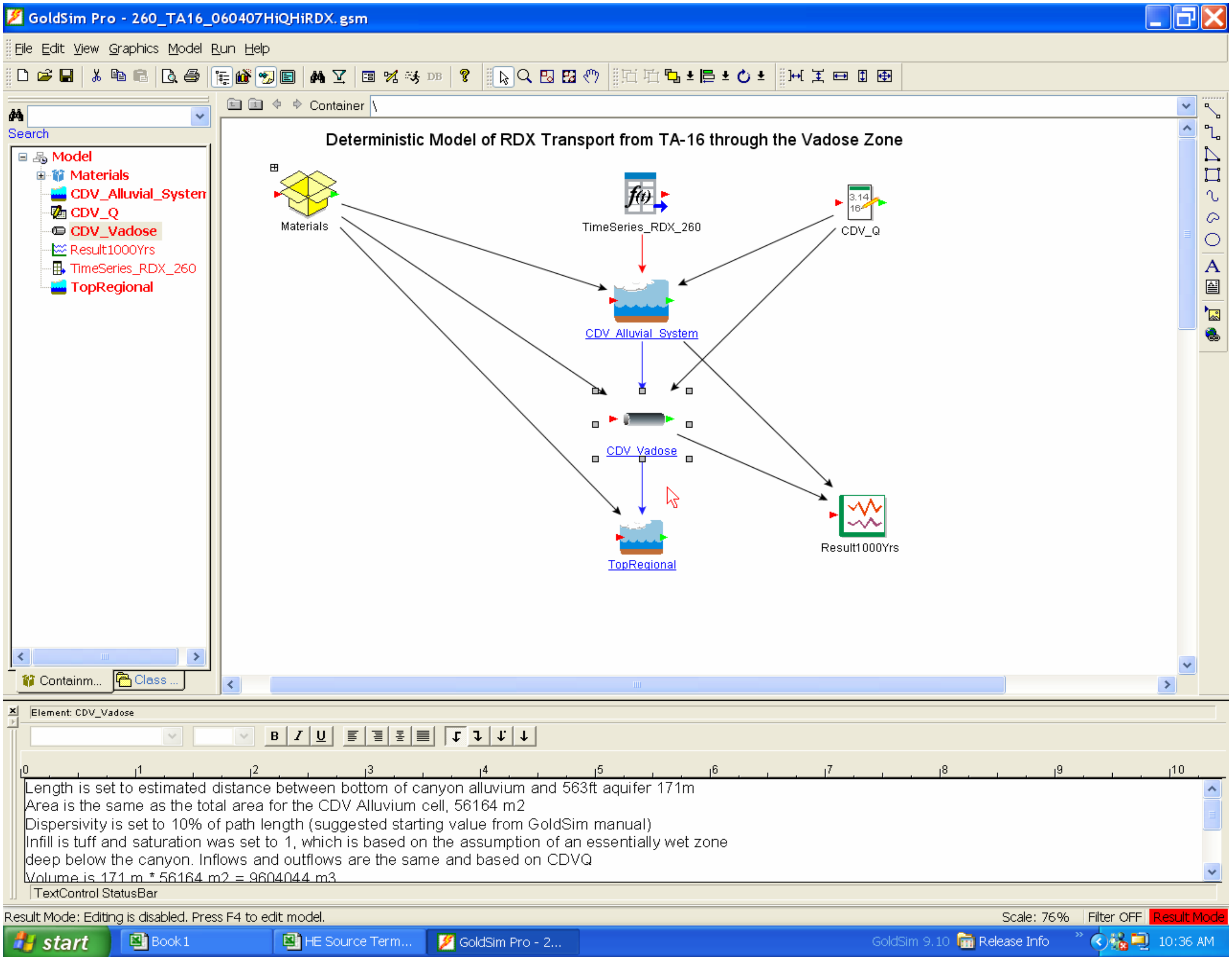
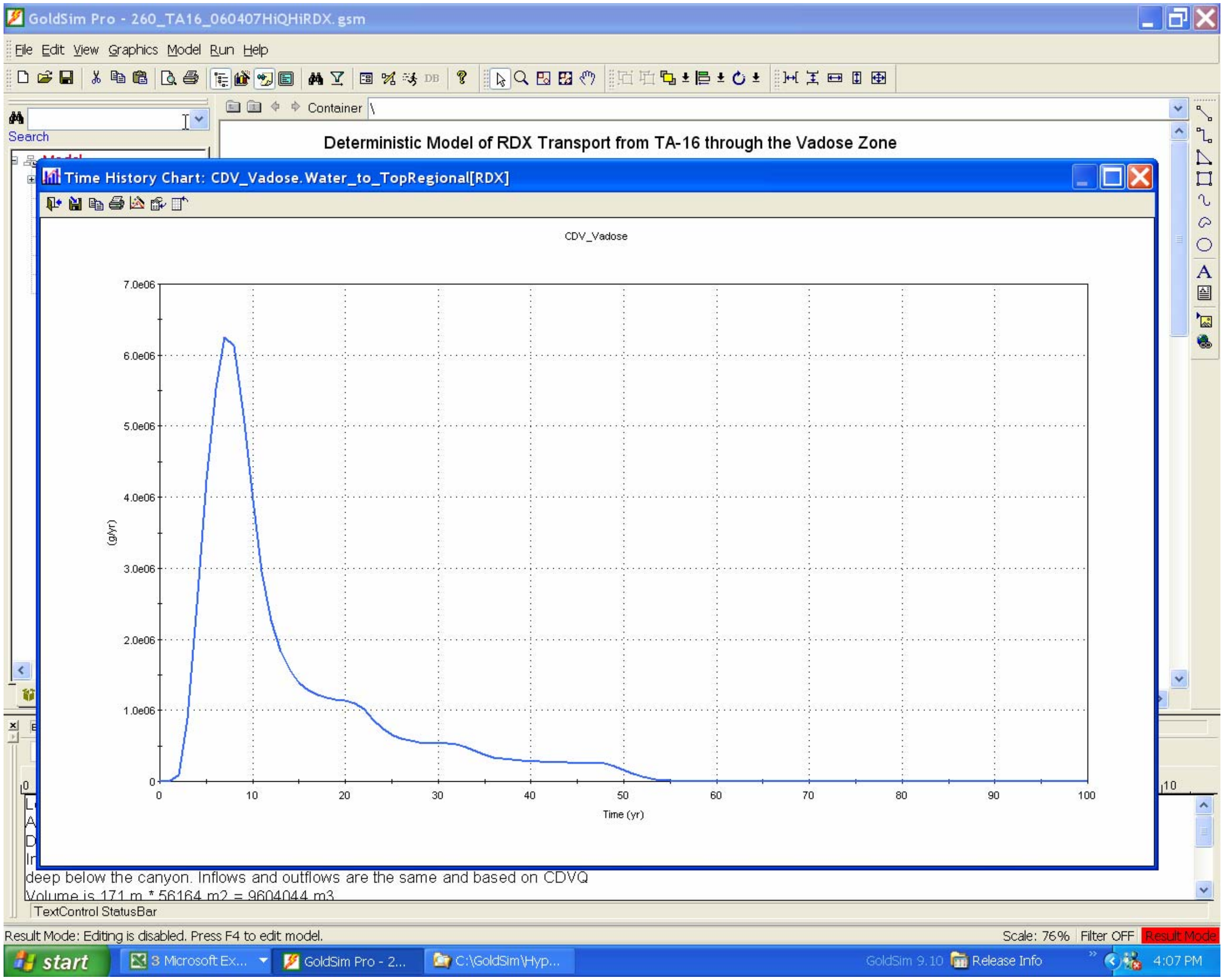


Length is set to estimated distance between bottom of canyon alluvium and 563ft aquifer 171m
Area is the same as the total area for the CDV Alluvium cell, 56164 m2
Dispersivity is set to 10% of path length (suggested starting value from GoldSim manual)
Infill is tuff and saturation was set to 1, which is based on the assumption of an essentially wet zone deep below the canyon. Inflows and outflows are the same and based on CDVQ
Volume is 171 m * 56164 m2 = 9604044 m3

**Figure C2-2.0-1 GoldSim model setup for vadose-zone RDX transport calculations**

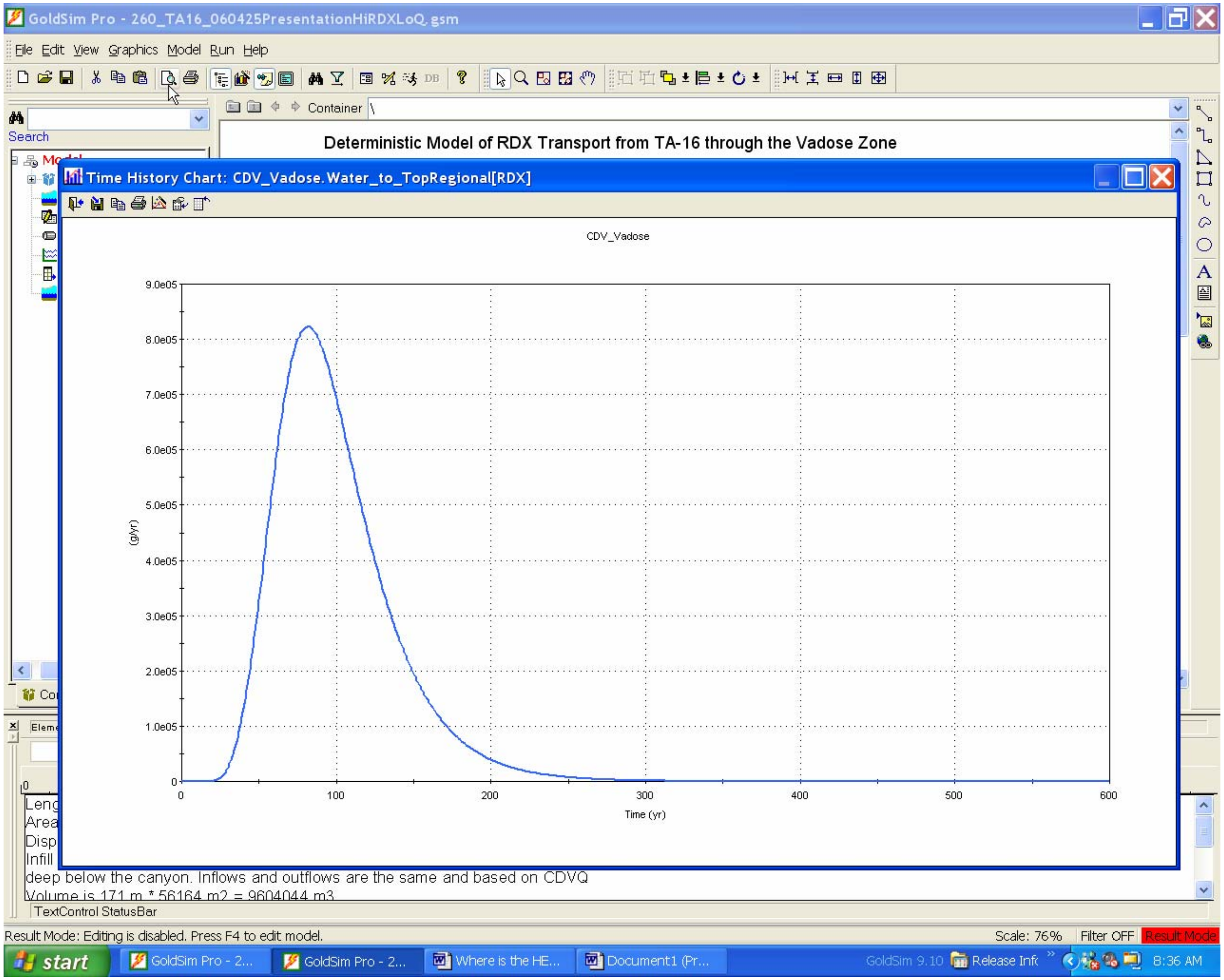


deep below the canyon. Inflows and outflows are the same and based on CDVQ

Volume is 171 m * 56164 m2 = 9604044 m3

Result Mode: Editing is disabled. Press F4 to edit model.

**Figure C2-3.0-1** **RDX breakthrough (g/yr) to the regional aquifer beneath Cañon de Valle as a function of time, assuming the high volumetric flow rate through the vadose zone and the largest estimated RDX inventory**



Leng

Area

Disp

Infill

deep below the canyon. Inflows and outflows are the same and based on CDVQ

Volume is 171 m * 56164 m2 = 9604044 m3

Result Mode: Editing is disabled. Press F4 to edit model.

**Figure C2-3.0-2** RDX breakthrough (g/yr) to the regional aquifer beneath Cañon de Valle as a function of time, assuming the low volumetric flow rate through the vadose zone and the largest estimated RDX inventory

## Table C2-2.0-1
## Input Parameters for the GoldSim Model

| Input Parameter | Value |
|---|---|
| RDX solubility | 44 mg/L |
| Tuff Bulk Density | 2000 kg/$m^3$ |
| Tuff Porosity | 0.34 |
| Dispersivity | 10% of path length 17.1 m |
| CdV Saturation | 1 |
| Reference Diffusivity (RDX) | 1e-9 $m^2$/s |

# *Appendix C3*

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## Intermediate-Groundwater Capture Zone Modeling

## C3-1.0 INTRODUCTION

A groundwater model was developed, and a series of numerical groundwater flow simulations were conducted in support of the corrective measures evaluation (CME) of a potential extraction and injection well system located at Los Alamos National Laboratory (LANL) in Los Alamos, New Mexico, for installation in the intermediate-groundwater aquifer at Cañon de Valle. The purpose of the model is to evaluate the hydraulic impact of extraction and injection wells on intermediate groundwater. This appendix describes the design of the groundwater flow model and the methods that were employed to evaluate the impact of the treatment system design on local groundwater flow, and it summarizes the results.

## C3-2.0 MODEL DESIGN

The following sections describe the primary design elements of the intermediate aquifer flow model for the Cañon de Valle. The elements described include the numerical code selected, assumptions made during model design, the model grid and layering, boundary conditions used in the model, and the properties assigned to the aquifer.

The model was implemented with Groundwater Vistas Graphical User Interface. Groundwater Vistas fully supports the model code MODFLOW (McDonald and Harbaugh 1988, 056041), which was used to develop the groundwater flow model.

### C3-2.1 Model Code

The model was developed using the numerical code MODFLOW (McDonald and Harbaugh 1988, 056041), a three-dimensional, finite-difference, groundwater flow model developed by the U.S. Geological Survey. MODFLOW was selected for use in this project because the code is nonproprietary and well documented, and it has been verified for a wide range of field problems (EPA 1993, 095777). Numerous models based on this code have been published in peer-reviewed, technical journals.

### C3-2.2 Assumptions of Model Design

The following assumptions were made to simplify the design of the model.

- No significant source of groundwater recharge to the intermediate aquifer in Cañon de Valle is present.
- Infiltration of precipitation and/or surface runoff into the aquifer is negligible.
- The intermediate aquifer is unconfined and of uniform thickness across the model domain.
- Aquifer property data and water levels measured at monitoring wells R-25 and CdV-16-2(i)r are representative of the entire model domain.
- Constant head conditions exist on the eastern and western boundaries.

### C3-2.3 Model Grid

The model grid constructed model domain is a single-layer, 80-row × 160-column, uniformly spaced, finite-difference grid. Each cell on the model grid is 50 ft long in the x direction and 50 ft long in the y direction. The long axis of the model grid has a total length of 8000 ft. The width of the grid along the y axis is 4000 ft. The model is oriented with the long axis oriented in the east-west direction at 10 degrees north of east (Figure C3-1). The model grid is not anchored to site coordinates.

### C3-2.4 Model Grid Layers

Flow was simulated in the model with a single layer. The thickness of the layer is constant throughout the domain and is equal to 290 ft; the intermediate aquifer is approximately 290 ft in thickness in the general area of the well treatment system (LANL 2007, 095787). The layer is sloped at a rate of change equal to the hydraulic gradient (0.08). The elevation used for the starting point for the calculation of the top elevation of the layer of the model grid was selected to be 7110 ft above mean sea level (amsl), approximately 10 ft above the head level at the western grid boundary. The bottom elevation of the grid was calculated from a starting elevation of 6820 ft amsl, which is 290 ft below the starting top elevation.

The division of the model domain into a single, sloped layer of equal thickness was done to simplify the model domain and to ensure the numerical stability of the model. It is assumed that the intermediate aquifer is homogeneous and isotropic; therefore, each aquifer property is constant throughout the domain.

### C3-2.5 Boundary Conditions

The following boundary conditions were used in the model:

- Upper boundary of the model grid—free-surface boundary
- East and west boundaries—constant-head boundaries
- North and south boundaries—no flow

The upper boundary of the model grid is a free-surface boundary to simulate the water table within the intermediate aquifer. The free-surface elevation varies during the simulation period and is calculated during solution of the model (McDonald and Harbaugh 1988, 056041).

The lower boundary of the model grid is a no-flow boundary because it is assumed that the downward movement of water from the intermediate aquifer into the underlying tuff is negligible (section C3-2.2).

The east and west grid boundaries are constant head boundaries (Figure C3-1). The constant head boundary values simulated the observed horizontal gradients in the area of the proposed extraction and injection well locations. The head values were computed from observed heads in wells R-25 and CdV-16-2(i)r and an assumed constant gradient of 0.08. A single value of head is used for each boundary during the steady-state models.

The north and south grid boundaries are treated as no-flow boundaries because the grid is oriented parallel to the primary direction of groundwater flow.

Monitoring well data collected from wells R-25 and CdV-16-2(i)r were used to calculate average head values and the hydraulic gradient. Groundwater gradients were monitored between the two wells during the course of 1 wk (January 1, 2007–January 6, 2007). The average head levels at R-25 and CdV-16-2(i)r are 6746.72 and 6618.87 ft amsl, respectively (Attachment C3-1). Little variation was observed in the gradient during that time period; therefore, it is assumed that the intermediate aquifer gradient is constant at a value of 0.08.

### C3-2.6 Aquifer Properties

#### C3-2.6.1 Recharge

No recharge was simulated in the model. The infiltration of precipitation and surface runoff is assumed to be negligible in the area of the proposed extraction and injection well system.

#### C3-2.6.2 Hydraulic Conductivity

The intermediate aquifer material is represented as a single zone of hydraulic conductivity. The hydraulic conductivity value of approximately 1 ft/d was calculated from the mean permeability value determined by site-specific hydraulic tests in Cañon de Valle (LANL 2007, 095787). The calculation of hydraulic conductivity from permeability used the density and viscosity of water at 20 degrees Celsius and 1 atmosphere pressure, which was 998.2 $kg/m^3$ and $1.002 \times 10^{-3}$ kg/(m × s), respectively.

#### C3-2.6.3 Model Calibration

Model calibration was not performed because of a lack of observation wells; only wells R-25 and CdV-16-2(i)r are located in the vicinity of the proposed extraction and injection well system.

#### C3-2.6.4 Evaluation of Proposed Extraction and Injection Well Design

The model, as described above, was used to evaluate the impact of four extraction wells and four injection wells on groundwater flow in the intermediate aquifer. Included in this evaluation was the determination of the relative levels of impact for three different pumping/injection rates per well: 50, 100, 125 gal./min.

#### C3-2.6.5 Simulation of the Extraction and Injection Well Design

The potential impact of an extraction and injection well system on the groundwater flow through the intermediate aquifer in Cañon de Valle was evaluated using four extraction wells (Rw) and four injection wells (Iw) (Figure C3-2). The same rate of pumping/injection was used for all proposed wells. Three rates of pumping/injection were evaluated to determine the impact on groundwater flow: 50, 100, and 125 gal./min. The maximum rate of pumping capacity of the proposed system is 500 gal./min cumulative between the four wells. Therefore, the maximum pumping rate was simulated by using a pumping/injection rate of 125 gal./min per well.

MODFLOW assumes that each well was screened over the entire thickness of the model domain. The top and bottom elevation of the well screens was calculated from the position of the well along the long axis of the well domain and the gradient (0.08).

Steady-state flow conditions were used to simulate the operation of the extraction and injection well system under typical groundwater flow conditions in the intermediate aquifer. A saturated thickness of 290 ft was used for the simulations. Particle tracks were included in the simulations to simulate the capture zone. The particles were run in the reverse direction, originating as circles around each of the extraction wells.

### C3-2.6.6 Hydraulic Impact on Flow in the Intermediate Groundwater

The steady-state head solution for intermediate groundwater after the installation of the proposed extraction and injection well system is shown in Figures C3-3, C3-4, and C3-5 for the three pumping/injection rates evaluated. These results show a perturbation in groundwater flow around the injection and extraction wells, but no drying out of the aquifer was observed for all three of the rates simulated. In addition, the particle tracks indicate that the proposed well system successfully captures the groundwater flowing between the injection and extraction wells. It is therefore concluded that the proposed well locations will efficiently and effectively capture contaminated groundwater in the intermediate aquifer for the range of pumping/injection rates evaluated.

No drying of the aquifer was observed for the maximum pumping rate of 125 gal./min per well or a cumulative rate of 500 gal./min. The pumping rate was increased incrementally, with an injection rate of 0 gal./min, to determine the rate at which drying of the aquifer would occur. Dry cells were observed in the model domain for a pumping rate of 150 gal./min (and no reinjection). This pumping rate is higher than the proposed maximum rate for the treatment system.

In summary, groundwater modeling of the proposed extraction and injection well system yielded several important findings.

- The installation of four extraction and four injection wells will adequately capture intermediate groundwater in Cañon de Valle.
- No drying of the aquifer will likely occur at the maximum capacity pumping rate of 125 gal./min as long as water is injected upgradient of the extraction wells.
- Capturing of intermediate groundwater occurs at the lowest pumping rate of 50 gal./min.

This is a simplified, conservative model that provides useful information as to the feasibility of an extraction and injection treatment system in Cañon de Valle. Prior to the design and implementation of an extraction and injection treatment system, an aquifer test should be conducted to properly characterize the intermediate groundwater response and to determine the effectiveness of the recovery system.

## C3-3.0 REFERENCES

*The following list includes all documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.*

*Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.*

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McDonald, M.G., and A.W. Harbaugh, 1988. “A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model,” Book 6, Chapter A1 abstract only, in *Techniques of Water-Resources Investigations of the United States Geological Survey*, Washington, D.C. (McDonald and Harbaugh 1988, 056041)

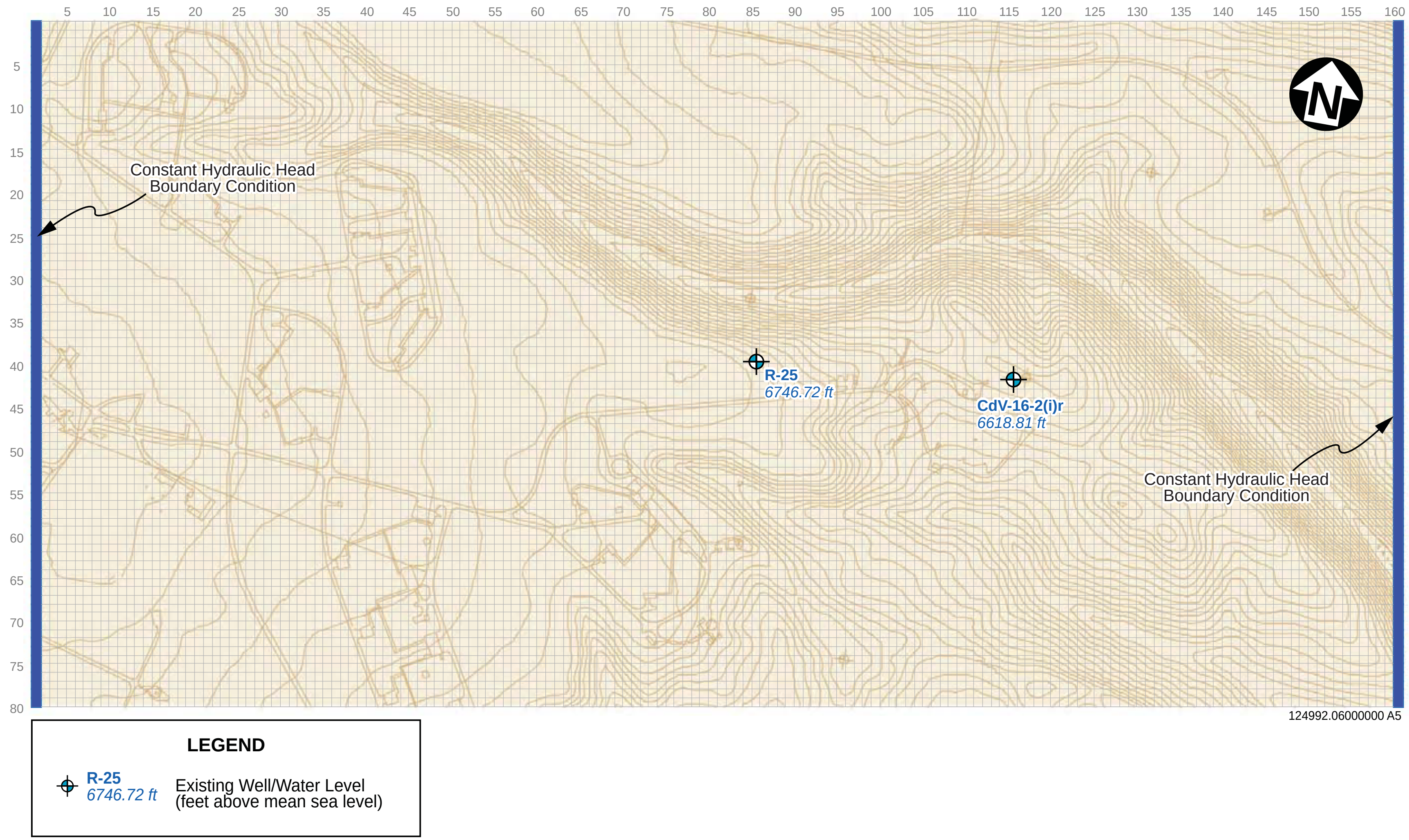
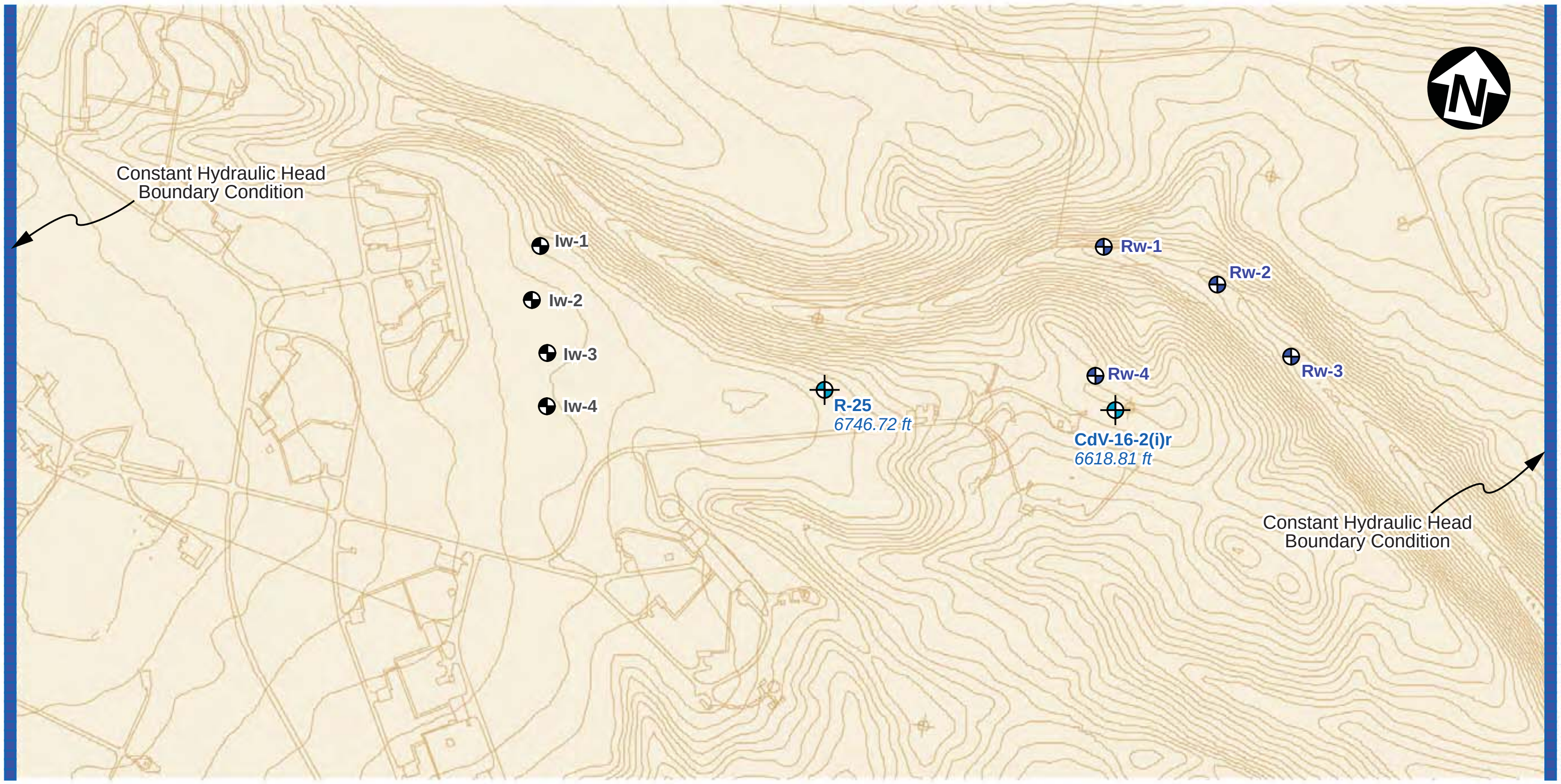


**Figure C3-1** Model domain with grid



**LEGEND**

| | |
|---|---|
| ⌖ **R-25** *6746.72 ft* | Existing Well/Water Level (feet above mean sea level) |
| ⊕ **Rw-1** | Hypothetical Extraction Well |
| ◐ **Iw-1** | Hypothetical Injection Well |

**Figure C3-2** **Base map model domain, pumping and injection wells**

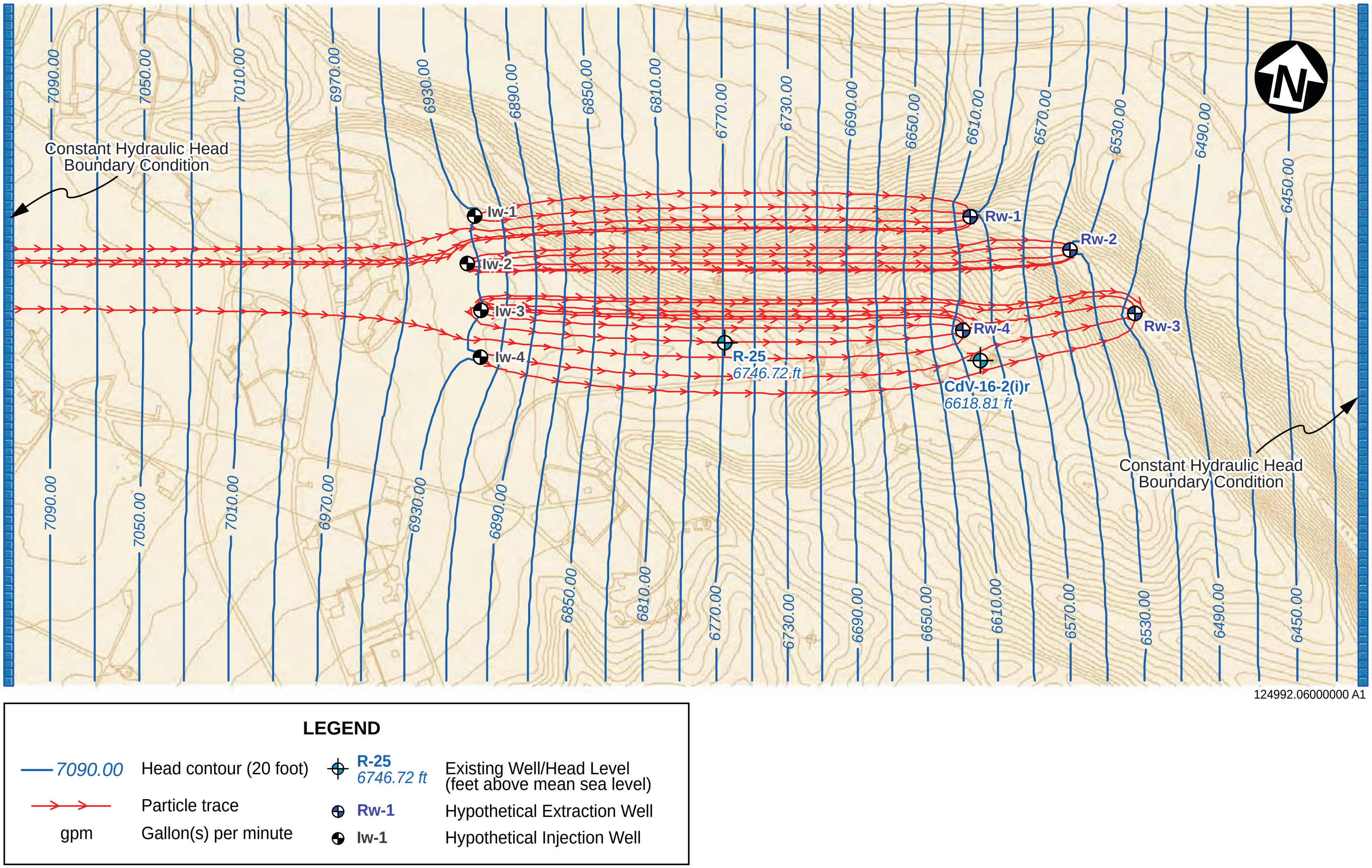
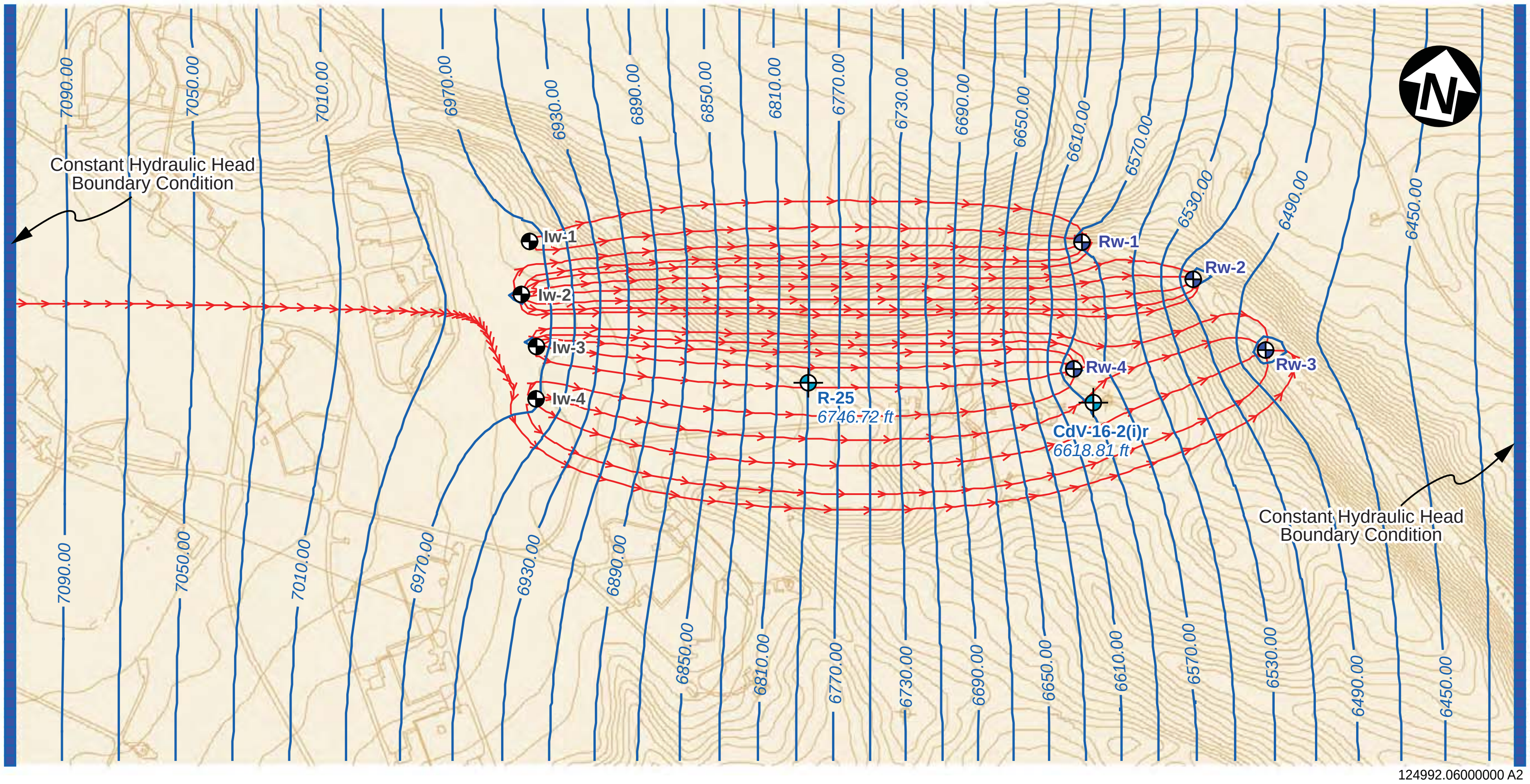


**Figure C3-3** Model results for 50 gal./min per well



**LEGEND**

| | | | | |
|---|---|---|---|---|
| —— 7090.00 | Head contour (20 foot) | ⊕ | **R-25** 6746.72 ft | Existing Well/Head Level (feet above mean sea level) |
| —>—> | Particle trace | ⊕ | **Rw-1** | Hypothetical Extraction Well |
| gpm | Gallon(s) per minute | ● | **Iw-1** | Hypothetical Injection Well |

**Figure C3-4** Model results for 100 gal./min per well

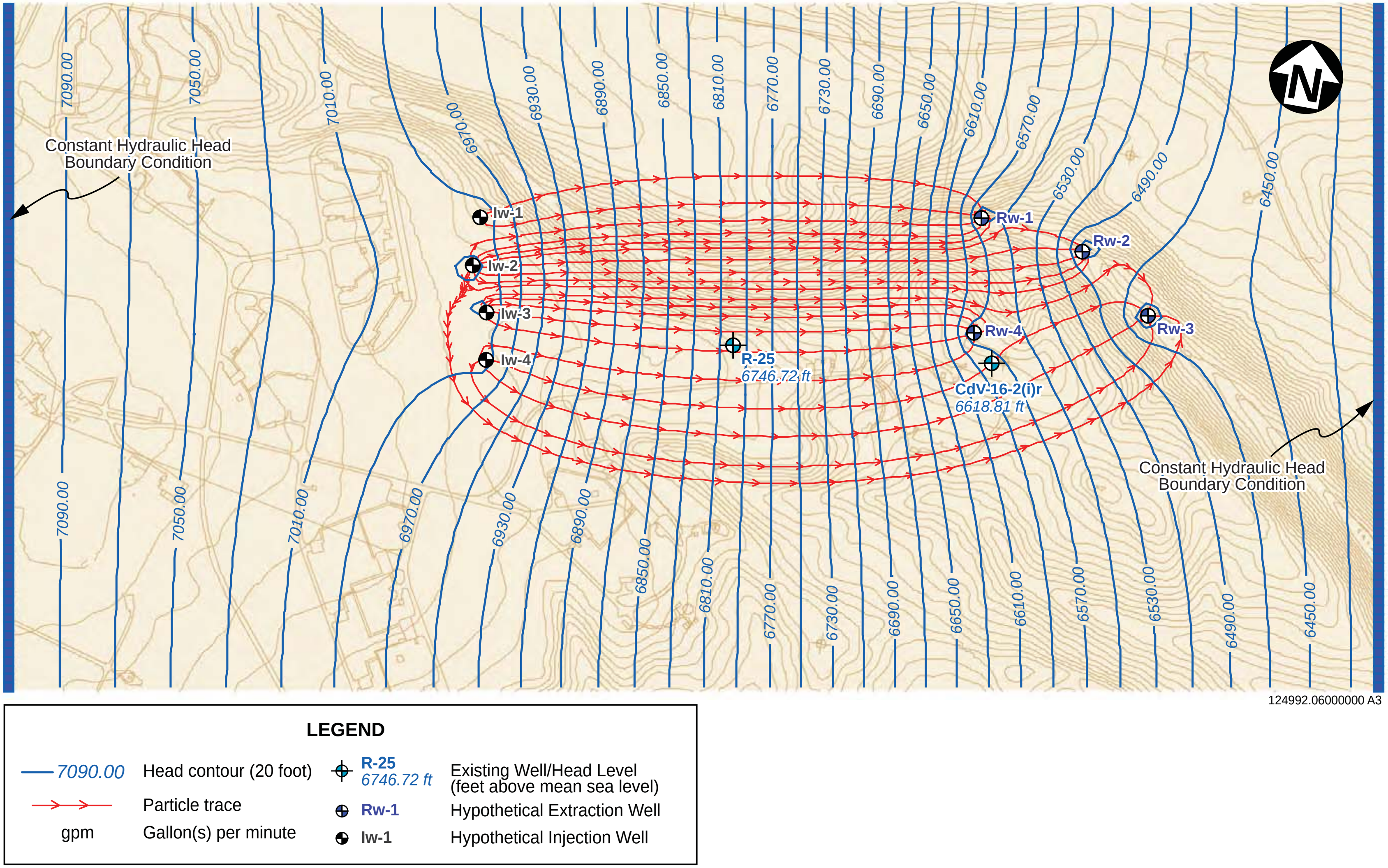


**Figure C3-5** **Model results for 125 gal./min per well**

# ATTACHMENT C3-1
# MODEL AVERAGE HEAD CALCULATIONS

By D. Agnew Date 08/13/07 Subject Calculation of Average Head for the CME Groundwater Model Sheet No. 1 of 4
Chkd. By JMP Date ________ Proj.No. 124992.06

## Purpose

The purpose of this calculation brief is to outline two calculations to determine hydraulic head parameters in Cañon de Valle. Part 1 of this calculation brief outlines the calculation of the average head at wells R-25 and CdV-16-2(i)r using data collected from each well. Part 2 of this calculation brief outlines how the constant head boundaries were calculated, using the average heads calculated in Part 1 and an assumed constant gradient.

## Abstract

This calculation brief will document the derivation of constant head at two wells, R-25 and CdV-16-2(i)r, required for the modeling of groundwater flow through Cañon de Valle within the area of interest. The hydraulic gradient across the model will be held constant and will be used to determine constant head boundaries, as outlined in this calculation brief (see Part 2).

## Background

A simplified groundwater model was developed, and a series of numerical solutions were conducted in support of a corrective measures evaluation (CME) of a potential extraction and injection well system for installation in the intermediate-groundwater aquifer at Cañon de Valle, located at Los Alamos Laboratory, New Mexico. A 4000 ft by 8000 ft model domain has been constructed to evaluate groundwater flow in Cañon de Valle at three different extraction/injection rates. Well R-25 is screened across the intermediate aquifer and is within the model domain. An additional well, CdV16-2(i)r, is located downgradient of the R-25 well and is also screened across the intermediate groundwater zone.

## Assumptions

1. The hydraulic conductivity values used for the natural aquifer system are from Reference 1 and are assumed to be true for the model domain.
2. The average gradient value calculated between wells R-25 and CdV-16-2(i)r is representative of current and future gradients for the model domain.
3. All information from References 1 and 2 are accurate and representative of the system being modeled.

## Methodology

Use field water-level data for determination of the natural gradient and calculation of average head for each of the two wells (R-25 and CdV-16-2(i)r). Calculate values for head elevations at model domain extents for a given gradient.

By D. Agnew Date 08/13/07 Subject Calculation of Average Head for the CME Sheet No. 2 of 4
Chkd. By JMP Date ________ Groundwater Model Proj.No. 124992.06

## Results

*Part 1*

**The table below summarizes the data used for the calculation of the natural gradient and average head values (Reference 1):**

| Date | Water Level (ft) R-25 | Water Level (ft) CdV-16-2(i)r |
|---|---|---|
| 1 January 2007 | 6746.73 | 6618.72 |
| 2 January 2007 | 6746.74 | 6618.68 |
| 3 January 2007 | 6746.72 | 6618.75 |
| 4 January 2007 | 6746.71 | 6618.89 |
| 5 January 2007 | 6746.67 | 6619.09 |
| 6 January 2007 | 6746.74 | 6618.75 |

*R-25 Average Head*

$$h_{average}\ (ft) = \frac{(6746.73 + 6746.74 + 6746.72 + 6746.71 + 6746.67 + 6746.74)\ ft}{6} = 6746.72\ ft$$

*CdV-16-2(i)r Average Head*

$$h_{average}\ (ft) = \frac{(6618.72 + 6618.68 + 6618.75 + 6618.89 + 6619.09 + 6618.75)\ ft}{6} = 6618.81\ ft$$

*Gradient*

$$\frac{dh}{dl} = \frac{6746.72\ ft - 6618.81\ ft}{1500\ ft} = 0.085$$

**By** D. Agnew **Date** 08/13/07 **Subject** Calculation of Average Head for the CME **Sheet No.** 3 of 4
**Chkd. By** **Date** Groundwater Model **Proj.No.** 124992.06

**The value of 1500 ft used in the above calculation is equal to the distance between the two wells, as measured from the site map (Reference 2). The distance between R-25 and CdV-16-2(i)r was measured to be 1.5 in. which is equal to 1500 ft from the map scale.**

***Part 2***

**The distance between well R-25 and the western boundary of the model domain is approximately 4188 ft, as measured from the site map. Using this distance, as well as the assumed constant, natural gradient, the constant head at the western boundary ($h_1$) was calculated as follows:**

$$\frac{dh}{dl} = \frac{h_1 - h_{R\text{-}25}}{4188\ \text{ft}} = 0.085$$

**The value of $h_{R\text{-}25}$ is equal to the average head for well R-25, calculated in *Part 1* of this calculation brief.**

$$h_1 = h_{R\text{-}25} + 0.085\ (4188\ \text{ft}) = 6746.72\ \text{ft} + 0.085\ (4188\ \text{ft}) = 7102.7\ \text{ft}$$

**The distance between well CdV-16-2(i)r and the eastern boundary of the model domain is approximately equal to 2375 ft, as measured from the site map. Using this distance, as well as the assumed constant, natural gradient, the constant head at the eastern boundary ($h_2$) was calculated as follows:**

$$\frac{dh}{dl} = \frac{h_{CdV\text{-}16\text{-}2(i)r} - h_2}{2375\ \text{ft}} = 0.085$$

**The value of $h_{CdV\text{-}16\text{-}2(i)r}$ is equal to the average head for well CdV-16-2(i)r, calculated in *Part 1* of this calculation brief.**

$$h_2 = h_{CdV\text{-}16\text{-}2(i)r} - 0.085\ (2375\ \text{ft}) = 6618.81\ \text{ft} - 0.085\ (2375\ \text{ft}) = 6416.9\ \text{ft}$$

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**By** D. Agnew **Date** 08/13/07 **Subject** Calculation of Average Head for the CME Groundwater Model **Sheet No.** 4 of 4
**Chkd. By** JMP **Date** ________ **Proj.No.** 124992.06

## References

1. John Pietz to Diane Agnew, Personal Communication 24 May 2007.
2. John Pietz to Diane Agnew, Personal Communication 22 May 2007.

D. Agnew 24 May 2007

| Date | R-25 1a | R-25 2A | CdV-16-1i | [illegible] |
|---|---|---|---|---|
| 1/1/07 | 6785.25 | 6746.73 | 6807.92 | 6618.72 |
| 1/2 | 6785.25 | 6746.74 | 6807.88 | 6618.68 |
| 1/3 | 6785.24 | 6746.72 | 6807.95 | 6618.75 |
| 1/4 | 6785.23 | 6746.71 | 6808.07 | 6618.89 |
| 1/5 | 6785.23 | 6746.67 | 6808.29 | 6619.09 |
| 1/6 | 6785.23 | 6746.74 | 6807.93 | 6618.75 |
|  | Average | 6746.72 |  | 6618.81 |

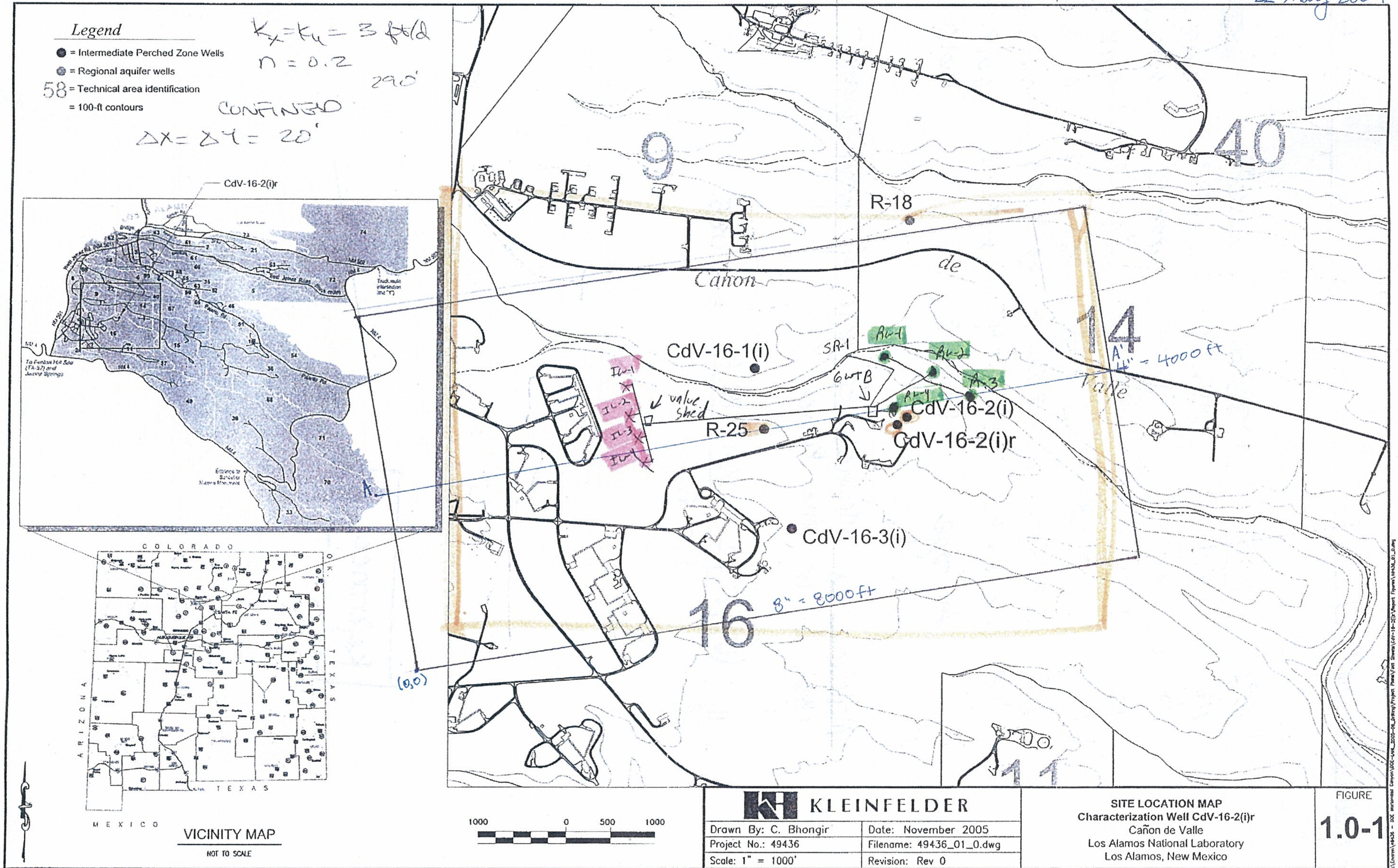
Modeling the intermediate zone of groundwater that is in the Puye

$$\frac{dh}{dl} = \frac{(6746.72 - 6618.81)\text{ft}}{1500\text{ ft}} = 0.085$$

Reference 1

MAP Ⓐ
22 May 2007

● RW
X IW



$K_x = K_y = 3$ ft/d

$n = 0.2$

290'

CONFINED

$\Delta x = \Delta y = 20'$

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| | |
|---|---|
| Drawn By: C. Bhongir | Date: November 2005 |
| Project No.: 49436 | Filename: 49436_01_0.dwg |
| Scale: 1" = 1000' | Revision: Rev 0 |

SITE LOCATION MAP
Characterization Well CdV-16-2(i)r
Cañon de Valle
Los Alamos National Laboratory
Los Alamos, New Mexico

FIGURE
1.0-1

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Reference 2

# *Appendix C4*

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## Numerical Evaluation of Groundwater Flow in the Regional Aquifer Near Technical Area 16, Cañon de Valle, Los Alamos National Laboratory, Los Alamos, New Mexico

## C4-1.0 INTRODUCTION

This appendix describes a groundwater modeling study designed to support the corrective measures evaluation (CME) at Technical Area (TA) 16. The goals of the study were to develop a groundwater flow and contaminant transport model and to use this model to predict future contaminant concentrations and contaminant transport times to area-monitoring wells and public supply wells under the monitored natural attenuation (MNA) and no-action remedial alternatives.

A conceptual model is described that outlines assumptions and the Los Alamos National Laboratory (the Laboratory, or LANL) interpretation of basin-scale flow in the Los Alamos region. Two strategies for development of the contaminant source term for the regional model are presented. (1) The unsaturated zone modeling results (Appendix C2), which incorporate the historical hexahydro-1,3,5-trinitro-1,3,5-triazine or research department explosive (RDX) mass-release study results (Appendix C1), are used as input to the model. (2) A source term mass-release rate derived from observed RDX concentrations at monitoring well R-25 is used as input to the model.

The contaminant-transport simulations include the effects of dispersion and dilution. The effects of degradation through hydroloysis are also presented. The transport simulations assume that there is no biodegradation or retardation by adsorption. The results of the simulations are presented in the form of RDX breakthrough curves at nearby monitoring and water-supply wells.

## C4-2.0 CONCEPTUAL MODEL

This section describes the hydrology and geology of both TA-16 and the Pajarito Plateau region. Particular emphasis is placed on describing regional groundwater flow and assumptions made about how water migrates from the plateau to the regional aquifer and to the Rio Grande.

### C4-2.1 Regional Aquifer

The regional aquifer beneath the Pajarito Plateau is a complex heterogeneous system. The elements of the water balance, properties of the flow medium, and hydrodynamics of the system are discussed in the following sections. The aquifer beneath the Laboratory is a subportion of the basin-scale aquifer associated with the Española Basin. Because the site-scale aquifer dynamic hydraulics is connected with the basin-scale aquifer, some of the characteristics of the Española Basin aquifer that influence the site-scale aquifer are discussed as well.

### C4-2.1.1 Structure of Saturated Zone

The top of the saturated zone beneath the Pajarito Plateau is predominantly under phreatic (water-table) condition. The regional water table is located about 300–400 m below ground surface across the Plateau (Figure C4-2.1-1). The spatial distribution of hydrostratigraphic units intersected by the water table is presented in Figure C4-2.1-2. From west to east, major hydrostratigraphic units intersecting the regional water table are Keres Group, Tschicoma Formation, Puye Formation, Cerros del Rio Basalts, Totavi Lentil, Santa Fe Group, and Bayo Canyon Basalts. Near TA-16 the important units that affect the flow near the water table are the Tschicoma and Puye Formations.

The total thickness of the regional aquifer is unknown. It can be assumed that at a minimum the aquifer encompasses the total thickness of the Española Basin fill. The approximate thickness of the fill varies from 300 m at the basin edges to 2000 m in the central portion. The amount of information available about the hydrogeological properties of the regional aquifer diminishes with depth because monitoring wells are not drilled deep into the aquifer. As a result, the portion of the aquifer below the phreatic zone is not adequately characterized. Most of the data relevant for the deep portion of the aquifer come from the water-supply wells and deep monitoring wells (e.g., R-19 and R-25). Because of screen lengths, information collected at the supply wells is characteristic of a large thickness of the formation (for example, the water levels measured at the supply wells are representative of an average pressure along the entire length of the screen).

The aquifer is composed of several sedimentary and volcanic hydrostratigraphic units. The sedimentary units comprise layers of varying thickness, lateral extent, and permeability. Relatively continuous horizontal zones of high permeability and low porosity are associated with the coarse-grained materials of the Totavi Lentil (in the area between the Laboratory and the Rio Grande) and the pumiceous Puye Formation. However, lateral continuity of low- and high-permeability layers within the sedimentary units is unknown because the layers cannot be accurately mapped in existing widely spaced boreholes. However, the existence of multiple low-permeability layers in the Puye Formation and the Santa Fe Group (Broxton and Vaniman 2005, 090038) potentially produces a large-scale aquitard, which causes the observed large-scale confinement of the deeper portions of the aquifers (Purtymun 1995, 045344).

The Pajarito fault zone and its associated deformational features are the principal structural features that may influence fluid transport at TA-16. The Rendija Canyon and Guaje Mountain faults are the other major faults with surface displacement of Pajarito Plateau strata. Both of these faults have surface expression to the north of TA-16. Additional north-trending normal faults within the Puye Formation and Santa Fe Group are probably present beneath the Pajarito Plateau; similar faulting of the Santa Fe Group is observed east of the Laboratory site (Collins et al. 2005, 092028, pp. 2-9).

Limited data are available concerning the effect of faults, fault zones fractures, deformation bands, and other deformational features on groundwater flow. It is expected that faults would significantly impact the groundwater flow and recharge distribution. Various studies have analyzed the impact of the Pajarito Fault zone on the groundwater flow from west to east, e.g., Dale (2005, 095002). The fault zone is considered to be a hydraulic conduit and/or barrier; for example, it might be a barrier for lateral flow and a conduit of vertical flow. If the fault zone is a lateral-flow barrier, it can cause some of the mountain block recharge to be diverted to the south and north, rather than flowing to the east toward the Pajarito Plateau. Water-level measurements (discussed further in section C4-2.1.6) suggest that the hydraulic gradients are much higher in the western part than in the central part of the plateau. The gradient increase may be a result of low-permeable cataclastic zones in the regional aquifer. Existing data obtained from large-scale, cross-hole, pumping tests indicate that low-permeability fault zones might be impacting the groundwater flow (1) in the vicinity of Guaje well field, (2) between saturated zones tapped by PM-1/PM-3 and PM-2/PM-4/PM-5 water-supply wells, and (3) between saturated zones tapped by PM-5 and PM-4 (McLin 2006, 092218). Other explanations of the observed flow impacts that do not involve low-permeability fault zones are possible as well.

The groundwater flow medium can be defined as a complex multiaquifer aquitard system. The existing groundwater flow exhibits a complex three-dimensional structure. Uncertainty in the conceptual model is associated with defining groundwater flow and contaminant transport in the regional aquifer. Currently, two alternative conceptual models address this uncertainty (Figure C4-2.1-3) as follows.

*Conceptual Model A.* No hydraulic separation exists between the shallow and deep (pumped) aquifer zones. Pumping drawdowns are manifested at the water table. Near the pumping wells, water-table hydraulic gradients are affected by pumping, and contaminants are drawn toward the supply wells. The shallow and deep aquifer zones have similar hydrodynamic properties and are not hydrodynamically distinct. Potential contaminants in the regional aquifer are expected to be predominantly captured by the water-supply wells. In both the shallow and deep portions of the regional aquifer, flow directions are west (Jemez Mountains) to east (Rio Grande), and groundwater flow is predominantly discharged at the Rio Grande. This conceptual model is close to the classical basin-scale flow structure (Figures C4-2.1-4 and C4-2.1-5) discussed in previous studies (Freeze and Cherry 1979, 088742; Keating et al. 1999, 088746; Keating et al. 2000, 090188; Keating et al. 2001, 095399; Collins et al. 2005, 092028).

*Conceptual Model B.* A strong hydraulic separation exists between the shallow (phreatic, water table) and deep (pumped) aquifer zones, which does not allow pumping drawdowns to reach the water table. As a result, hydraulic gradients in the phreatic zone are expected to be unaffected or negligibly affected by the pumping. The deep portion of the regional aquifer is estimated to be predominantly under confined conditions. Contaminants are likely to flow predominantly above the water-supply wells along the phreatic zone and to be captured by the springs near the Rio Grande. Nevertheless, due to substantial downward vertical hydraulic gradients between the shallow and deep aquifer zones, some contaminants may reach the water-supply wells by flow through hydraulic windows and along well filter packs (Vesselinov 2005, 090040; Vesselinov 2005, 089753; LANL 2006, 094431). In the shallow portion of the regional aquifer, flow directions are west (Jemez Mountains) to east (Rio Grande), and groundwater flow predominantly discharges at the Rio Grande. In the deep portion of the regional aquifer, flow directions might not be coincident with the flow directions in the phreatic zone (Figure C4-2.1-4). There is uncertainty, but the deep flow directions may have a more dominant southern component based on the basin-scale discharge boundaries to the south (Cochiti Lake, Albuquerque Basin) (Vesselinov 2005, 089753; Vesselinov 2005, 090040).

These alternative models represent two end members on a spectrum of potential flow configurations and therefore capture some aspects of the potential conceptual model uncertainty. The contaminant pathways in the regional aquifer depend strongly on the existence, or lack thereof, of a phreatic zone in the shallow portion of the regional aquifer, which is hydraulically separated from the deep portions of the regional aquifer.

Based on existing hydrogeological information, it is difficult to characterize the thickness of the phreatic zone. The thickness of the phreatic zone can be approximately defined based on the water-table response at individual wells. For example, the top regional screen in R-19 (Screen 3) responds as if located in the phreatic zone, and the deeper screen (Screen 4) is impacted by the water-supply pumping. (The data and detailed analyses are provided in the evaluation of area monitoring well screens.) (LANL 2007, 095787, section C4-4.2). The distance between the screens is 200 ft. Further, the top regional screen in R-17 responds as if located in the phreatic zone, and the deeper screen is impacted by the water-supply pumping. The distance between the screens is 44 ft. At these locations, the thickness of the phreatic zone is some unknown fraction of this distance. Spatial interpolation of phreatic zone thicknesses based on individual well data is even more complicated. However, the actual thickness of the phreatic zone may not be that important for contaminant transport predictions. It is much more important to evaluate the vertical dispersion of the plume at the top of the regional aquifer. For example, one of the objectives of drilling R-35 in Sandia Canyon is to evaluate vertical stratification of the potential chromium plume (LANL 2006, 091987). Based on the recently obtained R-35 data, it might be concluded that the thickness of the phreatic zone near R-35 is on the order of 100 ft.

In a previous report (LANL 2007, 095787, section C4-4.2), all the available hydrogeological data collected at the wells near TA-16 were analyzed to address this conceptual model uncertainty. It has been concluded that Conceptual Model B is more appropriate to characterize flow and transport conditions at the site. More recent data collection activities further demonstrated that Conceptual Model B might be more probable. Water levels observed at the top screens of R-35 and R-17 confirmed that the phreatic zone of the regional aquifer is negligibly or not all impacted by the water-supply pumping, while the deeper screens at these wells were showing clear response to the water-supply pumping. For the purpose of this report, it is concluded that Conceptual Model B provides more adequate representation of flow conditions. Only simulations based on this conceptual model are performed.

### C4-2.1.2 Recharge

A comprehensive study of aquifer recharge from (1) precipitation, (2) perennial and temporal surface water along the canyons, and (3) human-induced water discharges in the vicinity of the Laboratory was conducted (Kwicklis et al. 2005, 090069). Recharge is estimated for hydraulic conditions circa 1999 before the Cerro Grande fire, but it incorporates human-induced recharge post-1940s. A map of spatial distribution of infiltration recharge at the top of the vadose zone is presented in Figure C4-2.1-6. The recharge spatial distribution exhibits a complex structure influenced by various factors (spatial distribution of precipitation, surface runoff, geology, vegetation, etc.). The total amount of annually averaged recharge to the aquifer within the domain presented in Figure C4-2.1-6 is estimated to be about 336 kg/s. However, uncertainty is associated with this estimate, which will be addressed in upcoming studies. Aquifer recharge occurs primarily (~80% or 269 kg/s) in the Sierra de los Valles to the west of and within the Pajarito fault zone where the annually averaged infiltration rates vary from 25 to 500 mm/yr (Figure C4-2.1-6). Additional recharge occurs locally on the Pajarito Plateau (approximately 20% of the total volume or ~67 kg/s), and annually averaged infiltration rates vary from 0 to 25 mm/yr. Local recharge predominantly occurs along the canyons (Figure C4-2.1-6). The total recharge through the mesas between the canyons is small but not negligible (on the order of 15 kg/s, or less than 25% of the local recharge).

### C4-2.1.3 Discharge

Under pre-well development conditions, the regional aquifer discharged along the Rio Grande and to the south in the Albuquerque Basin. Existing studies suggest that the Española Basin is not a closed basin and is hydraulically connected with the Albuquerque Basin (Phillips et al. 2003, 097880; Phillips et al. 2004, 097879; Sanford et al. 2004, 097877). However, the spatial distribution of discharge along these boundaries is unknown.

Stream gauge data provide information on how much water the Rio Grande has potentially gained from the regional aquifer in the vicinity of Pajarito Plateau under pre-well development conditions. The best estimate is ~490 kg/s (Keating et al. 1999, 088746; Keating et al. 2005, 090039; Kwicklis et al. 2005, 090069). However, uncertainties associated with this flux estimate are potentially much higher than the uncertainty in the total recharge estimate discussed previously (Kwicklis et al. 2005, 090069). The river-gain flux estimate includes spring discharges and spring-induced surface flow. The total annually averaged rate of aquifer discharge at springs in the vicinity of the Rio Grande (predominantly along White Rock Canyon) is on the order of 60 kg/s and is also uncertain (Purtymun 1995, 045344). Existing data indicate that the White Rock Canyon springs rates are consistent without substantial annual variations. Based on the groundwater flow structure (Vesselinov 2005, 090040; Vesselinov 2005, 089753) and hydrogeochemical data (Longmire et al. 2007, 096660), it can be concluded that the springs discharge predominantly from the shallow portions of the regional aquifer.

Except for spring discharges, it is unknown what portion of the groundwater gained by the river adjacent to the Laboratory comes from western (Pajarito Plateau/Sierra de Los Valles), eastern (Pojoaque/Sangre de Cristo), and northern (Española) areas of the regional aquifer. The topography of the Española Basin suggests that the eastern margin of the basin (Sangre de Cristo) can be expected to contribute more recharge than the western margin (Jemez) because the recharge infiltration rates are expected to be proportional to the ground surface elevation (Kwicklis et al. 2005, 090069). However, the comparison of the discharge to the river (490 kg/s) with the recharge from the western margin (336 kg/s) suggests that the eastern margin potentially contributes less than 1/4 of the river discharge along the reach in the vicinity of the Pajarito Plateau (Kwicklis et al. 2005, 090069). One explanation for this discrepancy may be that a dominant portion of the potentially higher eastern margin recharge is flowing predominantly to the south. An alternative explanation is that some of the recharge accumulated along the western margin could be flowing to the south and contributes less to the Rio Grande discharge. Additional support for southbound flow of recharge accumulated at the Jemez and Sangre de Cristo Mountains comes from studies by Phillips et al. (2003, 097880; 2004, 097879). Their analysis of hydrologic and geochemical data along the Upper and Middle Rio Grande basins concludes that deep circulation groundwater is discharged at a limited rate to the Rio Grande within the Española Basin and potentially predominantly discharges as underflow in the Albuquerque Basin. Therefore, the estimates of recharge provide poor constraint on the groundwater discharge to the Rio Grande (Vesselinov 2005, 089753).

The nature of hydraulic connection between the river and regional aquifer is unknown. Limited field-test and literature data for similar sites along the Rio Grande suggest that this connection should be impeded by low-permeability zones associated with the alluvial aquifer extending along the Rio Grande. The deep regional aquifer wells drilled near the Rio Grande demonstrate strong confinement of the deep portions of the regional aquifer (Purtymun 1995, 045344). The confinement limits upward groundwater fluxes of regional aquifer flow discharging to the Rio Grande (Vesselinov 2005, 089753).

Since groundwater pumping started in 1946, a portion of the discharge of the Pajarito aquifer occurs at the following water-supply well fields: Pajarito, Otowi, Guaje, Buckman, and Los Alamos (currently decommissioned) (Figure C4-2.1-7a) (Koch and Rogers 2003, 088425). The total annually averaged pumping rate varies from 0 to more than 450 million gal./yr and is associated with a consistent temporal trend of pumping rate increase (Figure C4-2.1-7a). Existing data and analyses indicate that the well fields close to the Rio Grande, Buckman, and Los Alamos capture groundwater originating both to the east and to the west of the river (Theis and Conover 1962, 037144; Vesselinov and Keating 2002, 089752). All the well fields tap the deep confined zone of the regional aquifer. Field data indicate that pumping in the deeper zone has little effect on the water-table elevations (LANL 2007, 095787, section C4-4.2). Figure C4-2.1-7b summarizes monthly water production from the Pajarito Mesa wells in 2005 and 2006. PM-2 typically produces 22% to 34% of the water in the field, PM-4 approximately 6%, and PM-5 from 20% to 26%.

### C4-2.1.4 Vertical Components of Hydraulic Gradients and Transport Vectors

Along multiscreen wells, hydraulic heads tend to decrease with depth. Figure C4-2.1-8 presents head data from multiple wells in the southern portion of the Pajarito plateau (potentially downgradient of TA-16) (Keating et al. 2005, 090039). The vertical component of the head gradient ranges from 0 (neutral) to 0.245 (downward) (Keating et al. 2005, 090039). In general, the measured vertical components are greater than the horizontal components of the hydraulic gradients. Nevertheless, the flow vectors can be expected to predominantly coincide with the direction of the layering due to high anisotropy of the aquifer formations (large-scale permeability along the layering is expected to be 1 to 4 orders of magnitude higher than large-scale permeability perpendicular to the layering).

The observed magnitude of vertical components of the hydraulic gradients is potentially caused by the individual or combined effect of several hydrogeological factors. To begin with, medium-flow properties are expected to play an important role. Typically, well screens target zones in the aquifer associated with relatively higher permeability (Collins et al. 2005, 092028). As a result, some of these zones will be vertically bounded by zones with relatively lower permeability. The measured head differences between adjacent high-permeability layers and the difficulty in tracing these layers (Broxton and Vaniman 2005, 090038) demonstrate strong small-scale heterogeneity of the aquifer both laterally and vertically (or a certain level of aquifer compartmentalization). Therefore, the small-scale hydraulic head differences in a vertical direction are controlled by small-scale heterogeneous features that may not be important for the large-scale characterization of the medium properties and flow directions but are potentially extremely important for local pathway analysis of contaminant transport. In this sense, the vertical head measurements along a single well could be more representative of local medium heterogeneity rather than the regional three-dimensional structure of the flow.

Second, the structure of the groundwater flow system is defined by dominant mountain-block recharge occurring at high elevations and regional discharge at low elevations (Rio Grande, Albuquerque Basin), forming a steeply sloping water table. As a result, if the boreholes were slanted and perpendicular to the water-table slope, they should not exhibit pressure decline along the borehole. The boreholes at the site are vertical; as a result, even if the medium is homogeneous, decreasing pressures with depth can be expected (Freeze and Cherry 1979, 088742, Chapter 5, p. 187).

Finally, focused recharge along canyons and fault zones and intensive pumping in deeper portions of the aquifer (Rogers et al. 1996, 054714; Allen and Koch 2007, 095268) are also expected to impact vertical head distribution and cause downward flow components.

In conclusion, the pronounced downward vertical components of hydraulic gradients are not expected to define dominant downward vertical transport, especially in the shallow portions of the regional aquifer. Flow vectors are expected to be predominantly along the direction of the layering in the hydrostratigraphic units.

### C4-2.1.5 Hydrogeological Conditions in the Vicinity of TA-16

TA-16 is located near an area where a predominant portion of regional aquifer recharge occurs (mountain-block recharge along the flanks of the Sierra de los Valles). In this area, the regional aquifer is under water-table conditions and is characterized by a complex hydrostratigraphy (including potential impacts of the Pajarito fault zone and the existence of various stratigraphic units with contrasting hydrogeological properties) and a complex spatial and temporal distribution of aquifer recharge (infiltrating through a thick and heterogeneous unsaturated zone). As a result, the top of the regional aquifer is difficult to identify. It is possible that the phreatic zone may have such a complicated structure that a series of water tables may be associated vertically with water-bearing zones that are largely hydraulically separated. It may be difficult to clearly define the hydrogeological conditions based on existing borehole data. This is demonstrated by R-25 data. R-25 intersects a 130-m-thick saturated zone located about 30 m above the regional aquifer (Figure C4-2.1-9). As discussed in section C4-2.1.6, there are alternative ways to interpret these data and define the location of the regional water table.

### C4-2.1.6 Water Table Maps and Flow Directions

Figures C4-2.1-10a and C4-2.1-10b show two alternative maps of water-table elevation based on the existing water-level data (LANL 2007, 095787). The maps differ in the interpretation of R-25 data. The first map assumes that the water level at Screen 5 (6240 ft) defines the regional water-table elevation; the second map uses data from Screen 4 of R-25 (6360 ft) instead. Additional details are presented in section C4-4.2 and in the “2007 General Facility Information Report” (LANL 2007, 095787). Both alternative maps of the water table suggest an influence of groundwater recharge along Cañon de Valle on the shape of the water table. In the first case (Figure C4-2.1-10a), the impact is more significant. The water-table contours in Figures C4-2.1-10a and C4-2.1-10b are also impacted by potential recharge along Water Canyon. It is important to note that lateral hydraulic gradients at the water table in the vicinity of TA-16 are relatively high when compared with those beneath the rest of the Laboratory. The flow paths presented in Figure C4-2.1-10b are based on a hydrogeologic interpretation of the water-table data, not on the numerical-model simulations. The flow paths are intended to integrate and approximate several hydrogeologic variables (e.g., regional zones of recharge and discharge, measured hydraulic heads with their uncertainty, and medium properties) that affect local-scale flow.

At the water table, horizontal components of the hydraulic head gradient tend to have an easterly/southeasterly direction across the plateau, and the gradients range from 0.0026 to 0.162 m/m. Generally, gradients are higher to the west and lower to the east (Purtymun 1995, 045344). The hydraulic gradients at the water-table in the vicinity of TA-16 are relatively high when compared with those beneath the rest of the Laboratory.

In Figure C4-2.1-10b, flow paths are estimated based on hydrogeological interpretation of the water-table data (these are not based on the numerical model simulations). The flow paths are not perpendicular to the potentiometric lines in the area near CdV-R-15-3, R-17, and R-19. The deviation from the flownet conformity rule (Freeze and Cherry 1979, 088742, Chapter 5) is caused because, in general, the large-scale flow structure is expected to be from the western recharge areas to the eastern discharge areas (Purtymun 1995, 045344). The deviation from this rule on the map could be explained by measurement uncertainty (i.e., potentiometric lines are not accurately interpolated) or anisotropy/heterogeneity of the medium (flow- and head-gradient vectors do not coincide in an anisotropic medium when the flow gradient is not coincident with the principal directions of the permeability tensor) (Freeze and Cherry 1979, 088742, Chapter 5). Therefore, uncertainty is associated with the flow direction in the regional aquifer, which is addressed to the extent possible in the numerical-model simulations presented below.

It is important to note that flow structure of the regional aquifer to the south of TA-16 is highly uncertain. The groundwater flow structure to the south of TA-16 is poorly constrained because no monitoring wells are located in this part of the aquifer. In the water-table analyses presented above (and the modeling analyses discussed below), it is assumed that the flow structure has a general direction from west to east as observed elsewhere on Pajarito Plateau. However, the regional aquifer pathways originating beneath TA-16 may have a more southerly component than represented in the water-table maps. In these maps, the water-level measurements at CdV-R-16-3i are used to constrain this uncertainty. However, these data are characteristic for the Tschicoma dacites (Tt) that have a very low permeability at this well. The water levels in the deeper portion of the aquifer (in the Puye fanglomerate [Tpf] below dacites) may be different.

In addition, it should be emphasized that the water-table maps do not suggest that the intensive water-supply pumping in the deep zone of the regional aquifer on the Pajarito Plateau, downgradient of TA-16, impacts the shape of the regional water table. A prior, detailed analysis of the water levels at the monitoring wells near TA-16 (LANL 2007, 095787) also supports this conclusion. Therefore, it is concluded that hydraulic gradients at the water table in the vicinity of TA-16 are not affected by the water-supply pumping.

### C4-2.1.7 Initial Analyses of Transport Velocities

Before the modeling analyses presented in section C4-3.0 were conducted, the water-table maps (Figure C4-2.1-10) and information about medium properties were applied to approximate potential advective transport velocities in the regional aquifer and compared these estimates with the existing observations. Table C4-2.1-1 lists the available hydraulic conductivity data at boreholes near TA-16 that delineate the properties of the Puye Formation where the regional water table is located. The data indicate that the flow medium is highly heterogeneous. The permeability of the Puye Formation varies within approximately 5 orders of magnitude from 0.0007 to 44 m/d. The permeability estimates obtained at R-26 and CdV-R-15-3 are very low. The highest permeability values are measured at R-17. As the data do not indicate a clear spatial trend in the distribution of permeability values, they may represent heterogeneity of the medium. Based on the data, the average permeability of Puye can be estimated to be approximately 3 m/d. There are no estimates of medium porosity. Based on literature data, the effective advective-transport porosity is anticipated to be on the order of 0.1 (Freeze and Cherry 1979, 088742).

The distance between R-25 and CdV-R-16-3(i) is 550 m. The pressure difference between R-25 Screen 5 and CdV-R-16-3(i) is 30 m, and the hydraulic gradient is 0.054. Assuming effective permeability of 3 m/d and porosity of 0.1, the expected advective travel time between the wells is about 1 yr.

The distance between R-25 and R-18 is 1200 m. The hydraulic gradient between R-25 Screen 5 and R-18 is 0.031. In this case, the advective travel time between the wells can be expected to be on the order of 4 yr.

The distance between R-25 and CdV-R-15-3 is 2500 m. The pressure difference between R-25 Screen 5 and CdV-R-15-3 is 67 m, and the hydraulic gradient is 0.02. Assuming effective permeability of 3 m/d and porosity of 0.1, the advective travel time between the wells can be expected to be on the order of 9 yr. However, the local Puye permeabilities near the screens of CdV-R-15-3 are about 2 orders of magnitude lower than the average value used to estimate the travel time. Therefore, the contaminant transport may be substantially delayed and/or diverted away from CdV-R-15-3.

The distance between R-25 and R-17 is 3200 m. The hydraulic gradient between R-25 Screen 5 and R-17 is 0.033. Assuming effective permeability of 3 m/d and porosity of 0.1, the advective travel time between the wells can be expected to be on the order of 9 yr.

In conclusion, the transport velocities in the regional aquifer are expected to be relatively high. However, contaminants have not been detected at the monitoring wells discussed (CdV-R-16-3(i), CdV-R-15-3, R-17) with the exception of RDX near the analytical detection limit (~0.1 µg/L) at R-18. This discrepancy can be explained in the following ways.

1. The saturated zone at Screen 4 of R-25 may be in poor hydraulic communication with the regional aquifer. As a result, the contaminants observed at Screen 4 may not have reached the regional aquifer yet.

2. The contaminants may have already reached the regional aquifer, but they may be substantially diluted below detection levels in the regional aquifer.

3. The average medium permeability is overestimated. The actual permeability is much lower than 3 m/d. In general, the screens of the monitoring wells target the most productive sections of the regional aquifer, which may cause such bias. In addition, the groundwater flow is expected to be occurring at an angle to the medium anisotropy because the water-table flow directions dip at an angle to the stratification of the Puye Formation. For example, the stratification dips to the southwest at well R-18 while the water table dips to the east. Based on theoretical consideration and hydraulic literature data (Freeze and Cherry 1979, 088742, Chapter 5), it can be expected that the permeability of the Puye formation perpendicular to stratification may be approximately 2 to 3 orders of magnitude lower than the permeability parallel to stratification. If effective permeability of 0.03 m/d representing flow is occurring at an angle to the stratification, the estimated travel times will be 2 orders of magnitude lower than the estimates discussed above.

4. The contaminant flow paths may be heavily influenced by medium heterogeneity. As a result, the flow paths may have a much more complicated structure than the one presented in Figure C4-2.1-10. As discussed, this may be the case for CdV-R-15-3.

All of these explanations are viable and may be simultaneously affecting the contaminant transport near TA-16. The numerical analyses presented in the next section further address these issues.

## C4-3.0 NUMERICAL MODEL

The major objective of the numerical simulation is to determine the likely migration direction for contaminants released at TA-16 in the regional aquifer related to monitored natural attenuation. Uncertainties in the model predictions are also addressed. In these analyses, it is assumed that contaminant transport through the vadose zone is predominantly vertical and one-dimensional, without lateral divergence. Therefore, the potential contaminant sources at the top of the regional aquifer are derived based on the existing data about spatial extent of contaminated areas in the alluvium at the bottom of Cañon de Valle and in the shallow vadose zone.

### C4-3.1 Description of the Utilized Computer Codes

The Finite Element Heat and Mass transfer code (FEHM) developed by researchers at the Laboratory (Zyvoloski et al. 1996, 054421) is capable of simulating three-dimensional, time-dependent, multiphase, nonisothermal flow and multicomponent reactive groundwater transport through porous and fractured media. Flow and transport simulations are based on a finite volume formulation. The transport can also be simulated using random-walk, particle-tracking techniques (Robinson et al. 2000, 097897). The simulation of fracture flow is performed using a continuous (not a discrete) computational scheme, which allows for multiple flow and storage continua (e.g., generalized double-porosity model). Using LaGriT (LANL 1996, 097876), the computational grid can be designed to represent complex three-dimensional geologic media and fault/fracture structures. FEHM has been used in a wide variety of applications. The software is mature, has users throughout the world, and has been certified through the Yucca Mountain Project Software Quality Assurance Program. FEHM is available to the public and operates under various operating systems (including Microsoft Windows).

The numerical simulation of contaminant transport in the regional aquifer is performed using the random-walk, particle-tracking techniques of FEHM (Lichtner et al. 2002, 095397). In this case, a predefined, large number of particles is released within areas at the top of the regional aquifer where it is assumed that contaminants might reach the regional aquifer. The number of particles is selected to be large enough for sufficient characterization of contaminant dispersion in the model domain. The particles' movement is tracked through the model domain to estimate potential spatial migration of contaminants. Specially developed codes for numerical convolution (PlumeConvolute) and computation of plume statistics (PlumeStat) are used to process and analyze FEHM simulation outputs. The simulations and data processing are computationally highly intensive and produce a considerable amount of output data. The analyses are achieved efficiently through parallelization using the Laboratory's supercomputers. The code, MPRUN, is used to efficiently execute the Monte Carlo runs in a multiprocessor environment.

### C4-3.2 Assumptions of Model Design and Flow Conditions

The flow medium is represented in the numerical model as a single continuum. No discrete faults and fractures are explicitly built into the computational grid. The potential for preferential flow along faults/fractures and similar heterogeneity-based features are incorporated into the model through the input parameters. As discussed below, high-permeability and low-porosity values are defined so that the possibility of fracture flow is captured.

Based on prior work related to TA 16 (LANL 2007, 095787, section C4-4.2), it is also assumed that (1) the phreatic zone of the regional aquifer is predominantly hydraulically disconnected from the deeper portions of the regional aquifer, and (2) transients in flow magnitudes and directions along the water table caused by regional infiltration recharge and water-supply pumping are small. Similar conclusions for the regional aquifer have been made previously for other locations across the Pajarito Plateau (Vesselinov 2005, 090117; Vesselinov 2005, 090040; Vesselinov 2005, 089753; LANL 2006, 094431). The explicit simulation of the phreatic zone in the numerical model requires a complex representation of both the saturated and unsaturated zones in a single three-dimensional numerical model. FEHM can perform these simulations but computationally they are very intensive. As the water table does not exhibit substantial transients (LANL 2007, 095787, section C4-4.2), the development of such a complex model is not necessary in this case. A simpler approach is used to simulate contaminant transport in the shallow phreatic zone. It is assumed that the water-table gradients are at a steady state and defined by the two alternative maps of the water table in Figure C4-2.1-10. The steady-state assumption provides a close approximation of the current flow conditions in the evaluation where the 2005–2006 data record is analyzed (LANL 2007, 095787, section C4-4.2). It also is assumed that limited vertical mixing of contaminants occurs below the phreatic zone, so some of the model domains are reduced to capture a relatively thin zone along the water table (the zone thickness varies from 50 to 500 m as described below). Nevertheless, all the models also account for the probability of contaminant flux from the phreatic zone into the deep portions of the regional aquifer through hydraulic windows.

It is important to note that the hydraulic gradients in the model are constrained based on the two alternative maps of the water table (Figure C4-2.1-10). The permeabilities of various hydrostratigraphic units are assumed to be random variables that vary in predefined ranges. Groundwater flow (darcy) velocity is equal to the hydraulic gradient times permeability (Freeze and Cherry 1979, 088742, Chapter 5). As a result, high-permeability values may produce groundwater flow velocities that are unexpectedly high when compared with prior estimates. The prior estimates are computed by dividing the total groundwater flow rate by the flow area (Freeze and Cherry 1979, 088742). As a result, the groundwater velocities through the phreatic zone in the western parts of the Laboratory are expected to be on the order of 0.6 cm/d with plausible local variations within an order of magnitude above and below this estimate (Vesselinov 2005, 090040). However, there is justification for this discrepancy in groundwater flow velocities. The transport velocities simulated in the model are considered to be characteristic only of the fraction of the groundwater flow medium where a dominant portion of contaminant transport occurs. Such a situation may arise in the case of a dominant fracture flow. In this way, the model implicitly accounts for preferential flow through the aquifer, for example, fracture flow. Therefore, the total amount of groundwater flowing through the aquifer may yet be consistent with existing hydrogeological information. In summary, the simulations target estimation of potential uncertainties associated with contaminant transport velocities rather than groundwater flow velocities.

### C4-3.3 Model Domain and Computational Grid

In these numerical analyses, three different models are utilized for different simulation purposes. Each model is based on different model domains and computational grids. The three model domains are shown in Figure C4-3.3-1. The model shown in green is applied to simulate three-dimensional flow and transport in the vicinity close to the potential contaminant source at the regional aquifer. The two site-scale models (also called “pancake” models) are shown in pink and blue. These models are applied to simulate flow and transport downgradient of the TA-16 source. For reference purposes, the green domain is termed a "site" model (labeled as Model 1 in Figure C4-3.3-1). The pink domain is Model 3—a thick pancake model—and the blue domain is Model 2—a thin pancake model.

The computational grid of the site model is predominantly structured but includes a zone of octree-mesh refinements. Its thickness is about 2000 m (Figure C4-3.3-1). The grid cells are not uniform in size. Laterally, the grid cells form squares with sizes varying from 67.5 to 500 m. Vertically, the thickness of the cell layers varies from 1.25 to 300 m (Figure C4-3.3-2).

The grids of the two pancake models (pink and blue domains in Figure C4-3.3-1) extend from the flanks of the Sierra de los Valles on the west to the Rio Grande on the east. The entire Laboratory, as well as all the existing monitoring and Los Alamos County water-supply wells, is within the boundaries of these domains. The tops of both model domains are defined by the shape of the regional water table. The computational grids are structured. Laterally, the size of the grid cells is uniform and equal to 125 × 125 m in the thick pancake model (Figure C4-3.3-2) and 25 × 25 m in the thin pancake model (Figure C4-3.3-2). For the thick pancake model, the size of the grid cells is not uniform vertically and varies from 7 to 50 m; vertical refinements are in areas where there are hydrostratigrahic units with limited vertical thickness (e.g., Totavi Lentil); the total vertical thickness of the grid is about 500 m below the water table. For the thin pancake model, the thickness of the grid is 50 m and includes a single layer of grid cells.

The total number of nodes and elements in the models are as follows: site model—244,048 nodes and 1,394,880 elements; thick pancake model—980,553 nodes and 5,520,462 elements; thin pancake model—693,948 nodes and 2,072,862 elements. The grids are designed so that they can sufficiently characterize medium heterogeneity, and the total number of nodes does not exceed 1 million nodes; this limitation is caused by the size of the computer memory.

The three-dimensional geologic model (Cole et al. 2006, 095079) is applied to define in the numerical models the spatial distribution of various hydrostratigraphic units (Figure C4-3.3-2). Table C4-3.3-1 lists the hydrostratigraphic units identified in the three models and describes their spatial representation within the model domain.

### C4-3.4 Boundary Conditions

All the boundaries of the model domain are defined as no-flow boundaries (Figure C4-3.4-1). The existing recharge along the flanks of the Sierra de los Valles, recharge along canyons and mesas of the Pajarito Plateau, and discharge near the Rio Grande (including the White Rock Canyon springs) are not explicitly defined in the model. They are implicitly defined by the shape of the water table, which is affected by these recharge/discharge mechanisms. In this way, for example, the model can still compute contaminant concentrations at the White Rock Canyon springs.

In addition, internal boundary conditions are defined at the pumping of the water-supply wells of Otowi (O-1 and O-4) and Pajarito well fields (PM-1, PM-2, PM-3, PM-4, and PM-5). The wells are capturing contaminants migrating along the phreatic zone by vertical flow through hydraulic windows. The model also accounts for the mixing that occurs at the water-supply wells when it computes contaminant concentrations.

### C4-3.5 Medium Properties

Permeability and porosity values of the hydrostratigraphic units are uncertain and are represented as random variables, as defined in Table C4-3.5-1. The permeability ranges are based on site-specific field hydraulic tests reported in McLin (2006, 093670) and literature data (Freeze and Cherry 1979, 088742). The ranges of porosity values for the regional aquifer units are defined based on data from the literature

(Freeze and Cherry 1979, 088742). The only site-specific data available are for the Cerros del Rio basalt (Tb 4) and Puye fanglomerate (Tpf); these data were considered in developing the distributions for those two units (Keating et al. 2001, 095399). The parameter ranges include high-permeability values and low-porosity values that are expected to occur in the case of fracture flow.

The permeability and porosity of various hydrostratigraphic units are represented in the numerical model as spatially uniform. Theoretical probability distribution functions based on the data provided in Table C4-3.5-1 are presented in Figures C4-3.5-1 and C4-3.5-2.

It is important to note that for the case of contaminant transport near TA-16 only flow properties (permeability, porosity) of the Puye fanglomerate (Tpf) and Tschicoma Formation (Tt) are directly relevant. The flow properties of the other hydrostratigraphic units are not expected to significantly influence the flow near TA-16 because the water-table surface intersects Tpf and Tt only in the vicinity of TA-16.

To represent the dispersion of the contaminant plumes, an axisymmetric form of the dispersion tensor was used (Lichtner et al. 2002, 095397); the longitudinal and transverse dispersivities are defined to characterize the tensor. It is assumed that longitudinal and transverse dispersivities are random variables with the statistical parameters presented in Table C4-3.5-2. Site-specific data supporting these values are not available. Based on data from the literature, the selected range of values is reasonable for the spatial scale of simulated contaminant transport (approximately 1 km [0.62 mi]) (Neuman 1990, 090184) and the properties of the flow medium.

### C4-3.6 Model Calibration

Because the water-table maps are directly applied to defined hydraulic heads in the models, there is no need to calibrate against the existing water-level data. However, it is crucial to calibrate against the existing RDX data for the regional aquifer. None of the monitoring wells in the vicinity of R-25 show RDX detections except for R-18. At R-18, RDX is present sporadically at low concentrations (LANL 2007, 095787). These data are used to scale (decrease) permeability of Puye fanglomerate by 1 order of magnitude because the current data ranges (Table C4-3.5-1 and Figure C4-3.5-1) cause substantial overprediction of the RDX concentrations. The mean permeability is defined to be equal to 1012.5 $m^2$ (Table C4-3.5-1, Figure C4-3.5-1), which is approximately 0.3 m/d. The average permeability based on pumping tests near TA-16 is 3 m/d (Table C4-2.1-1).

In addition to the calibration described above, which used a contaminant source term derived from historical data of potential RDX release rates (Appendix C1) and the current RDX hydrological inventory (Appendix C2), a second source term was derived from calibration to RDX data from R-25, which is located at TA-16. As described below in section C4-4.0, several release rates were assumed under both of these source term formulations.

Finally, the model results using both source term formulations are compared against existing data for area monitoring wells and municipal wells, and the model which best matches current data is selected. This final comparison serves as a model validation, which enables predictive model simulations to be conducted and assessed with more confidence.

### C4-3.7 Estimation of Uncertainty in the Model Predictions

To estimate uncertainty in the model predictions, a Monte Carlo analysis is performed. A set of 1000 uncorrelated, equally probable random realizations are generated using a Latin Hypercube sampling technique with the software Crystal Ball. Each realization includes 26 random variables representing various model parameters that include the permeability and the porosity of the hydrostratigraphic units and the longitudinal and transverse dispersivities. As the parameter range includes high-permeability values and low-porosity values characteristic of fracture flow, a fraction of the realizations simulate fast preferential flow paths. Therefore, this accounts for the probability that contaminant plumes may be affected by fracture flow.

In this case, a relatively limited set of hydrogeological parameters in the model affects contaminant transport near TA-16. These parameters are the permeability and porosity of Tpf and Tt, as well as the longitudinal and transverse dispersivities, a total of six parameters. Therefore, using 1000 realizations to characterize uncertainties numerically is reasonable for evaluating the potential range of contaminant flow direction in the regional aquifer.

## C4-4.0 MODEL RESULTS

Numerical simulations are performed to evaluate the breakthrough curves of RDX at regional aquifer monitoring and water-supply wells across the Pajarito Plateau using both source term approaches.

For the first source term approach (referred to as Source Term One), which uses the results of a historical study on potential RDX release rates (Appendix C1) and calculations of contaminant migration through the vadose zone (Appendix C2), a series of alternative release rates are applied to characterize the contaminant mass arrival at the top of the regional aquifer beneath Cañon de Valle. The models are described in Appendix C2 and are labeled as HQ-HM (high infiltration flux/high mass), HQ-LM (high infiltration flux/low mass), LQ-HM (low infiltration flux/high mass), and LQ-LM (low infiltration flux/low mass).

Under the second source term approach (referred to as Source Term Two), two vadose-zone flux rates are applied consisting of 0.035 and 0.005 kg/yr. The mass rates are estimated so that a constant RDX concentration commensurate with observed R-25 concentrations (assuming these were not just introduced during drilling) is approximately achieved, considering the uncertainty in the groundwater fluxes in the regional aquifer (the mean groundwater flux generated by the model is approximately 0.016 kg/s or $5 \times 10^7$ kg/yr). The release rates of 0.035 and 0.005 kg/yr are derived from the highest concentrations observed at Screens 1 and 4 of R-25, respectively (LANL 2007, 095787). In this case, a conservative assumption is made that these concentrations can be associated with the contaminant source at the top of the regional aquifer.

As discussed in Section C4-2.1.1, all the regional aquifer simulations are based on Conceptual Model B (discussed in section C4-2.1-1) and assuming hydraulic gradients in the regional aquifer are characterized by the water-table map presented in Figure C4-2.1-10a. Simulations using the alternative water-table map (Figure C4-2.1-10b) produced similar results; the major difference is that the shape of the water table produced more focused contaminant transport toward R-17 (and therefore the model predicted higher concentrations in this well). A summary of all source term scenarios used with the regional model is shown in Table C4-4.0-1. In the case of Conceptual Model B, the directions of contaminant flow are predominantly controlled by the cones of water-table depression surrounding the water-supply wells. As a result, all of the contaminants are captured by the water-supply wells (PM-2, PM-5, and PM-4; wells are ordered from high to low percentage of capturing).

### C4-4.1 RDX Predictions Associated with Source Term One: High Infiltration Flux

Figures C4-4.1-1 and C4-4.1-2 show RDX breakthrough curves at selected monitoring (R-18, R-17, CdV-R-15-3, CdV-R-37-2) and water-supply wells (PM-1, PM-2, PM-3, PM-4, PM-5). Concentrations are plotted in ppb. Model predictions characterize the best estimates (blue solid line) and uncertainty bounds (red dashed lines represent the 5th and 95th confidence intervals). Figures C4-4.1-1 and C4-4.1-2 show the results for high- and low-mass models, respectively. The regional aquifer simulations do not consider potential RDX hydrolysis or biodegradation (Layton et al. 1987, 014703). Among the monitoring wells, the highest concentrations are observed at R-18. Among the water-supply wells, the highest concentrations are observed at PM-2. The model predicted concentrations substantially exceed the currently observed concentrations that in general are zero or below detection levels (1 ppb). Using Source Term One and a high infiltration rate, peak RDX concentrations are observed at the municipal wells in approximately 10 yr.

### C4-4.2 RDX Predictions Associated with Source Term One: Low Infiltration Flux

Assuming low infiltration flux, model-predicted RDX breakthrough curves are shown in Figures C4-4.2-1 and C4-4.2-2, for high- and low-mass models, respectively. Concentrations are again plotted in ppb. No hydrolysis or biodegradation is considered. Even for the low-mass case, the model-predicted concentrations substantially exceed the currently observed concentrations that in general are zero or below detection levels (1 ppb).

To estimate the impact of hydrolysis, simulations assuming low-mass source and using half-life decay of 58 and 5.8 yr are also performed. The pH decay rate is pH dependent (Layton et al. 1987, 014703) and estimated, considering the observed pH values in the regional aquifer that vary between 7 and 8. Model results are presented in Figures C4-4.2-3 and C4-4.2-4. The 58-yr half-life reduces the predicted concentrations but these still substantially exceed currently observed RDX concentrations. Using a 5.8-yr half-life, the model predicts concentrations that are somewhat consistent with observations; in all wells, RDX is below detection levels, except at R-18 and CdVR-15-3. However, the concentrations at these two wells exceed the current observations. Using Source Term One and a low infiltration rate, peak RDX concentrations are observed at the municipal wells in approximately 90–100 yr.

### C4-4.3 RDX Predictions Associated with Source Term Two and Constant Mass Fluxes

Additional modeling analyses are performed using Source Term Two where the source is characterized by two constant mass fluxes of 0.005 and 0.035 kg/s, respectively. The mass rates are estimated so that a constant RDX concentration within the source area is approximately achieved. The target RDX concentrations with the source zone at the top of the regional aquifer are 10 and 70 ppb. These concentrations are estimated based on the highest concentrations observed at Screens 4 and 14 of R-25, respectively (LANL 2007, 095787). In this case, a conservative assumption is made that these concentrations can be associated with the contaminant source at the top of the regional aquifer.

The obtained results are presented in Figures C4-4.3-1 and C4-4.3-2. As these figures show, the new breakthrough curves at the wells have very different shapes. The breakthrough curves discussed previously in the text are caused by a source with transient mass distribution that peaks at a given time and declines afterward. The source is of constant mass flux in the new simulations, and this causes the asymptotic behavior of the breakthrough curves.

In the case where the source is 0.035 kg/yr (Figure C4-4.3-2), the model predicts RDX concentrations that are below detection (<0.1 ppb) in all wells, except at R-17, R-18 and CdVR-15-3. However, the concentrations predicted at these three wells exceed the current observations. In the case where the source is 0.005 kg/yr (Figure C4-4.3-1), the model predicts RDX concentrations that are below detection in all wells, except R-18 and CdV-R-15-3. This is more consistent with what is currently observed, although levels at R-18 and CdV-R-15-3 are still overestimated by the model. These simulations did not include RDX degradation by hydrolysis.

Use of Source Two and its constant flux rate starting from time zero (rather than use of Source One and its time-variant breakthrough curve depicting the mass release rate from the overburden into the regional) is also informative with regard to the travel time to area wells. Based on the results for Source Two, it is assumed that travel times to these wells (R-18 and CdV-R-15-3) range from 1 to 5 yr.

## C4-5.0 CONCLUSIONS

A regional-scale groundwater flow and contaminant transport model was developed to support the CME for TA-16. The groundwater flow model was a stochastic flow model constructed using the FEHM code (Zyvoloski et al. 1996, 054421). Site-specific hydrogeologic parameters were used as input, and two source term approaches (Source Terms One and Two) assuming various rates for RDX discharging from the vadose zone to the regional aquifer were developed. Source Term One used the results of historical studies on potential RDX mass release rates (Appendix C1) and conservative hydrologic assumptions for flow through the vadose zone (Appendix C2) in several release rates; in particular, a high-flux rate and a low-flux rate. For Source Term Two, existing R-25 RDX data were used to develop a high mass and a low mass of RDX release rate to the regional aquifer.

The results indicate that Source Term One overestimated RDX concentrations at nearby water-supply and monitoring wells, even when degradation by hydrolysis was included. More specifically, model results for the present time period show substantial RDX concentrations at nearby monitoring wells (R-18, CdV-R-15-3, and CdV-R-37-2), where RDX has not been consistently detected. For the purpose of predicting long-term contaminant fate and transport under either the MNA or no-action alternatives, Source Term One is overly conservative. On average, travel times to the water-supply wells predicted by the model are relatively short (on the order of 1–5 yr). Depending on the uncertainties represented in the model, the fastest and highest concentration arrivals are at PM-2 and PM-4.

For Source Term Two, the higher mass release rate results showed RDX concentrations that were below detection limits at area municipal wells but at detectable levels of approximately 1–5 ppb at R-18 and CdV-R-15-3. Use of the lower release rate showed lower levels at these wells, approximately 0.1–0.6 ppb. Model simulations using Source Term Two did not include degradation by hydrolysis.

Of the two source term formulations, Source Term Two yielded model results that more closely matched the observed RDX data, thus validating use of the model for predictive modeling of future contaminant levels. Predicted concentration trends at area wells show levels near or below the detection limit for RDX. In particular, levels at the municipal wells are predicted to be significantly below the RDX detection limit of 0.1 ppb.

These results, which are conservative, indicate that RDX concentrations at municipal wells are unlikely to exceed RDX detection limits. These results are conservative given that hydrolysis and retardation were not included in the model. In addition, well bore dilution effects were not incorporated into the model; the municipal wells are screened across an interval that is much longer than the model assumed. Based on these results, the existing RDX groundwater contamination at TA-16 does not pose an imminent threat under either an MNA or no-action alternative. Moreover, monitoring wells CdV-R-15-3, R-18, and CdV-R-37-2 will probably provide adequate warning of increasing downgradient levels of RDX. Further analysis related to this question will be presented in the response to the notice of deficiency (NMED 2007, 097874) on the “Evaluation of the Suitability of Wells Near TA-16 for Monitoring Contaminant Releases from Consolidated Unit 16-021(c)-99” (LANL 2007, 095787) that is due to the New Mexico Environment Department on September 30, 2007.

It is important to emphasize that although the groundwater model used a stochastic approach, the parameter distributions are themselves uncertain, with the degree of uncertainty related to the number of constituent data points. In particular, the permeability data set is relatively small in comparison with the large model domain. With a small data set, there is a higher potential for outlying values to influence the parameter distribution.

## C4-6.0 REFERENCES

*The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID number. This information is also included in text citations. ER ID numbers are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.*

*Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau; the U.S. Department of Energy–Los Alamos Site Office; the U.S. Environmental Protection Agency, Region 6; and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.*

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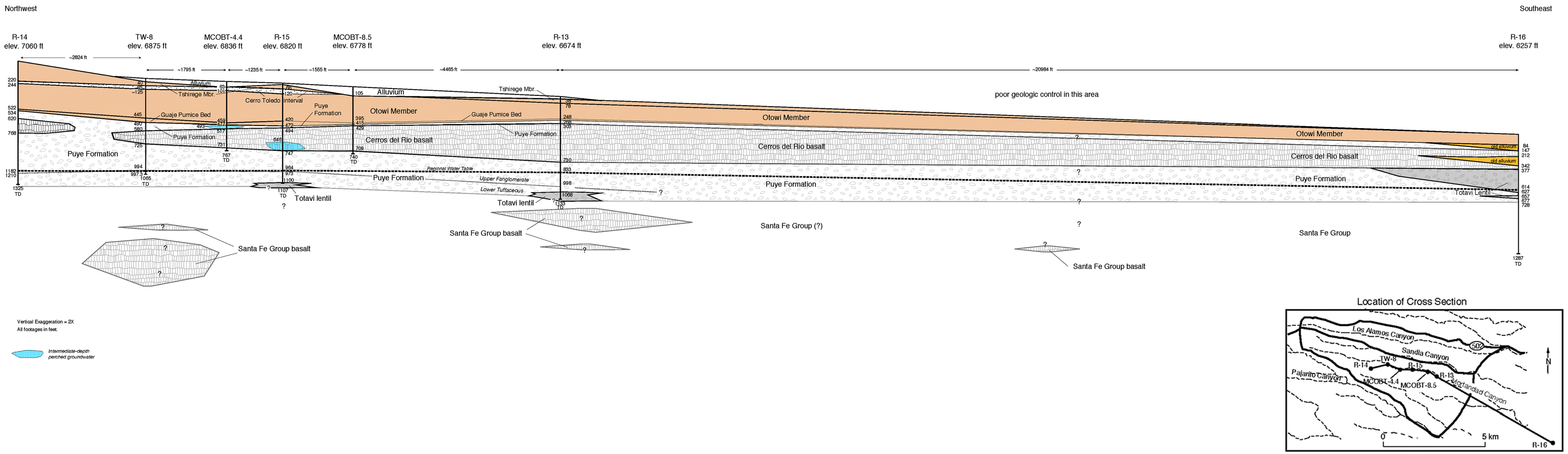

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**Figure C4-2.1-1**

**Hydrogeologic cross-section of the vadose zone and regional aquifer beneath the Pajarito Plateau (from Broxton & Vaniman 2004, 090038)**

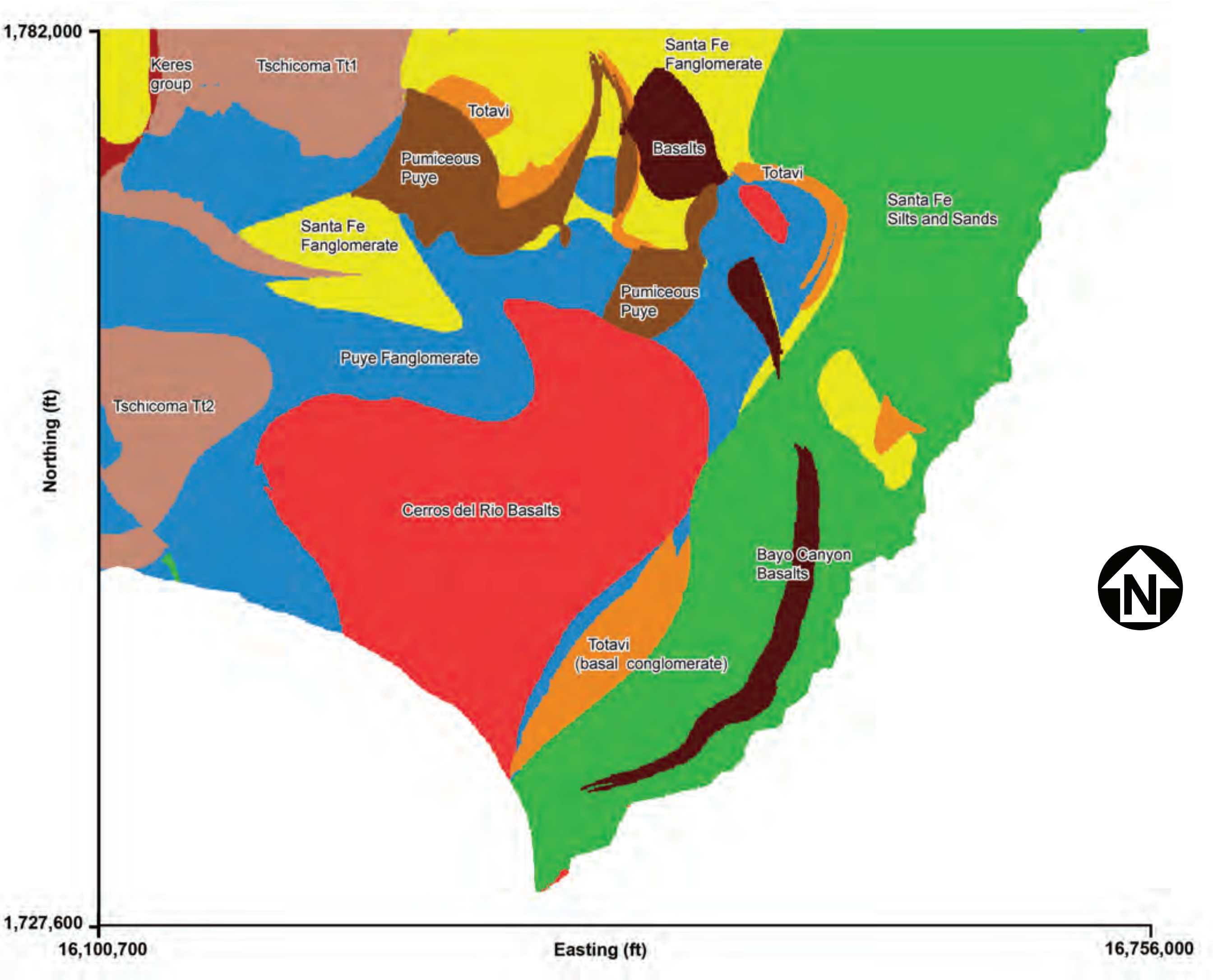

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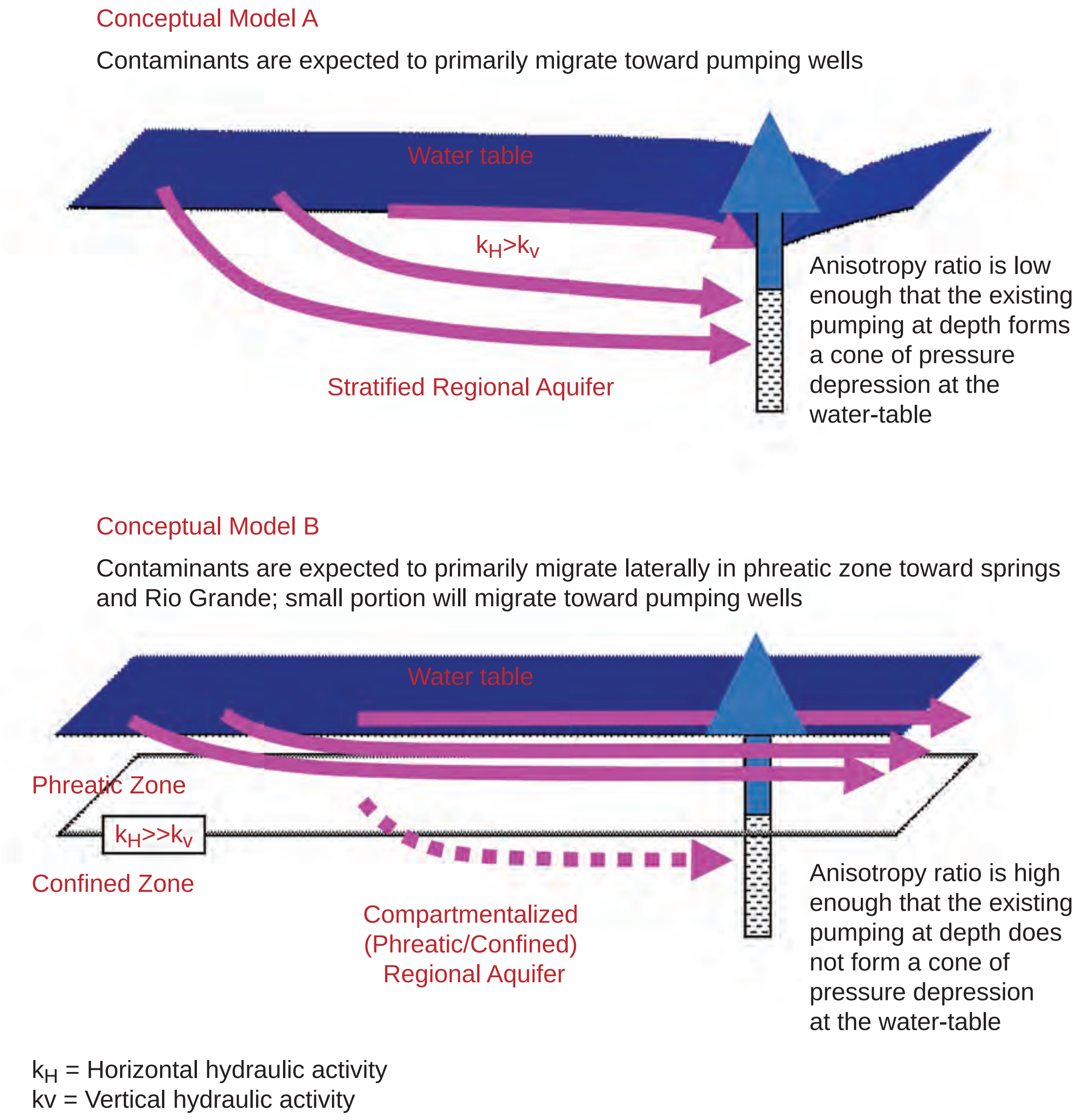
Figure C4-2.1-2
Hydrostratigraphy along the water-table



Conceptual Model A

Contaminants are expected to primarily migrate toward pumping wells

Anisotropy ratio is low enough that the existing pumping at depth forms a cone of pressure depression at the water-table

Conceptual Model B

Contaminants are expected to primarily migrate laterally in phreatic zone toward springs and Rio Grande; small portion will migrate toward pumping wells

Anisotropy ratio is high enough that the existing pumping at depth does not form a cone of pressure depression at the water-table

$k_H$ = Horizontal hydraulic activity
kv = Vertical hydraulic activity

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**Figure C4-2.1-3**

**Schematic representation of alternative conceptual models of the flow and transport in the regional aquifer near water supply wells**

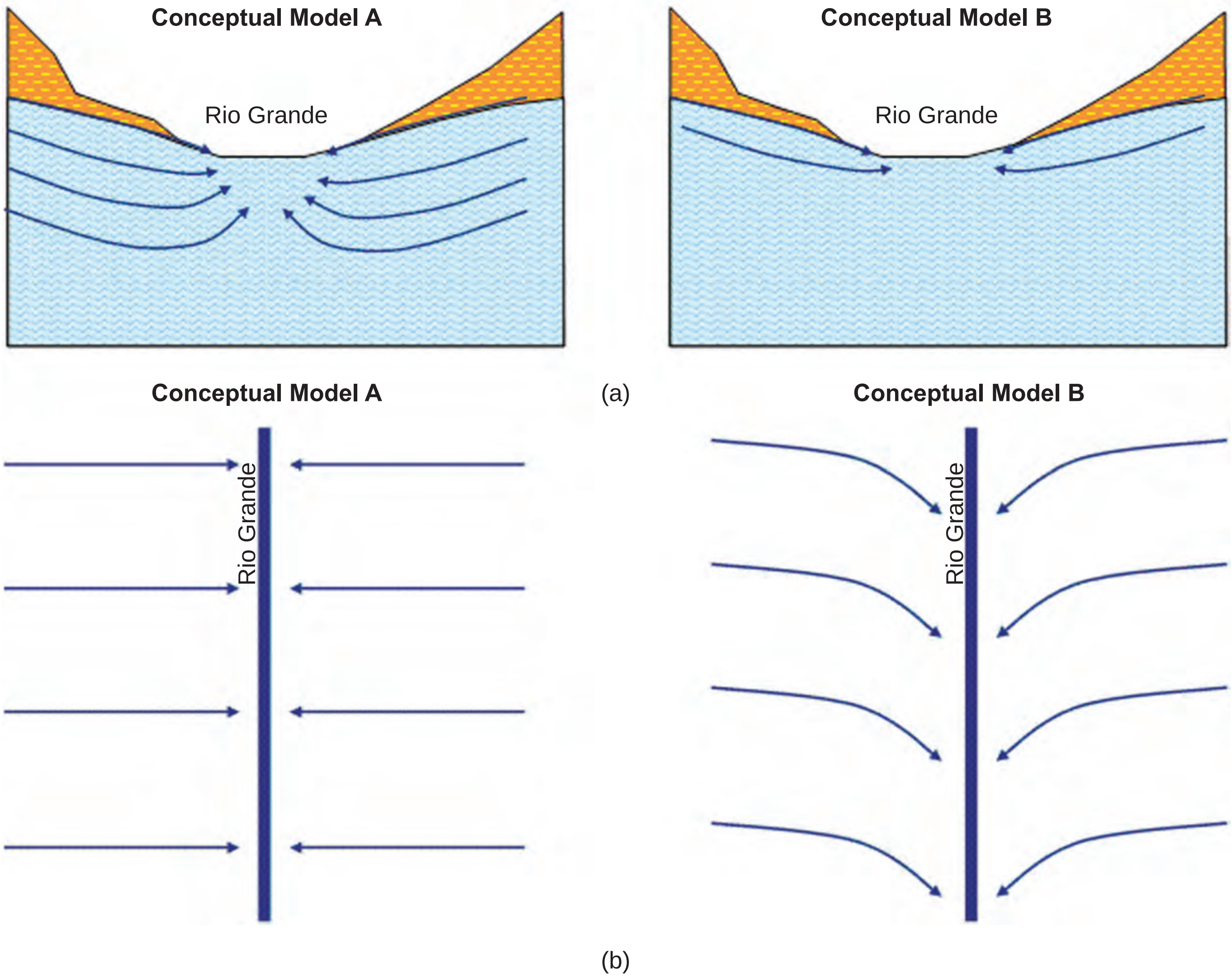

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**Figure C4-2.1-4**

**Schematic representation of alternative conceptual models of the flow and transport in the regional aquifer close to the Rio Grande: (a) representation of potentialvertical distribution of discharge flowpaths; (b) lateral flowpaths of aquifer discharge in the deep zone of the regional aquifer**

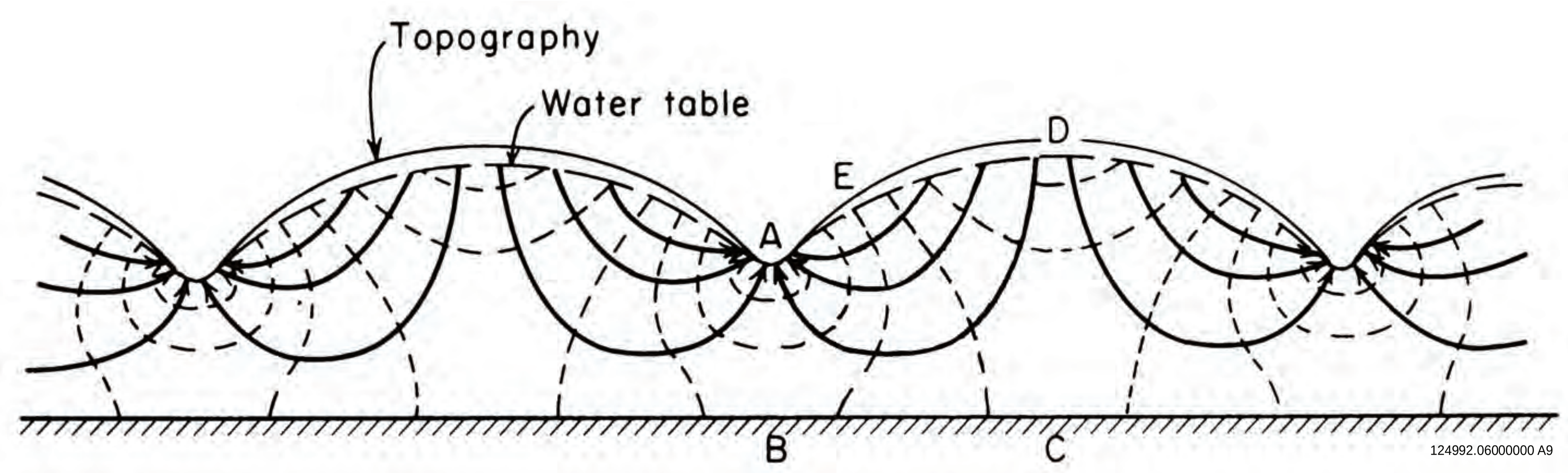
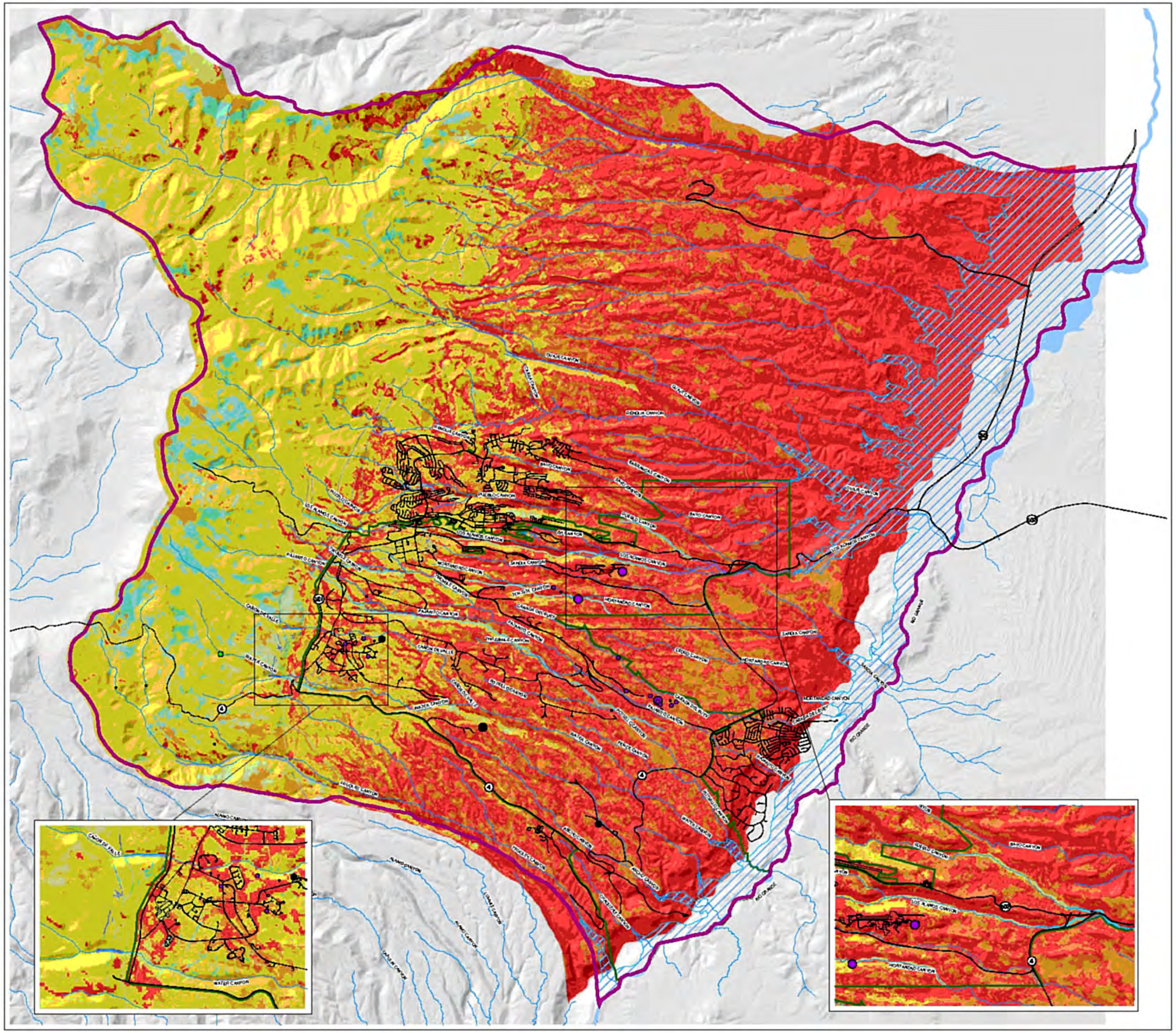


**Figure C4-2.1-5**

**Classical basin-scale structure flow of groundwater flow**



**DATA SOURCES FOR PLOT: 200540**

Title; Owner; Pub Date; Intended Scale; (ER ID); (GISLab ID)

Boundary, LANL: Los Alamos National Laboratory, Unknown: Unknown: Unknown: (NA): (Unknown)

Drainages, client supplied: Los Alamos National Laboratory, Unknown: Unknown: Unknown: (NA): (Unknown)

Infiltration Model: Los Alamos National Laboratory, GISLab: Unknown: Unknown: (NA): (Unknown)

Landscape: Los Alamos National Laboratory, FWO: Unknown: Unknown: (Unknown): (00904-0002)

Rio Grande Polygon, client supplied: Los Alamos National Laboratory, Unknown: Unknown: Unknown: (NA): (Unknown)

Roads, surfaced, client supplied: Los Alamos National Laboratory, ER: Unknown: Unknown: (NA): (Unknown)

Roads, surfaced: Los Alamos National Laboratory, FWO: Unknown: Unknown: (Unknown): (00907-0002)

Roads, unsurfaced: Los Alamos National Laboratory, FWO: Unknown: Unknown: (Unknown): (00908-0002)

R15 and R31 Wells: Los Alamos National Laboratory, ER: Unknown: Unknown: (NA): (Unknown)

Springs: Los Alamos National Laboratory, ER: Unknown: 1:24000: (2002-0593): (00886-0001)

Study Area Polygon, client supplied: Los Alamos National Laboratory, ER, Unknown: Unknown: (NA): (Unknown)

Wells with Flux Values, client supplied: Los Alamos National Laboratory, ER: Unknown, Unknown: (NA): (Unknown)

**Work Performed on Behalf of RRES-ER**
**Los Alamos National Laboratory**
**Los Alamos, NM 87545**

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State Plane Coordinate System
New Mexico Central Zone
1983 North American Datum
Grid Provides Units in Feet

GISLab Map No. m200542
Cartography by Doug Walther
14-January-2002

RRES

GISLab
Los Alamos National Laboratory

Figure C4-2.1-6

Map of spatial distribution of infiltration recharge at the top of the vadose zone (from Kwicklis et al. 2005, 090069)

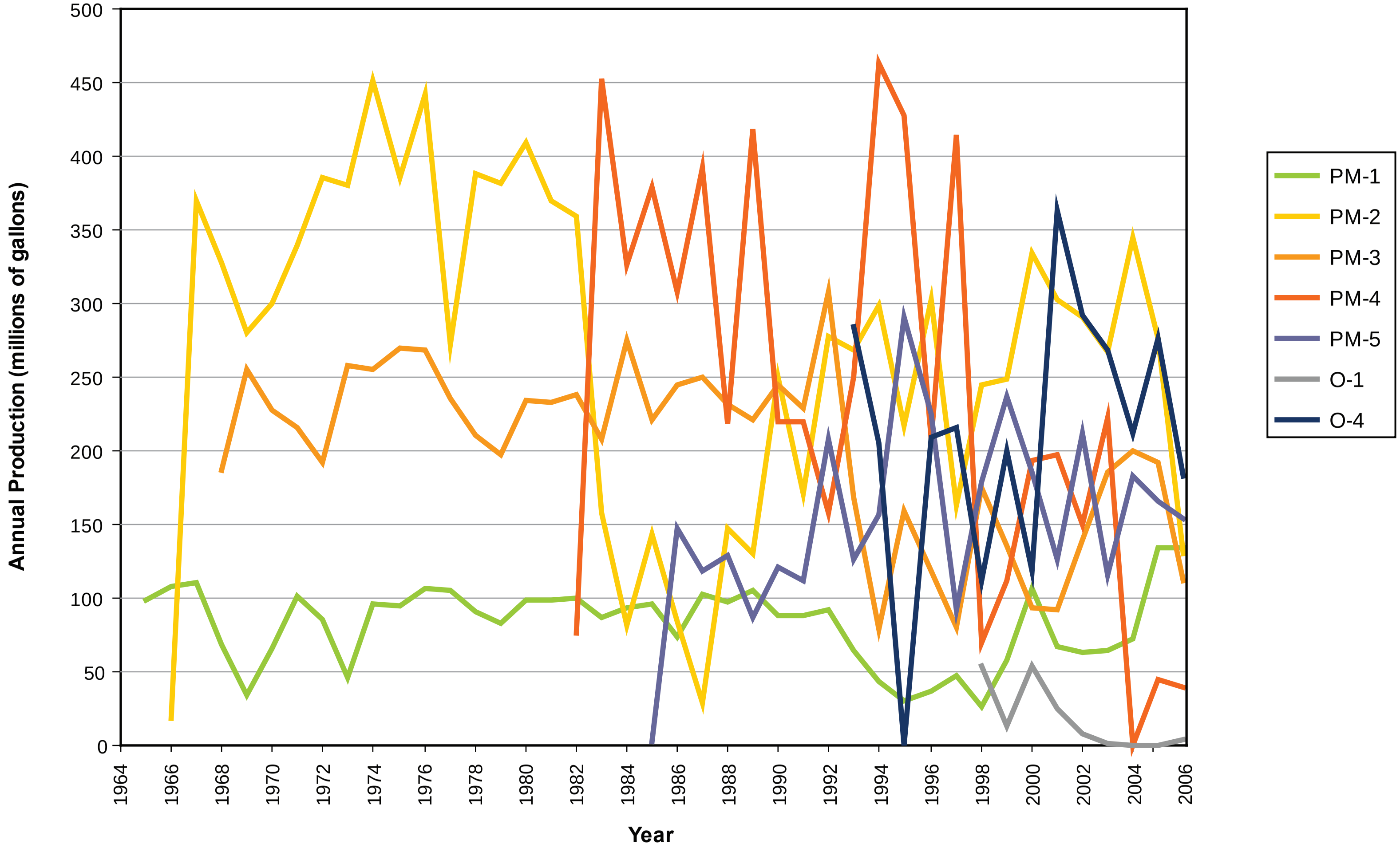

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Figure C4-2.1-7a

Temporal variability of pumping rates at the water supply wells in vicinity of TA-16

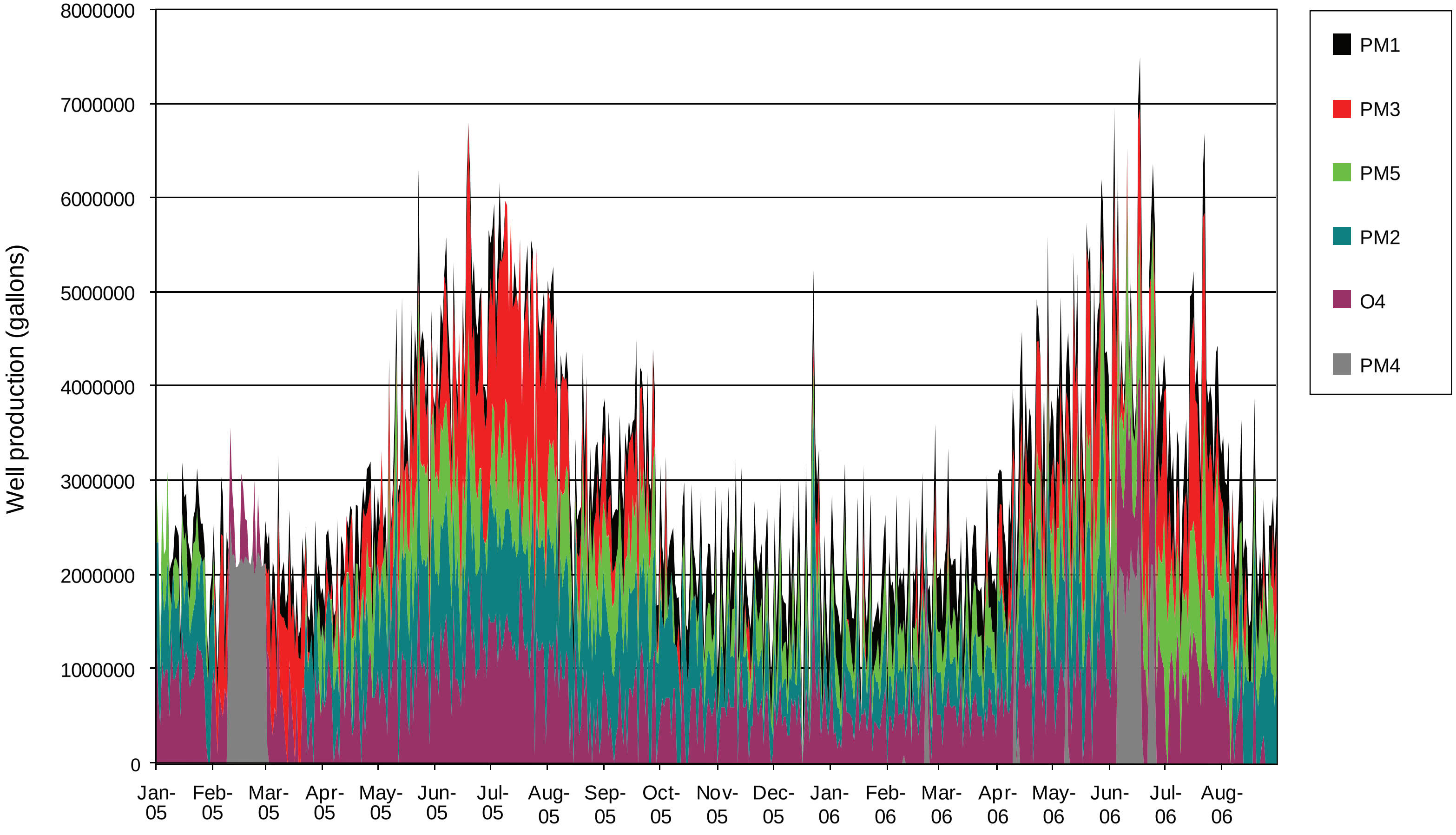

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Figure C4-2.1-7b

Temporal variability of pumping rates at the water supply wells in vicinity of TA-16

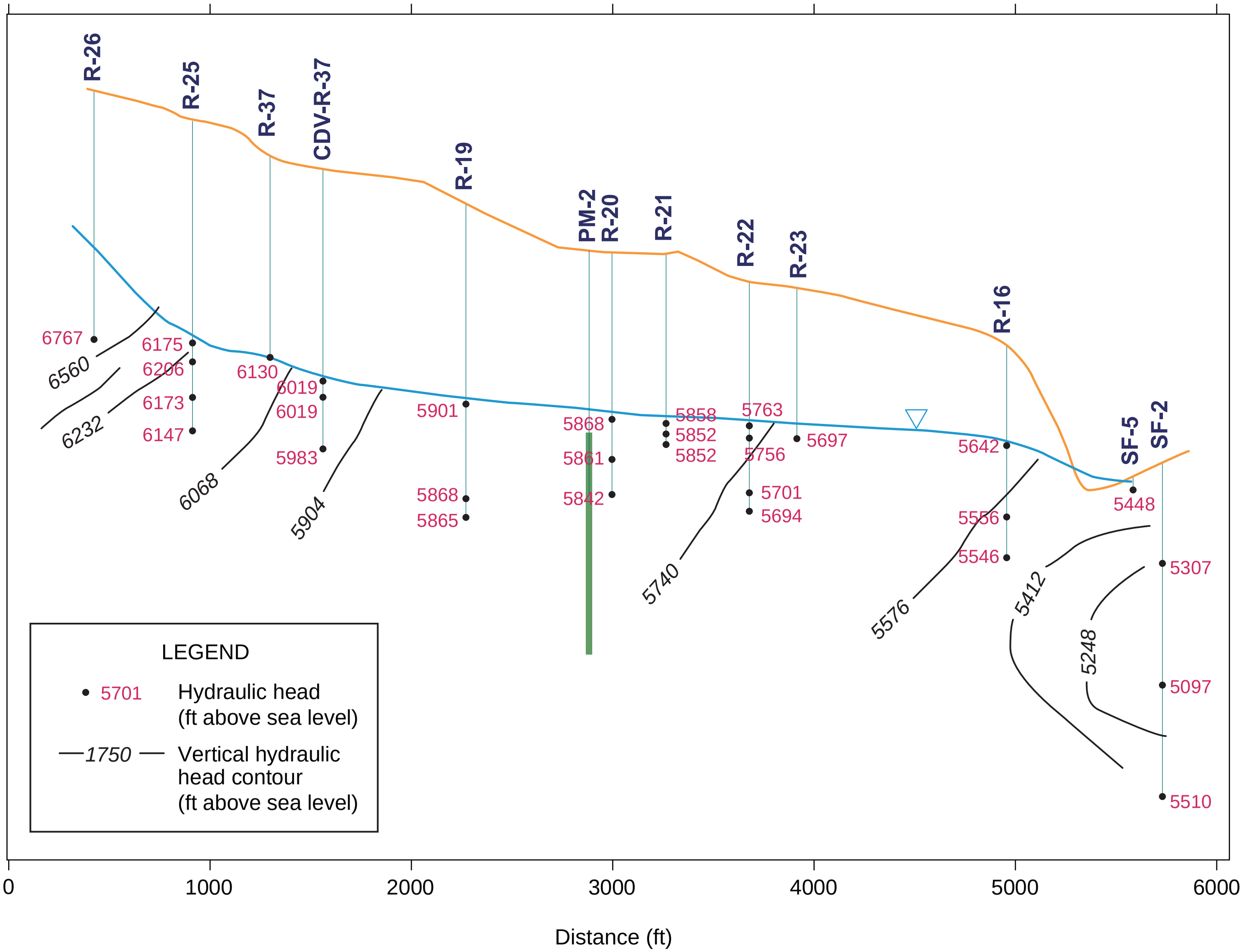

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**Figure C4-2.1-8**

**Hydraulic head data from cross section through southern portion of the plateau (after Keating et al. 2005, 090039)**

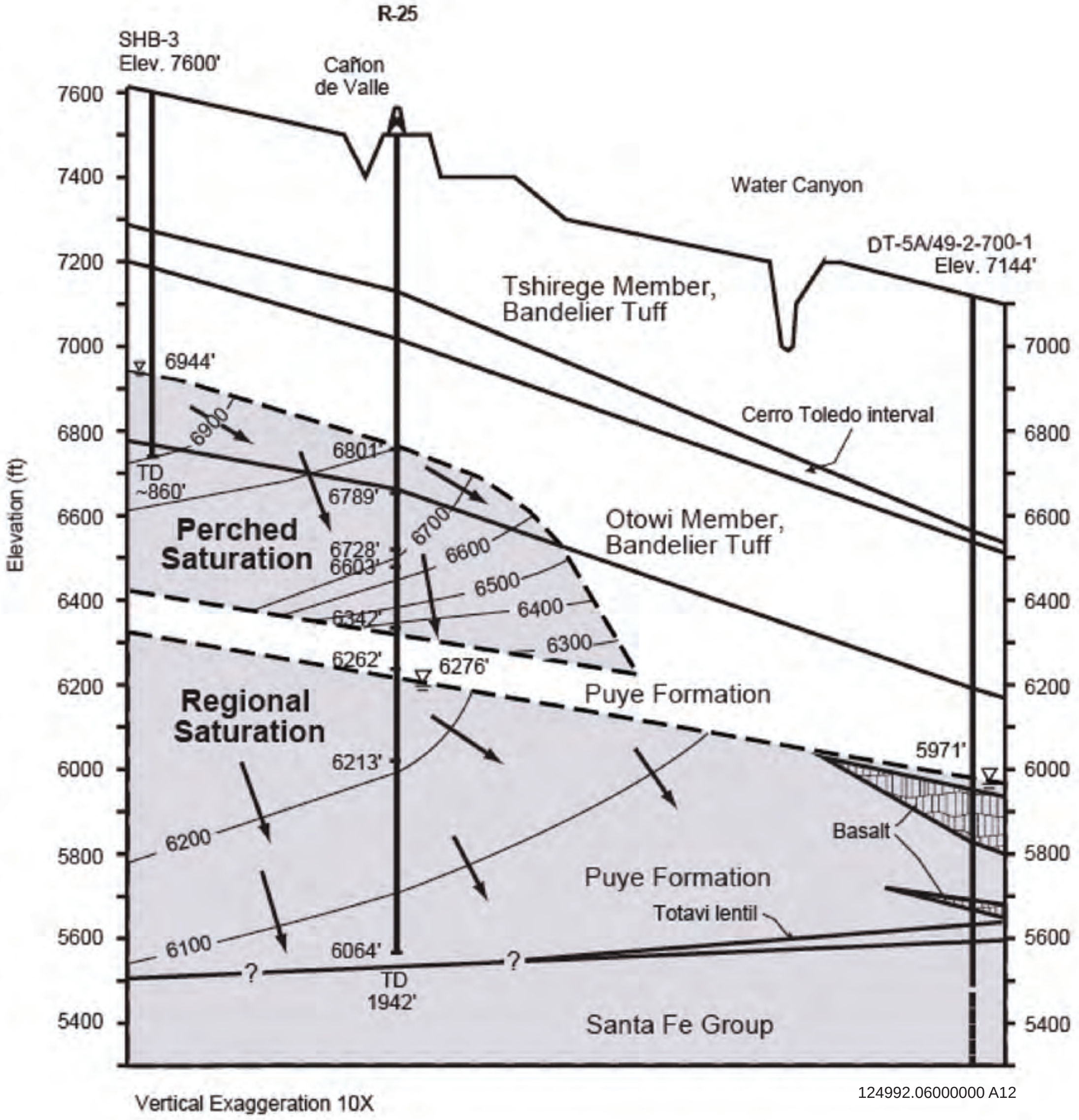

**Figure C4-2.1-9**

**Cross-section of regional and intermediate (perched) saturation zones at R-25. Isocontours represent pressure heads and vectors show groundwater flow directions**

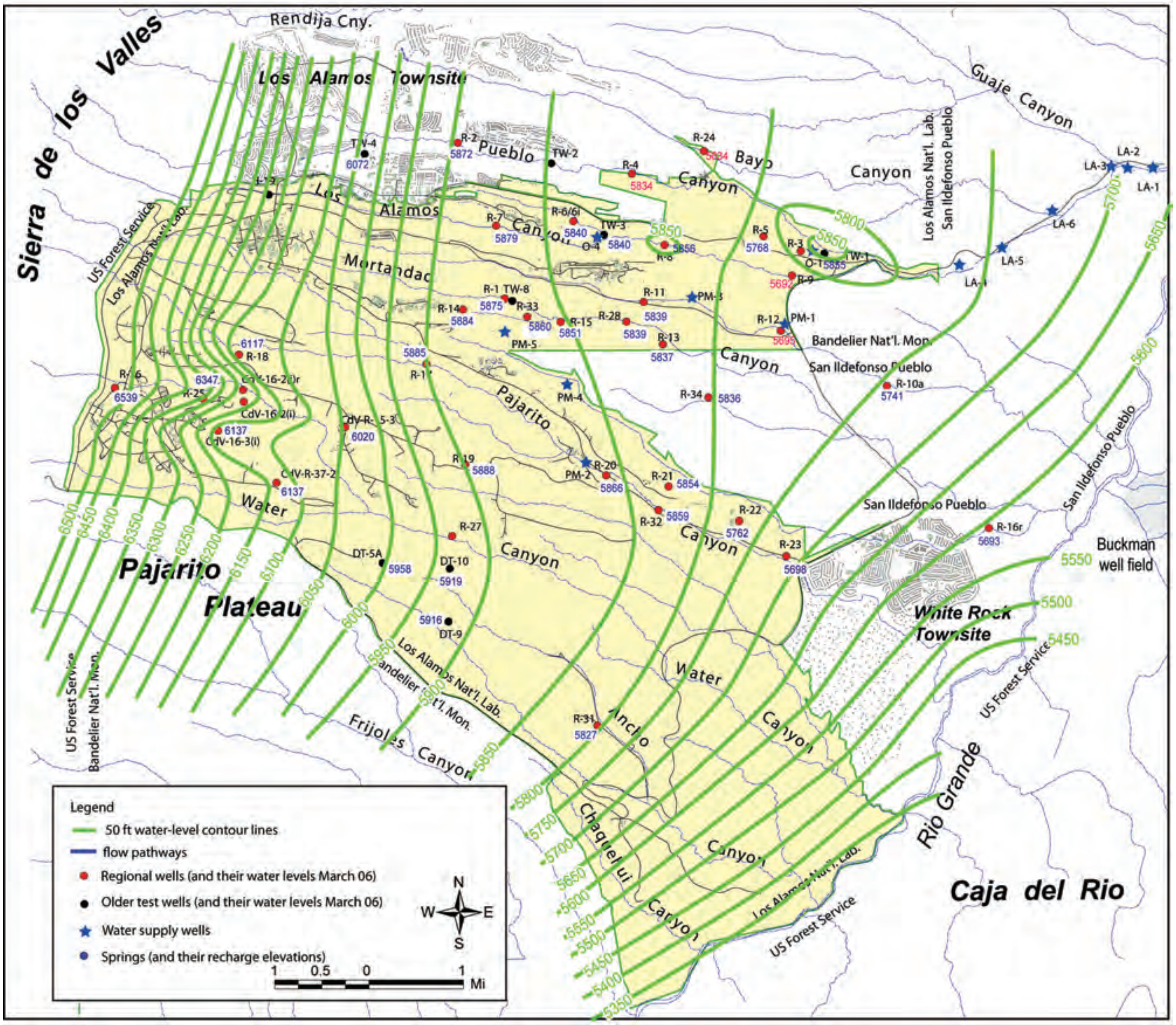

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Figure C4-2.1-10a

Contour map of average water-table elevations in March 2006; assumes water level at R-25 is defined by Screen 5 (after LANL 2007, 095787)

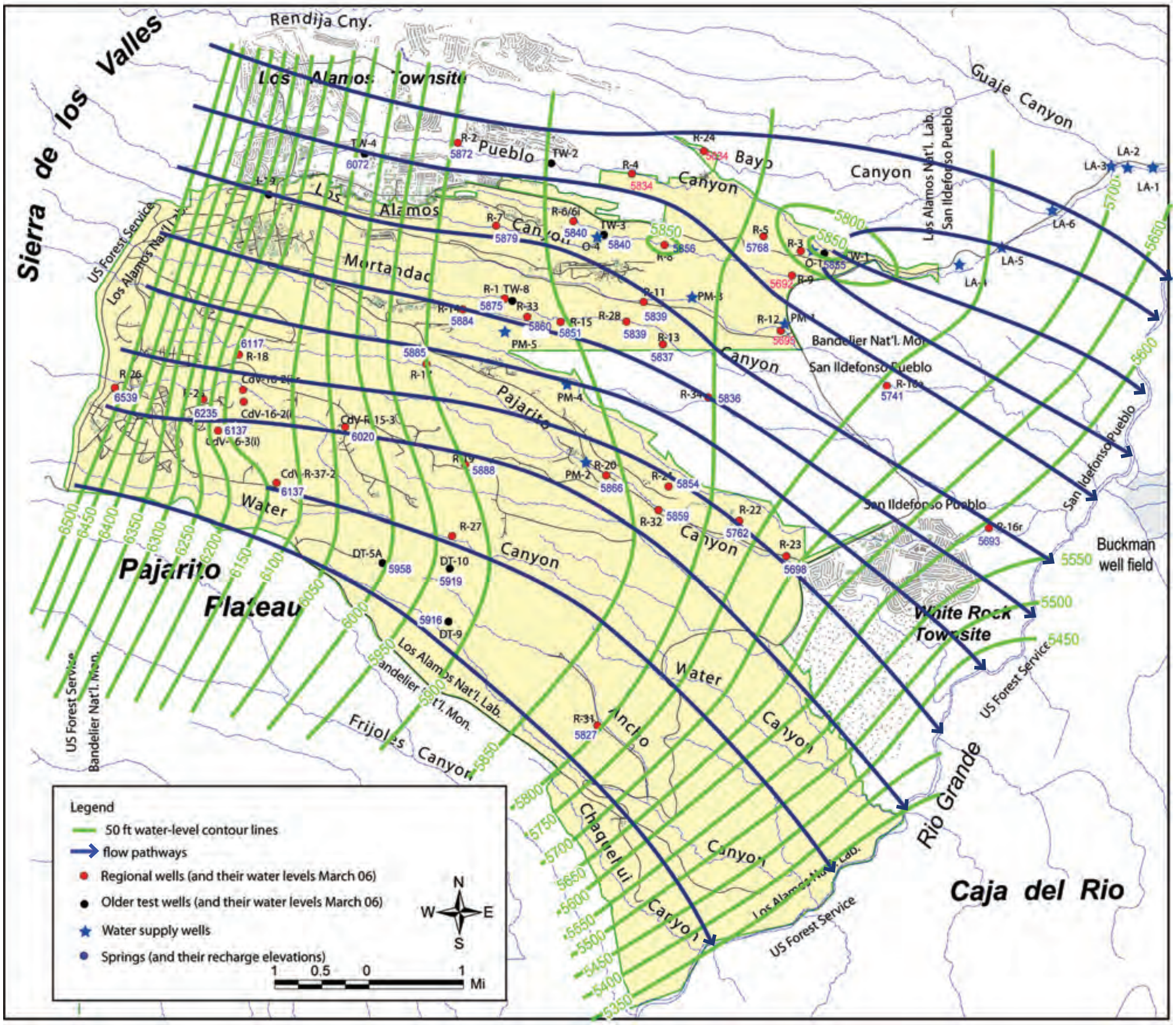

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Figure C4-2.1-10b

Contour map of average water-table elevations in March 2006; assumes that water level at R-25 is defined by Screen 4 (after LANL 2007, 095787)

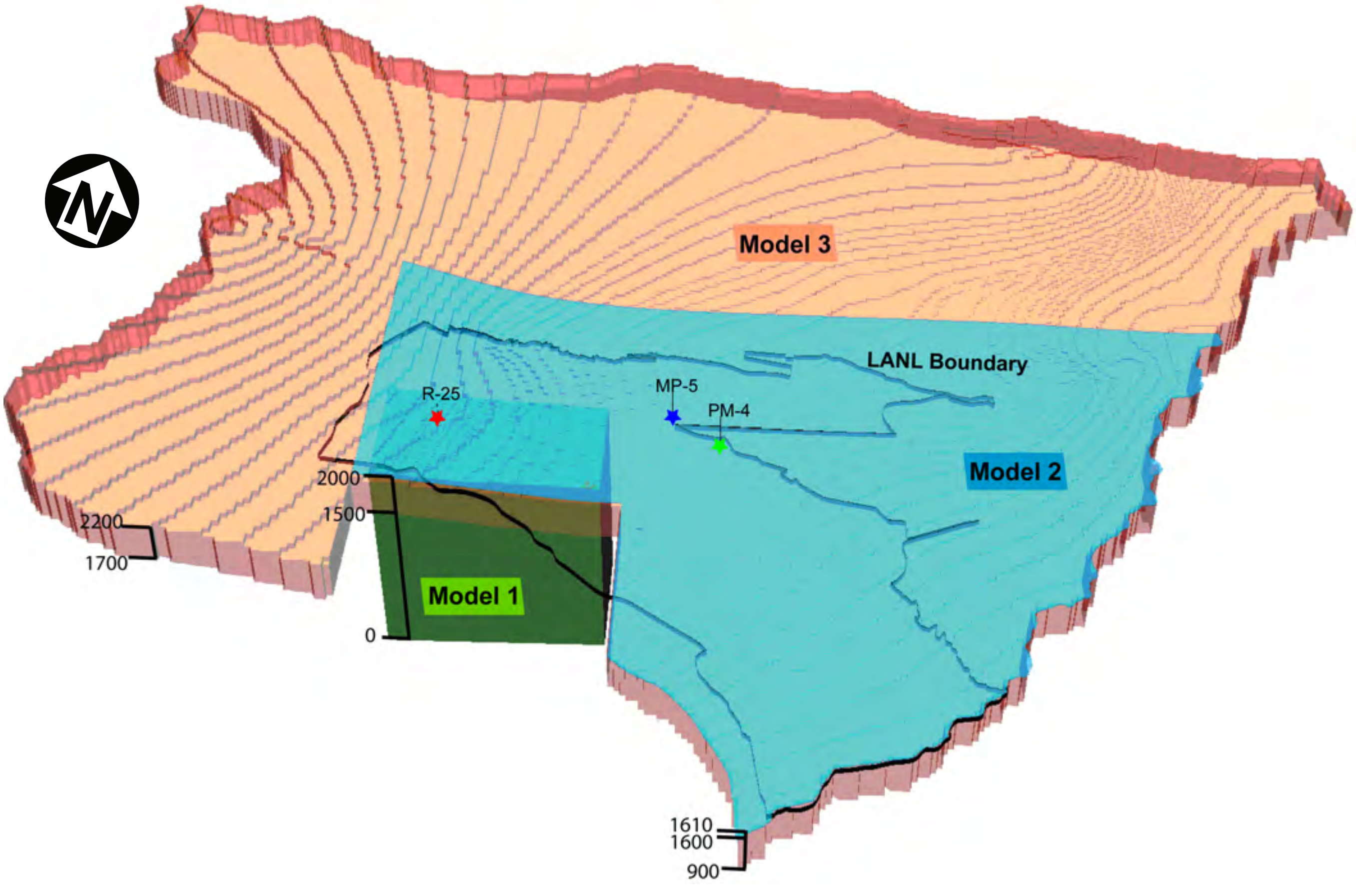
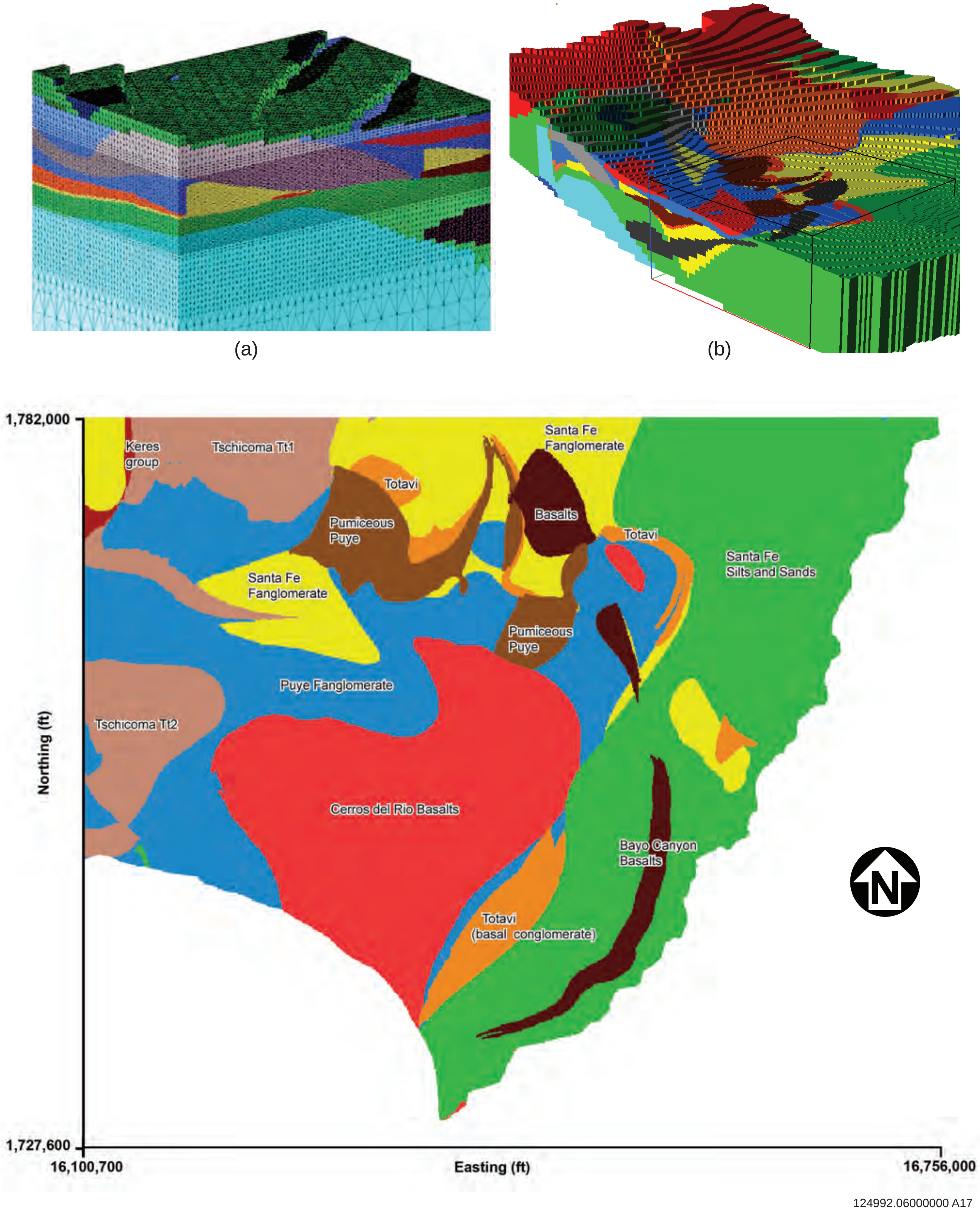


Figure C4-3.3-1

Domains associated with (1) the “site model”, (2) the “thin pancake” model, and (3) the “thick pancake” model



(a)

(b)

(c)

**Figure C4-3.3-2**

**Computational grids and representation of hydrostratigraphy in the numerical models**

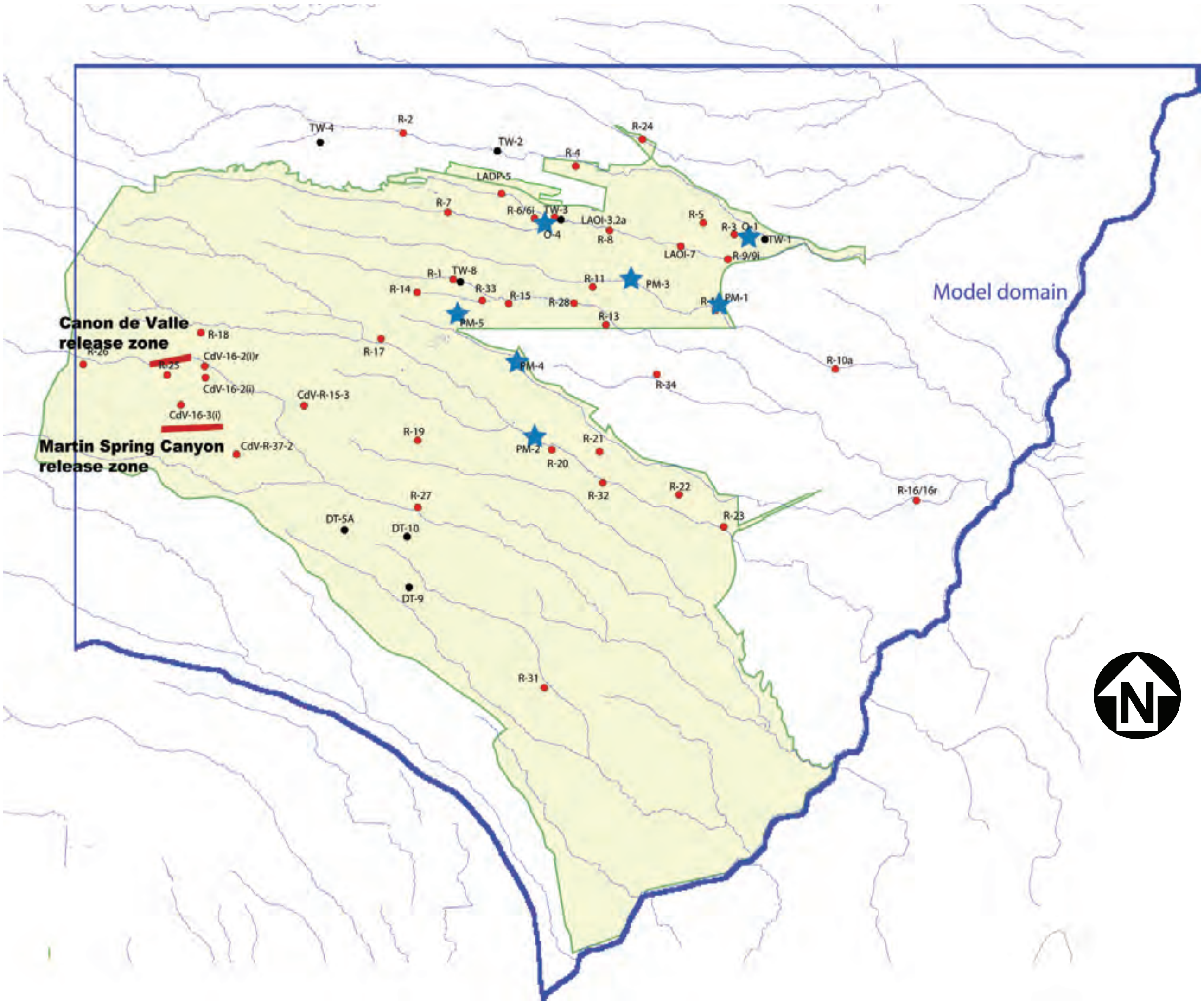


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**Figure C4-3.4-1**

**Domain of the “thick pancake” model and zones of possible contaminant release at the regional aquifer beneath TA-16**

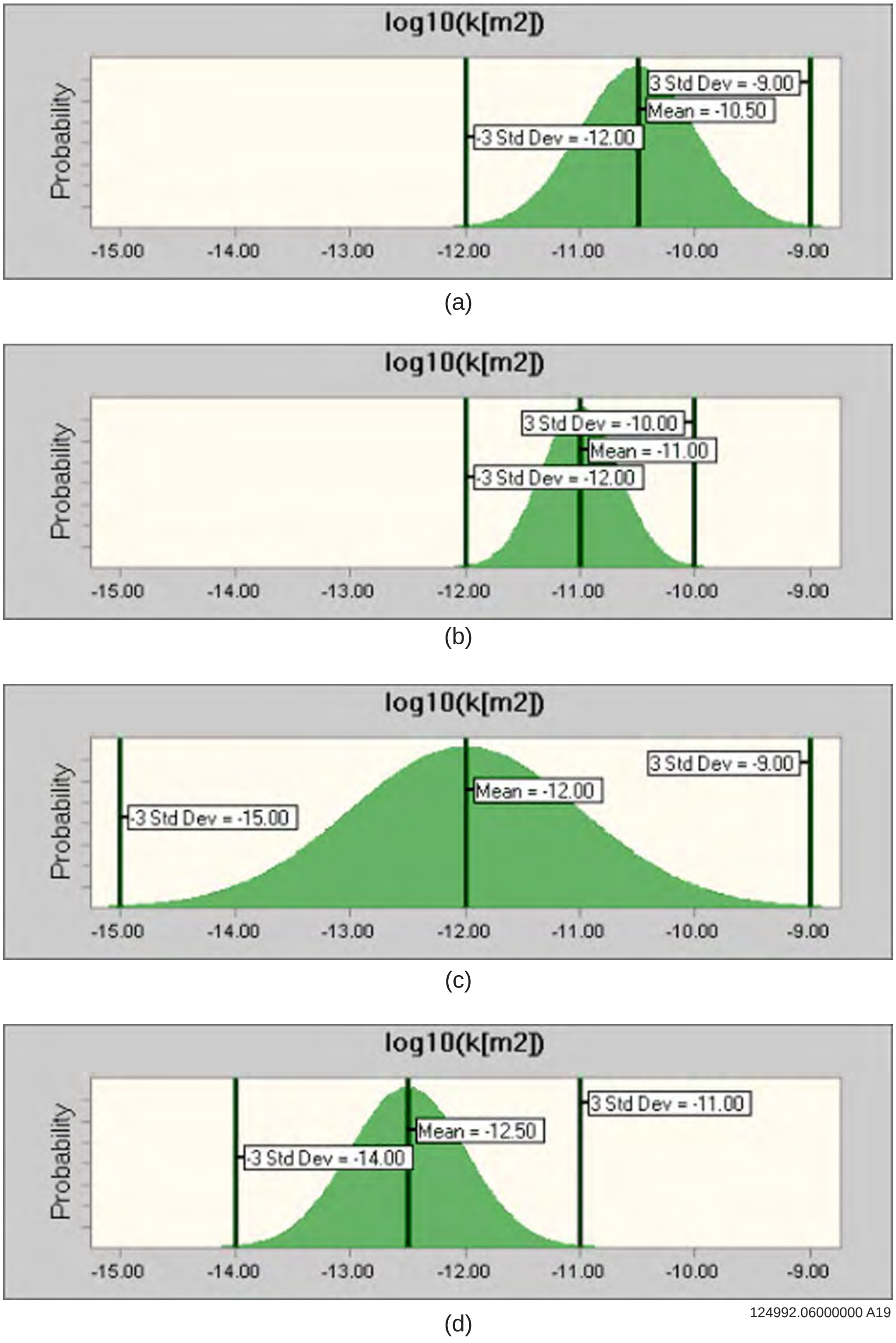

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**Figure C4-3.5-1**

**Probability distributions of permeability for different hydrostratigraphic units: (a) Tschicoma, Keres Group; (b) Totavi Lentil; (c) Cerros del Rio Basalt, Bayo Canyon Basalt; (d) Pumiceous Puye, Puye Fanglomerate, Santa Fe Fanglomerate, Santa Fe Silt and Sands**

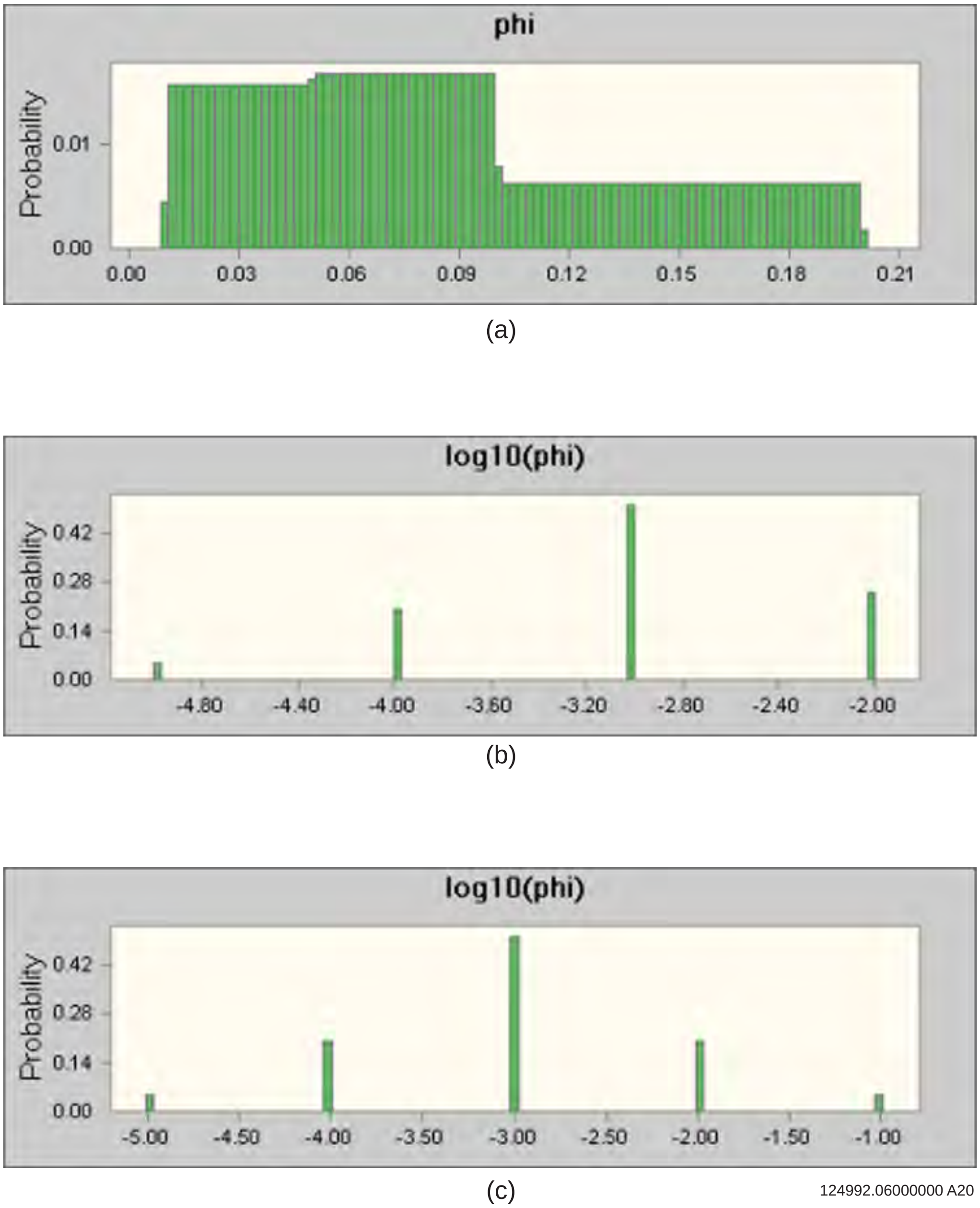

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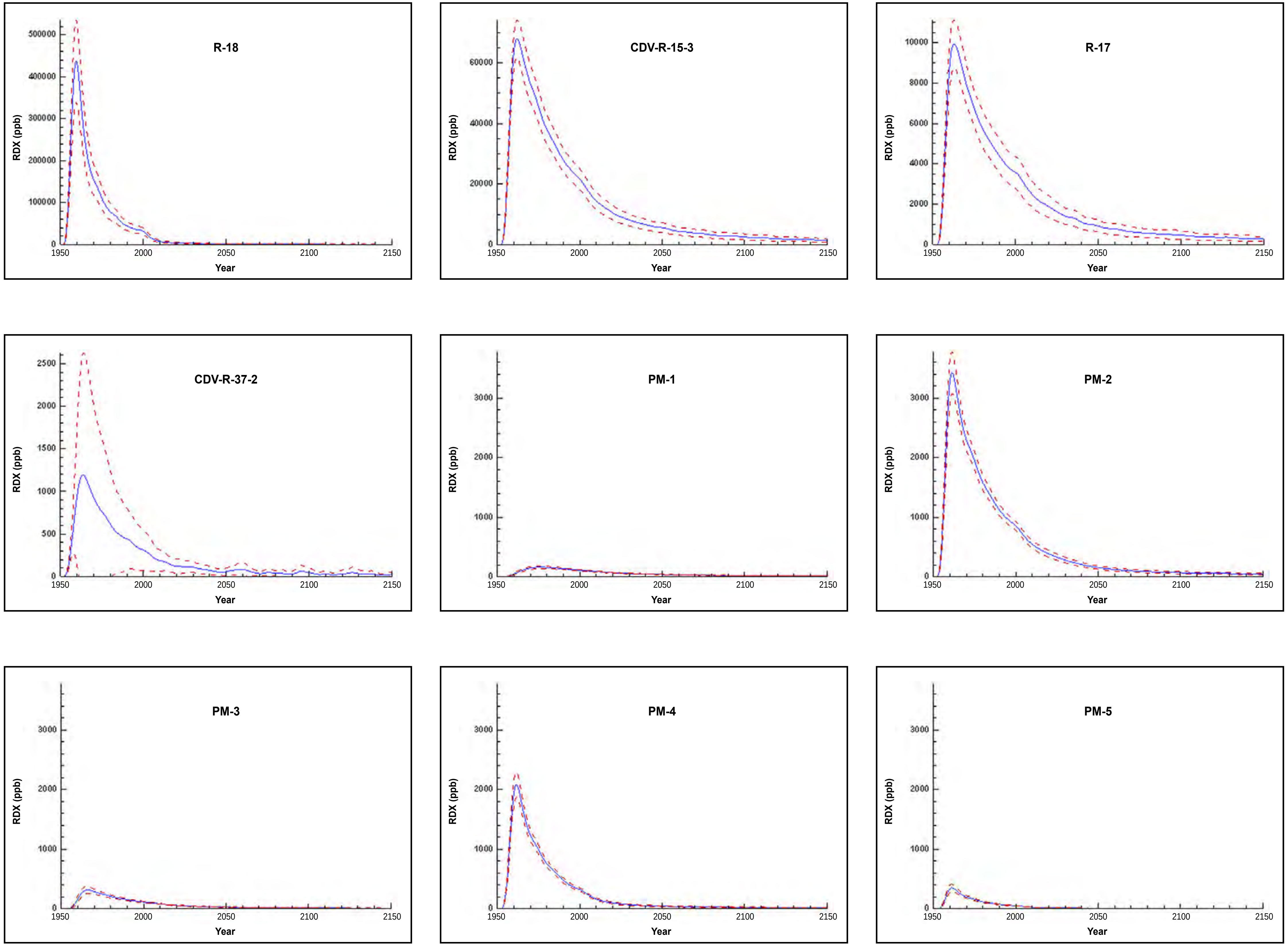
**Figure C4-3.5-2**

**Probability distributions of effective porosity for different hydrostratigraphic units: (a) Totavi Lentil, Pumiceous Puye, Puye Fanglomerate, Santa Fe Fanglomerate, Santa Fe Silt and Sands; (b) Tschicoma, Keres Group; and (c) Cerros del Rio Basalt, Bayo Canyon Basalt**



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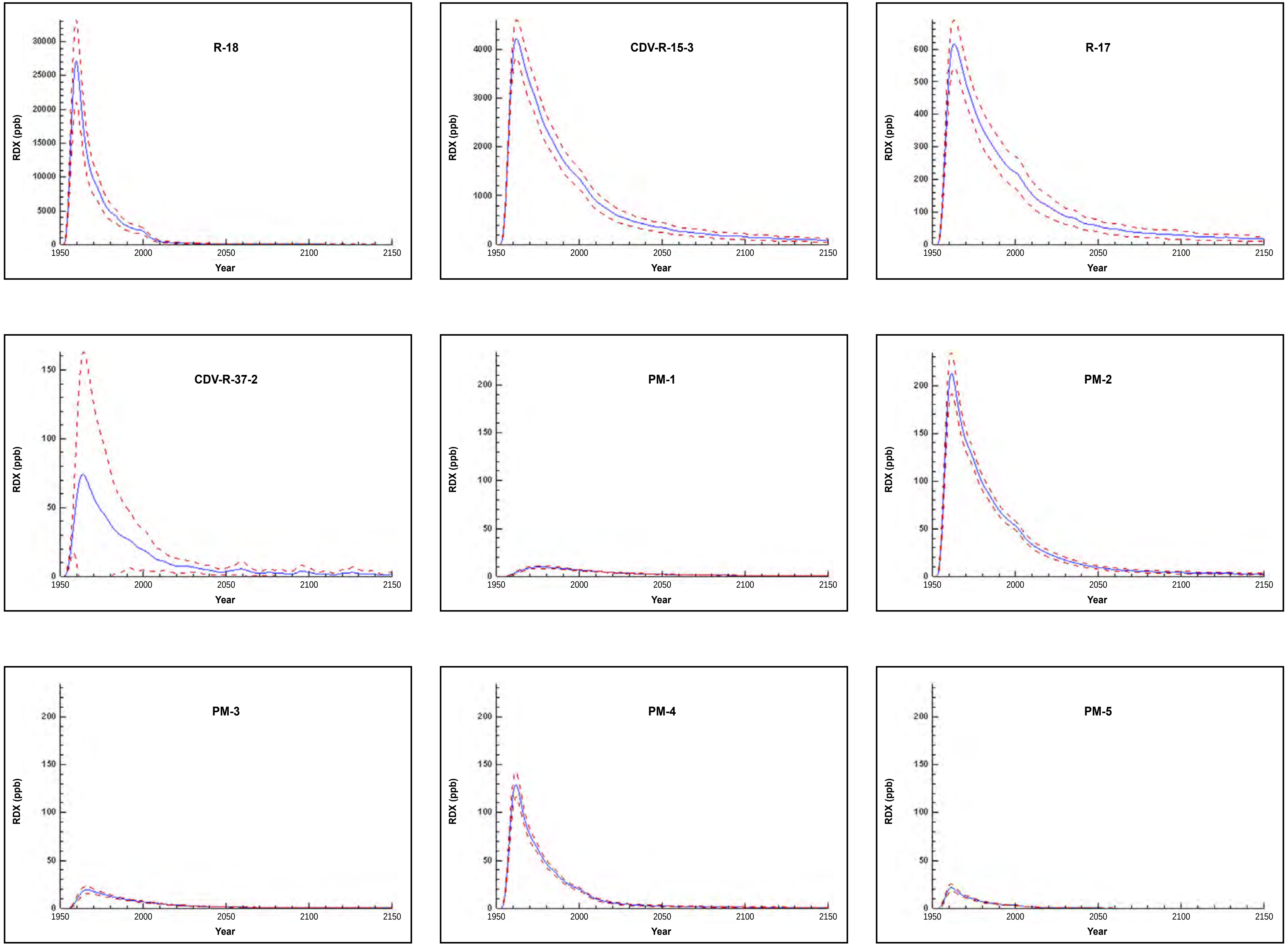
**LEGEND**

| | |
|---|---|
| — | Predicted concentration |
| – – – | 5th and 95th Percent confidence intervals |
| RDX | hexahydro-1,3,5-trinitro-1,3,5-triazine |
| ppb | Parts per billion |

Figure C4-4.1-1

Model predicted RDX concentration breakthrough curves at various monitoring and water-supply wells. The contaminant source at the top of the regional aquifer is estimated assuming high infiltration rate and high RDX mass. The simulations are based on conceptual model B and no hydrolysis



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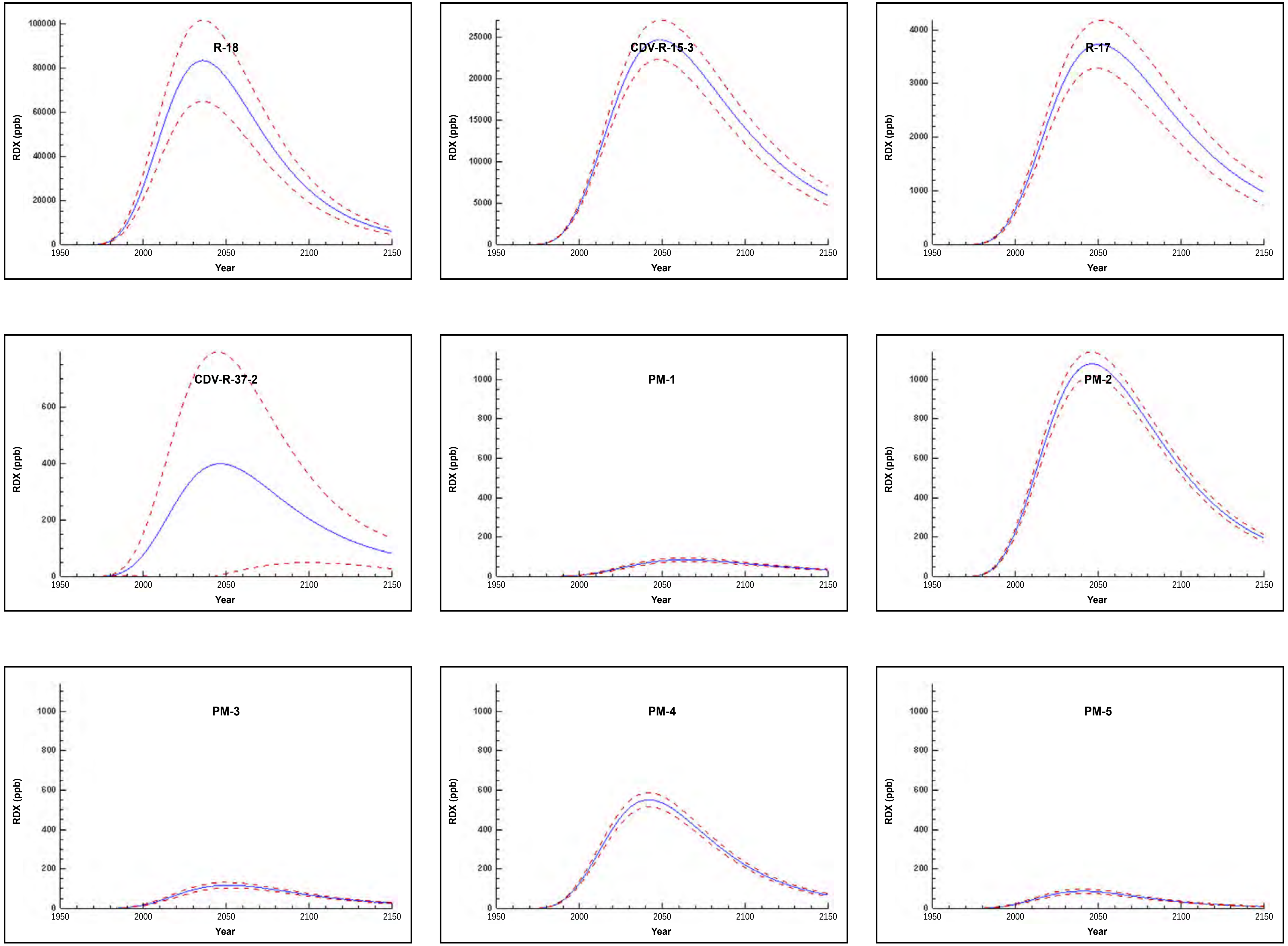
**LEGEND**

| | |
|---|---|
| — | Predicted concentration |
| - - - | 5th and 95th Percent confidence intervals |
| RDX | hexahydro-1,3,5-trinitro-1,3,5-triazine |
| ppb | Parts per billion |

**Figure C4-4.1-2**

**Model predicted RDX concentration breakthrough curves at various monitoring and water-supply wells. The contaminant source at the top of the regional aquifer is estimated assuming high infiltration rate and low RDX mass. The simulations are based on conceptual model B and no hydrolysis**



**LEGEND**

| | |
|---|---|
| ── | Predicted concentration |
| – – – | 5th and 95th Percent confidence intervals |
| RDX | hexahydro-1,3,5-trinitro-1,3,5-triazine |
| ppb | Parts per billion |

124992.06000000 B5

**Figure C4-4.2-1**

**Model predicted RDX concentration breakthrough curves at various monitoring and water-supply wells. The contaminant source at the top of the regional aquifer is estimated assuming low infiltration rate and high RDX mass. The simulations are based on conceptual model B and no hydrolysis**

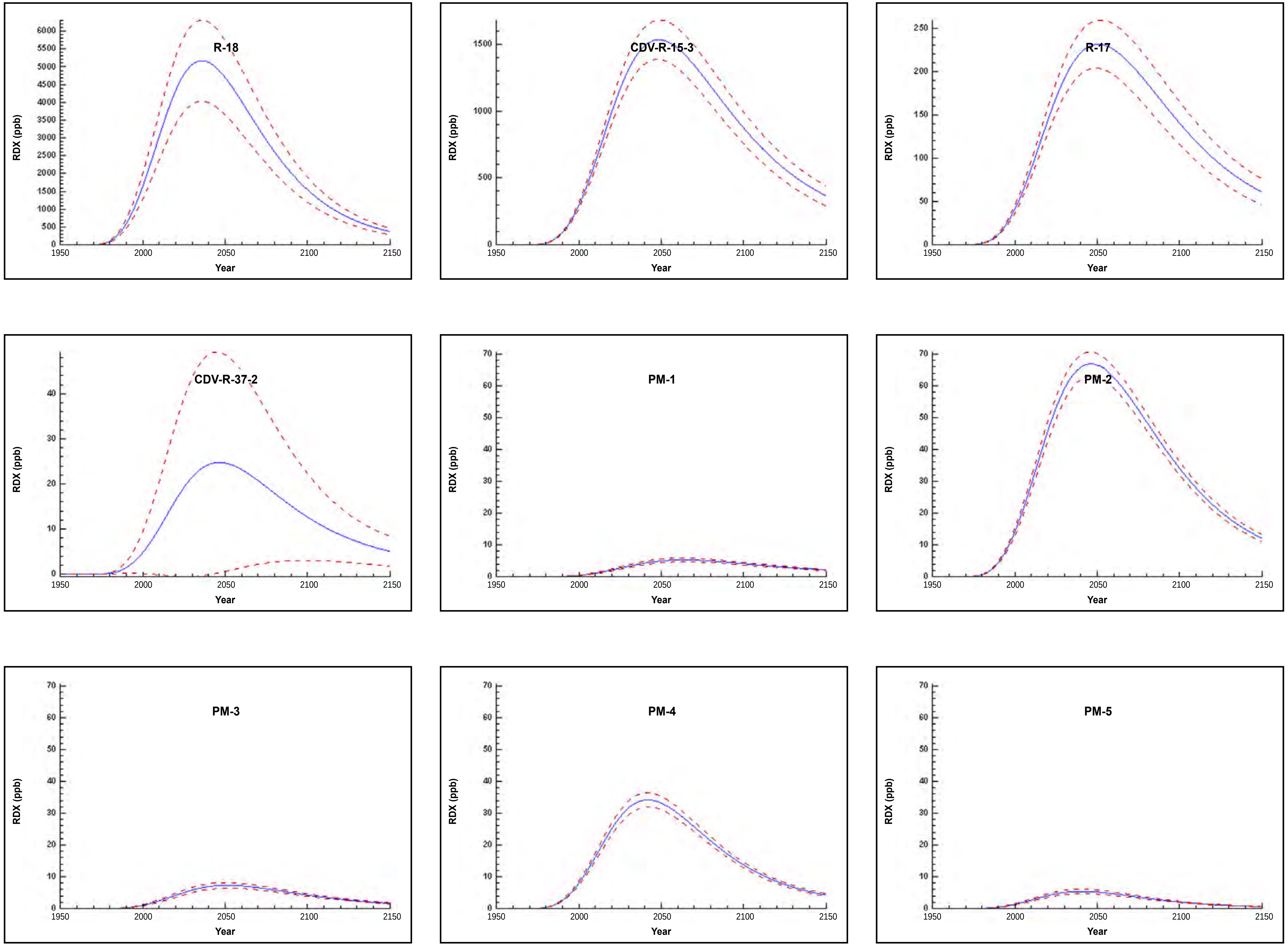
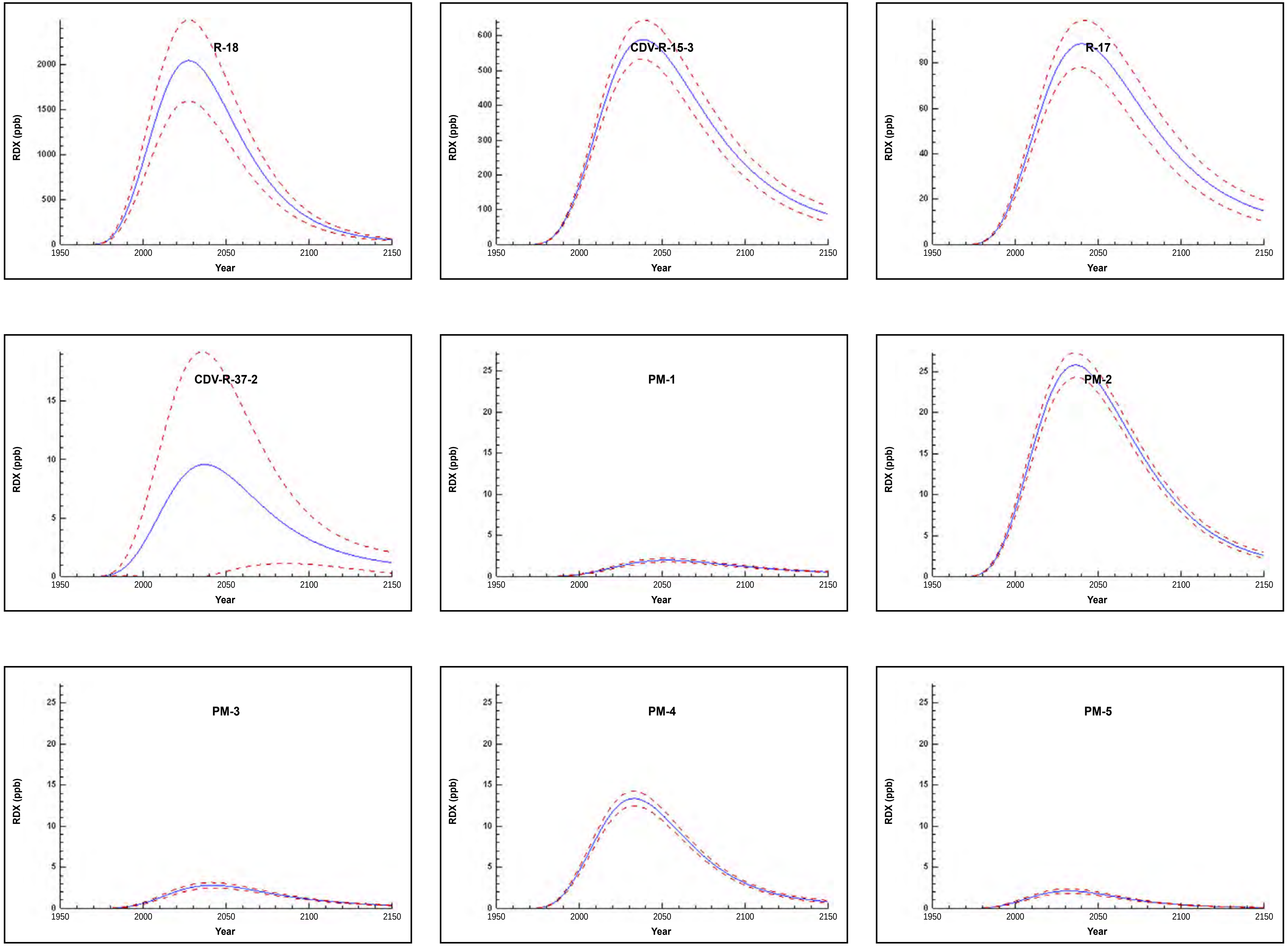


**Figure C4-4.2-2**

**Model predicted RDX concentration breakthrough curves at various monitoring and water-supply wells. The contaminant source at the top of the regional aquifer is estimated assuming low infiltration rate and low RDX mass. The simulations are based on conceptual model B and no hydrolysis**



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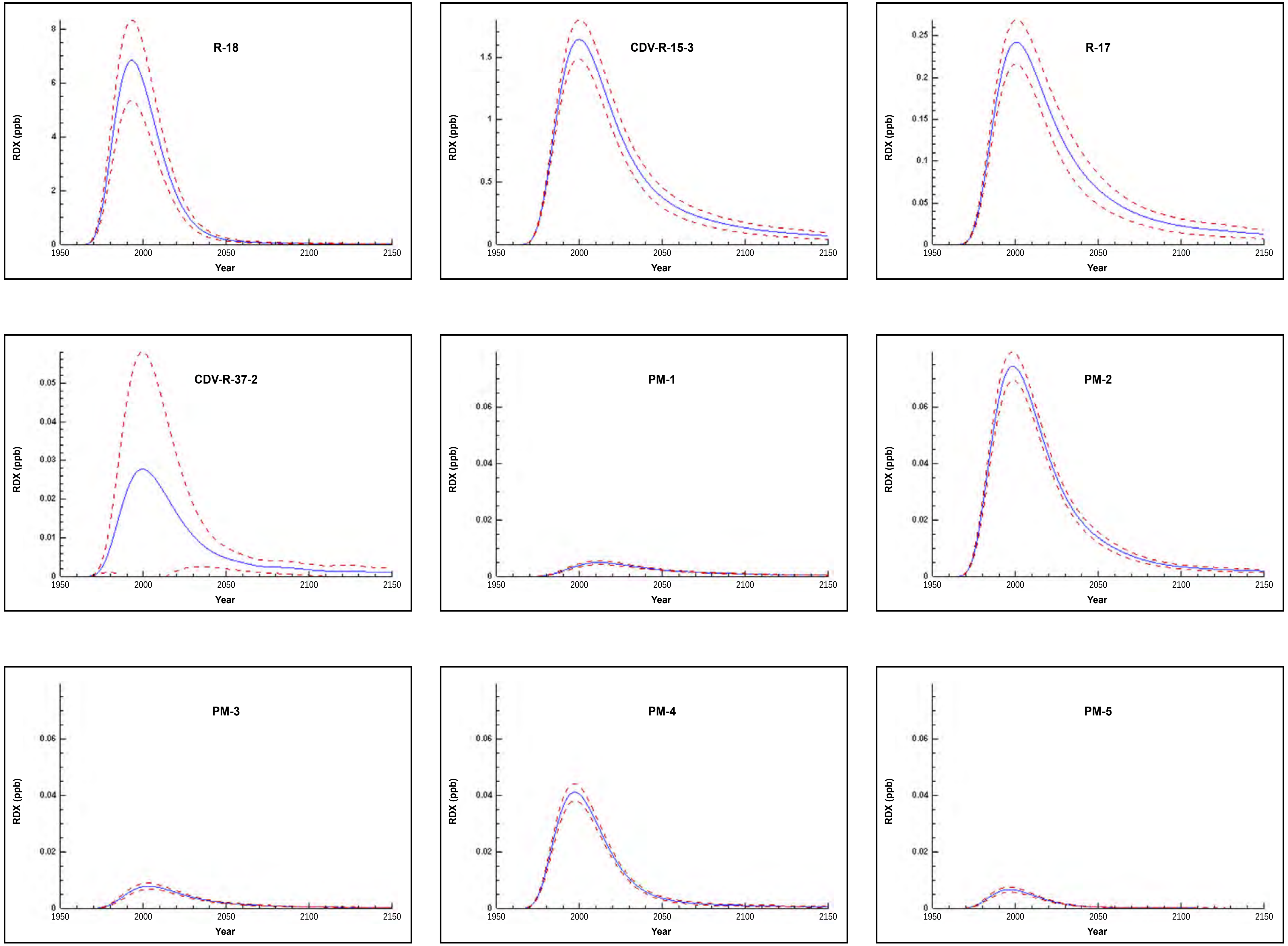
**LEGEND**

| | |
|---|---|
| — | Predicted concentration |
| – – – – | 5th and 95th Percent confidence intervals |
| RDX | hexahydro-1,3,5-trinitro-1,3,5-triazine |
| ppb | Parts per billion |

**Figure C4-4.2-3**

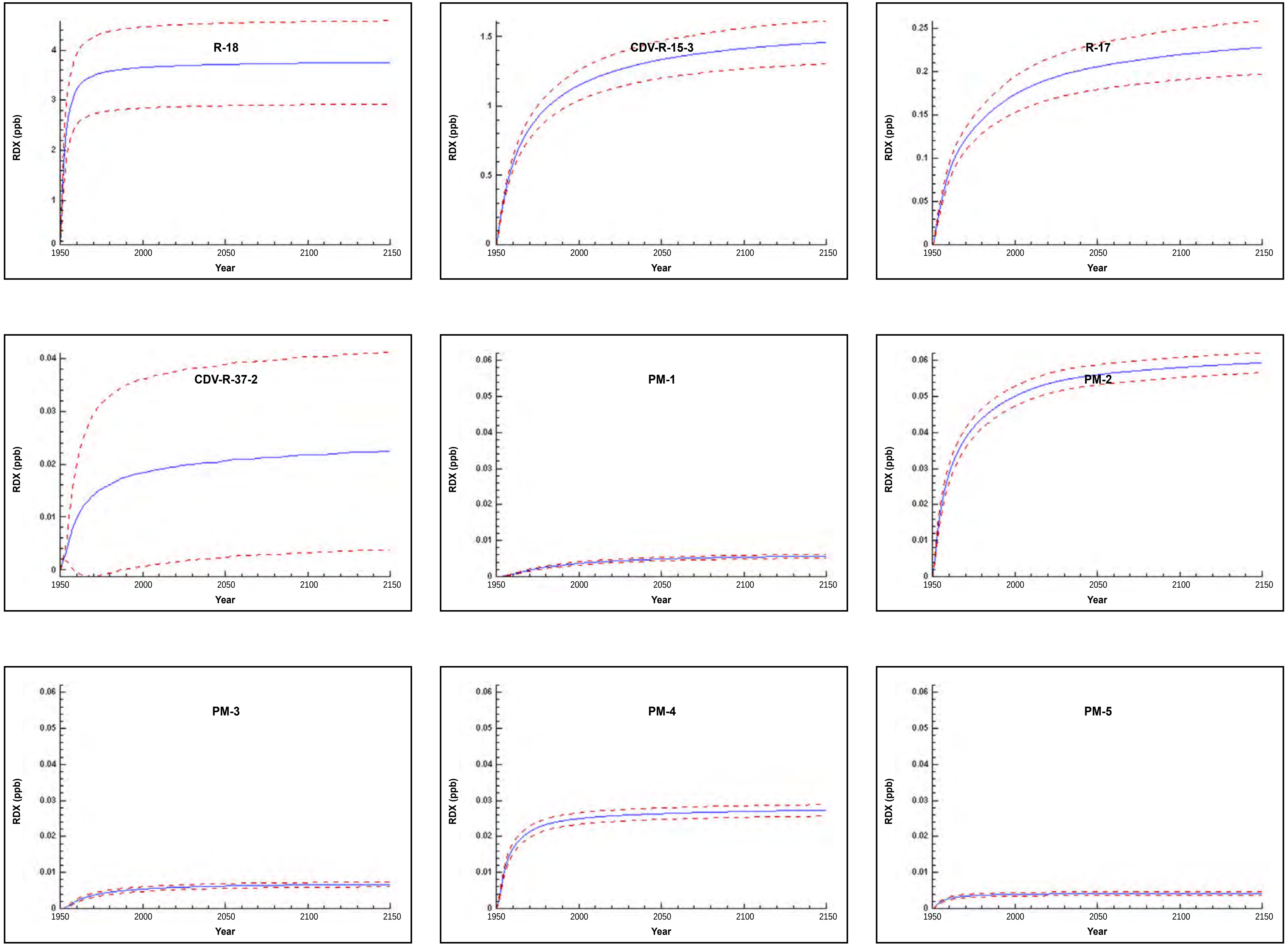
**Model predicted RDX concentration breakthrough curves at various monitoring and water-supply wells. The contaminant source at the top of the regional aquifer is estimated assuming low infiltration rate and low RDX mass. The simulations are based on conceptual model B and hydrolysis with a half-life of 58 years**



124992.06000000 B8

**Figure C4-4.2-4**

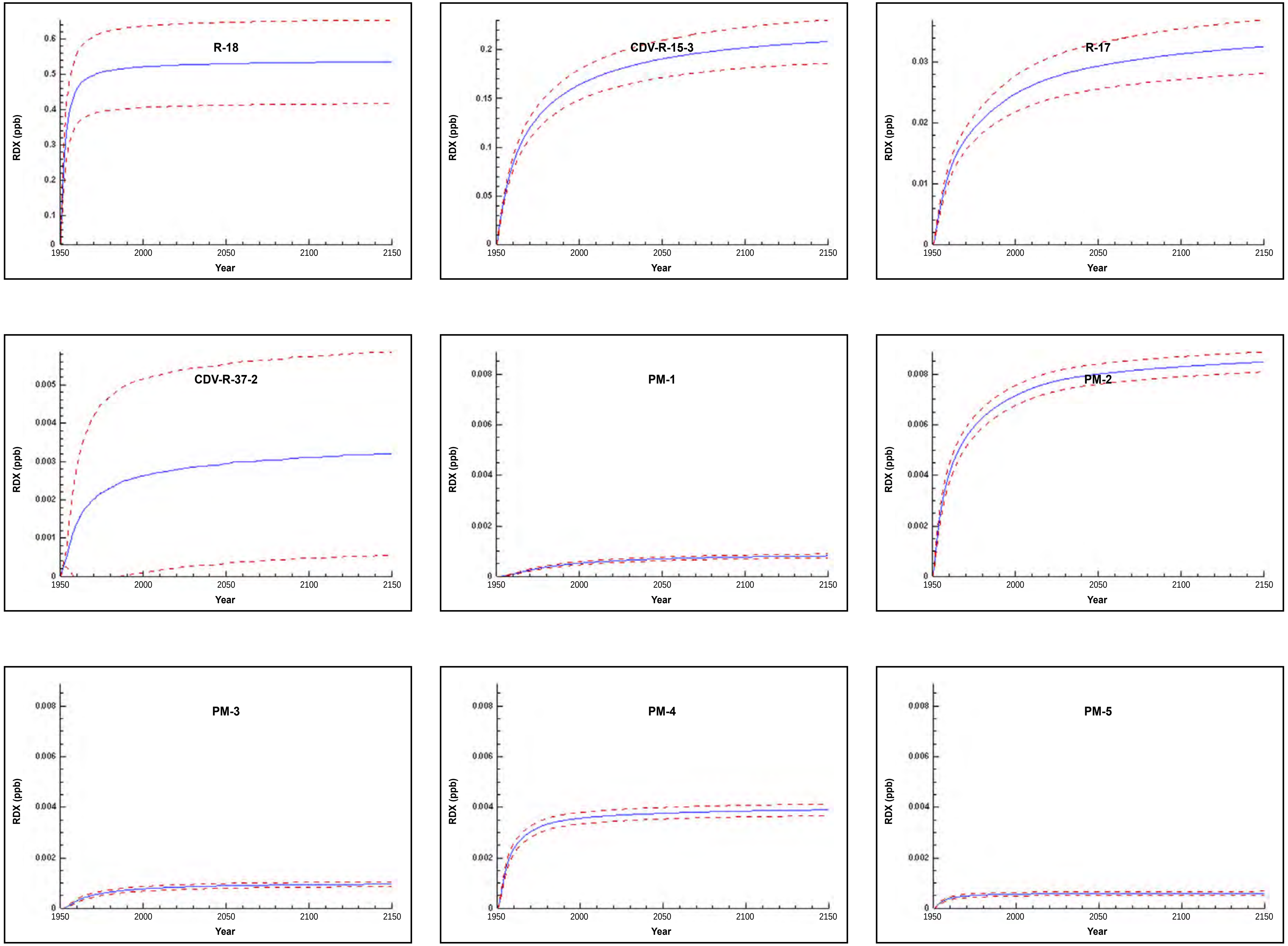
**Model predicted RDX concentration [ppb] breakthrough curves at various monitoring and water-supply wells. The contaminant source at the top of the regional aquifer is estimated assuming low infiltration rate and low RDX mass. The simulations are based on conceptual model B and hydrolysis with a half-life of 5.8 years**



124992.06000000 B9

**Figure C4-4.3-1**

**Model predicted RDX concentration breakthrough curves at various monitoring and water-supply wells. The contaminant source is estimated assuming a constant RDX concentration of 70 ppb at the top of the regional aquifer (the concentrations is consistent with the highest RDX concentration observed at R-25 Screen #4). The simulations are based on conceptual model B and no hydrolysis**



124992.06000000 B10

**LEGEND**

| | |
|---|---|
| ― | Predicted concentration |
| – – – | 5th and 95th Percent confidence intervals |
| RDX | hexahydro-1,3,5-trinitro-1,3,5-triazine |
| ppb | Parts per billion |

**Figure C4-4.3-2**

**Model predicted RDX concentration breakthrough curves at various monitoring and water-supply wells. The contaminant source is estimated assuming a constant RDX concentration of 10 ppb at the top of the regional aquifer (the concentrations is consistent with the highest RDX concentration observed at R-25 Screen #4). The simulations are based on conceptual model B and no hydrolysis**

## Table C4-2.1-1
## Summary of Screen Hydraulic Properties and Sampling Characteristics of Monitoring Wells Near TA-16

| Well | Screen | Geologic Unit | Hydraulic Conductivity | | | Screen Sampling Characteristics | Comment |
|---|---|---|---|---|---|---|---|
| | | | (ft/d) | (m/d) | ($m^2 \times 10^{-12}$) | | |
| CdV-R-15-3 | 4 | Puye | —* | — | — | No drawdown during low- flow sampling | Screen not tested for hydraulic properties |
| CdV-R-15-3 | 5 | Puye | 0.25 | 0.08 | 0.1 | No drawdown during low-flow sampling | None |
| CdV-R-15-3 | 6 | Puye | 0.10 | 0.03 | 0.035 | No drawdown during low-flow sampling | Screen exhibited very slow equilibration after installation of Westbay |
| CdV-R-37-2 | 2 | Tschicoma | — | — | — | No drawdown during low-flow sampling | Screen not tested for hydraulic properties |
| CdV-R-37-2 | 3 | Tschicoma | 7.0 | 2.1 | 2.5 | No drawdown during low-flow sampling | None |
| CdV-R-37-2 | 4 | Tschicoma | 11.4 | 3.5 | 4 | No drawdown during low-flow sampling | None |
| R-17 | 1 | Puye | 1.7 | 0.5 | 0.6 | Drawdown 3.7 ft or more during pumping | Pump rate about 2.5 gal./min |
| R-17 | 2 | Puye | 147.0 | 44 | 53 | Drawdown about 0.2 ft during pumping | Pump rate about 2.5 gal./min |
| R-18 | Single | Puye | 6.5 | 2 | 2.5 | Drawdown about 6 ft during sampling, quick recovery | None |
| R-19 | 3 | Puye | — | — | — | No drawdown during low- flow sampling | Sampling flow rates reported to be low |
| R-19 | 4 | Puye | — | — | — | No drawdown during low-flow sampling | Screen not tested for hydraulic properties |
| R-19 | 5 | Puye | — | — | — | No drawdown during low-flow sampling | Screen not tested for hydraulic properties |
| R-19 | 6 | Puye | 17.5 | 5.3 | 6.3 | No drawdown during low-flow sampling | None |
| R-19 | 7 | Puye | 19.6 | 5.9 | 7 | No drawdown during low-flow sampling | None |

### Table C4-2.1-1 (continued)

| Well | Screen | Geologic Unit | Hydraulic Conductivity | | | Screen Sampling Characteristics | Comment |
|---|---|---|---|---|---|---|---|
| | | | (ft/d) | (m/d) | ($m^2 \times 10^{-12}$) | | |
| R-25 | 4 | Puye | — | — | — | No drawdown during low-flow sampling | Probable intermediate zone |
| R-25 | 5 | Puye | — | — | — | Head falls significantly (>5 ft) during low flow sampling | Screen would not take slug-injection water; recovery after sampling slow |
| R-25 | 6 | Puye | — | — | — | No drawdown during low-flow sampling | Screen would not take slug-injection water |
| R-25 | 7 | Puye | — | — | — | No drawdown during low-flow sampling | Screen would not take slug-injection water |
| R-25 | 8 | Puye | — | — | — | Head falls 2 to 4 ft during low-flow sampling | Screen would not take slug-injection water; recovery after sampling slow |
| R-26 | 2 | Puye | 0.0022 | 0.0007 | 0.0009 | Cannot sample; bentonite plugs sampler | Screen accepted injection water very slowly |
| R-27 | Single | Puye | 25.0 | 7.6 | 8.5 | No data | Specific capacity about 4.1 gal./min/ft |

* No data.

## Table C4-3.3-1
## Spatial Representation of Hydrostratigraphic Units Represented in the Three Models

| Unit | Short Name | "Site" Model 244,048 Nodes | | "Thick Pancake" Model 980,553 Nodes | | "Thin Pancake" Model 693,948 Nodes | |
|---|---|---|---|---|---|---|---|
| | | Number of Nodes | Percentage in the Model | Number of Nodes | Percentage in the Model | Number of Nodes | Percentage in the Model |
| Bandelier Tuff | Qb | 0 | 0 | 785 | 0.1% | —* | —* |
| Cerro Toledo Interval | Qct | 0 | 0 | 120 | 0% | —* | —* |
| Tschicoma | Tt | 37130 | 15.2% | 51187 | 5.2% | 73049 | 10.5% |
| Keres Group | Tk | 0 | 0 | 60723 | 6.2% | 2865 | 0.4% |
| Cerros del Rio Basalt | Tb4 | 87 | 0 | 12157 | 1.2% | 97099 | 14.0% |
| Bayo Canyon Basalt | Tb2 | 1003 | 0.4% | 22948 | 2.3% | 24007 | 3.5% |
| Older Basalts | Tb1 | 0 | 0 | 13526 | 1.4% | 0 | 0 |
| Totavi Lentil | Tpt | 150 | 0.1% | 7661 | 0.8% | 22543 | 3.2% |
| Pumiceous Puye | Tpp | 15111 | 6.2% | 13395 | 1.4% | 29116 | 4.2% |
| Puye Fanglomerate | Tpf | 40754 | 16.7% | 45270 | 4.6% | 152808 | 22.0% |
| Santa Fe Fanglomerate | Tf | 22282 | 9.1% | 192275 | 19.6% | 78269 | 11.3% |
| Santa Fe Silt and Sands | Ts | 127174 | 52.1% | 560566 | 57.2% | 214192 | 30.9% |
| Older Sedimentary | Pal | 357 | 0.2% | 0 | 0 | 0 | 0 |

*— = Geologic units have been combined. Galisteo is combined with Santa Fe Silt and Sands. Bandelier Tuff and Cerro Toledo members are not expected at these model elevations and are combined with Tschicoma in the thin pancake model.

## Table C4-3.5-1
## Statistical Properties of Hydrogeologic Parameters Related to Various Hydrostratigraphic Units Represented in the Model

| Unit | Name | Permeability | | | Porosity | | |
|---|---|---|---|---|---|---|---|
| | | Distribution Type | Mean | Standard Deviation | Distribution Type | Minimum | Maximum |
| Tschicoma | Tt | Log normal | -10.5 | 0.50 | Discrete | 1.E-05 | 1.E-02 |
| Keres Group | Tk | Log normal | -10.5 | 0.50 | Discrete | 1.E-05 | 1.E-02 |
| Cerros del Rio Basalt | Tb4 | Log normal | -12.0 | 1.00 | Discrete | 1.E-05 | 1.E-01 |
| Bayo Canyon Basalt | Tb2 | Log normal | -12.0 | 1.00 | Discrete | 1.E-05 | 1.E-01 |
| Totavi Lentil | Tpt | Log normal | -11.0 | 0.33 | Discrete | 1.E-02 | 2.E-01 |
| Pumiceous Puye | Tpp | Log normal | -12.5 | 0.50 | Discrete | 1.E-02 | 2.E-01 |
| Puye Fanglomerate | Tpf | Log normal | -12.5 | 0.50 | Discrete | 1.E-02 | 2.E-01 |
| Santa Fe Fanglomerate | Tf | Log normal | -12.5 | 0.50 | Discrete | 1.E-02 | 2.E-01 |
| Santa Fe Silt and Sands | Ts | Log normal | -12.5 | 0.50 | Discrete | 1.E-02 | 2.E-01 |

## Table C4-3.5-2
## Statistical Properties of Dispersivities

| | Distribution Type | Minimum | Maximum |
|---|---|---|---|
| Longitudinal dispersivity | Uniform | 50 | 300 |
| Transverse dispersivity | Uniform | 5 | 30 |

## Table C4-4.0-1
## Summary of the Source Term Scenarios for the Regional Aquifer Model

| Source Term/ Scenario | RDX Mass in Vadose Zone (kg) | Groundwater Discharge Rate to Regional Aquifer ($m^3$/yr) | Type of RDX Discharge to Regional Aquifer | Maximum RDX Discharge Rate to Regional Aquifer (kg/yr) | Hydrolysis Half-Life (years) | Constant Concentration Source in the Regional Aquifer (ppb) |
|---|---|---|---|---|---|---|
| 1/1 | 64,000 | 753,721 | transient | 6,246 | na* | na |
| 1/2 | 4000 | 753,721 | transient | 388 | na | na |
| 1/3 | 64,000 | 40,755 | transient | 823 | na | na |
| 1/4 | 4000 | 40,755 | transient | 51 | na | na |
| 1/5 | 4000 | 40,755 | transient | 51 | 58 | na |
| 1/6 | 4000 | 40,755 | transient | 51 | 5.8 | na |
| 2/7 | na | na | steady | 0.035 | na | ~70 |
| 2/8 | na | na | steady | 0.005 | na | ~10 |

*na = Not available.

# Appendix D

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*Public Involvement Plan*

## D-1.0 PURPOSE OF PUBLIC INVOLVEMENT

As described in Section Q, Task II, Section D of Module VIII of Los Alamos National Laboratory's (LANL's, or the Laboratory's) Hazardous Waste Facility permit, the Laboratory is required to incorporate community relations planning into the corrective measures evaluation (CME) process. Environmental Programs (EP) Directorate has developed an outreach program to provide the public timely and complete access to information and the decision-making process.

This public involvement plan identifies specific activities that the Laboratory will undertake to disseminate information and facilitate public involvement during the CME project at Consolidated Unit 16-021(c)-99. This plan is considered a working document; therefore, some of the processes or schedule may change throughout the duration of the project. The objectives of the plan are to

- provide the public/stakeholders with timely and objective information to assist them in understanding the potential risks associated with the site, the proposed remediation alternatives, and solutions;
- provide interpretations of data;
- ensure that the public/stakeholders concerns are understood and considered in the decision-making process;
- provide the surrounding communities with public access to program technical staff; and
- increase EP contact with the public/stakeholders in ways that encourage interaction and involvement in the corrective action process.

The EP Directorate is accountable to

- anyone who resides in the communities surrounding the Laboratory or has an interest in the activities of the Resource Conservation and Recovery Act (RCRA) corrective action process at the Laboratory;
- organizations representing or protecting specific groups or interests in our region; and
- public agencies including local, state, federal, and tribal governments.

## D-2.0 PROJECT DESCRIPTION

Technical Area (TA) 16 was established during World War II for the development of explosive formulations, production and machining of explosive charges, and the assembly and testing of explosive components for the U.S. nuclear weapons program. Present-day use of this site is essentially unchanged, although facilities have been upgraded and expanded as explosive and manufacturing technologies have advanced.

The TA-16-260 facility is a high explosives (HE)-machining building that processes large quantities of HE. Machine turnings and HE wastewater were routed as waste to 13 sumps associated with the building. Historically, discharge from the sumps was routed to an outfall that was permitted to operate by the U.S. Environmental Protection Agency (EPA) as EPA 05A056 under the Laboratory's National Pollution Discharge Elimination System (NPDES) permit. The last NPDES-permitting effort for this outfall occurred in 1994. The NPDES outfall was deactivated in November 1996, and it was officially removed from the Laboratory's NPDES permit by EPA in January 1998.

The outfall, drainage channel below the outfall, underlying alluvium, and vadose zone are contaminated with chemicals of potential concern, primarily HE wastes and barium. The combined areas of the outfall, pond area, and drainage are designated as Consolidated Unit 16-021(c)-99. Potential exposure pathways to human and ecological receptors include ingestion of groundwater and surface water, soil and sediment inhalation of suspended particulate matter, adsorption through dermal contact with affected soils or water, and ingestion related to food chain effects.

TA-16 is located in the southwest corner of the Laboratory. It covers 2410 acres, or 3.8 $mi^2$. The land is a portion of what was acquired by the U.S. Department of Army for the Manhattan Project in 1943. TA-16 is bordered by Bandelier National Monument along State Highway 4 to the south and by the Santa Fe National Forest along State Highway 501 to the west. To the north and east, it is bordered by TA-08, -09, -14, -15, and -49. TA-16 is fenced and posted along State Highway 4. Water Canyon, a 200-ft-deep ravine with steep walls, separates State Highway 4 from active sites at TA-16. Cañon de Valle forms the northern border of TA-16.

The Laboratory has implemented a phased corrective action program for Consolidated Unit 16-021(c)-99 in accordance with the requirements if the Compliance Order on Consent. The corrective action process, including those phases currently being implemented, include the following:

- RCRA facility assessment (RFA)
- Phase I RCRA facility investigation (RFI)
- RFI Phase II
- Interim measure of source removal
- RFI Phase III
- Corrective measures study for shallow soil, spring water, surface water, and groundwater
- Corrective measure implementation shallow soil, spring water, surface water, and groundwater
- Investigation report for intermediate and regional groundwater
- CME for intermediate and regional groundwater

## D-3.0 TARGET AUDIENCE

For the purposes of this plan, the public includes all individuals, organizations, or public agencies potentially affected by the CME phase of the project. Surrounding communities potentially affected by the CME include Los Alamos County, San Ildefonso Pueblo, Santa Clara Pueblo, Cochiti Pueblo, Santa Fe, Española, and smaller communities.

## D-4.0 PROJECT OBJECTIVES

The purpose of the CME is to evaluate the alternatives for remediation and to propose corrective measures, media cleanup standards, and a long-term monitoring program for Consolidated Unit 16-021(c)-99 and nearby Cañon de Valle and Martin Spring Canyon.

## D-5.0 PROPOSED ACTIVITIES, PURPOSE, AND DATE

| Activity | Purpose | Projected Date |
|---|---|---|
| Mailer to Laboratory's mailing list, composed of individuals, organizations, and government and tribal officials in northern New Mexico | Introduce EP Directorate, the Consolidated Unit 16-021(c)-99 team, the corrective action process, and the current RFI/CME phases of the project. Notify public of planned open house. | First conducted in April 2008 and held every April at a time to be determined. |
| Information sheet to be posted online and made available in public reading room | Highlight the history and current activities at Consolidated Unit-16-021(c)-99 site. Provide update of CME status. | First conducted in April 2008 and held every April at a time to be determined. |
| Newspaper notice informing the public about Consolidated Unit 16-021(c)-99 activities | Placed in the *Albuquerque Journal North*, Santa Fe *New Mexican*, *Rio Grand Sun*, and the *Los Alamos Monitor* to advise the public on general project activities. Notify public of planned open house. | First conducted in April 2008 and held every April at a time to be determined. |
| Open house hosted at Los Alamos Area Office or elsewhere | Provide informal overview through posters, handouts, and provide for interaction/questions and answers with EP and Environmental Remediation Support Services (ERSS) project Directorate staff. | First conducted in April 2008 and held every April at a time to be determined. |
| Web Site at http://erproject.lanl.gov/ | Access to all RFI and CME documentation on the EP-ERSS virtual library website and available at the Laboratory's public reading room. Documents posted will include the CME plan and the CME report. | Ongoing |
| Tour of Cañon de Valle | Tour to view site setting, site habitat, and other site conditions. | To be determined by interest shown at the public meetings |
| Public comments to be maintained and made available online | Comments will be solicited throughout the project via all mechanisms listed above. The EP-ERSS project staff will identify major public concerns. | Ongoing |

## D-6.0 KEY MESSAGES

The CME process proposes preferred alternatives for site remediation. The choice of a preferred alternative involved criteria such as effectiveness, reliability, safety, ability to meet the remediation objectives, institutional constraints, and cost. At this site, additional important factors for consideration include the presence of wetlands and Mexican spotted owl habitat in Cañon de Valle. The proposed preferred alternatives are the result of a balanced approach that considers these criteria and factors.

## D-7.0 KEY CONTACTS

| Name | Organization | Phone | Email | Role |
|---|---|---|---|---|
| Donald Hickmott | LANL | 505-667-8753 | dhickmott@lanl.gov | LANL Lead |
| Lance Woodworth | Department of Energy (DOE) | 505-665-5820 | lwoodworth@doeal.gov | DOE Project Lead |
| Lorrie Bonds-Lopez | LANL | 505-667-0216 | lorrie@lanl.gov | EP Outreach/Public Involvement Lead |
| John McCann | LANL | 505-665-1091 | jmccann@lanl.gov | LANL EP Project Lead |
| David Gregory | DOE | 505-667-5808 | dgregory@lanl.gov | DOE EP Project Lead |

# Appendix E

*Schedule*

| Activity | Schedule |
|---|---|
| Corrective measures evaluation(CME) report | August 31, 2007 |
| Draft statement of basis (SB) issued by New Mexico Environment Department (NMED) | 90 d after submittal of CME report |
| Public comment period | 60 d |
| Final SB issued by NMED | April 21, 2008 |
| Submit corrective measures implementation (CMI) plan to NMED | November 2008 |
| NMED approves CMI plan | 120 d after submittal of CMI plan to NMED |
| CMI implementation | April 2009 |

# Appendix F

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*Los Alamos National Laboratory Current Sitewide Groundwater Monitoring Plan*
*(see enclosed CD)*

# Appendix G

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*Previous Reports*
*(see enclosed CD)*