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Corrective Measures Evaluation Work Plan Technical Area V Groundwater

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Corrective Measures Evaluation Work Plan Technical Area-V Groundwater

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Abstract

This document, which is prepared as directed by the Compliance Order on Consent (COOC) issued by the New Mexico Environment Department, identifies and outlines a process to evaluate remedial alternatives to identify a corrective measure for the Sandia National Laboratories/New Mexico Technical Area (TA)-V Groundwater. The COOC provides guidance for implementation of a Corrective Measures Evaluation (CME) for the TA-V Groundwater. This Work Plan documents an initial screening of remedial technologies and presents a list of possible remedial alternatives for those technologies that passed the screening. This Work Plan outlines the methods for evaluating these remedial alternatives and describes possible site-specific evaluation activities necessary to estimate remedy effectiveness and cost. These methods will be reported in the CME Report. This Work Plan outlines the CME Report, including key components and a description of the corrective measures process.

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Acronyms

ARD	anaerobic reductive dechlorination
ARG	ancestral Rio Grande
CME	Corrective Measures Evaluation
COA	City of Albuquerque
COC	contaminant of concern
COOC	Compliance Order on Consent
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
DOE-NM	U.S. Department of Energy New Mexico Office
EPA	Environmental Protection Agency
ER	Environmental Restoration
ESTCP	Environmental Security Technology Certification Program
FDA	Food and Drug Administration
FY	fiscal year
GWRTAC	Ground-Water Remediation Technologies Analysis Center
ISB	in situ bioremediation
ISCO	in situ chemical oxidation
KAFB	Kirtland Air Force Base
LNAPL	light non-aqueous phase liquid
LTES	long-term environmental stewardship
LWDS	Liquid Waste Disposal System
MCL	maximum contaminant level
MMO	methane monooxygenase
MNA	monitored natural attenuation
MWL	Mixed Waste Landfill
NAPL	non-aqueous phase liquid
NEPA	National Environmental Policy Act
NFA	No Further Action
NMED	New Mexico Environment Department
NNSA	National Nuclear Security Administration
PCB	polychlorinated biphenol

PCE	tetrachloroethene
PMP	Project Management Plan
POTW	publicly owned treatment works
PRB	permeable reactive barrier
RCRA	Resource Conservation and Recovery Act
RSI	Request for Supplemental Information
SERF	Sandia Engineering Reactor Facility
SNL/NM	Sandia National Laboratories/New Mexico
SVOC	semivolatile organic compound
SWMU	Solid Waste Management Unit
TA	technical area
TCE	trichloroethene
VC	vinyl chloride
VOC	volatile organic compound
WQCC	Water Quality Control Commission

1.0 INTRODUCTION

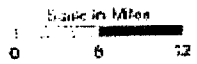
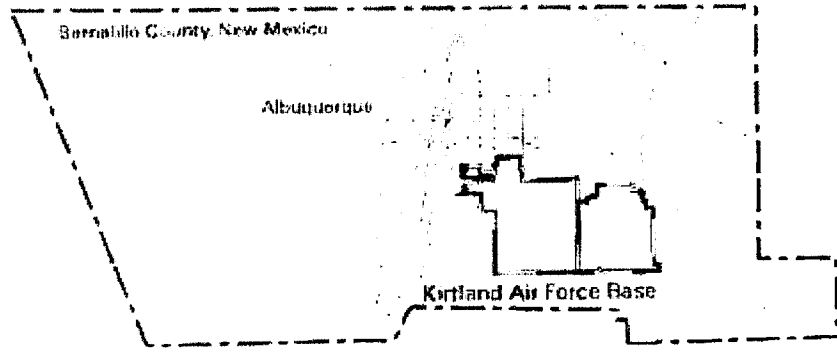
Sandia National Laboratories/New Mexico (SNL/NM), located on Kirtland Air Force Base (KAFB), south of Albuquerque, New Mexico (Figure 1-1), are owned and operated by the U.S. Department of Energy (DOE) and are co-operated by Sandia Corporation. SNL/NM operates five technical areas (TAs) (i.e., TA-I, TA-II, TA-III, TA-IV, and TA-V). TA-V is a secured 35-acre research and testing area located in the northeastern corner of TA-III at SNL/NM. TA-V has been operating since the 1960s. The facility conducts research and development of advanced nuclear reactors, simulation sources, reactor safety, energy-related programs, and nuclear weapons systems.

The SNL/NM Environmental Restoration (ER) Project has reported concentrations of trichloroethene (TCE) exceeding the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) in groundwater in one TA-V monitoring well since 1993. Since this initial discovery of TCE in groundwater, the ER Project has voluntarily undertaken various activities to determine the nature and extent of groundwater contamination, particularly to identify potential sources for this contamination (SNL/NM 1999).

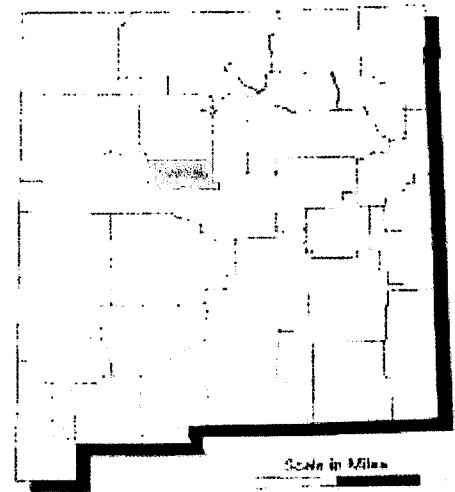
This Work Plan has been developed under the direction of the Compliance Order on Consent (COOC) issued by the New Mexico Environment Department (NMED 2003). The COOC identifies TA-V as an area of groundwater contamination requiring completion of a Corrective Measures Evaluation (CME) (see Section VI, "Facility Investigation" of the COOC). This CME Work Plan was completed to comply with requirements set forth in the COOC and with the guidance of the Resource Conservation and Recovery Act (RCRA) Corrective Action Plan (EPA 1994).

1.1 Purpose and Organization

The purpose of this document is to identify and outline a process to evaluate remedial alternatives for implementation at TA-V at SNL/NM. Remedial alternatives consist of a strategy for implementing one or more technologies at TA-V. The CME will be conducted to determine a preferred remedy that most effectively meets the project goals and objectives for cleanup within the regulatory framework and will be the recommended corrective measure. This evaluation will examine remedial alternatives against the known physical characteristics of the contaminant plume and the corrective measure cleanup goals and objectives outlined in this document. The outcome of the evaluation will be a recommendation for a preferred remedy to be applied as the corrective measure for long-term operations.



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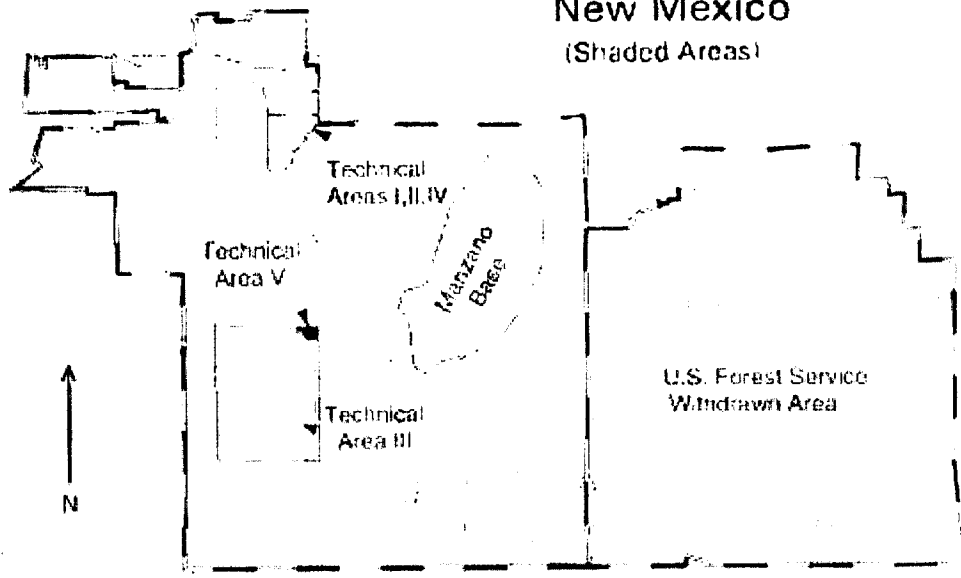


Figure 1-1. Location map of SNL/NM and TA-V.

This document is organized according to guidance presented in the RCRA Corrective Action Plan (EPA 1994). Table 1-1 shows a crosswalk of the sections specified by the guidance and the sections of this document. An important aspect of meeting the requirements of the COOC, and an objective of the CME, is evaluation of existing groundwater and subsurface data and compilation of that information into a Current Conceptual Model to accurately reflect the nature and extent of the groundwater plume. The “Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Technical Area V” (SNL/NM 2004a), referred to in this document as the TA-V Current Conceptual Model, is summarized in Section 1.2. Section 2 presents the cleanup goals and objectives for TA-V groundwater remediation. Section 3 identifies, describes, and screens potential technologies considered for implementation as a TA-V corrective measure. Section 4 presents remedial alternatives to be evaluated and outlines the evaluation approach, while Section 5 details the remedial alternative evaluation plan. Section 6 forecasts the content of the CME Report, and Section 7 presents the project management plan for the TA-V CME.

Table 1-1. CME Work Plan crosswalk table.

RCRA CMS Guidance Section (EPA 1994)	TA-V CME Work Plan (Section)
1.0 Purpose	1.0 Introduction
2.0 Cleanup Goals, Objectives and Requirements	2.0 Cleanup Goals, Objectives and Requirements
3.0 Technology Identification and Development	3.0 Technology Identification and Development
4.0 Technology Evaluation Approach	4.0 Remedial Alternative Evaluation Approach
5.0 Technology Evaluation Plan	5.0 Remedial Alternative Evaluation Plan
6.0 CMS Report	6.0 CME Report
7.0 Project Management Plan	7.0 Project Management Plan

1.2 Site Description

Contaminants of concern (COCs) in groundwater at TA-V have been identified based on detections above MCLs in samples collected from monitoring wells. These COCs consist of tetrachloroethene (PCE), TCE, and nitrate. Table 1-2 identifies the COCs for this project and includes the maximum concentrations and MCLs for each COC. Unique features of TA-V include low concentrations of COCs in a very deep aquifer. The extent of contamination is estimated to be 1,200 ft long and approximately 600 ft wide. Figure 1-2 illustrates the location of the TCE plume within the TA-V area.

Table 1-2. COCs in TA-V groundwater.

Contaminant	Maximum Concentrations	Federal Drinking Water Standard (MCL) ^a
<i>VOLATILE ORGANIC COMPOUNDS</i>		
trichloroethene (TCE)	23 - 26 µg/L ^b	5 µg/L
tetrachloroethene (PCE)	5.15 - 7.5 µg/L ^c	5 µg/L
<i>INORGANIC CHEMICAL</i>		
Nitrate (as nitrogen)	13 - 19 mg/L ^d	10 mg/L

µg/L = micrograms per liter
mg/L = milligrams per liter

- 40 CFR 141.61, "Maximum Contaminant Levels for Organic Contaminants"
- Results reported for sampling event on November 13, 2000 at LWDS-MW1.
- PCE was reported above MCLs at TAV-MW7 for three sampling events: November 12, 2001 (5.2 µg/L), February 26, 2002 (7.5 µg/L), and August 13, 2002 (5.15 µg/L).
- Highest reported concentrations at wells: AVN-1, 13 mg/L on May 14, 2001; AVN-2, 16 mg/L on October 27, 1999; TAV-MW5, 13 mg/L on August 18, 1999; and LWDS-MW1, 19 mg/L on November 13 2000 and February 16, 2001.

TA-V lies within the Albuquerque Basin of the Rio Grande Rift in north central New Mexico. The Albuquerque Basin is filled with sedimentary deposits of the alluvial fan lithofacies and ancestral Rio Grande (ARG) lithofacies of the Santa Fe Group. The vadose zone at TA-V is approximately 500 ft thick and consists of heterogeneous, lenticular, coarse- to fine-grained deposits. The underlying aquifer at TA-V consists of fine-grained, clay-rich, alluvial-fan sediments. Groundwater in the vicinity of TA-V flows generally from east to west. To the west of TA-V, groundwater flow paths turn to the north in response to pumpage from large municipal well fields north of KAFB.

Since the initial discovery of TCE in the well KAFB-10 (non-potable production well), numerous characterization activities have been conducted. The results of these characterization activities are summarized below. Table 1-3 provides a list of documents used to support the summary of investigations. The following conclusions about the contaminant source term, vadose-zone transport, and contaminant distribution and transport in the aquifer are drawn from the previous investigations.

1.2.1 Contaminant Source Term

Wastewater disposal facilities at the TA-V are believed to be the primary sources for low levels of TCE contamination in the groundwater in this area. These facilities include drainfields and surface impoundments of the Liquid Waste Disposal System (LWDS) and TA-V seepage pits. The LWDS consists of a set of three holding tanks and associated pumping system (Solid Waste Management Unit [SWMU] 52), a drainfield (SWMU 5), and two surface impoundments (SWMU 4). The LWDS was used for the disposal of reactor cooling process water from the Sandia Engineering Reactor Facility (SERF) and liquid wastes from other reactor support facilities in TA-V. The LWDS drainfield was operated from 1963 until it reportedly collapsed in 1967, receiving a total volume of 6,486,000 gal of wastewater (SNL/NM 1999).

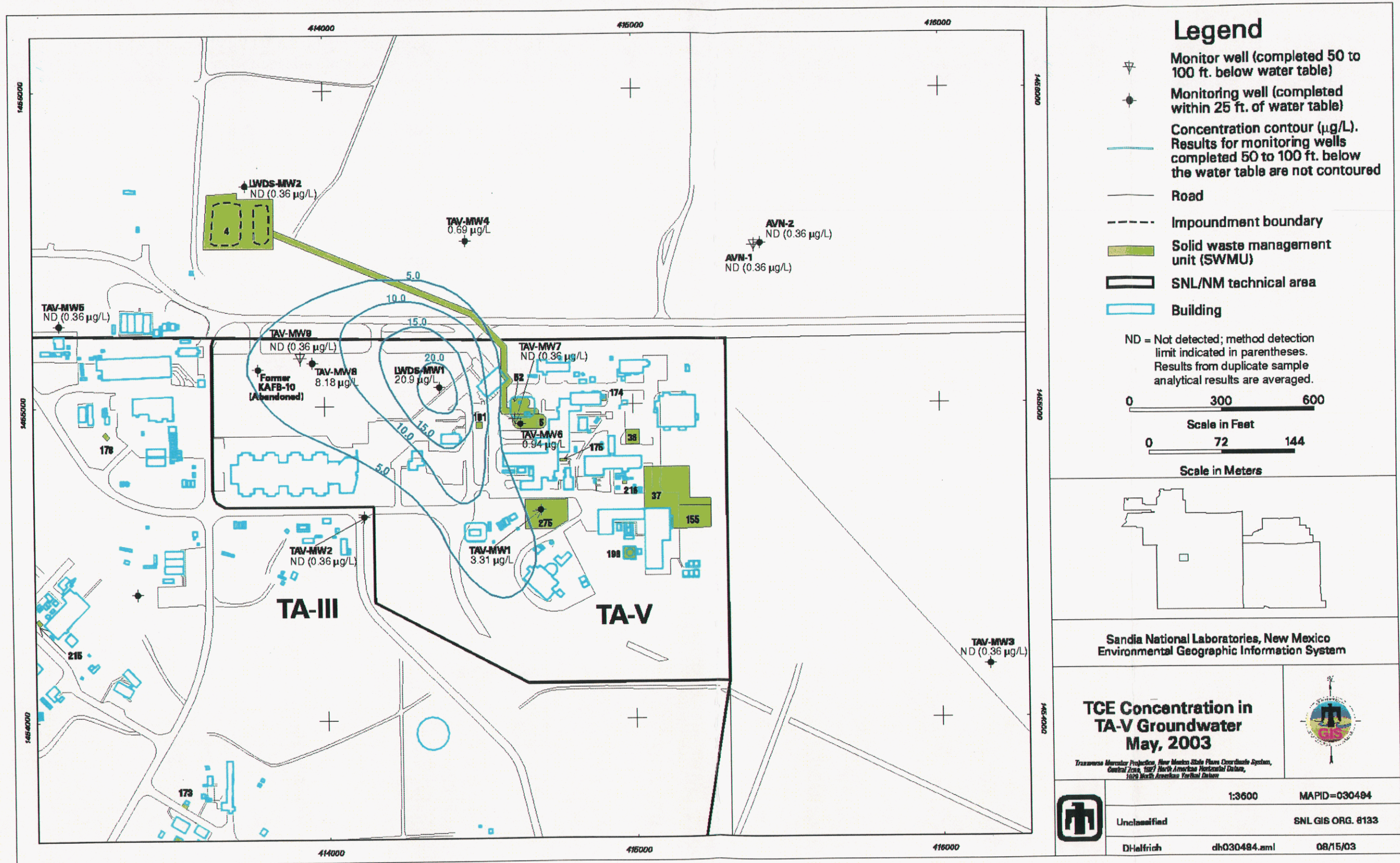


Figure 1-2. Location of the TCE plume within the TA-V area.

Table 1-3. Key documents for the TA-V LWDS groundwater plume characterization.

Date	Title	Reference
1993	<i>Sandia National Laboratories/New Mexico. Site-Wide Hydrogeologic Characterization Project Calendar Year 1992 Annual Report</i>	SNL/NM 1993
1994	<i>Sandia National Laboratories/New Mexico. Site-Wide Hydrogeologic Characterization Project Calendar Year 1993 Annual Report</i>	SNL/NM 1994
1995	<i>Sandia National Laboratories/New Mexico. Site-Wide Hydrogeologic Characterization Project Calendar Year 1994 Annual Report</i>	SNL/NM 1995
1996	<i>Sandia National Laboratories/New Mexico. Site-Wide Hydrogeologic Characterization Project Calendar Year 1995 Annual Report</i>	SNL/NM 1996
1998	<i>Sandia National Laboratories/New Mexico. Site-Wide Hydrogeologic Characterization Project Calendar Year 1995 Annual Report</i>	SNL/NM 1998
1999	<i>SNL/NM Summary Report of Groundwater Investigations at Technical Area V, Operable Units 1306 and 1307</i>	SNL/NM 1999
2001	<i>SNL/NM Environmental Restoration Project Long-Term Monitoring Strategy for Groundwater</i>	SNL/NM 2001a
2001	<i>SNL/NM TA-V Groundwater Investigation Fiscal Years 1999 and 2000</i>	SNL/NM 2001b
2001	<i>SNL/NM Summary of Monitoring Well Drilling Activities, TA-V Groundwater Investigation</i>	SNL/NM 2001c
2002	<i>Groundwater Resources of the Middle Rio Grande Basin</i>	Bartolino & Cole 2002
2003	<i>Geologic Investigation: An Update of Subsurface Geology on Kirtland Air Force Base, New Mexico</i>	Van Hart 2003

Wastewater disposal history at TA-V includes disposal in the TA-V seepage pits (SWMU 275) from the early 1960s until 1992 (30 to 50 million gal of water), LWDS drainfield disposal from 1963-1967 (6.5 million gal of water), and disposal to the unlined LWDS impoundments from 1967-1972 (12 million gal of water). After 1992, treated wastewater was disposed to the City of Albuquerque (COA) sewage system. Other potential sources of local recharge may have included leakage from wastewater transfer piping.

Industrial solvents, including TCE, used in conjunction with operations and activities at TA-V machine shops and chemistry laboratories were contained in wastewater disposed to the TA-V seepage pits and to the LWDS drainfield and impoundments. The amounts of these solvents are not documented. Solvent disposal was eliminated in the early 1980s as guidance was provided concerning appropriate use and disposal of solvents. Based on distribution of TCE in groundwater, the most plausible sources of disposal are the LWDS drainfield and the TA-V seepage pits.

The seepage pits also were used to dispose of sanitary wastes that were disposed to TA-V septic systems. These sanitary wastes contained nitrate that served as a local source of nitrate contamination in groundwater.

Nitrate occurs primarily in the aqueous phase in both the vadose zone and the aquifer. It is nonsorptive and for the most part does not exchange on sediment surfaces in the vadose zone or groundwater. Therefore, any locally derived nitrate was most likely transported through the vadose zone with the initially disposed wastewater and does not represent a residual source term in the vadose zone.

1.2.2 Contaminant Transport through the Vadose Zone

Vadose zone soil-vapor and soil samples collected from the land surface to the water table during recent drilling operations have indicated only minor evidence of solvent concentrations. Soil samples collected during these operations have contained no excessive moisture. Based on these data, movement of water and contaminants through the 500-ft thick vadose zone was likely rapid and vadose-zone drainage occurred soon after cessation of wastewater disposal.

Although TCE disposal was discontinued during the early 1980s, wastewater disposal to the TA-V seepage pits continued until 1992. This likely flushed any residual vapor-phase or aqueous-phase contaminants from the vadose zone beneath the LWDS drainfield and TA-V seepage pits. No secondary source of TCE or nitrate remains in the vadose zone.

1.2.3 Contaminant Distribution and Transport in the Santa Fe Group Aquifer

TCE is present in water from the Santa Fe Group aquifer beneath TA-V. TCE plume dimensions at concentrations exceeding 5 µg/L were approximately 600 × 1,200 ft during May 2003 (Figure 1-2). The May 2003 concentration in water from well LWDS-MW1 was 20.9 µg/L (as high as 26 µg/L in November 2000). Based on residual TCE concentrations and moisture content in the vadose zone, present concentrations of TCE in groundwater were derived from previous aqueous disposals and do not represent a secondary release from residual contaminant source terms.

TCE concentration isopleths for 2003 (Figure 1-2) indicate that the center of TCE mass has migrated approximately 300 ft west and northwest from the LWDS drainfield since disposals ceased. TCE travel time in the aquifer is estimated to be 8 ft/year. A dilute lobe of the plume extending to the south is attributed to TCE originating from the TA-V seepage pits and subsequently diluted by continued discharges to the pits. The distribution of TCE in groundwater at TA-V supports potentiometric surface information showing radial groundwater flow to the northwest, west, and south, away from a subtle groundwater mound beneath the northwest part of TA-V.

PCE was detected at concentrations exceeding the MCL of 5 µg/L in water samples from one well completed approximately 100 ft below the water table during several sampling events. PCE was not detected in nearby water-table wells.

Nitrate has been detected above the MCL of 10 mg/L (as nitrogen) in water from several TA-V wells. Sampling events through May 2003 showed nitrate concentrations ranging from less than 5 to more than 10 mg/L (as nitrogen). Nitrate in water within the extent of the TA-V TCE plume is attributed to local septic system disposals. Nitrate in water from wells east of TA-V exceeded 10 mg/L (as nitrogen) during the summer and fall of 2001. These nitrate concentrations are derived from upgradient sources and are not within the scope of TA-V remedial activities.

Potential downgradient receptors for the TA-V groundwater plume are the COA and KAFB well fields to the north. Pumpage from the COA well fields will prevent TCE and other contaminants from migrating southward toward Isleta Pueblo or westward toward the proposed Mesa del Sol well field.

Additionally, downgradient TCE concentrations are decreasing in groundwater to below detection limits through dispersion and dilution as the plume moves into the more hydraulically conductive ARG deposits west of TA-V. Capture-zone analyses for downgradient receptors in the COA and KAFB wellfields indicates that contaminant travel times exceed 100 years from TA-V.

The distribution of contaminants in groundwater at TA-V is adequately defined from the existing monitoring network. Based on the information available from the groundwater monitoring network, geohydrologic conditions at TA-V are sufficiently characterized to conduct the TA-V CME.

2.0 CLEANUP GOALS, OBJECTIVES, AND REQUIREMENTS

This CME Work Plan provides a framework for identifying the most effective corrective measure for implementation at TA-V. An effective corrective measure will be cost effective and must ensure that cleanup goals and objectives are met. Cleanup goals and objectives can be divided into two types (performance and compliance) based on when the goal or objective is to be achieved. Goals are established as the milestones to meet upon completion of remediation. Objectives are tasks to be completed in order to meet the goals.

Performance goals and objectives are defined to support remedy performance evaluation during implementation of the remedy but before final closure of the site. Compliance goals and objectives are defined to support decision making at the end of the remedy to provide the framework to determine that the remedy has restored groundwater to beneficial use within the restoration timeframe. Because the type of data collected may be quite different, it is important to distinguish between performance and compliance goals and objectives. The performance and compliance goals and objectives stated in this document will be finalized in the CME Report. The following sections outline the performance and compliance goals and objectives for remediation of the TA-V groundwater plume.

2.1 Performance Goals and Objectives

Performance goals and objectives are criteria and actions used to evaluate remedy performance during the operations phase to support evaluation of system performance data relative to end-state objectives. Analysis of performance monitoring data leads to periodic decisions that the remedy is performing as expected and that the remedy will ultimately achieve the final remediation goal. The performance goals and objectives for the TA-V groundwater plume include:

Performance Goals:

- Establishing and operating a remedy intended to reduce COC concentrations,
- Monitoring distribution and changes in COC concentrations, and
- Collecting sufficient data to support a decision to move into the compliance phase.

Performance Objectives:

- Collecting groundwater samples for performance parameters (i.e., in addition to COCs) from TA-V wells,
- Compiling and analyzing groundwater monitoring data to evaluate trends in COC concentrations,
- Comparing trends to the COC cleanup standards, and
- Recommending continued operation of the remediation system or strategy and proceeding to compliance evaluation.

2.2 Compliance Goals and Objectives

Compliance goals and objectives are criteria and actions used to evaluate remediation system or strategy effectiveness both during and at completion of the corrective measure. Compliance requirements may be imposed during remediation system or strategy operations (e.g., air emissions or waste management). In addition, compliance requirements exist for final closure of the site. These compliance goals and objectives serve to show that the remedy is being implemented in a fashion that is consistent with the COOC (NMED 2003) during implementation and that the remedy has accomplished the remediation goals at the end of the corrective measure. Groundwater cleanup levels for TA-V are defined in Section VI.K.1.a of the COOC as the more restrictive of EPA MCLs or Water Quality Control Commission (WQCC) standards. As presented in Section 1.2 and Table 1-2, the cleanup levels for COCs at TA-V are defined by the MCLs, as these are the more restrictive of the two standards. The remedial timeframe for TA-V will be defined in the Corrective Measures Implementation Plan. The compliance goals and objectives for the TA-V groundwater plume include:

Compliance Goals:

- Operating all remediation systems or strategies in compliance with applicable requirements
- Reducing COC concentrations throughout the plume to below MCLs (refer to Table 1-2), and
- Implementing institutional controls to protect human health and the environment during the remediation timeframe.

Compliance Objectives:

- Monitoring all remediation systems or strategies for compliance with applicable requirements,
- Collecting groundwater samples at TA-V wells for COCs,
- Comparing COC concentrations to cleanup standards, and
- Recommending site closure or continuation of long-term operations.

3.0 TECHNOLOGY IDENTIFICATION AND SCREENING

This technology identification and screening is an initial evaluation to determine feasible technologies to be considered for implementation at TA-V. The primary objective of this section is to identify potential remediation technologies and subject these technologies to a screening process. The *Survey of Subsurface Treatment Technologies for Environment Restoration Sites at Sandia National Laboratories, New Mexico* (SNL/NM 2003) and other scientific and engineering literature were used to facilitate selection of the technologies. This section includes a description of the threshold criteria to be used in the initial screening process, identification and description of remediation technologies, the initial screening process, and results of the initial technology screening.

3.1. Threshold Criteria

In the COOC (NMED 2003), the NMED identified threshold criteria to use for evaluating each remedial alternative. These threshold criteria are reflective of cleanup standards identified in the RCRA Corrective Action Plan for evaluation of a final corrective measure alternative (EPA 1994). Technologies potentially used as part of a remedy and other remedy components also need to be evaluated against these threshold criteria. The four threshold criteria listed in the COOC are described below. A description of relevance to the TA-V site is also included.

1. **Protective of human health and the environment.** Any proposed remedy must be protective of human health and the environment. As stated in the RCRA Corrective Action Plan, “Remedies may include those measures that are needed to be protective, but are not directly related to media cleanup, source control, or management of wastes” (EPA 1994). Components of remedies considered at TA-V include evaluating protection of human health and the environment for air emissions, potential formation of hazardous degradation products, any hazards associated with operations and maintenance of the remedy, and remediation within an appropriate timeframe.
2. **Attain media cleanup standard or alternative, approved risk-based cleanup goals.** Any proposed remedy must attain groundwater cleanup standards or goals. As stated in the RCRA Corrective Action Plan, “Remedies will be required to attain media cleanup standards set by the implementing agency, which may be derived from existing state or federal regulations (e.g., groundwater standards) or other standards. The media cleanup standards for a remedy will often play a large role in determining the extent of, and technical approaches to, the remedy” (EPA 1994). The potential effectiveness of attaining media cleanup standards for a remedy relies on a number of site-specific factors. Site-specific factors for TA-V include:
 - a. **Contamination in a deep aquifer:** Depth to groundwater at TA-V is approximately 500 ft. Will the proposed remedy be effective in a deep aquifer?
 - b. **Slow groundwater velocities:** Groundwater velocities at TA-V are 0.5 to 168 ft/year. The center of TCE mass in TA-V groundwater has migrated approximately 300 ft in 36 years, which equates to a transport velocity of approximately 8 ft/year (assuming no retardation). Will the proposed remedy be effective given this range of groundwater velocities?

- c. **Arid environment:** Recharge from annual precipitation is considered to be insignificant as a mechanism for transporting contaminants through the vadose zone at TA-V. Recharge from sporadic, ephemeral streamflows from mountainous drainages does not produce an observable effect within the vadose zone or aquifer at TA-V. Will characteristics of an arid environment impact the effectiveness of the proposed remedy?
 - d. **Heterogeneous subsurface:** The TA-V aquifer consists of unconsolidated to semi-consolidated alluvial sediments. Upper sections of the alluvial-fan sediments are relatively coarse-grained, becoming fine-grained and clay rich with depth. In the aquifer, the alluvial fan lithofacies interfingers to the west with coarser fluvial sediments of the ARG. Will the proposed remedy be effective in a heterogeneous subsurface environment?
 - e. **Effective porosity 25%:** The effective porosity in the aquifer at TA-V has been estimated to be 25% (SNL/NM 2004a). This estimate of effective porosity is considered to be conservative. The effective porosity may affect technologies involving injection or extraction of water. Will the proposed remedy be effective in an aquifer with an effective porosity of 25%?
 - f. **Declining water levels:** Water levels at TA-V have declined steadily as a result of pumping from municipal wells to the north. These declines average 0.7 ft/year. Will declining water levels impact the effectiveness of the proposed remedy?
 - g. **Peak historic TCE concentrations of 23 to 26 µg/L:** TCE concentrations at TA-V are low. Will the proposed remedy effectively reduce these low concentrations to below the TCE MCL of 5 µg/L?
 - h. **Peak historic PCE concentrations of 7.5 µg/L:** PCE concentrations at TA-V are low. Will the proposed remedy effectively reduce these low concentrations to below the PCE MCL of 5 µg/L?
 - i. **Peak historic nitrate concentration of 19 mg/L:** Nitrate concentrations at TA-V slightly above the MCL. Will the proposed remedy effectively reduce these low concentrations to below the nitrate MCL of 10 mg/L?
3. **Control the source or sources of releases so as to reduce or eliminate, to the extent practicable, further releases of contaminants that may pose a threat to human health and the environment.** Any proposed remedy must control the original source of the contamination in order to prevent any further releases. As stated in the RCRA Corrective Action Plan, “Unless source control measures are taken, efforts to clean up releases may be ineffective or, at best, will essentially involve a perpetual cleanup” (EPA 1994). Section 1.2 identifies that there is not a secondary source of release present in the vadose zone or the saturated zone at TA-V. Evidence supporting this statement is detailed in the “Current Conceptual Model of Groundwater Flow and Contaminant Transport at SNL/NM TA-V” (SNL/NM 2004a). Because there is no active source, source control is not a required component of the TA-V corrective measure and any technologies designed for source zone control or remediation are not needed for TA-V.

4. **Comply with standards for management of wastes.** Any proposed remedy must comply with all applicable state or federal regulations. As stated in the RCRA Corrective Action Plan, “Waste management activities will be conducted in compliance with all applicable state or federal regulations (e.g., closure requirements, land disposal restrictions)” (EPA 1994). For remedies considered at TA-V, waste could be generated during the life cycle of the remedy in the form of contaminated groundwater brought to the surface and laboratory and field sampling wastes, and at the completion of the remedy during final decommissioning of the remedy system.

3.2 Technology Identification and Description

A number of treatment technologies are considered for remediation of groundwater contaminants present at TA-V. This section identifies technologies selected for initial screening (Table 3-1) and provides a description of the technologies. Table 3-1 lists the technologies alphabetically and identifies if the technology is applicable for volatile organic compound (VOC) and/or nitrate remediation. A literature review of the technologies was performed to compile information for technology descriptions. A description of each technology includes information about applicability, system design, and operation. Also included in this section are the advantages, disadvantages, and references for each technology.

Table 3-1. Technologies to be evaluated for remediation of VOCs and nitrate during the initial screening process.

Technologies	Applicable for VOCs	Applicable for Nitrate	TA-V CME Work Plan Section
Air Sparging	X		3.2.1
Groundwater Monitoring	X	X	3.2.2
In Situ Bioremediation	X	X	3.2.3
In Situ Chemical Oxidation	X		3.2.4
In Situ Flushing	X		3.2.5
Monitored Natural Attenuation	X	X	3.2.6
Monolithic Confinement	X	X	3.2.7
Nanoscale Iron Injection	X		3.2.8
Permeable Reactive Barriers	X	X	3.2.9
Phytoremediation	X	X	3.2.10
Pump and Treat	X	X	3.2.11
Soil Vapor Extraction	X		3.2.12
Thermal Technologies	X		3.2.13

Groundwater contamination at TA-V consists of VOCs (TCE and PCE) and nitrate present at concentrations slightly above their respective MCLs. Contamination is located in a deep aquifer with relatively low groundwater velocities. Recharge is insignificant and does not produce an observable effect within the vadose zone or aquifer. There are no immediate groundwater receptors; therefore, risk to human health and the environment is minimal. Given these TA-V site characteristics, it is appropriate to consider low-cost, minimal impact remedies for cleanup of TA-V groundwater.

3.2.1 Air Sparging

Air sparging is used to treat a wide range of organic contaminants, including dissolved phase VOCs, by injecting clean gas (most often oxygen or clean air) into contaminated groundwater. The injected air causes a phase change in the contaminant from liquid to vapor. The vapor passes into the vadose zone and is often treated using a separate technology (e.g., soil vapor extraction). This is a relatively new technology; therefore, documentation of the effectiveness of this potential remedy is limited. This remedy should not be used if: 1) free product is present, 2) the potential exists for uncontrolled migration of vapors into basements, sewers, etc., or 3) the contaminant source is within a confined aquifer.

Advantages:

- Commercially available equipment, easy installation,
- Minimal site disturbance,
- Short treatment times (usually 1 to 3 years in duration),
- Less costly than aboveground treatment systems,
- In situ technology requiring no removal, treatment, or storage of groundwater, and
- When combined with soil vapor extraction, removal can be enhanced.

Disadvantages:

- Cannot be used if free product is present,
- Cannot be used for treatment in confined aquifer systems,
- Stratified soils may render this remedy ineffective,
- Needs extensive site characterization for maximum effectiveness and safety,
- Potential for migration of contaminants,
- Lack of field and laboratory research to support design considerations,
- May not be effective in removing contaminants present at low concentrations,

- May not be compatible with technologies that rely upon anaerobic degradation, and
- Not applicable for nitrate.

References:

- US Department of Defense, December 2000, Environmental Security Technology Certification Program (ESTCP) Cost and Performance Report: Multi-Site In Situ Air Sparging, CU-9808, <http://www.estcp.org/documents/techdocs/199808.pdf>.
- US EPA, March 2003, Air Sparging, <http://www.epa.gov/swerust1/cat/airsparg.htm>.
- Sandia National Laboratories (SNL), August 2003, "Survey of Subsurface Treatment Technologies for Environmental Restoration Sites at Sandia National Laboratories, New Mexico," Sandia National Laboratories, Albuquerque, NM.

3.2.2 Groundwater Monitoring

Groundwater monitoring consists of collecting samples from a network of monitoring wells with the objective of monitoring contaminant concentrations and transport in groundwater over time. Groundwater monitoring is applicable for relatively low concentration groundwater plumes with long remedial timeframes and minimal risk of harm to human health and the environment. A monitoring plan will be established to identify monitoring locations, frequency and duration of sample collection, and analysis parameters. Extensive knowledge of site-specific geohydrologic conditions and contaminant distribution and transport is required to establish an appropriate monitoring plan.

Groundwater monitoring is not considered to be a no action approach because active monitoring will take place and a contingency plan will be established. If a no action approach was selected, then monitoring would not take place and a contingency plan would not be established. A contingency plan will include reevaluation criteria in the event that groundwater monitoring is no longer effectively protecting human health and the environment (e.g., dramatic increases in contaminant concentrations and contaminant distribution and transport beyond control location). Unlike monitored natural attenuation (MNA), the groundwater monitoring approach makes no attempt to verify pathways of natural attenuation or to predict contaminant transport and degradation.

Advantages:

- Potentially less expensive, although required project duration is unknown,
- Minimal risk to workers compared to aggressive technologies,
- Minimal site disturbance,
- Implementation flexibility, and
- In situ technology requiring no removal, treatment, storage, or destruction of groundwater.

Disadvantages:

- Monitoring can proceed for an indefinite period, resulting in increased life-cycle cost,
- End point may be undefined,
- Potential for transport of contaminants toward receptors, and
- Regulatory approval can be difficult because this technology does not involve active removal or destruction of contaminants.

3.2.3 In Situ Bioremediation

Bioremediation is the application of biological treatment for remediation of contaminants. In situ bioremediation (ISB) is the application of bioremediation in the subsurface and can be used for remediation of a wide variety of contaminants, both organic and inorganic, under both aerobic and anaerobic conditions. It combines an understanding of biology, geochemistry, hydrogeology, and engineering into a cohesive strategy for the destruction of groundwater contaminants using microbes. Thorough data evaluation is necessary to evaluate ISB effectiveness. Data evaluation includes knowledge of the type of microorganisms, the type of contaminant, and the geological conditions at the site.

Bioremediation can involve aerobic or anaerobic processes. Aerobic bioremediation techniques can include implementation of biosparging. Biosparging is similar to air sparging except that the injected air (or oxygen) can be amended with nutrients, increasing activity of indigenous microorganisms to stimulate aerobic degradation. Contaminants are removed through microbial degradation and volatilization, whereas air sparging removes contaminants through volatilization only. The operating principles are the same as air sparging and this technology is often used with other technologies (e.g., soil vapor extraction).

Anaerobic bioremediation techniques can include injection of an electron donor to increase activity of indigenous microorganisms to stimulate anaerobic degradation to remove contaminants through microbial degradation. VOC and nitrate reduction can occur in the absence of oxygen and the presence of an electron donor where VOCs and nitrate can act as electron acceptors in the microbial respiration process. This results in anaerobic reductive dechlorination (ARD) of VOCs to ethene and conversion of nitrate to nitrite and ultimately to nitrogen (N_2).

Advantages:

- Contaminant degradation occurs in situ, minimizing worker exposure to hazardous contaminants,
- Effective on a wide range of contaminants and concentration levels,
- Commercially available equipment,

- Effective for both dissolved and sorbed phases of contamination,
- In situ technology requiring no removal, treatment, or storage of groundwater, and
- Anaerobic application can be easily combined with other technologies.

Disadvantages:

- Biological growth may affect injection wells and flowpaths (biofouling),
- High contaminant concentrations may be toxic to microbiological community,
- Operations and monitoring may be continuous,
- Difficult to implement in low-permeability aquifers,
- Aerobic application (bioparging) cannot be used for treatment in confined aquifer systems, may not be effective in removing contaminants present at low concentrations, and is not compatible with technologies that rely upon anaerobic degradation,
- Remediation may only occur within the higher permeability channels in the aquifer, and
- The potential for activation (transformation of the contaminant into a more hazardous substance) exists.

References:

- Interstate Technology and Regulatory Cooperation Work Group, 2002. "Technical and Regulatory Guidance for In Situ Bioremediation in Groundwater," 129 pp.
- Martin, J.P., Allison, A.M., Keck, J.F., Peterson, L.N., 2002, "Evaluation of Remediation Technologies for DNAPL Source Zone Clean-Up at the OK Tool Site, Milford, NH," North Wind, Inc.
- US EPA, March 2003, Biosparging, <http://www.epa.gov/swerust1/cat/biosparg.htm>.

3.2.4 In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) is implemented by injecting an oxidizing compound (usually hydrogen peroxide or permanganate) into a non-aqueous phase liquid (NAPL) source zone. The oxidant reacts quickly to destroy the aqueous phase contaminant, which acts to drive more contaminant from the NAPL phase to the aqueous phase. Laboratory studies have shown that a 5:1 ratio of oxidant to TCE is needed. This process is non-selective (i.e., anything that can be oxidized in the subsurface will react with the reagent), potentially increasing the amount of reagent needed.

Advantages:

- Capability to destroy large masses of organic contaminants in a relatively short period of time,
- Contaminants are fully degraded into harmless byproducts,
- Effective on high contaminant concentrations,
- Potential lower cost than other technologies due to shorter remedial timeframe,
- Can be used at sites with deep contamination, and
- Destruction takes place in the aqueous phase.

Disadvantages:

- Subsurface heterogeneities may cause non-uniform distribution of oxidant,
- Effective porosity of the subsurface may be reduced due to the formation of metal oxide precipitates,
- Often requires more than one application due to rebound effects,
- Not effective in low concentration areas,
- Oxidation may harm the indigenous microbial community, potentially limiting options for future aerobic or anaerobic degradation of contaminants, and
- Not applicable for nitrate.

References:

- Martin, J.P., Allison, A.M., Keck, J.F., Peterson, L.N., 2002, "Evaluation of Remediation Technologies for DNAPL Source Zone Clean-Up at the OK Tool Site, Milford, NH," North Wind, Inc.
- Sandia National Laboratories (SNL), August 2003, "Survey of Subsurface Treatment Technologies for Environmental Restoration Sites at Sandia National Laboratories, New Mexico," Sandia National Laboratories, Albuquerque, NM.
- DOE, 1999, "Innovative Technology Summary Report: In Situ Chemical Oxidation Using Potassium Permanganate", DOE/EM-0496, 35 pp.
<http://apps.em.doe.gov/ost/pubs/istrs/itsr167.pdf>.

3.2.5 In Situ Flushing

In situ flushing involves injection of a solution into a dense nonaqueous phase liquid (DNAPL) source zone in order to remove DNAPL by dissolution and/or mobilization followed by downgradient extraction of the groundwater and flushing solution. Upon extraction, the flushing solution, which is mixed with the contaminants, is subjected to above ground treatment and reinjected.

Flushing relies on an increase in solubility of hydrophobic organic compounds resulting from the addition of the flushing solution to groundwater, and from the reduction of interfacial tension that accompanies this increase in solubility. A typical system consists of arrays of injection and extraction wells arranged to provide an efficient flood of the source zone. Horizontal wells, trenches, or other delivery systems may also be used. Either hydraulic control or containment walls may be used to contain the flushing area. The effluent solution produced at the extraction wells contains water, solvent, and contaminants and must be treated prior to injection or disposal. Flushing solutions may consist of alcohol, cosolvents, acids, bases, solvents, surfactants, or plain water. This technology can be used for a variety of organic contaminants, including DNAPL, and may have some application to inorganic contaminants. Optimal application of this technology is in moderate to high permeability soils with an excellent understanding of the hydrogeology.

The use of surfactants or cosolvents for in situ flushing is common. Remediation using surfactants involves injection of a solution of water plus surfactants into the source zone to remove contaminants through a combination of dissolution, mobilization, and displacement. Selection of surfactants requires consideration of performance, toxicity, biodegradability, possible chemical reactions with constituents in the water, and potential for sorption. After extraction, surfactants may be separated from the contaminants and reused (e.g., separation through air stripping or a permeable membrane system for nonvolatile contaminants). If surfactants are not separated, the extracted solution of water, surfactant, contaminants, and other additives must be treated prior to reinjection in the subsurface or disposal in a surface water body or sewer.

Advantages:

- Chemical principles are simple,
- Alcohols are not sorbed significantly,
- Suitable for removal of DNAPL at very high saturations,
- Many surfactants are Food and Drug Administration (FDA) food-grade compounds and readily biodegradable,
- No significant site disruption, and
- High removal of DNAPL can be achieved in relatively homogeneous areas with moderate to high permeability.

Disadvantages:

- Heterogeneities in the aquifer will decrease extraction efficiency; therefore, some areas will require longer treatment times and larger treatment volumes,
- Alcohols are less dense than water, so high concentration solutions will be less dense than groundwater, creating problems with even circulation,
- Field trials have required multiple pore volumes of treatment solution with no recycling; therefore, substantial volumes of flushing solution were used and large volumes of extracted fluids had to be treated,
- Decreasing interfacial tension, combined with the addition of solvents, creates a risk that DNAPLs will be mobilized,
- Ultimate cleanup level is unknown, and
- Not applicable for nitrate.

References:

- National Research Council, 1999, "Groundwater and Soil Cleanup: Improving Management of Persistent Contaminants", National Academy Press: Washington D.C., 285 pp.
- Ground-Water Remediation Technologies Analysis Center (GWRTAC), 2001, Remediation Technologies, <http://www.gwrtac.org/html/techs.html>.
- Fountain, J.C., December 1998, "Technologies for Dense Nonaqueous Phase Liquid Source Zone Remediation," TE-98-02, GWRTAC, Pittsburgh, Pennsylvania, http://www.gwrtac.org/pdf/e_dnapl.pdf.

3.2.6 Monitored Natural Attenuation

MNA typically operates on the principle of indigenous microorganisms using a supply of nutrients and electron acceptors (or donors) already present in the environment to completely metabolize or cometabolize pollutants. In certain applications, non-destructive attenuation mechanisms (i.e., dispersion or dilution) may be sufficient to meet site-specific cleanup goals. Careful characterization and thorough monitoring are essential to ensure that sufficient attenuation will take place to comply with all regulatory requirements. This characterization is the difference between MNA and groundwater monitoring because groundwater monitoring makes no attempt to verify pathways of natural attenuation or to predict contaminant transport and degradation. MNA has wide applicability, relative low cost, and requires minimal infrastructure. The primary costs associated with this remedy are monitoring costs. It can be used for remediation of common groundwater contaminants, including light non-aqueous phase liquids (LNAPLs) and DNAPLs. Biodegradation or cometabolism can result in reduction of VOC concentrations, and nitrate can be transformed through redox processes (e.g., denitrification) that are operative in the subsurface.

Advantages:

- Less construction and maintenance is required than other treatment options making the technology less costly,
- Contaminants are ultimately transformed into innocuous byproducts,
- The non-intrusive nature of MNA allows continued use of infrastructure during remediation,
- Requires no removal, treatment, or storage of groundwater. There is less risk than engineered remedies that may transfer contaminants to the air during remediation,
- Not subjected to equipment limitations such as malfunction or other downtime, and
- Can be used in conjunction with or following other remedial measures conducted under similar conditions (e.g., anaerobic).

Disadvantages:

- Subject to natural and induced changes in local hydrogeology,
- Aquifer heterogeneity can make characterization difficult,
- Potential for contaminant migration,
- May not be compatible with technologies that introduce oxygen into the subsurface (i.e., air sparging), and
- Remediation timeframes may be longer than some active remediation technologies.

References:

- DOE, May 1999, *Decision-Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites*, Office of Environmental Restoration, <http://web.em.doe.gov/framework/>.
- US EPA, April 1999, *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*, OSWER Directive 9200.4-17P, <http://www.epa.gov/swerust1/directiv/d9200417.pdf>.
- US EPA, September 1998, *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*, EPA/600/R-98/128, <http://www.clu-in.org/download/remed/protocol.pdf>.
- Wiedemeier, T.H., J.T. Wilson, K.H. Kampbell, R.N. Miller, J.E. Hansen, 1999, "Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater," Volume I, Revision 0, Air Force Center for Environmental Excellence, Brooks Air Force Base, S.A., Texas.

3.2.7 Monolithic Confinement

Monolithic confinement consists of constructing barriers (e.g., cement or grout) to confine groundwater contamination. Barriers can be constructed by digging a trench and backfilling it or by injecting grouting fluids (i.e., cement, clay, or a solution to react in the subsurface to form a low permeability material) into a series of boreholes in order to reduce the permeability of the geologic materials. Surrounding a contaminant source with a barrier can reduce the flux of contaminants from the source limiting production of additional groundwater contamination. If the barrier is not set in impermeable areas, then the system will be open and contamination will not be contained.

Advantages:

- Passive technology that uses no above ground infrastructure,
- In situ technology requiring no removal, treatment, or storage of groundwater,
- If installed properly, no contaminant migration occurs,
- Can be used for any type or state of contamination, and
- If installed properly, can be effective under a variety of geohydrologic characteristics.

Disadvantages:

- Expensive and difficult to implement for deep aquifer contamination,
- Emplacement can be disruptive to the site and is permanent,
- Used as a containment remedy; source area may remain indefinitely,
- Monitoring can proceed for an indefinite period resulting in increased cost,
- End point may be undefined, and
- Regulatory approval can be difficult because this technology does not involve active removal or destruction of contaminants.

References:

- National Research Council, 1999, "Groundwater and Soil Cleanup: Improving Management of Persistent Contaminants", National Academy Press: Washington D.C., 285 pp.

3.2.8 Nanoscale Iron Injection

This technology involves injecting zero valent nanoscale iron directly into a DNAPL source zone. The nanoscale iron particles are between 1 and 100 nm in diameter. Because of the small size of these particles, it is easy to distribute the amendment by incorporating it into a slurry and injecting the slurry into the aquifer. The iron particles are small enough to reach and react with TCE present in the pore spaces of the aquifer. The addition of nanoscale iron is an application of metal enhanced reduction of contaminants in the subsurface. According to the manufacturer, approximately 25 lb is required to treat an area of 100 m² from a single injection point.

Advantages:

- Works on the same principles as metal enhanced reduction, so the degradation mechanism is well understood,
- This remedy is passive, requiring no infrastructure once the remedy is emplaced,
- According to the manufacturer, nanoscale iron has the potential to degrade a wide variety of contaminants,
- Contaminant degradation occurs in situ, and
- Reaction rates are rapid.

Disadvantages:

- Precipitates may interfere with hydraulic conductivity,
- The amendment is expensive,
- Competing electron acceptors may increase the demand for the amendment,
- Not as useful on low concentrations, and
- Not applicable for nitrate.

References:

- Nanitech LLC, 2004, Information brochure.

3.2.9 Permeable Reactive Barriers

A permeable reactive barrier (PRB) is a physical barrier that is installed in the aquifer downgradient along the flow path of the contaminant. As the contaminated groundwater passes through the barrier, the contaminants react with the barrier to either transform the contaminant into a less harmful byproduct or the contaminants are irreversibly absorbed into the permeable material. A PRB can contain such agents as zero-valent metals, chelators, sorbents, microbes, or other agents. A funnel and gate approach can be utilized to contain the contaminant plume with

low hydraulic conductivity barriers in the crossgradient direction and direct the flow of the contaminant plume toward the downgradient PRB. PRBs can be used for a wide range of organic and inorganic contaminants. In general, PRBs are only effective for contamination that is shallower than 50 ft below the surface.

A biological barrier is a PRB installed across the flow path of a contaminated groundwater plume. It is similar to a conventional PRB in that it consists of an excavated trench filled with a sorbent media. This media retards the movement of organics and supports microbial growth to biodegrade the sorbed organics. Addition of nutrients, co-substrates, and/or electron donors or acceptors to the barrier helps stimulate biodegradation. The target contaminants include aerobically and anaerobically biodegradable compounds such as halogenated and nonhalogenated VOCs and semi-volatile organic compounds (SVOCs), polychlorinated biphenols (PCBs), nitrates, and other inorganics.

Another method used in PRBs is metal-enhanced reduction of contaminants. Metal-enhanced dechlorination technology uses an electrochemical process involving oxidation of iron and reductive dehalogenation of halogenated VOCs to convert VOCs to hydrocarbons and inorganic halides either in situ or ex situ. The treatment process stimulated by a metal-enhanced dechlorination PRB is the same as that of nanoscale iron injection except that the media is employed using a PRB or treatment wall where contaminated groundwater flows through and the contaminants are either sorbed or destroyed.

Advantages:

- Passive technology that uses no above ground infrastructure,
- If installed properly, no contaminant migration occurs beyond the barrier,
- Requires no removal, treatment, or aboveground storage of groundwater,
- Can incorporate different materials to treat a wide range of contaminants,
- Once the barrier is installed, no further costs are incurred (other than monitoring), and
- Metal enhanced reduction uses inexpensive zero-valence iron.

Disadvantages:

- Emplacement of the barrier can be disruptive to the site and difficult where the aquifer is deep,
- The barrier is permanent and the timeframe for contaminated groundwater to pass through the PRB may be long,
- Used as a containment remedy, the source area may remain indefinitely depending on concentration, sorption, and other factors,

- Very high contaminant concentrations and heavy metals can be toxic to microorganisms if using a biological barrier,
- Precipitation of metals and other inorganics may reduce hydraulic conductivity,
- For a biological barrier, generation of biomass may limit the permeability of the barrier, and
- For metal enhanced reduction barriers, reactivity of iron may necessitate periodic replacement or treatment of the iron medium.

References:

- Sandia National Laboratories (SNL), August 2003, "Survey of Subsurface Treatment Technologies for Environmental Restoration Sites at Sandia National Laboratories, New Mexico," Sandia National Laboratories, Albuquerque, NM.
- Strietelmeier, B.A., M.L. Espinosa, M.W. Jones, J.D. Adams, E.M. Hodge, S.D. Ware, P.A. Leonard, P. Longmire, J.P. Kaszuba, and J.L. Conca, 2001, "Remediation of Nitrate-Contaminated Groundwater Using a Biobarrier," Waste Management 2001 Conference, February 25-March 1, 2001, Tucson, Arizona, <http://www.wmsym.org/Abstracts/2001/54/54-2.pdf>.
- US EPA, June 1997, "Metal-Enhanced Dechlorination of Volatile Organic Compounds Using an Above-Ground Reactor," EPA/540/R-96/503, Superfund Innovative Technology Evaluation Report, EnviroMetal Technologies, Inc., <http://www.epa.gov/ORD/SITE/reports/540r96503.pdf>.

3.2.10 Phytoremediation

Phytoremediation uses plants for remediation of groundwater by taking advantage of the natural abilities of plants to take up, accumulate, and/or degrade constituents of their soil and water environments. It is most appropriate for sites where groundwater is within 10 ft of the ground surface and large areas where contaminants are found in low concentrations.

Advantages:

- Effective for large areas with low contaminant concentrations,
- Potentially less expensive than an aggressive removal technology,
- Implementation flexibility of location for ex situ application, and
- Plants are used for remediation of contaminants, minimizing worker exposure.

Disadvantages:

- Can only be used at sites with very shallow groundwater (40 ft),
- Monitoring can proceed for an indefinite period, resulting in increased cost,
- May be difficult to implement in an arid environment, and
- Requires land space for plant growth that may not be possible at some sites.

References:

- Ground-Water Remediation Technologies Analysis Center (GWRTAC), 2001, Remediation Technologies, <http://www.gwrtac.org/html/techs.html>.

3.2.11 Pump and Treat

Pump and treat is a broad term used to describe the pumping of contaminated groundwater to the surface where it can be treated and possibly injected after treatment. Since this is an ex situ treatment, a wide range of contaminants can be treated with a variety of technologies. Designs of pump and treatment systems vary greatly. Systems consist of at least one extraction well used to remove contaminated groundwater for ex situ treatment and a disposition method for the treated water. Disposition of treated water can include injection into the aquifer, onsite reuse (irrigation), misting, or disposal to infiltration trenches or surface water bodies.

Ex situ treatment of the contaminated groundwater can be performed using a variety of technologies. Often, the treatment is in the form of air stripping, which passes air through the contaminated water and volatilizes organic contaminants. Sorption to activated carbon and ion exchange resins may also be used to remove contaminants. Ex situ bioreactors can be constructed in enclosed chambers and used to degrade contaminants using microorganisms. Contaminated groundwater is pumped to the enclosed chamber where it is circulated in an aeration basin creating an environment for microbes to degrade organic matter. Microbial populations are either located on a rotating biological matrix or on a packed bed with a surface area for microbial growth.

Advantages:

- Because of widespread use, it is a well developed technology,
- Generally effective in preventing the spread of contamination in the subsurface, and
- Can be used on a wide range of contaminants.

Disadvantages:

- Timeframe for remediation can be long,
- May not be capable of reducing contaminant concentrations to meet cleanup standards,

- Requires extensive site characterization to determine potential for effectiveness,
- Rebound and trailing effects can reduce effectiveness of this remedy,
- Not always effective for cleaning up source areas of contamination, and subsurface heterogeneities can reduce contaminant capture efficiency,
- Operation and maintenance costs can be expensive,
- Contaminated groundwater is often too dilute to support an adequate microbial population in bioreactors,
- When an air stripper is used, pollution controls may be needed to manage volatilization of contaminants,
- Nuisance microorganisms can predominate and reduce treatment effectiveness in ex situ bioreactors, and some intermediate degradation products are more toxic than the original contaminants in bioreactors, and
- Treatment media may require treatment or disposal.

References:

- US EPA, July 1996, "Pump-and-Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners," EPA/625/R-95/005, Office of Research and Development, Washington D.C., <http://www.epa.gov/ORD/WebPubs/pumptreat/>.
- Center for Public Environmental Oversight, 2000, Technology Tree: Bio-reactors. <http://www.cpeo.org/techtree/ttdescript/biorec.htm>.

3.2.12 Soil Vapor Extraction

Soil vapor extraction consists of venting air through the soil to evaporate and entrain contaminant vapors. The vapor and effluent gas are brought to the surface through vacuum extraction wells where the contaminant vapors are treated or destroyed before the effluent gas is released back into the atmosphere. It is primarily used to treat the unsaturated zone and not applicable to groundwater remediation unless combined with air sparging. When used in the unsaturated zone, it may not be cost effective for remediation of very low concentrations due to mass-transfer limitations.

Soil vapor extraction system designs vary, but a typical setup consists of at least one location where air is injected into the subsurface and at least one extraction point where the vapors are collected and treated or destroyed. In shallow applications (~5 ft), it is common to cap the treatment area with an impermeable barrier to avoid short-circuiting of air from the atmosphere. Passive soil ventilation systems can also be designed that utilize atmospheric fluctuations in barometric pressure. The Baro Ball™ was developed for this passive soil ventilation application. The Baro Ball™ allows air to escape from the subsurface (result of lower atmospheric pressure) but seals the opening of the well to prevent air from entering the subsurface through the well (result of higher atmospheric pressure).

Advantages:

- Wide application for in-situ remediation of VOCs,
- Minimal disturbance to site operations,
- Easily combined with other technologies,
- Technology has been successfully demonstrated in the vadose zone, and
- Potential to remove large quantities of contaminant from the subsurface.

Disadvantages:

- Treatment of extracted vapors can be costly,
- Used primarily for vadose zone treatment,
- Difficult to achieve contaminant reductions greater than 90%, and
- Not applicable for nitrate.

References:

- Sandia National Laboratories (SNL), August 2003, "Survey of Subsurface Treatment Technologies for Environmental Restoration Sites at Sandia National Laboratories, New Mexico," Sandia National Laboratories, Albuquerque, NM.
- Martin, J.P., Allison, A.M., Keck, J.F., Peterson, L.N., 2002, "Evaluation of Remediation Technologies for DNAPL Source Zone Clean-Up at the OK Tool Site, Milford, NH," North Wind, Inc.

3.2.13 Thermal Technologies

Thermal technologies include different methods of altering temperature-dependent properties of in situ contaminants in order to enhance mobility and solubility of DNAPLs. Common mechanisms used during thermal remediation to enhance contaminant removal include: 1) flushing of mobile contaminant from pore spaces, 2) reduction of contaminant viscosity, and 3) vaporization of VOCs and SVOCs. Common types of thermal technologies include steam injection, hot air injection, hot water injection, electrical resistance heating, radio frequency heating, and thermal conduction. A companion technology (i.e., soil vapor extraction) is usually needed to capture contaminant vapors. Any form of thermal remediation will most likely involve a great deal of infrastructure, both in the setup of the thermal system and the removal system, whether it is soil vapor extraction or pump and treat. However, this technology is quick, aggressive, and useful on high concentrations of both the dissolved phase and DNAPLs.

Advantages:

- Potentially quick remediation timeframe,
- Useful in areas where soil removal is not feasible,
- Effective in areas with high contaminant concentrations,
- No excavation needed, and
- Residual heat may provide a polishing step via heat-enhanced bioremediation or hydrolysis.

Disadvantages:

- Very expensive,
- Extensive infrastructure,
- Not effective for low contaminant concentrations,
- Potential safety issues due to presence of high voltage and thermal hazards,
- May move contaminants deeper or into undesirable locations, and
- Not applicable for nitrate.

References:

- Martin, J.P., Allison, A.M., Keck, J.F., Peterson, L.N., 2002. "Evaluation of Remediation Technologies for DNAPL Source Zone Clean-Up at the OK Tool Site, Milford, NH," North Wind, Inc.
- Sandia National Laboratories (SNL), August 2003, "Survey of Subsurface Treatment Technologies for Environmental Restoration Sites at Sandia National Laboratories, New Mexico," Sandia National Laboratories, Albuquerque, NM.
- Ground-Water Remediation Technologies Analysis Center (GWRTAC), 2001, Remediation Technologies, <http://www.gwrtac.org/html/techs.html>.

3.3 Initial Technology Screening

The threshold criteria described in Section 3.1 were used in the initial screening described in this section. Initial screening was performed on all technologies identified and described in Section 3.2. Table 3-2 lists all technologies and the four threshold criteria. Evaluation was conducted on a YES/NO basis, as follows:

- YES = the technology meets the threshold criterion.
- NO = the technology does not meet the threshold criterion.

Table 3-2. Initial screening process for technologies using the COOC threshold criteria.

Technologies	Protective of Human Health and Environment	Attain Media Cleanup Standards ¹		Source Control ²	Waste Management Standards Compliance
		VOCs	Nitrate		
Air Sparging	YES	NO	NA	YES	YES
Groundwater Monitoring	YES	YES	YES	YES	YES
In Situ Bioremediation	YES	YES	YES	YES	YES
In Situ Chemical Oxidation	YES	YES	NA	NO	YES
In Situ Flushing	YES	YES	NA	NO	YES
Monitored Natural Attenuation	YES	YES	YES	YES	YES
Monolithic Confinement	YES	NO	NO	NO	YES
Nanoscale Iron Injection	YES	YES	NA	NO	YES
Permeable Reactive Barriers	YES	NO	NO	YES	YES
Phytoremediation	YES	NO	NO	YES	YES
Pump and Treat	YES	YES	YES	YES	YES
Soil Vapor Extraction	YES	NO	NA	YES	YES
Thermal Technologies	YES	NO	NA	NO	YES

YES = the technology meets the threshold criterion

NO = the technology does not meet the threshold criterion

NA = the technology was identified as not applicable for nitrate in Table 3-1

1: This threshold criterion will be evaluated using the TA-V site-specific characteristics listed in Table 3-3. If a technology receives an evaluation of YES for all of the site-specific characteristics listed in Table 3-3, then a YES will be recorded in the appropriate location on this table. If a technology receives an evaluation of NO for one or more of the characteristics listed in Table 3-3, then a NO will be recorded in the appropriate location on this table.

2: Since a secondary source of release is not present in the vadose zone or the saturated zone at TA-V, technologies designed to aggressively remediate or control a source zone will be evaluated as NO.

The first threshold criterion, *Protective of Human Health and the Environment*, was evaluated based on whether appropriate measures could be taken to ensure that implementation of the technology would be protective of human health and the environment.

The second threshold criterion, *Attain Media Cleanup Standards*, was evaluated using the TA-V technical site-specific characteristics listed in Table 3-3. Each technology was evaluated to determine if the individual technology would be effective or applicable based on these site-specific characteristics, without consideration of cost and schedule. Evaluation was conducted on a YES/NO basis, as follows:

- YES = the technology will work given this characteristic, or this characteristic is not applicable to the technology.
- NO = the technology will not work given this characteristic.

If a technology received a YES evaluation for all of the technical site-specific characteristics listed in Table 3-3, then a YES was recorded in the *Attain Media Cleanup Standards* location on Table 3-2. If a technology received a NO evaluation for one or more of the characteristics listed in Table 3-3, then a NO was recorded in the *Attain Media Cleanup Standards* location on Table 3-2.

The YES/NO evaluation for the last three technical site-specific categories listed in Table 3-3 (*Peak historic TCE concentrations 23 to 26 ug/L*, *Peak historic PCE concentrations 7.5 ug/L*, and *Peak historic nitrate concentration 19 mg/L*) apply only to the evaluation of either the VOCs or nitrate category under the threshold criterion *Attain Media Cleanup Standards* in Table 3-2.

For example, if a technology received a NO evaluation under *Peak historic Nitrate concentration 19 mg/L* but a YES under *Peak historic TCE concentrations 23 to 26 ug/L* and *Peak historic PCE concentrations 7.5 ug/L*, and all of the other technical site-specific characteristics received a YES evaluation, then a YES was recorded for *Attain Media Cleanup Standards* for VOCs and a NO was recorded for *Attain Media Cleanup Standards* for nitrate.

Since a secondary source of release is not present in the vadose zone or the saturated zone at TA-V, a NO evaluation for the third criterion, *Source Control*, was recorded for technologies designed to aggressively remediate or control a source zone.

The fourth threshold criterion, *Waste Management Standards Compliance*, was evaluated based on whether compliance with all applicable state or federal regulations could be met for all waste generated during the life cycle of the technology.

All technologies that received a YES evaluation for all threshold criteria passed this initial screening. These selected technologies will be carried forward for further evaluation in Section 4 to determine remedial alternatives for groundwater cleanup at TA-V.

Table 3-3. TA-V technical site-specific characteristics for evaluating the threshold criterion: Attain Media Cleanup Standards.

Technologies	Contamination in a deep aquifer	Slow groundwater velocities	Arid environment	Heterogeneous subsurface	Effective porosity 25%	Declining water levels	Peak historic TCE concentrations 23 to 26 ug/L ¹	Peak historic PCE concentrations 7.5 ug/L ¹	Peak historic Nitrate concentration 19 mg/L ¹
Air Sparging	YES	YES	YES	YES	YES	YES	NO	NO	NA
Groundwater Monitoring	YES	YES	YES	YES	YES	YES	YES	YES	YES
In Situ Bioremediation	YES	YES	YES	YES	YES	YES	YES	YES	YES
In Situ Chemical Oxidation	YES	YES	YES	YES	YES	YES	YES	YES	NA
In Situ Flushing	YES	YES	YES	YES	YES	YES	YES	YES	NA
Monitored Natural Attenuation	YES	YES	YES	YES	YES	YES	YES	YES	YES
Monolithic Confinement	NO	YES	YES	YES	YES	YES	YES	YES	YES
Nanoscale Iron Injection	YES	YES	YES	YES	YES	YES	YES	YES	NA
Permeable Reactive Barriers	NO	YES	YES	YES	YES	YES	YES	YES	YES
Phytoremediation	NO	YES	NO	YES	YES	YES	YES	YES	YES
Pump and Treat	YES	YES	YES	YES	YES	YES	YES	YES	YES
Soil Vapor Extraction	YES	YES	YES	YES	YES	YES	NO	NO	NA
Thermal Technologies	NO	YES	YES	YES	YES	YES	YES	YES	NA

YES = the technology will work given this characteristic or this characteristic is not applicable to the technology
 NO = the technology will not work given this characteristic
 NA = the technology was identified as not applicable for nitrate in Table 3-1

1: These categories apply only to the evaluation of either the VOCs or nitrate category under the threshold criterion *Attain Media Cleanup Standards*. For example, if a technology receives a NO evaluation under *Peak historic Nitrate concentration 19 mg/L* but a YES under *Peak historic TCE concentrations 23 to 26 ug/L* and *Peak historic PCE concentrations 7.5 ug/L* and all of the other technical site-specific characteristics receive a YES evaluation, then a YES will be recorded for *Attain Media Cleanup Standards* for VOCs and a NO will be recorded for *Attain Media Cleanup Standards* for nitrate in the appropriate locations in Table 3-2.

3.4 Initial Technology Screening Results

Based on the results of the initial screening of technologies conducted in Section 3.3, technologies are categorized as either eliminated technologies or applicable technologies. Eliminated technologies will no longer be considered and applicable technologies will be used in Section 4 to create remedial alternatives.

3.4.1 Eliminated Technologies

Technologies that did not meet all of the threshold criteria did not pass the initial screening. These technologies will be eliminated at this point and will not be considered for creating remedial alternatives in Section 4. An explanation of why each technology was eliminated is discussed below.

3.4.1.1 Source Control Technologies

ISCO, in situ flushing, monolithic confinement, nanoscale iron injection, and thermal technologies were all eliminated because they are aggressive source control technologies and therefore are not applicable to the TA-V groundwater plume. ISCO, in situ flushing, and nanoscale iron injection technologies are designed to target DNAPL/NAPL source zones and are not practical for remediation of low contaminant concentrations in groundwater. Monolithic confinement involves constructing barriers to confine groundwater contamination, either by digging a trench or drilling boreholes. Construction of such a barrier around the TA-V groundwater plume at greater than 500 ft below ground surface would be an extremely difficult task. Thermal technologies are generally applied as an aggressive removal of high concentrations in source areas. Injection of steam or hot air is intended to increase volatilization and decrease viscosity of VOCs. The technology would not be an efficient method for treating the low concentrations of TCE and PCE in a deep aquifer.

3.4.1.2 Air Sparging

Air sparging is applicable for removing volatile chemicals from groundwater; however, it was determined that air sparging would not be able to remove VOCs from the groundwater at TA-V because of the insufficient gradient between the water and air phase due to the low concentrations of PCE and TCE. Therefore, it was determined that air sparging is not applicable for attaining media cleanup standards at TA-V.

3.4.1.3 Permeable Reactive Barriers

A PRB would need to be constructed downgradient of the plume and would need to be large enough to inhibit flow of contaminated groundwater underneath or around the barrier. Construction of such a barrier around the TA-V groundwater plume would be an extremely difficult task considering depth to groundwater approximately 500 ft below ground surface and the size of the plume. Therefore, it was determined that PRBs are not applicable at this site.

3.4.1.4 Phytoremediation

In situ phytoremediation is most applicable when the groundwater is within 10 ft of the surface. Implementation of this technology at TA-V would be ineffective considering the depth to groundwater (approximately 500 ft below ground surface) and the need for irrigation of plants in this arid environment. Therefore, it was determined that phytoremediation is not applicable at this site.

3.4.1.5 Soil Vapor Extraction

Soil vapor extraction is most applicable when contaminants are within the vadose zone. The contamination at TA-V is in the groundwater. Soil vapor extraction is also only useful for achieving contaminant reductions of less than 90%. Therefore, it was determined that soil vapor extraction is not applicable for attaining media cleanup standards at TA-V.

3.4.2 Applicable Technologies

Technologies that met all of the threshold criteria passed the initial screening. These technologies or combinations of these technologies will be used in Section 4 to determine remedial alternatives for groundwater cleanup at TA-V.

Applicable technologies include:

- Groundwater monitoring,
- ISB,
- MNA, and
- Pump and treat (ex-situ treatment technology to be determined).

4.0 REMEDIAL ALTERNATIVE EVALUATION APPROACH

Technologies that passed the initial screening process in Section 3.0 are used to create remedial alternatives that include combinations of the technologies and strategies for remedy implementation. Considerations of technology capabilities in relation to site-specific characteristics and cleanup goals were used to create a list of remedial alternatives. It was determined that ISB and pump and treat technologies would need to be followed by MNA or groundwater monitoring to ensure that cleanup goals are met. MNA allows additional time for natural attenuation mechanisms to further reduce the already decreased concentrations, and groundwater monitoring allows additional time to ensure that decreased concentrations will remain below MCLs. This section lists and describes each remedial alternative and includes the general description and approach to investigating and evaluating these potential remedies.

Upon selection of a preferred remedy, a contingency plan and institutional controls, specific to implementation for groundwater cleanup at TA-V, will be established. A contingency plan will be established to identify circumstances when the remedy will no longer effectively protect human health and the environment. At that point, the preferred remedy will be reevaluated and appropriate actions taken. Institutional controls will be established based on the characteristics of the implemented remedy at TA-V and in accordance with SNL/NM guidance. In August 2001, the DOE and SNL/NM, with input from the public, completed a draft "Long-Term Environmental Stewardship Plan." The outcome of the draft plan was a listing of issues that need resolution for the success of long-term environmental stewardship (LTES). These issues include the difficulties of maintaining institutional controls inherent in long-term groundwater monitoring. The DOE and SNL are continuing to work on the issues identified in the draft plan (SNL/NM 2001d).

Initial screening of technologies, as conducted in Section 3.3, identified technologies that could be used for remediation of groundwater at TA-V. Possible remedial alternatives were identified using these technologies:

1. **Groundwater Monitoring for VOCs and Nitrate.** A groundwater monitoring remedy would track concentrations, distribution, and transport of VOCs and nitrate during the remedial timeframe. A monitoring plan would be written, based on the "Current Conceptual Model of Groundwater Flow and Contaminant Transport at SNL/NM TA-V" (SNL/NM 2004a), to identify frequency and duration of sample collection and analysis from an adequate network of monitoring wells.
2. **MNA for VOCs and Groundwater Monitoring for Nitrate.** Implementing MNA for VOCs will allow for attenuation of VOCs in the subsurface without active remediation. Prior to MNA implementation, characterization activities will be performed (e.g., identification of indigenous microorganisms and presence of nutrients and electron donors) to determine if intrinsic contaminant degradation is taking place in the subsurface. Numerical groundwater modeling will be used to predict contaminant transport to potential receptors. Groundwater monitoring for nitrate would track nitrate concentrations, distribution, and transport during the remedial timeframe and can take place at the same time as MNA for VOCs.

3. **MNA for VOCs and Nitrate.** Implementing MNA for VOCs and nitrate would allow for attenuation of these contaminants in the subsurface to daughter products without active remediation. Prior to MNA implementation, characterization activities will be performed (e.g., identification of indigenous microorganisms and presence of nutrients and electron donors) to determine if intrinsic contaminant degradation is taking place in the subsurface. Numerical groundwater modeling will be used to predict contaminant transport to potential receptors.
4. **ISB followed by MNA for VOCs and Nitrate.** This remedy would begin with implementation of ISB for VOCs and nitrate. Following concentration reduction, MNA would be implemented to further reduce contaminant concentrations and ensure that sufficient degradation will take place during the remedial timeframe.
5. **ISB followed by MNA for VOCs and Groundwater Monitoring for Nitrate.** This remedy would begin with implementation of ISB for VOCs. Following concentration reduction, MNA would be implemented to further reduce VOC concentrations and ensure that sufficient degradation will take place during the remedial timeframe. Groundwater monitoring for nitrate would track nitrate concentrations, distribution, and transport during the remedial timeframe and would take place at the same time as ISB and MNA for VOCs.
6. **ISB followed by MNA for VOCs and MNA for Nitrate.** This remedy would begin with implementation of ISB for VOCs and MNA for nitrate. Following concentration reduction of VOCs using ISB, MNA would be implemented for VOCs and continued for nitrate to further reduce contaminant concentrations and ensure that sufficient attenuation is taking place during the remedial timeframe.
7. **Pump and Treat followed by MNA for VOCs and Nitrate.** This remedy would begin with implementation of pump and treat for VOCs and nitrate. Following concentration reduction, MNA would be implemented for these contaminants to further reduce contaminant concentrations and ensure that sufficient degradation is taking place during the remedial timeframe.
8. **Pump and Treat followed by MNA for VOCs and Groundwater Monitoring for Nitrate.** This remedy would begin with implementation of pump and treat for VOCs. Following concentration reduction, MNA would be implemented for VOCs to further reduce contaminant concentrations and ensure that sufficient degradation is taking place during the remedial timeframe. Groundwater monitoring for nitrate would track nitrate concentrations, distribution, and transport during the remedial timeframe and could take place at the same time as ISB and MNA for VOCs.
9. **Pump and Treat followed by MNA for VOCs and MNA for Nitrate.** This remedy would begin with implementation of pump and treat for VOCs and MNA for nitrate. Following concentration reduction of VOCs using pump and treat, MNA would be implemented for VOCs and continued for nitrate to further reduce contaminant concentrations and ensure that sufficient attenuation is taking place during the remedial timeframe.

The remedial alternative evaluation approach will involve continued screening of remedial alternatives based on the results of evaluation studies; details are presented in Section 5. The approach is intended to choose a remedy that is protective of human health and the environment. Studies can then focus on demonstrating remedy effectiveness and calculating design parameters. The CME threshold criteria, used in Section 3 during initial screening of technologies, will also be used to screen the remedial alternatives. Remedial alternative evaluation criteria derived from the requirements stated in the COOC (NMED 2003) will be used to quantitatively analyze remedy effectiveness and choose a preferred remedy (see Section 5.1).

5.0 REMEDIAL ALTERNATIVE EVALUATION PLAN

This Remedial Alternative Evaluation Plan provides guidance on activities and evaluation criteria to be used for evaluating the remedial alternatives presented in Section 4. This document presents the structure of the plan. Details of the evaluation will be presented in the CME Report. The Remedial Alternative Evaluation Plan includes a plan description, evaluation criteria, and potential activities for remedy evaluation that can be carried out to gather data. It is intended that the remedy implemented at TA-V will reduce COC concentrations throughout the plume to below MCLs within a remedial timeframe to be established in the Corrective Measures Implementation Work Plan. This evaluation will lead to the recommendation for implementation of the preferred remedial alternative as the corrective measure for TA-V.

5.1 Plan Description

The remedial alternative evaluation will include activities conducted to gather and evaluate data for each remedy using threshold and remedial alternative evaluation criteria. The remedial alternative evaluation will be conducted in such a way as to optimize data gathering activities. Evaluation of data will be ongoing during data gathering to screen any remedial alternative that does not meet the evaluation criteria.

Data gathering activities will be carried out in a staged process beginning with a paper study (Stage 1). In addition to paper studies, data gathering activities may include numerical modeling (Stage 2), laboratory studies (Stage 3), and field scale studies (Stage 4). These activities will provide site-specific data necessary to evaluate the remedies, provide a recommendation, and calculate design parameters. Each of these studies will only be performed as necessary to provide relevant site-specific data. A description of each stage is as follows:

- **Stage 1 – Paper Study** – will be conducted to evaluate the current literature and use existing data to calculate or demonstrate the potential cost and effectiveness of the remedy. A literature review has already been performed to provide information necessary for the initial technology screening described in Section 3. However, the paper study will be used to evaluate the remedial alternatives according to the remedial alternative evaluation criteria. Information in the current professional literature and from experience with the technologies will be combined with the site characteristics to create a conceptual design of each remedy. The conceptual design will be used to create initial cost estimates and secondary waste generation estimates. When conducting cost estimates, appropriate timeframes for the technologies within a remedy will be considered (e.g., a short pump and treat timeframe combined with a long MNA timeframe is more appropriate for a cost estimate than considering a long pump and treat timeframe combined with a short MNA timeframe). Costs will be estimated and effectiveness evaluated for application of this conceptual design.
- **Stage 2 – Numerical Modeling** – will be conducted to predict contaminant transport. If it is demonstrated during the paper study that a remedy is obviously not applicable, it will not be considered in the numerical modeling study. Data obtained during the laboratory or field scale studies will be used to refine the model. The predictions will account for the effects of each remedial alternative application. This will refine the conceptual model and prediction of the time necessary to comply with remedial action objectives for each remedy.

- **Stage 3 – Laboratory Studies** – will be conducted if the paper study results and calculations suggest a potential for remediation performance improvement or cost savings, but with uncertainties remaining that can be addressed through laboratory testing. Laboratory investigations will be designed to verify initial evaluation assumptions (reaction rates, mass balance, etc.), refine lifecycle costs and evaluate potential savings over base case costs, and provide data for field demonstration design or conceptual full-scale design.
- **Stage 4 – Field Scale Studies** – will provide two significant pieces of information: 1) verification that the performance projections calculated in the Stage 1, 2, or 3 results are accurate and 2) collection of treatment system performance data to support full-scale design. Prominent activities at this stage include obtaining design and cost data for full-scale performance based upon field demonstration of the technology.

Anticipated data gathering activities are detailed in Section 5.3. However, it is important to note that these activities may not be necessary due to the staged elimination process that will be used. Also, studies that are not included in this Work Plan may be necessary as additional data gaps are identified.

5.2 Evaluation Criteria

The purpose of the evaluation criteria is to provide a method for comparing the data gathered for each remedial alternative. Evaluation criteria will be used, as specified in the COOC (Section VII.C.3, CME Criteria [NMED 2003]). The remedial alternative evaluation will select the best remedy for implementation as the corrective measure at TA-V. During the evaluation, each remedial alternative will be evaluated based on the threshold criteria and the remedial alternative evaluation criteria identified here. Evaluation of the remedial alternative evaluation criteria will be a quantitative evaluation, while evaluation of threshold criteria will be qualitative. Remedial alternative evaluation criteria will be assigned a numerical value, which will be detailed in the CME Report. If a remedy does not meet a threshold criterion, it will be eliminated. If a remedy is significantly less effective than other remedies based on the remedial alternative evaluation criteria, it will also be eliminated.

5.2.1 Threshold Criteria

Threshold criteria were used in the initial evaluation to screen out technologies that cannot be implemented at the TA-V site (see Section 3). All of the technologies used to create the remedial alternatives met the threshold criteria. However, site-specific data gathered during the remedial alternative evaluation may demonstrate that a remedial alternative cannot reasonably meet one of the threshold criteria. Therefore, each remedial alternative will be evaluated following each data gathering activity to assure that it can meet the threshold criteria. The following threshold criteria will be evaluated:

- **Protective of human health and the environment.** Any proposed remedy must be protective of human health and the environment. As stated in the RCRA Corrective Action Plan, “Remedies may include those measures that are needed to be protective, but are not directly related to media cleanup, source control, or management of wastes” (EPA 1994). Components of remedies considered at TA-V include evaluating protection of human health and the environment for air emissions, potential formation of hazardous degradation products, any hazards associated with operations and maintenance of the remedy, and remediation within an appropriate timeframe.

- **Attain media cleanup standard or alternative, approved risk-based cleanup goals.** Any proposed remedy must attain groundwater cleanup standards or goals. As stated in the RCRA Corrective Action Plan, “Remedies will be required to attain media cleanup standards set by the implementing agency, which may be derived from existing state or federal regulations (e.g., groundwater standards) or other standards. The media cleanup standards for a remedy will often play a large role in determining the extent of, and technical approaches to, the remedy” (EPA 1994). The cleanup goals and objectives for TA-V are described in Section 2. If a remedy cannot meet any one of these goals or objectives, it should no longer be considered.

- **Comply with standards for management of wastes.** Any proposed remedy must comply with all applicable state or federal regulations. As stated in the RCRA Corrective Action Plan, “Waste management activities will be conducted in compliance with all applicable state or federal regulations (e.g., closure requirements, land disposal restrictions)” (EPA 1994). For remedies considered at TA-V, waste could be generated during the life cycle of the remedy in the form of contaminated groundwater brought to the surface and laboratory and field sampling wastes, and at the completion of the remedy during final decommissioning of the remedy system.

As discussed in the TA-V Current Conceptual Model (SNL/NM 2004a), it is believed that no source of residual contaminants remains at TA-V; therefore, the source control threshold criteria will not be evaluated. If a remedial alternative does not meet one of the threshold criteria, then it will be eliminated from further evaluation. The threshold criteria will be evaluated using a matrix similar to the example in Table 5-1. Evaluation will be conducted on a YES/NO basis. A remedy will be eliminated if a NO evaluation is given for any of the criteria.

5.2.2 Remedial Alternative Evaluation Criteria

Remedial alternative evaluation criteria will be evaluated for each remedy. A summary of this comparison will be included in a matrix, as shown in the example in Table 5-2. Numerical values will be assigned to each criterion for the factors that are described in the following sections. These remedial alternative evaluation criteria will be evaluated several times following data gathering activities. If at any time it is determined that a remedy is significantly less effective than the other remedies, then it will no longer be considered. The criteria and considerations for evaluating each remedy are described below.

Table 5-1. Example remedial alternative evaluation using the COOC threshold criteria.

Remedial Alternatives	Protective of Human Health and Environment	Attain Media Cleanup Standards	Waste Management Standards Compliance
Groundwater Monitoring for VOCs and Nitrate			
MNA for VOCs and Groundwater Monitoring for Nitrate			
MNA for VOCs and Nitrate			
ISB followed by MNA for VOCs and Nitrate			
ISB followed by MNA for VOCs and Groundwater Monitoring for Nitrate			
ISB followed by MNA for VOCs and MNA for Nitrate			
Pump and Treat followed by MNA for VOCs and Nitrate			
Pump and Treat followed by MNA for VOCs and Groundwater Monitoring for Nitrate			
Pump and Treat followed by MNA for VOCs and MNA for Nitrate			
<p>YES = the remedy meets the threshold criterion NO = the remedy does not meet the threshold criterion</p> <p>Note: The threshold criterion, <i>Source Control</i>, is not included since a secondary source of release is not present in the vadose zone or saturated zone at TA-V.</p>			

Table 5-2. Example CME evaluation using the COOC corrective measures remedial alternative evaluation criteria.

Remedial Alternatives	Long-Term Reliability and Effectiveness	Reduction of Toxicity, Mobility, or Volume	Short-Term Effectiveness	Feasibility	Cost
Groundwater Monitoring for VOCs and Nitrate					
MNA for VOCs and Groundwater Monitoring for Nitrate					
MNA for VOCs and Nitrate					
ISB followed by MNA for VOCs and Nitrate					
ISB followed by MNA for VOCs and Groundwater Monitoring for Nitrate					
ISB followed by MNA for VOCs and MNA for Nitrate					
Pump and Treat followed by MNA for VOCs and Nitrate					
Pump and Treat followed by MNA for VOCs and Groundwater Monitoring for Nitrate					
Pump and Treat followed by MNA for VOCs and MNA for Nitrate					

- **Long-term reliability and effectiveness.** In general, this criterion will evaluate the reliability of the remedy to meet cleanup standards and reduce risk. As stated in the COOC, “Each remedy shall be evaluated for long-term reliability and effectiveness. This factor includes consideration of the magnitude of the risks that will remain after implementation of the remedy; the extent of long-term monitoring or other management that will be required after implementation of the remedy; the uncertainties associated with leaving contaminants in place; and the potential for failure of the remedy. A remedy that reduces risks with little long-term management, and that has proven effective under similar conditions, shall be preferred” (NMED 2003). This criterion will include defining the institutional controls to be established at TA-V for each remedy.
- **Reduction of toxicity, mobility, or volume.** This criterion is intended to evaluate the effectiveness of the remedy at reducing TCE, PCE, and nitrate concentrations in the TA-V groundwater plume. As stated in the COOC, “Each remedy shall be evaluated for its reduction in the toxicity, mobility, and volume of contaminants. A remedy that more completely and permanently reduces the toxicity, mobility, and volume of contaminants shall be preferred” (NMED 2003).
- **Short-term effectiveness.** In general, short-term effectiveness applies to the ability of the remedy to reduce risks during the remediation process. These risks include reducing exposure to contaminants during remedy implementation and risks and hazards introduced by remedy implementation. As stated in the COOC, “Each remedy shall be evaluated for its short-term effectiveness. This factor includes consideration of the short-term reduction in existing risks that the remedy would achieve; the time needed to achieve that reduction; and the short-term risks that might be posed to the community, workers, and the environment during implementation of the remedy. A remedy that quickly reduces short-term risks, without creating significant additional risks, shall be preferred” (NMED 2003).
- **Feasibility.** As stated in the COOC, “Each remedy shall be evaluated for its feasibility, or the difficulty of implementing the remedy. This factor includes consideration of installation and construction difficulties; operation and maintenance difficulties; difficulties with cleanup technology; permitting and approvals; and the availability of necessary equipment, services, expertise, and storage and disposal capacity. A remedy that can be implemented quickly and easily and poses fewer and lesser difficulties shall be preferred” (NMED 2003).
- **Cost.** As stated in the COOC, “Each remedy shall be evaluated for its cost. This factor includes a consideration of both capital costs and operation and maintenance costs. Capital costs shall include, without limitation, construction and installation costs; equipment costs; land development costs; and indirect costs including engineering costs, legal fees, permitting fees, startup and shakedown costs, and contingency allowances. Operation and maintenance costs shall include, without limitation, operating labor and materials costs; maintenance labor and materials costs; replacement costs; utilities; monitoring and reporting costs; administrative costs; indirect costs; and contingency allowances. All costs shall be calculated based on their net present value. A remedy that is less costly, but does not sacrifice protection of health and the environment, shall be preferred” (NMED 2003).

5.3 Potential Activities for Remedy Evaluation

In order to identify potential study needs for inclusion in this Work Plan, a preliminary evaluation of the data needs was performed. Both the threshold and the remedial alternative evaluation criteria were considered. Paper, numerical modeling, laboratory, and field scale studies were derived to answer the data needs that are necessary to evaluate each remedy. These stages are described in greater detail in the following sections. Following each stage, the data will be reevaluated to eliminate remedial alternatives that are not feasible or are ineffective to determine which studies will need to be carried out in the next stage. These studies will be performed as necessary considering the results of the ongoing evaluation process. Results of the studies will be used to evaluate each remedial alternative and calculate design parameters for corrective measure implementation.

5.3.1 Stage 1 – Paper Study

The data gathering activities will begin with a paper study. Information about each remedy and the site will come from professional literature, site characterization (TA-V Current Conceptual Model), and professional experience. This information will be used to evaluate each remedy for each of the threshold criteria and each of the remedial alternative evaluation criteria discussed in Section 5.2. The following is a list of example calculations or evaluations:

- The risk of remedy failure can be evaluated by searching the professional literature and professional experience for application of the remedy to a site with similar contaminant concentrations and subsurface conditions. If the remedy has proven effective at a similar site, then it will be rated high depending on the weight of evidence. If application of the remedy at another site with similar characteristics suggests that the remedy would fail or be marginally successful, then the remedy will be rated accordingly.
- A conceptual design of each remedial alternative will be devised using site-specific and remedy-specific information. The conceptual design will include a description of how proposed treatment mechanisms will work. It can include a description of planned construction, operations, and monitoring and will include the operation timeframe of each technology that is part of the overall remedy.
- Capital costs and operations and maintenance costs will be estimated for each remedy. For instance, the cost estimates for MNA will include cost of possible construction of new monitoring wells, periodic groundwater monitoring, data reduction, and modeling; whereas the cost for ISB followed by MNA will include all of these costs with the additional cost of construction, operation, maintenance, and materials.
- The timeframe and magnitude of institutional controls will be evaluated based on risks to human health and the environment associated with both the short-term effectiveness and long-term reliability and effectiveness of the remedy. Institutional controls associated with long-term reliability and effectiveness can be evaluated by considering the risks remaining after remedy implementation and the extent of long-term monitoring or other management required for the remedy. Overall institutional control requirements for any long-term action will be defined in the CME Report. Some of these institutional controls will be the same for all remedial alternatives. Remedy-specific institutional controls will be identified in the Paper Study.

- Secondary waste stream production will be calculated based on knowledge of each remedy and site-specific characteristics. For instance, the secondary waste stream for MNA would only include waste generated during sampling. Secondary waste for pump and treat followed by MNA would include sampling wastes and wastes generated during treatment. Treatment wastes would be calculated considering observed COC concentrations and estimated total volume to be treated. Difficulty dealing with the phase of the waste stream will depend on the type of treatment.

It is anticipated that the paper study will provide much of the information necessary to evaluate the remedial alternatives. The data necessary to answer the remaining questions are referred to as data gaps. A preliminary identification of these data gaps considered each evaluation criterion for all remedial alternatives. Table A-1, Appendix A, documents the results of this preliminary evaluation. The studies described below for Stages 2, 3, and 4 will be performed for those remedies that pass the paper study evaluation.

5.3.2 Stage 2 – Numerical Modeling

Numerical modeling will consider those remedies that passed the evaluation following the Stage 1 paper study. Additional information is needed to adequately determine the fate and transport of contaminants in groundwater at TA-V, especially regarding contaminant transport to downgradient receptors. Two numerical modeling studies were introduced in the TA-V Current Conceptual Model (SNL/NM 2004a) and are further described in this Work Plan.

- Numerical modeling studies have been conducted to evaluate capture zones for production wells located north of TA-V (SNL/NM 2001b). These capture zone studies indicate that travel times to production wells may be as long as 100 years. However, contaminant concentrations along the flow path were not estimated. Evaluation of contaminant breakthrough at different locations along the flow path (including the sharp change in flow direction associated with the distribution of ARG deposits) will be performed to determine the fate of contaminants, effects of dilution, and order-of-magnitude concentration changes at downgradient receptors. This evaluation of the fate of contaminants downgradient from TA-V will utilize existing numerical simulators.
- Municipal pumpage from the COA Ridgecrest well field has greatly modified the direction of flow in the aquifer to the west of TA-V. One long-term water-use scenario may include discontinuing or reducing pumping from this well field. A numerical modeling study of this scenario will be conducted to show particle tracking of contaminants without the influence, or a reduced influence, of pumpage from the COA Ridgecrest well field. Results of contaminant transport will help determine a timeframe and magnitude of risk reduction to downgradient receptors.

5.3.3 Stage 3 – Laboratory Studies

The preliminary identification of data gaps demonstrated that laboratory studies would only be performed for remedies involving ISB if those remedies pass the paper study evaluation (see Table A-1) and it is determined that a field study cannot be completed without laboratory investigations. Laboratory microcosm studies may be necessary to verify that conditions are

conductive in the aquifer for effective ISB. TCE, PCE, and nitrate are known to degrade to less toxic products under anaerobic conditions. Certain site-specific conditions that are not known to be present in the aquifer at TA-V are necessary for complete ARD. One possible condition is the presence of the proper microbial community to drive complete ARD of PCE and TCE to ethene. It is also possible that an incomplete microbial community is present that would cause dechlorination to stall at cis-DCE, which is considered to be less toxic than PCE or TCE.

One way to evaluate the dechlorination potential of the indigenous microbial community is through microcosm studies. These studies would consist of electron donor amended microcosms, prepared and maintained under controlled anaerobic conditions using appropriate TCE-, PCE-, and nitrate-impacted groundwater samples from the site. The microcosms would be monitored for PCE, TCE, dechlorination daughter products, and sodium lactate degradation products. Results of the microcosm studies will demonstrate whether the indigenous microbial community has the ability to completely dechlorinate PCE and TCE, or if the microbial community only has the ability to degrade PCE and TCE to cis-DCE. The studies can be used to determine the effect of nitrate in the water on the ARD process. The laboratory studies will provide information relevant to a field scale test (i.e., dechlorination and denitrification rates). However, direct application of these parameters in designing the corrective measure is to be avoided.

5.3.4 Stage 4 – Field Scale Studies

Field scale studies or demonstrations may be performed to verify predictions obtained from paper, modeling, and/or laboratory studies. These field scale demonstrations would be used to verify MNA, ISB, and pump and treat effectiveness at the site.

5.3.4.1 Investigating natural attenuation mechanisms (MNA):

In order to establish that natural attenuation of COCs in the TA-V groundwater plume will occur, mechanisms for contaminant degradation need to be established. Historical evaluation of TA-V groundwater suggests that the low concentrations of chlorinated solvents (generally less than 30 µg/L) may be undergoing natural degradation due to processes that are as yet undefined. More recent data have provided an opportunity to review groundwater reduction-oxidation conditions to evaluate the potential for aerobic or anaerobic biodegradation. In addition, nitrate has been detected above regulatory limits in TA-V groundwater. Additional sampling is being performed under the *Sandia National Laboratories TA-V Groundwater Remediation Sampling and Analysis Plan* (Dettmers and Wymore 2003) in order to fill data gaps in historical data to complete a biodegradation assessment for these contaminants.

The purpose of this sampling is to collect appropriate analytes during one or more quarterly TA-V groundwater sampling events to provide adequate data for a TCE biodegradation screening assessment, as defined by the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (EPA 1998), and for an assessment of the potential for nitrate biodegradation. These data will be integrated with historical site data to provide the most current understanding of the TA-V system.

In addition to the parameters being monitored (SNL/NM 2004b), enzyme probe analyses may be applied to TA-V samples to provide direct evidence of the presence of TCE cometabolizing enzymes. Cometabolism is defined as the transformation of an organic compound by a microorganism that is unable to use the substrate as a source of energy or as one of its constituent elements (Alexander 1967). Cometabolism, as the name implies, occurs in conjunction with the metabolism of another substrate, which the microorganisms use for carbon and/or energy. Thus, aerobic cometabolism requires the presence of the primary substrate, oxygen, and the cometabolic substrate. The primary substrate is required because the same enzyme that transforms the primary substrate also fortuitously transforms the cometabolic substrate. If the primary substrate is absent, the enzyme required for cometabolic transformation will not be induced and the cometabolic transformation will not occur.

TCE, cis-DCE, trans-DCE, and vinyl chloride (VC) have all been shown to be susceptible to cometabolic oxidation under aerobic conditions (Wilson and Wilson 1985; Semprini et. al. 1990). In addition, DCE and VC have been shown to be susceptible to direct oxidation under aerobic conditions (Vogel, Criddle, and McCarty 1987; Bradley and Chapelle 2000) and more recently under anoxic conditions (Bradley and Chapelle 1998). PCE has been shown to be resistant to both direct and cometabolic oxidation (McCarty 1996). Several primary substrates induce aerobic cometabolism of chlorinated ethenes. Among them are methane, propane, butane, phenol, toluene, and ammonia. The enzyme methane monooxygenase (MMO), present in methanotrophs, is known to cometabolize TCE. For a review of these enzymes and cometabolic mechanisms, refer to the *Final Quick Win Vertical Profile Sampling Report* (Wymore and Sorenson 2003).

Activity-dependent enzyme probes are research tools that have the potential to provide direct evidence that the mechanism for aerobic cometabolic oxidation of chlorinated ethenes is present and active in the aquifer. The probes work by reacting with enzymes that are known to degrade TCE. If an appropriate enzyme is present and active within a given sample, then application of the probes will result in a fluorescent product that can easily be seen under a microscope. If the appropriate enzyme is not present, or it is present but not active in a given sample, then the probes will not be transformed into a fluorescent product. Activity dependent probes have been developed to detect the presence of enzymes that aerobically cometabolize TCE.

5.3.4.2 Lactate injection field demonstration (ISB):

A field scale demonstration of ISB will be performed if it is necessary to demonstrate the ISB effectiveness at reducing concentrations of PCE, TCE and/or nitrate at the site. Paper studies and laboratory microcosm studies may be sufficient to demonstrate that a remedial alternative involving ISB may be the most effective remedy. However, a field scale demonstration will be necessary to confirm ISB effectiveness at the site and calculate design parameters. Site-specific data will be necessary for long-term corrective measures planning. A field demonstration would have the following objectives:

- Estimate ARD and/or denitrification rates in the field and provide an estimated timeframe,
- Determine the fate of degradation products,
- Determine the extent of electron donor transport compared to the distribution of contaminants,
- Determine the effect of competing electron acceptors, and
- Determine the extent of COC concentration rebound after donor injections have ceased.

5.3.4.3 Aquifer tests (pump and treat):

Much of the data necessary to evaluate remedial alternatives involving pump and treat can be estimated during the paper study and numerical modeling exercises using the existing information about aquifer parameters. However, demonstration of pump and treat performance for application in a corrective measure will require site-specific well data. These data could be collected by conducting an aquifer test involving proposed pumping wells. Objectives of such an aquifer test would be:

- Estimation or verification of predicted capture zones and comparison to the contaminant distribution, and
- Obtaining well yield information to estimate treatment volumes.

6.0 CORRECTIVE MEASURES EVALUATION REPORT

The results of the CME will be presented in the CME report. This report will provide the technical basis for any recommendation for implementation of a corrective measure and will include technical and functional requirements for remedy implementation. This report will serve to document the regulatory agreements and will serve as the regulatory basis for the implementation of the corrective measure. The key components of the CME report are designated requirements from the COOC (NMED 2003). Guidelines of the RCRA Corrective Action Plan (EPA 1994) were also considered. The following is an outline of the key components of the CME report:

- I. Title Page and Signature Block
- II. Executive Summary
- III. Table of Contents
- IV. Figures
- V. Tables
- VI. Introduction/Purpose
- VII. Background Information
- VIII. Site Conditions:
 - a. A summary of surface, subsurface, and groundwater conditions as appropriate.
 - b. A brief summary/discussion of any new information since the field investigation.
- IX. Potential Receptors:
 - a. Including discussion of sources, pathways, and receptors.
- X. Regulatory Criteria
- XI. Identification of Corrective Measures Options:
 - a. Identification.
 - b. Screening.

XII. Evaluation of Corrective Measures Options:

- a. Overview of the evaluation criteria and approach.
- b. Presentation of evaluation results.

XIII. Selection of a Preferred Corrective Measure:

- a. Demonstrate that the corrective measure will protect human health and the environment.
- b. Demonstrate that the corrective measure will attain media cleanup standards.
- c. Demonstrate that the corrective measure will comply with any applicable standards for waste management.
- d. Demonstrate that the corrective measure is effective in other factors.

XIV. Design Criteria to Meet Cleanup Objectives

XV. Schedule

XVI. Appendices

7.0 PROJECT MANAGEMENT PLAN

This section presents the Project Management Plan (PMP) for the TA-V CME. This includes the overall approach, the project organizational structure, project schedule and deliverables, project budget, and the project assumptions.

7.1 Project Approach

The corrective measures process that is being undertaken for the TA-V contaminant groundwater plume, by requirement of the COOC (NMED 2003) and under the direction of the RCRA Corrective Action Plan (EPA 1994), is a phased approach illustrated in Figure 7-1. This approach will be used to determine and implement the selected remedy as the corrective measure for meeting the cleanup standards, objectives, and requirements for TA-V. The process includes the following four steps:

1. Defining the problem (CME Work Plan),
2. Remedy evaluation (CME Report),
3. Long-term corrective measures planning (Corrective Measures Implementation Plan),
and
4. Corrective measures implementation (Corrective Measures Implementation Report).

Following each step will be a decision point to obtain concurrence from the regulatory agencies before proceeding with the next phase of the process.

In conjunction with the TA-V Current Conceptual Model (SNL/NM 2004a), this CME Work Plan is represented in Figure 7-1 under the problem definition step. Following agency approval of this CME Work Plan, the CME will proceed. The CME will result in recommendations for the corrective measure, which will be presented in the CME report.

This process will define the cleanup approach and document understandings and agreements between SNL and the regulatory agencies regarding corrective measure execution. The approach being developed will determine the most cost- and schedule-effective corrective measure that can gain public and regulatory acceptance. An important aspect of this approach, and an objective of this Work Plan, is outlining and defining all of the goals, objectives, requirements, and other criteria that must be addressed in order to design and implement a corrective measure. It is likely that the team of regulators and technical staff that developed the cleanup approach will change during the corrective measure timeframe. For continuity in achieving the project goals and objectives, well-documented requirements and implementation strategies will help future parties execute the cleanup approach in the manner envisioned by the initial project team. The overall goal of developing this document base is to provide clear direction for implementing and attaining the regulatory standards, periodic reporting requirements, and the scope, schedule, and budget, with all leading toward site closure in accordance with pre-determined requirements.

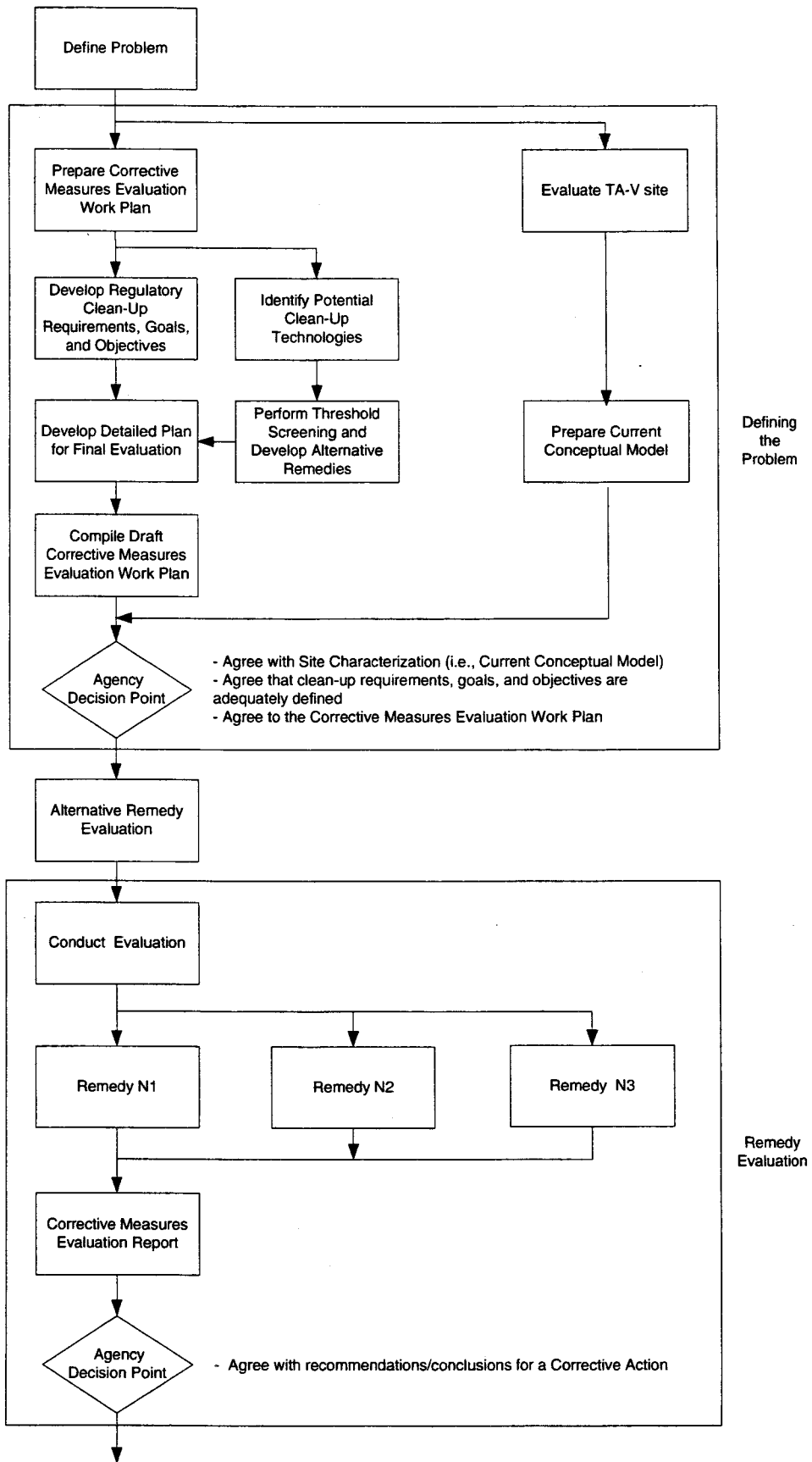


Figure 7-1. Logic diagram for the TA-V project.

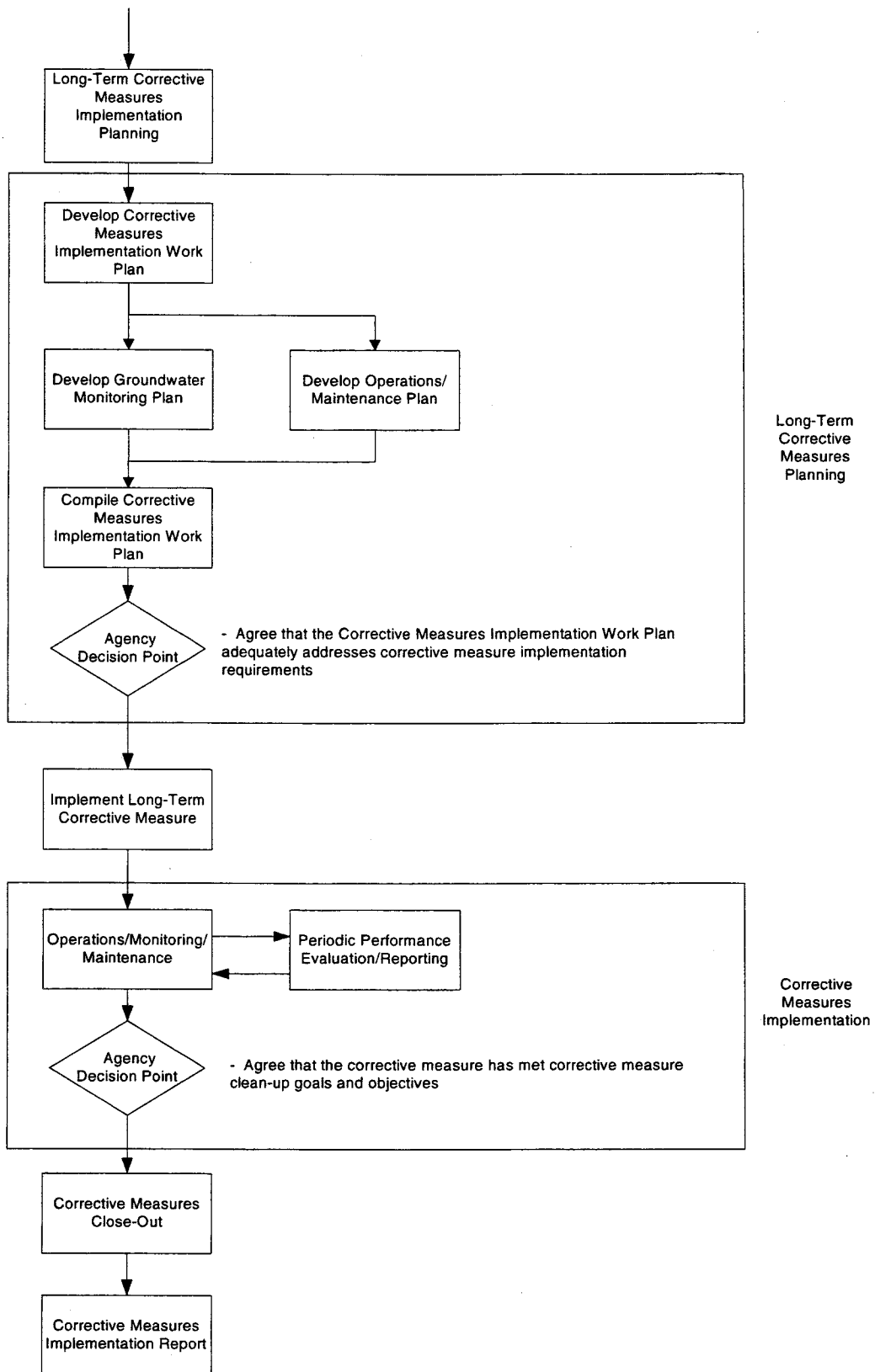


Figure 7-1. (continued).

It is important throughout this process to maintain a strong relationship between the team (i.e., technical, regulatory, and the public). An important part of this process consists of scheduled reviews and communication with the regulatory agencies and other pertinent stakeholders to develop a common understanding of the desired outcome of the CME.

7.2 Organizational Structure

Figure 7-2 presents the organizational structure for the TA-V CME. The primary functional entities of this project are the Sandia Groundwater Project Leader, the Agencies, the CME Implementation Team, Site Technical and Field Services, and the Technical Peer Review Panel.

The Sandia Groundwater Project Leader is responsible for the overall project (i.e., scope, schedule, and budget). This position is responsible to implement the COOC (NMED 2003) for TA-V and to meet regulatory requirements, milestones, and objectives. This position also serves as an interface between the CME Implementation Team, Site Technical and Field Services, and the Agencies. The Sandia Groundwater Project Leader identifies and acquires technical and operational resources to complete the project scope.

NMED is the regulatory agency and is responsible for enforcing the requirements identified in the COOC for the TA-V CME. The DOE owns and operates SNL/NM and Sandia Corporation is the co-operator of SNL/NM.

The CME Implementation Team reports to the Sandia Groundwater Project Leader and works with technical support personnel. The primary function of the CME Implementation Team is to lead the screening and evaluation of potential technologies and remedial alternatives that will meet cleanup standards for TA-V groundwater. This includes execution of individual technical tasks as well as overall responsibility for the technical direction of the project. The CME Implementation Team is responsible for interpreting all technical data and for making decisions based on these interpretations.

Technical support personnel report to the Sandia Groundwater Project Leader and work with the CME Implementation Team. They are responsible for performance and oversight of all onsite field activities that are conducted in support of the TA-V CME. This may include groundwater monitoring and analysis, well installation, data compilation, and report writing. Technical support personnel also provide site historical and process knowledge as it pertains to the TA-V CME.

A Technical Peer Review Panel may be utilized to ensure that the project is executed in the most technically rigorous and defensible manner possible. This panel, comprised of recognized experts in the field of groundwater characterization and remediation, would be used to review work plans, technical documents, and project reports. The members of the panel may also serve as technical resources for other members of the project team.

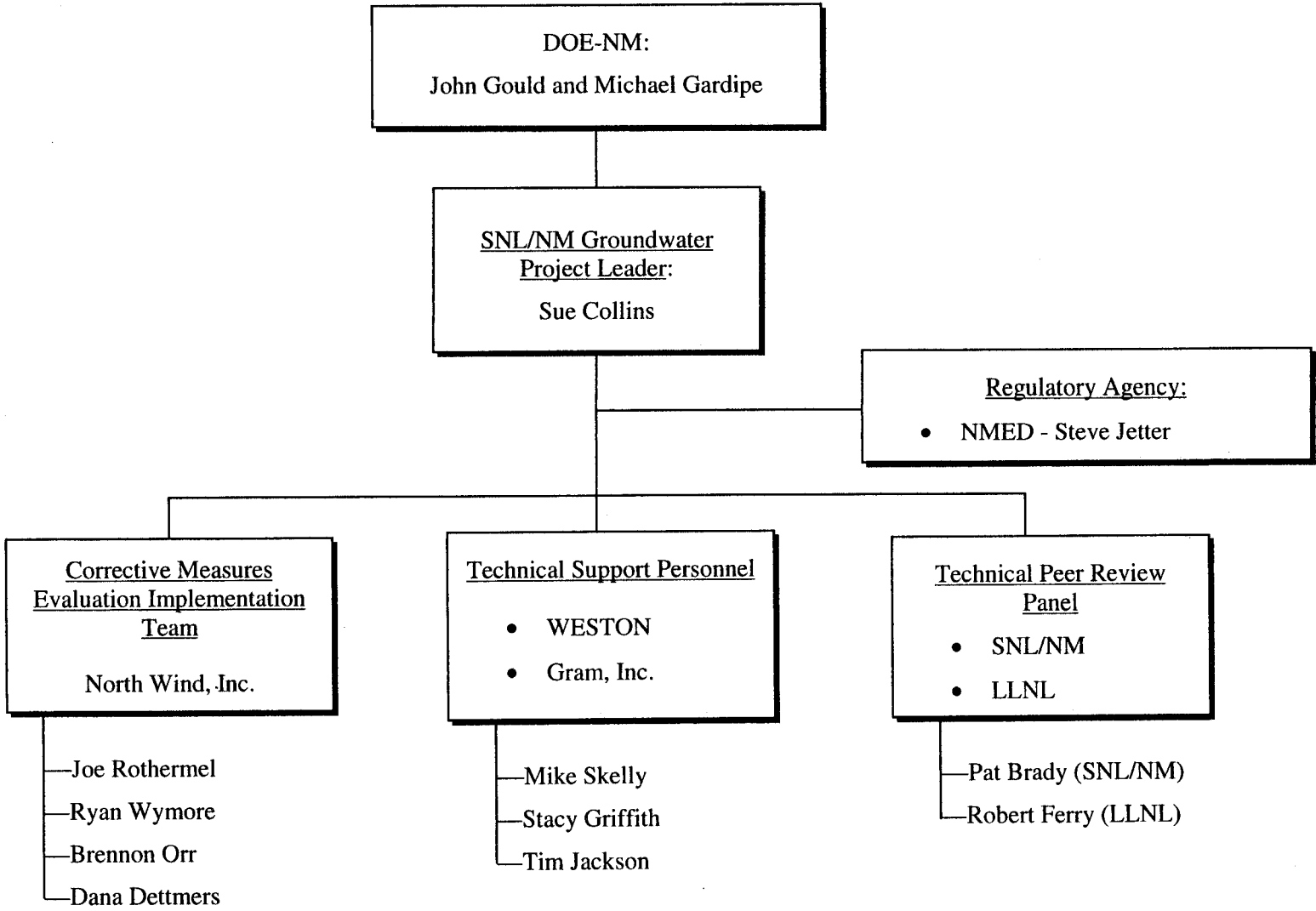


Figure 7-2. Project organizational chart for the TA-V CME.

7.3 Schedule

The corrective measures schedule has been derived through development of the project requirements. The basis for the schedule is the logical development of project tasks and activities, which will support the corrective measure under the COOC. This schedule will include corrective measure commitments, milestones, and NMED decision points. Certain documents require NMED review and approval. These documents are identified deliverables, which are identified within the project schedule as such, and have clearly defined agency review/comment and comment resolution periods.

7.3.1 Description

The corrective measures schedule is presented in Figure 7-3. This schedule identifies the logical progression of tasks and activities aimed at achieving the corrective measures cleanup objectives. This schedule covers development of site characterization knowledge, delineation and preparation of the corrective measures work plan, technology development and evaluation, the corrective measures report, and development and implementation of the corrective measure.

The project schedule has been developed to expedite project execution performance to meet enforceable milestone commitments. As such, the schedule indicates planned and enforceable execution dates. The enforceable dates are those set by the COOC for the completion of certain aspects of the project. The planned completion dates are not enforceable, but are the dates by which the project will endeavor to execute the work. The planned dates are usually 1 to 2 months ahead of the actual corresponding enforceable date.

7.3.2 Deliverables

The documents to be submitted to the Agencies as deliverables, with the corresponding submittal dates in accordance with the COOC requirements, are presented in Table 7-1. Additional documents and delivery dates may be identified in subsequent documents as the work progresses. The corrective measures schedule may be revised from time to time to reflect these changes.

Table 7-1. Agency deliverable documents.

Deliverable	Planned Submittal Date	Enforceable Submittal Date	Agency Review Duration
Current Conceptual Model	4/22/04	N/A	30 days
CME Work Plan ¹	4/22/04	TBD	30 days
CME Report	8/8/05	9/30/05	44 days
Corrective Measures Implementation Plan	5/4/06	9/30/06	30 days

1: 90 days after signing the COOC.

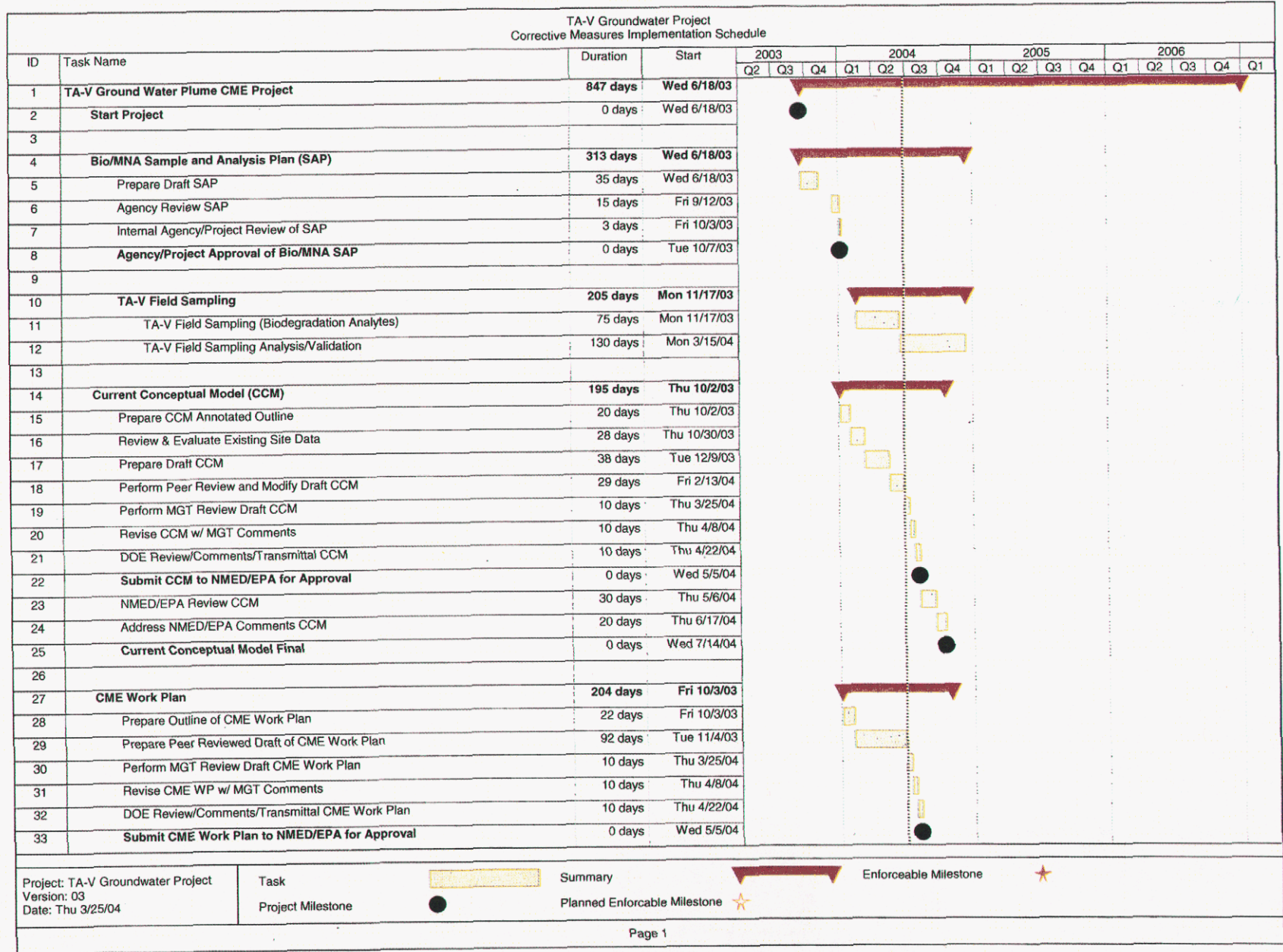


Figure 7-3. COOC schedule.

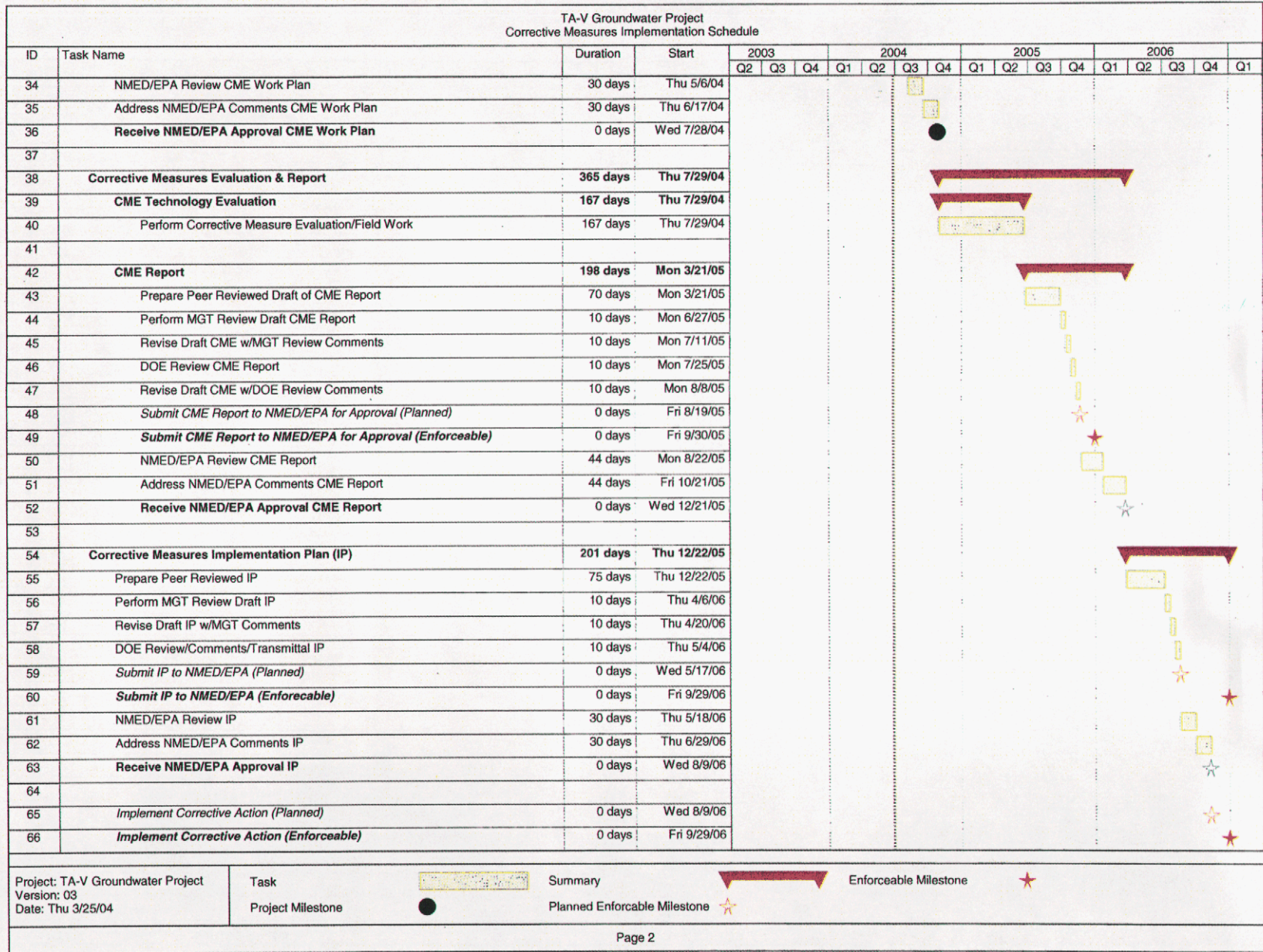


Figure 7-3. (continued).

7.4 Budget

Table 7-2 presents the current TA-V budget, based on the SNL/NM ER Project Life-Cycle Baseline calculated to 2070 and approved through 2006. It is broken down by project management activities, technology evaluation costs, and site technical services for Fiscal Year (FY) 2004 through FY 2006. A lump sum that assumes an FY 2006 implementation of the final corrective measure is presented for long-term operations.

Table 7-2. TA-V CME budget.

Category	Timeframe (Fiscal Year)	Amount (\$)
Overall Project Management (Sandia Project Office Costs) ¹	2004 through 2006	386,000
Technology Evaluation (Current Conceptual Model, CME Work Plan, Evaluation, Implementation Documents) ¹	2004 through 2006	536,000
Site Technical Services (Field Sampling, Modeling, Peer Review, etc.) ¹	2004 through 2006	676,000
Long-Term Operations ²	2007 through 2070 (lump sum based on 2006 CME implementation)	9,096,000

1. Based on the SNL/NM ER Project Life-Cycle Baseline calculated to 2070 and approved through 2006
 2. Currently based on groundwater monitoring operations, but will require re-baselining based on outcome of the CME.

7.5 Assumptions

The TA-V groundwater project is managed as part of the SNL/NM ER Project. The funding targets listed above for TA-V depend on funding for the entire ER Project. As such, the relevant assumptions for the entire ER Project, as well as those for TA-V, are listed below.

7.5.1 General Assumptions

ER Program Assumptions are as follows:

- The ER Project mission, objective, and scope are stable and will proceed as represented by the project documents delivered to the DOE and the baseline from FY 2004 through FY 2006,
- SNL/NM and DOE management will support ER project management as necessary to meet project and regulatory objectives, as described in the project documents developed under the COOC and delivered to DOE,
- The current DOE working and teaming relationships with SNL/NM will be maintained and streamlined to conform with implementation of the project goals, and
- No catastrophic events will occur that would significantly delay the project schedule or significantly increase the project scope.

7.5.2 Financial Assumptions

This funding profile is based on the following assumptions:

- DOE will provide funding necessary to implement the corrective measures evaluation as enumerated in the approved TA-V CME Work Plan through the completion of the CME Report, and
- DOE will provide funding for additional scope resulting from the realization of programmatic risk.

7.5.3 Regulatory Assumptions

- The COOC will be the governing document for enumerating the requirements for this corrective action. Changes to the requirements for the corrective measure will be done in accordance with the process for change outlined in the COOC.
- The documents that are required under the COOC are enumerated in Section 7.3.2 of this document. These documents comprise the project's team basis and implementation requirements, as required by the COOC, for the execution of the CME for TA-V. If one or more parties to the COOC desire to change a project requirement, either through a COOC modification, a change to a Law, permit or statute, or a change in the site conditions, then the Documents which govern the project implementation basis and requirements will be required to be modified. This may include some or all of the scope, schedule and budget.
- Regulatory agencies, and particularly the NMED, will have adequate resources to provide regulatory decisions and document reviews in support of the schedule.
- NMED regulatory review periods will not increase and the document approval backlog will steadily decrease through time.
- Positive relationships and cooperation with the regulatory agencies will continue and administrative requirements will not increase.

7.5.4 Project Scope Assumptions

- Project scope will not change significantly from that which is currently incorporated in the baseline,
- Unforeseen circumstances will allow the extension of the completion milestone beyond FY 2006, and
- Final stewardship requirements will not significantly increase baseline scope above the level that is currently anticipated.

The monitoring assumptions specific to TA-V are as follows:

- The COCs include TCE, PCE, and nitrate,
- Conventional pumping methods will be used (e.g., Bennett pumps). Labor hours are based on FY 2003 estimates, and
- Waste management requirements or disposition costs will not change significantly from those currently in place (e.g., purge water volumes will continue to be about four drums or less per well). It will always be possible to discharge the purge water to a nearby drain connected to a publicly owned treatment works (POTW).

7.5.5 Project Schedule and Planning Assumptions

- The project schedule outlined in this document is the basis for the implementation of the CME. This schedule is based upon the requirements of the COOC. As stated in Section 7.5.4 above, changes to the CME documents or the COOC are grounds for modification of the schedule.
- The schedule presented in this document represents the CME schedule for achieving the 2005 enforceable delivery date of the CME Report. This schedule illustrates agency review periods necessary to achieve the evaluations and preparation of the report.

7.5.6 Technical Assumptions

- The current technical direction of the project will not change significantly. All stakeholders and regulatory authorities will reach a common consensus through their review, recommendation, and/or approval authority on the current technical direction.
- Sufficient independent technical review will be utilized to ensure that approaches are technically sound.
- Proven and tested technologies will be utilized and no technology development activities will be required that would delay planned activities.

7.5.7 Public Involvement Assumptions

- The results of actions or recommendations by the public will not increase project scope or schedule beyond FY 2006, and
- Working groups with public representation will continue to serve as the mode for close involvement of stakeholders in the corrective-action process.

REFERENCES

1. 40 CFR 141.61, 2002, Title 40, "Protection of Environment," Subchapter D, "Water Programs," Part 141, "National Primary Drinking Water Regulations," Section .61, "Maximum Contaminant Levels for Organic Contaminants," *Code of Federal Regulations*, Office of the Federal Register.
2. Alexander, M., 1967, In "Agriculture and the Quality of Our Environment" (N.C. Brady ed.), *American Association for the Advancement of Science*, Washington D.C., pp. 331-342.
3. Bartolino, J.R., and J.C. Cole, 2002, "Groundwater Resources of the Middle Rio Grande Basin," U.S. Geological Survey, Circular 1222, <http://water.usgs.gov/pubs/circ/2002/circ1222/>.
4. Bradley, P.M. and F.H. Chapelle, 2000, "Aerobic Microbial Mineralization of Dichloroethene as Sole Carbon Substrate," *Environmental Science and Technology*, Volume 34, Issue 1, pp. 221-223.
5. Bradley, P.M. and F.H. Chapelle, 1998, "Humic Acids as Electron Acceptors for Anaerobic Microbial Oxidation of Vinyl Chloride and Dichloroethene," *Applied and Environmental Microbiology*, Volume 64, Number 8, pp. 3102-3105.
6. Center for Public Environmental Oversight, 2000, Technology Tree: Bio-reactors. <http://www.cpeo.org/techtree/ttdescript/biorec.htm>.
7. Department of Defense, December 2000, Environmental Security Technology Certification Program (ESTCP) Cost and Performance Report: Multi-Site In Situ Air Sparging, CU-9808, <http://www.estcp.org/documents/techdocs/199808.pdf>.
8. Dettmers, D.L. and Wymore R.A., October 2003, *Sandia National Laboratories TA-V Groundwater Remediation Sampling and Analysis Plan*, NW-ID-2003-072, Rev. 0, North Wind, Inc.
9. DOE, May 1999, *Decision-Making Framework Guide for the Evaluation and Selection of Monitored Natural Attenuation Remedies at Department of Energy Sites*, Office of Environmental Restoration, <http://web.em.doe.gov/framework/>.
10. DOE, 1999, "Innovative Technology Summary Report: In Situ Chemical Oxidation Using Potassium Permanganate", DOE/EM-0496, 35 pp. <http://apps.em.doe.gov/ost/pubs/istrs/itsr167.pdf>.
11. EPA, March 2003, Air Sparging, <http://www.epa.gov/swerust1/cat/airsparg.htm>.
12. EPA, March 2003, Biosparging, <http://www.epa.gov/swerust1/cat/biosparg.htm>.
13. EPA, April 1999, *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*, OSWER Directive 9200.4-17P, <http://www.epa.gov/swerust1/directiv/d9200417.pdf>.

14. EPA, September 1998, *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*, EPA/600/R-98/128, <http://www.clu-in.org/download/remed/protocol.pdf>.
15. EPA, June 1997, "Metal-Enhanced Dechlorination of Volatile Organic Compounds Using an Above-Ground Reactor," EPA/540/R-96/503, Superfund Innovative Technology Evaluation Report, EnviroMetal Technologies, Inc., <http://www.epa.gov/ORD/SITE/reports/540r96503.pdf>.
16. EPA, July 1996, "Pump-and-Treat Ground-Water Remediation: A Guide for Decision Makers and Practitioners," EPA/625/R-95/005, Office of Research and Development, Washington D.C., <http://www.epa.gov/ORD/WebPubs/pumptreat/>.
17. EPA, 1996, *RCRA Public Participation Manual*, U.S. Environmental Protection Agency, Office of Solid Waste, 1996.
18. EPA, 1994, *RCRA Corrective Action Plan (Final)*, OSWER 9902.3-2A, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, May 1994.
19. Fountain, J.C., December 1998, "Technologies for Dense Nonaqueous Phase Liquid Source Zone Remediation," TE-98-02, GWRTAC, Pittsburgh, Pennsylvania, http://www.gwrtac.org/pdf/e_dnapl.pdf.
20. Ground-Water Remediation Technologies Analysis Center (GWRTAC), 2001, Remediation Technologies, <http://www.gwrtac.org/html/techs.html>.
21. Interstate Technology and Regulatory Cooperation Work Group, 2002. "Technical and Regulatory Guidance for In Situ Bioremediation in Groundwater," 129 pp.
22. Martin, J.P., Allison, A.M., Keck, J.F., Peterson, L.N., 2002, "Evaluation of Remediation Technologies for DNAPL Source Zone Clean-Up at the OK Tool Site, Milford, NH," North Wind, Inc.
23. McCarty, P.L., 1996, "Biotic and Abiotic Transformations of Chlorinated Solvents in Ground Water," In: Symposium on Natural Attenuation of Chlorinated Organics in Ground Water, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C., EPA/540/R-97/504, pp. 7-11.
24. Nanitech LLC, 2004, Information brochure.
25. National Research Council, 1999, "Groundwater and Soil Cleanup: Improving Management of Persistent Contaminants," National Academy Press: Washington D.C., 285 pp.
26. NMED, 2003, "Compliance Order on Consent Pursuant to the New Mexico Hazardous Waste Act 74-4-10: Sandia National Laboratories Consent Order," New Mexico Environment Department, December 16, 2003.

27. Semprini, L., Roberts, P.V., Hopkins, G.D., McCarty, P.L., 1990, "A Field Evaluation of In-Situ Biodegradation of Chlorinated Ethenes: Part 2, Results of Biostimulation and Biotransformation Experiments," *Ground Water*, Vol. 28, No. 5, pp. 715 – 727.
28. SNL/NM, 2004a, "Current Conceptual Model of Groundwater Flow and Contaminant Transport at Sandia National Laboratories/New Mexico Technical Area V," Sandia National Laboratories/New Mexico .
29. SNL/NM, August 2003, *Survey of Subsurface Treatment Technologies for Environment Restoration Sites at Sandia National Laboratories, New Mexico*, Sandia National Laboratories/New Mexico, Albuquerque, NM.
30. SNL/NM, 2001a, *SNL/NM Environmental Restoration Project Long-Term Monitoring Strategy for Groundwater*, Sandia National Laboratories/New Mexico.
31. SNL/NM, 2001b, *SNL/NM TA-V Groundwater Investigation Fiscal Years 1999 and 2000*, Sandia National Laboratories/New Mexico.
32. SNL/NM, 2001c, *SNL/NM Summary of Monitoring Well Drilling Activities, TA-V Groundwater Investigation*, Sandia National Laboratories/New Mexico.
33. SNL/NM, 2001d, *Environmental Restoration Project, Sandia National Laboratories/New Mexico in Association with the US Department of Energy, Kirtland Area Office, Draft Long-Term Environmental Stewardship Plan*, Sandia National Laboratories/New Mexico.
34. SNL/NM, 1999, *SNL/NM Summary Report of Groundwater Investigations at Technical Area V, Operable Units 1306 and 1307*, Environmental Restoration Project, U.S. Department of Energy, Albuquerque Operations Office, Sandia National Laboratories/New Mexico, March 1999.
35. SNL/NM, 1998, *Site-Wide Hydrogeologic Characterization Project Calendar Year 1995 Annual Report*. Sandia National Laboratories/New Mexico.
36. SNL/NM, 1996, *Site-Wide Hydrogeologic Characterization Project Calendar Year 1995 Annual Report*. Sandia National Laboratories/New Mexico.
37. SNL/NM, 1995, *Site-Wide Hydrogeologic Characterization Project Calendar Year 1994 Annual Report*, Sandia National Laboratories/New Mexico.
38. SNL/NM, 1994, *Site-Wide Hydrogeologic Characterization Project Calendar Year 1993 Annual Report*. Sandia National Laboratories/New Mexico.
39. SNL/NM, 1993, *Site-Wide Hydrogeologic Characterization Project Calendar Year 1992 Annual Report*, Sandia National Laboratories/New Mexico.
40. Strietelmeier, B.A., M.L. Espinosa, M.W. Jones, J.D. Adams, E.M. Hodge, S.D. Ware, P.A. Leonard, P. Longmire, J.P. Kaszuba, and J.L. Conca, 2001, "Remediation of Nitrate-Contaminated Groundwater Using a Biobarrier," Waste Management 2001 Conference, February 25-March 1, 2001, Tucson, Arizona, <http://www.wmsym.org/Abstracts/2001/54/54-2.pdf>.

41. Van Hart, D., 2003, "Geologic Investigation: An Update of Subsurface Geology on Kirtland Air Force Base, New Mexico," SAND2003-1869, Sandia National Laboratories, June 2003.
42. Vogel, T.M., C.S. Criddle, and P.L. McCarty, 1987, "Transformations of Halogenated Aliphatic Compounds," *Environmental Science and Technology*, Vol. 21, No. 8, pp. 722-736.
43. Wiedemeier, T.H., J.T. Wilson, K.H. Kampbell, R.N. Miller, J.E. Hansen, 1999, "Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater," Volume I, Revision 0, Air Force Center for Environmental Excellence, Brooks Air Force Base, S.A., Texas.
44. Wilson, J.T. and Wilson, B. H., 1985, "Biotransformation of Trichloroethylene in Soil," *Applied and Environmental Microbiology*, 49: 242-243.
45. Wymore, R.A., and K.S. Sorenson, 2003, *Final Quick Win Vertical Profile Sampling Report*, NWE-ID-2003-046, Revision 0, North Wind, Inc. Idaho Falls, Idaho.

Appendix A Identification Of Data Gaps

Table A-1. Identification of anticipated data gaps following the paper study.

	Long-Term Reliability and Effectiveness				Reduction of Toxicity, Mobility, or Volume			Short-Term Effectiveness			Feasibility					Costs	
	Risks Remaining after Remedy Implementation	Extent of Long-Term Monitoring/Management	Uncertainties Associated with Leaving Contaminants in Place	Risk of Remedy Failure	Reduction of Toxicity, Mobility, or Volume	Groundwater Alteration/Residuals Produced	Secondary Waste Stream Production	Magnitude of Risk Reduction	Time Required for Risk Reduction	Risks to Workers, Community, and the Environment during Remedy Implementation	Installation and Construction Difficulties	Operation and Maintenance Difficulties	Cleanup Technology Difficulties	Permitting and Approvals	Availability of Resources (equipment, services, expertise, and storage and disposal capacity)	Capital Costs	Operation and Maintenance Costs
Groundwater Monitoring for VOCs and Nitrate																	
MNA for VOCs and Groundwater Monitoring for Nitrate.	Modeling		Modeling	Modeling	Modeling	Field Study		Modeling	Modeling								
MNA for VOCs and Nitrate	Modeling		Modeling	Modeling	Modeling	Field Study		Modeling	Modeling								
ISB followed by MNA for VOCs and Nitrate	Modeling		Modeling	Modeling	Lab and field studies	Lab and field studies		Modeling	Modeling			Field Study	Field Study				

Table A-1. (continued).

	Long-Term Reliability and Effectiveness			Reduction of Toxicity, Mobility, or Volume			Short-Term Effectiveness			Feasibility				Costs			
	Risks Remaining after Remedy Implementation	Extent of Long-Term Monitoring/Management	Uncertainties Associated with Leaving Contaminants in Place	Risk of Remedy Failure	Reduction of Toxicity, Mobility, or Volume	Groundwater Alteration/Residuals Produced	Secondary Waste Stream Production	Magnitude of Risk Reduction	Time Required for Risk Reduction	Risks to Workers, Community, and the Environment during Remedy Implementation	Installation and Construction Difficulties	Operation and Maintenance Difficulties	Cleanup Technology Difficulties	Permitting and Approvals	Availability of Resources (equipment, services, expertise, and storage and disposal capacity)	Capital Costs	Operation and Maintenance Costs
ISB followed by MNA for VOCs and Groundwater Monitoring for Nitrate	Modeling		Modeling	Modeling	Lab and field studies	Lab and field studies		Modeling	Modeling			Field Study	Field Study				
ISB followed by MNA for VOCs and MNA for Nitrate	Modeling		Modeling	Modeling	Lab and field studies	Lab and field studies		Modeling	Modeling			Field Study	Field Study				
Pump and Treat followed by MNA for VOCs and Nitrate	Modeling		Modeling	Modeling	Field Study			Modeling	Modeling			Field Study	Field Study				
Pump and Treat followed by MNA for VOCs and Groundwater Monitoring for Nitrate	Modeling		Modeling	Modeling	Field Study			Modeling	Modeling			Field Study	Field Study				
Pump and Treat followed by MNA for VOCs and MNA for Nitrate	Modeling		Modeling	Modeling	Field Study			Modeling	Modeling			Field Study	Field Study				

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