FINAL

FOCUSED FEASIBILITY STUDY

FOR THE

FORMER NAVAL AMMUNITION DEPOT, MECKLENBURG COUNTY, CHARLOTTE, NORTH CAROLINA

Prepared for

U. S. ARMY CORPS OF ENGINEERS

SAVANNAH DISTRICT

CONTRACT NO. W912HN-07-D-0029
DELIVERY ORDER 0001

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Prepared for:

U. S. Army Corps of Engineers
Savannah District
Under Contract W912HN-07-D-0029
Delivery Order Number 0001

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LIST OF ACRONYMS

ARAR	applicable or relevant and appropriate requirement
ASIP	Arrowood Southern Industrial Park
AT123D	Analytical Transient 1-, 2-, 3-Dimensional (model)
BGS	below ground surface
BRA	baseline risk assessment
CBP	Commerce Business Park
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	*Code of Federal Regulations*
COC	constituent of concern
COD	chemical oxygen demand
COPC	constituent of potential concern
CSM	conceptual site model
CVOC	chlorinated volatile organic compound
CY	calendar year
DCE	dichloroethene
DNA	deoxyribonucleic acid
DNAPL	dense nonaqueous-phase liquid
DO	dissolved oxygen
DoD	U. S. Department of Defense
EPA	U. S. Environmental Protection Agency
FLUTe™	Flexible Liner Underground Technology
FFS	focused feasibility study
FS	feasibility study
gpm	gallons per minute
GRA	general response action
HI	hazard index
KBr	potassium bromide
LDR	land disposal restriction
M&E	Metcalf and Eddy, Inc.
MCL	maximum contaminant level
MNA	monitored natural attenuation
NaBr	sodium bromide
NAD	Naval Ammunition Depot
NCAC	North Carolina Administrative Code
NCDENR	North Carolina Department of Environment and Natural Resources
NCP	National Oil and Hazardous Substances Pollution Contingency Plan (referred to as "National Contingency Plan")
NRHP	National Register of Historic Places

LIST OF ACRONYMS (CONTINUED)

O&M	operation and maintenance
ORP	oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
PCE	tetrachloroethene
PPE	personal protective equipment
PVC	polyvinyl chloride
RAO	remedial action objective
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act of 1976
RD	Remedial Design
Redox	oxidation-reduction
RI	Remedial Investigation
ROD	Record of Decision
SADA	Spatial Analysis and Decision Assistance
SAIC	Science Applications International Corporation
SHPO	State Historic Preservation Office
SVOC	semivolatile organic compound
TBC	to be considered
TCE	trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure
TNT	trinitrotoluene
UIC	underground injection control
USACE	U. S. Army Corps of Engineers
VOC	volatile organic compound

EXECUTIVE SUMMARY

This focused feasibility study (FFS) has been prepared to develop, screen, and evaluate remedial alternatives for addressing contaminated groundwater at the Former Naval Ammunition Depot (NAD) located on Nevada Boulevard in Charlotte, Mecklenburg County, North Carolina. A pilot study to evaluate the use of an electron donor (sodium lactate) for promoting reductive dechlorination as a remedial approach was conducted in the presumed source area at the Former NAD site from October 2003 through October 2004; a subsequent site-wide groundwater sampling event was conducted in August and September 2006. This remedial approach proved to be very successful in reducing the chlorinated solvent contaminant concentrations in the groundwater at the site. Therefore, this report will focus on the evaluation of this alternative to reduce the contaminant concentrations across the entire site. Investigation and cleanup of the site are being administered under the U. S. Department of Defense (DoD) Environmental Restoration Program–Formerly Utilized Defense Sites Program. This FFS was prepared by TerranearPMC, LLC under Contract No. W912HN-07-D-0029, Task Order 0001, administered by the Savannah District of the U. S. Army Corps of Engineers (USACE). The FFS was based upon a draft document prepared by Science Applications International Corporation (SAIC).

The Former NAD site occupied approximately 2,266 acres of land southwest of Charlotte, North Carolina, and was used to support DoD operations from 1942 to 1959. The complex was sold to commercial developers in 1959 and all buildings related to the Former NAD complex were demolished. The area is currently occupied by light industrial and commercial businesses as well as residential developments. The investigation focus area consists of Areas 1 and 2, which are located in the present-day Arrowood Southern Industrial Park. This area is primarily used for distribution and warehousing operations. Both areas were formerly used for the production of 40-mm antiaircraft munitions. Area 2 was also used to process ammunition "fleet returns" (returned ammunition) after World War II. Part of the return process included removing cutting oil and preservatives on the exterior of the returned shells through a trichloroethene (TCE) vapor-degreasing operation.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Phase I and II Remedial Investigations (RIs) were conducted at the site by Metcalf and Eddy, on behalf of USACE, from 1994 through 1995 and 1996 through 2000, respectively. Supplemental investigations were conducted by SAIC from 2000 to 2003, a pilot study was conducted from 2003 to 2004, and a site-wide groundwater sampling effort was conducted in 2006. Conclusions from these investigations are summarized in the following paragraphs.

Remedial Investigation and Supplemental Investigation Findings

Hydrogeology in the NAD area represents a complex system of interconnected aquifers, corresponding to the hydrogeologic zones: shallow zone, transition zone, and bedrock zone. The shallow zone is characterized by the unconsolidated residuum and the saprolitic soil. The transition zone is identified as the zone of transition along the overburden/bedrock interface. This zone consists of partially weathered parent material and the upper fractured bedrock. The bedrock zone is characterized by the presence of water-bearing fractures within the competent granodiorite. The shallow zone and the transition zone are hydraulically interconnected and there is anisotropy with the transition zone and the bedrock zone. Groundwater in each of these zones was monitored.

The groundwater hydraulics at the Former NAD site have been altered during the performance of the RI/feasibility study process by both on-site alteration of drainage patterns and off-site pumping. Data collected during the RI and supplemental investigations, as well as the pilot study, demonstrate the anisotropic nature of the formation. The groundwater flow direction is predominantly west but there is also a flow component to the south that appears to be associated with an identified fracture trace lineament. The flow in this fracture system may have been enhanced by the increase in the hydraulically gradient induced by the usage of the three production wells located at Plant #1, which is located on a property adjacent to Area 2 of the Former NAD site. Based on reported usage rates, it is estimated that approximately 144 million gallons of water were removed from the aquifer during a 1-year period.

The Phase I and II RIs and supplemental investigations concluded that TCE concentrations in groundwater exceeded the North Carolina drinking water standard of 2.8 μg/L across the entire site. TCE was found to be the predominant contaminant by mass with TCE breakdown products including *cis*-1,2-dichloroethene (DCE); 1,1-DCE; 1,2-dichloroethane; and vinyl chloride also present. No specific source for the TCE in groundwater has been identified and efforts to locate an actual dense non-aqueous phase liquid source have failed. However, the significant concentrations of TCE in the area of NAD MW-21 and SAIC-14 indicate this area is most likely the source of contamination and corresponds to the location of the former vapor degreaser building.

Pilot Study and Site-Wide Groundwater Sampling Event

At the conclusion of the 2002 supplemental investigation effort, it was agreed that it was technically impractical to actively reduce the TCE plume in both the transition and bedrock zones to below the North Carolina Administrative Code (NCAC) 2L standard of 2.8 μg/L. A decision was made to focus the remedial action on areas that exhibited TCE concentrations greater than 500 μg/L. Recommendations were made to conduct a pilot study to evaluate the use of an electron donor for promoting reductive dechlorination as a remedial approach for the transition and bedrock zones and to better understand the hydraulics near the assumed source area (NAD MW-21). Injection of a combination bromide tracer and sodium lactate (electron donor) food source was accomplished in October 2003 with subsequent monitoring for 8 months through June 2004. In September 2006, a site-wide groundwater sampling event was also conducted. The results of the pilot study indicated that reducing conditions were present in most wells of the study area and that the sodium lactate injection assisted the aquifer in becoming more reductive by enhancing the microbial activity of the *Dehalococcoides* population that was detected. The pilot study and subsequent sampling event conducted in 2006 proved that at the Former NAD site, sodium lactate could be effectively distributed through the aquifer and that it is an effective remedial technology in promoting biodegradation and reduction of the chlorinated volatile organic compound (CVOC) contamination present in the aquifer.

Contaminant Nature and Extent

The distribution of the groundwater contamination can be separated into two distinct TCE plumes based on the hydrogeologic zone (i.e., transition zone and bedrock zone). Within the transition zone at the Former NAD site, concentrations of TCE ranged from non-detect to 6,200 μg/L with the plume extending to a depth of ~42 ft below ground surface (BGS). Within the bedrock zone, concentrations of TCE ranged from 2.0 to 40,000 μg/L at SAIC-14 with the plume extending to a depth of 305 ft BGS. For the transition zone, the plume was refined by applying the Spatial Analysis and Decision Assistance (SADA) software package (SADA 2002). SADA analysis indicated five separate plumes (hot spot areas) with TCE concentrations exceeding 500 μg/L. Unlike the transition zone, a single large TCE plume centered around SAIC-14 was observed for the bedrock zone.

Exposure Pathways

An evaluation of potential exposure pathways at the site concluded that the surface and subsurface soil, as wells as the surface water, were incomplete.

Several contaminants of potential concern (COPCs) were identified from the Phase I, Phase II, and supplemental sampling results. Although groundwater is not used currently as a source of potable water in this area, based on their prevalence in the groundwater at high concentrations, the following COPCs were identified as contaminants of concern in groundwater for potential future exposure:

- *cis*-1,2-DCE;
- 1,1-DCE;
- 1,2-dichloroethane;
- 1,2-dichloropropane;
- 1,1,2-trichloroethane;
- 2-butanone;
- tetrachloroethene;
- TCE; and
- vinyl chloride.

Remedial Action Objective

Therefore, the only medium requiring further evaluation is groundwater. The North Carolina Department of Environment and Natural Resources and USACE, Savannah District agreed that active remediation would focus on reducing areas in both the transition and bedrock zones where TCE concentrations were greater than 500 μg/L. Based on these agreements, the remedial action objective (RAO) for the Former NAD site is to actively treat the areas where the TCE concentrations exceed 500 μg/L. The treatment will consist of reducing the TCE concentrations in the groundwater of both the transition and bedrock zones to 500 μg/L via active treatment with the implementation of monitoring natural attenuation (MNA) to achieve the remedial goal (RG) of 2.8 μg/L.

Alternative Description

The no action alternative and two action alternatives were identified for further evaluation of the contaminated groundwater.

- Alternative 1 – "No Action";
- Alternative 2 – "Monitored Natural Attenuation";
- Alternative 3 – "Enhanced Bioremediation Using Sodium Lactate Injection."

The no action alternative is considered in accordance with CERCLA and the National Oil and Hazardous Substances Pollution Contingency Plan (referred to as the "National Contingency Plan") requirements for comparison with other alternatives. Under this alternative, no remedial action would be implemented at the Former NAD site to reduce contaminant concentrations in the contaminant plume to return the impaired groundwater to beneficial use. Access to contaminated groundwater would be unrestricted, allowing exposure to contaminated media, and no monitoring of groundwater would be performed.

Alternative 2 would implement groundwater MNA involving the use of institutional controls, such as restricting groundwater access and legal controls. Access controls would restrict access to the area of remediation through physical controls. Physical controls would include posting warning signs to deter unauthorized access to the site. Deed restrictions limiting the use of groundwater for consumption and irrigation would be implemented for the life of this remedial alternative.

Groundwater monitoring would be included as an institutional action. The purpose of groundwater monitoring would be to show that natural attenuation was decreasing the CVOCs contamination as predicted. Analytical results would be evaluated after each monitoring event to verify that concentrations of CVOCs are decreasing and that the RAO is ultimately achieved. Long-term monitoring would allow assessment of contaminant migration and would be an important part of preventing potential unacceptable exposures.

Modeling has indicated that CVOCs in the transition zone groundwater would naturally attenuate to the NCAC 2L standards within 47 years; whereas, in the bedrock zone groundwater, it would take approximately 63 years for the CVOCs to be reduced to the NCAC 2L standards. Therefore, the transition zone groundwater would be monitored for 47 years and the bedrock zone groundwater would be monitored for 63 years or until such time as the transition zone and bedrock zone groundwater at the site meets the NCAC 2L standards. Restriction on site groundwater use would be imposed until groundwater at the site meets the NCAC 2L standards. Five-year reviews of the data would be conducted to determine how rapidly the aquifer is attenuating residual contaminants. The 5-year review might determine that no further monitoring is required or that additional remedial measures should be undertaken.

Alternative 3 would use a combination of enhanced bioremediation (sodium lactate injection) and MNA to achieve the remedial levels in groundwater at the Former NAD site. The plume area with contamination greater than 500 μg/L will be treated using a sodium lactate injection program. The residual contamination within the treatment areas and the contamination located outside of the radius of influence of the horizontal injection wells will attenuate naturally following the treatment period.

Contamination levels would be monitored to ensure natural attenuation of contamination to below remedial levels. Modeling predicted that after active treatment of TCE to 500 μg/L using sodium lactate, natural attenuation would degrade contaminants to the RG of 2.8 μg/L in approximately 14 years in the transition zone and 12 years in the bedrock zone.

Alternative Evaluation

All alternatives would meet the RAO of reducing the TCE concentrations in the groundwater to the RG of 2.8 μg/L. However, implementation of the second action alternative (Alternative 3) would achieve the RG in less time (approximately 14 years) than Alternatives 1 and 2 (~63 years).

The no action alternative does not reduce the toxicity of contaminated groundwater at the site. However, the present concentration of CVOCs in transition zone groundwater would require approximately 47 years to naturally attenuate to below remedial levels, and for the CVOCs in the groundwater of the bedrock zone, it would take approximately 63 years to naturally attenuate to below remedial levels. Therefore, there would be a gradual decrease in the volume or mass of contamination. Under no action, however, no monitoring would be performed to evaluate such decreases or mobility (further migration). Some future impact/unknown factor at the site could potentially increase the toxicity, mobility, or volume of contamination at the site. The no action alternative does not meet the U. S. Environmental Protection Agency's statutory preference for treatment.

Implementation of Alternative 2, MNA, is similar to the no action alternative in that no active remedial action would be implemented to reduce the contaminants to below remedial levels; however, legal controls preventing the use of groundwater for drinking or irrigation would be implemented to eliminate potential contact (i.e., risk) from the groundwater. This alternative would provide protection of human health through controls placed on the use of groundwater. The groundwater monitoring and reporting program established for the alternative would confirm natural attenuation of the CVOCs and the 5-year review would confirm that institutional controls were in place and that the CVOC contamination is being reduced through natural attenuation without migrating beyond the predicted boundary. The time to reach the RG for this alternative would be the same as the no action alternative.

Alternative 3 would treat the source areas by the injection of sodium lactate into both the transition and bedrock zones to reduce the concentrations of CVOCs and daughter products in groundwater to below 500 μg/L and allow subsequent MNA to reduce the concentration of the residual contamination to below the NCAC 2L standards. This in-situ alternative would be protective of human health and the environment. The risks from the high concentrations of CVOCs would be reduced by enhanced bioremediation and through natural attenuation. The CVOC plumes in the transition zone groundwater would be treated to below remedial levels in approximately 14 years after the completion of the sodium lactate injection; whereas, the CVOC plumes in the bedrock zone groundwater would be treated to below remedial levels in approximately 12 years after completion of the sodium lactate injection. Upon completion of the treatment, risks to human health and the environment would be eliminated from this area because the contaminants in groundwater would have been degraded to non-chlorinated and non-hazardous constituents. Upon achieving the RG level, contaminants would no longer be present in groundwater; therefore, the alternative would have long-term effectiveness.

Alternative 1 would have no costs because no action would be taken. Alternative 2, MNA with institutional controls, would have a cost of $6,563,242. Alternative 3, enhanced bioremediation using sodium lactate injection with MNA, would have the highest costs at $7,124,076 but would reach the RAO in a substantially less amount of time than Alternatives 1 and 2.

Alternative Selection

The selected remedial alternative for the groundwater contamination at the Former NAD site is Alternative 3, "Enhanced Bioremediation Using Sodium Lactate Injection." This alternative was selected because the remedial technology was proven to be effective in promoting biodegradation and reducing the CVOC contamination present in the aquifer at the Former NAD Site. This alternative was also selected because it would achieve the RG levels in a reasonable amount of time and provide the highest overall protection of human health and the environment.

Alternative 3 will use a combination of enhanced bioremediation (sodium lactate injection) and MNA to reduce the concentration of the contamination to below the NCAC 2L standards. With this alternative, groundwater in the highly contaminated areas would be actively treated and the risk to human health and the environment would be significantly reduced within approximately 1 year. Modeling estimated that the CVOC plume in the transition zone groundwater would attenuate to below remedial levels in approximately 14 years after the completion of the sodium lactate injection; whereas, the CVOC plume in the bedrock zone groundwater would attenuate to below remedial levels in approximately 12 years after completion of the sodium lactate injection.

This in-situ alternative would be protective of human health and the environment, and upon completion of this alternative, risks to human health and the environment would be eliminated. The cost to implement Alternative 3 would be higher than the other alternatives as the treatment technology would require the installation of injection wells along with bi-monthly injections of sodium lactate for a 1-year period. This alternative would cost $7.12M but, through the injection of the sodium lactate, the RG would be reached in substantially less amount of time than Alternatives 1 and 2.

1.0 INTRODUCTION

This focused feasibility study (FFS) was prepared by TerranearPMC, LLC under Contract No. W912HN-07-D-0029, Task Order 0001, administered by the Savannah District of the U. S. Army Corps of Engineers (USACE). The FFS was based upon a draft document prepared by Science Applications International Corporation (SAIC).

1.1 PURPOSE AND ORGANIZATION

This FFS has been prepared to develop, screen, and evaluate remedial alternatives for addressing contaminated groundwater at the Former Naval Ammunition Depot (NAD) located in Charlotte, Mecklenburg County, North Carolina (Figure 1-1). This document evaluates the alternatives for remedial action in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendment and Reauthorization Act of 1986. The document was also prepared in accordance with the National Oil and Hazardous Substances Pollution Contingency Plan, referred to as the "National Contingency Plan" (NCP), and the U. S. Environmental Protection Agency's (EPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA/540/G-89/004; EPA 1988).

A pilot study to evaluate the use of an electron donor (sodium lactate) for promoting reductive dechlorination as a remedial approach was conducted in the presumed source area at the Former NAD site from October 2003 through October 2004 with additional sampling conducted in August and September 2006. The results of this study are discussed later in this FFS. This FFS will focus on the evaluation of this alternative in addition to the other alternatives presented to reduce the contaminant concentrations across the entire site.

The FFS is divided into eight chapters. Chapter 1.0 describes the purpose and organization of the FFS and provides a summary of the previous investigations. Chapter 2.0 provides a discussion of the site characteristics, the contaminant nature and extent, and the conceptual site model (CSM). Chapter 3.0 discusses the remedial action objectives (RAO), and Chapter 4.0 identifies and screens applicable remedial technologies. The results of the pilot study are discussed in Chapter 5.0, with the development and description of alternatives in Chapter 6.0. Chapter 7.0 contains a detailed analysis of alternatives and ends with a comparative analysis of alternatives and remedial actions for further consideration. Chapter 8.0 discusses the recommendations for the site. Chapter 9.0 provides full citations for documents used in the preparation of this report. Appendix A contains the fate and transport modeling for the Former NAD site. Boring logs and well construction diagrams are presented in Appendix B. Appendix C is a summary of analytical data in both tabular format and concentration versus time graphs. Validated laboratory analytical data sheets for the pilot study and 2006 site-wide sampling event are presented in Appendix D. Appendix E presents costs for each alternative.

1.2 SITE BACKGROUND

1.2.1 Site Description

At the time of operation, the entire NAD complex occupied approximately 2,266 acres of land southwest of Charlotte, Mecklenburg County, North Carolina. Figure 1-2 shows the Former NAD complex as it existed on June 30, 1950. The property was sold to commercial developers in 1959 and all buildings related to the Former NAD site were demolished. The area is currently occupied by light industrial and commercial businesses, as well as some residential developments. The focus of the Phase I and Phase II Remedial Investigations (RIs), as well as the FFS, is in an area identified as Former NAD Areas 1 and 2 (Figure 1-2). This property is in an area roughly bounded by Brookford Street, Wilmar Boulevard, Nevada Boulevard, and Westinghouse Boulevard in Mecklenberg County, Charlotte, North Carolina (Figure 1-3). This area, known as the Arrowood Southern Industrial Park (ASIP), is currently occupied by light industrial and commercial businesses. Several buildings, including AISP Buildings II, III, and IV, are located within the study area. The large buildings, located adjacent to Cordage Street, were constructed in 1980. Some of the structures are situated directly over Former NAD Areas 1 and 2.

Both historical and current building activities have impacted the area topography. Graded building pads, foundation structures, drainage features, rail lines, and roads are evident across the site. The buildings and associated structures, both historical and current, are generally oriented northeast-southwest. The rail lines' average grade is 6 ft below the building pads to facilitate loading docks.

Between 1996 and 1997, Norfolk Southern expanded their rail lines causing significant changes to occur to the topography in the area. During construction, approximately 6 to 8 ft of overburden was removed and the area graded to accommodate the new railroad shipping facility operated by Bulkmatic Inc. in Former NAD Area 2 and another railroad shipping facility operated by Roll and Hold in former NAD Area 1. The majority of Former NAD Areas 1 and 2, and the mass of the contaminant plume, are located on property owned by Arrowood Southern Company and Norfolk Southern Railway Company. The remaining portions of the site are owned by Alliance IV LLC, Box USA Group Inc., Textron Incorporated, Cabot Industrial Properties, Prologis North Carolina LP, and Frito-Lay Incorporated.

The developed areas are covered with asphalt, concrete, and buildings. Soil has been cut, filled, and graded, and few natural surface features remain in these areas. The site also has several areas that remain undeveloped and are covered with trees and brush. Relief at the site is approximately 25 ft with maximum elevation along a northwest trending ridge in the center of the study area. A major portion of the area slopes away from this ridge to the southwest. Drainage around structures in the area has been diverted to the southwest.

1.2.2 Site History

On June 1, 1942, the Bureau of Ordnance, Department of Navy signed a contract with the United States Rubber Company for the construction of a 40-mm anti-aircraft ammunition shell loading and assembly plant. Operations began in December 1942. In 1945, plant production was cut and the operation of the facility was transferred to the U. S. Navy. In 1956, the Naval Depot status was changed from Maintenance Status to Inactive Status, and in 1959, the Former NAD complex was sold to a local partnership. The facility was, in large part, dormant from 1959 until the early 1980s.

Former NAD Areas 1 and 2 were used for the production of 40-mm antiaircraft munitions (Figure 1-2). Figure 1-4 depicts the locations of the Former NAD buildings superimposed on the current building footprint (M&E 2000). Area 1 consisted of anti-aircraft ammunition loading lines. This area was dedicated to the assembly of final rounds and was composed of 22 buildings. The largest of the buildings in Area 1, Buildings I-60 and I-70, were used for final assembly, packaging, and shipping of munitions (M&E 2000). A trinitrotoluene (TNT)-consolidating unit was also reportedly located in this area.

The operations carried out in Area 2 were reportedly identical to those conducted in Area 1. Area 2 was also used to process ammunition "fleet returns" (returned ammunition) after World War II for distribution to other Allied Forces Branches. Only Area 2 was used after 1945 for reconditioning of returned munitions. A trichloroethene (TCE) vapor-degreasing operation was also located on the southeast corner of Building 2-30 (Figure 1-4). The unit was used to remove cutting oil and preservatives on the exteriors of returned shells (M&E 2000). A drainage ditch was reported to have been located at the southeast corner of Building 2-30. Sludge from the degreasing vessel was removed approximately once per week and reportedly disposed of at the NAD burn pit area.

1.3 PREVIOUS INVESTIGATIONS

Previous investigations have been conducted at the Former NAD site since the late 1980's. Beginning in 1989, investigations have been conducted by Soil and Material Engineering, Dames and Moore, VERSAR, Trammel Crow, and Metcalf and Eddy (M&E). Table 1-1 provides a summary of the investigation history for the site.

1.3.1 Summary of Site Assessments

Trammel Crow conducted an investigation at the Commerce Business Park (CBP), located northeast of the NAD Areas 1and 2 across from Westinghouse Boulevard and the ASIP (Figure 1-5). A Phase I site assessment conducted by VERSAR in February 1990 recommended a Phase II study for potential groundwater contamination. Phase II, Stage 1 investigative activities were conducted by VERSAR in July 1990, and a Phase II, Stage 2 investigation was conducted in October 1990. The investigation reported low levels of TCE and toluene in the soil, and TCE and 1,2-dichloroethane were present in the groundwater at levels above maximum contaminant levels (MCLs). A baseline risk/health assessment was also conducted by VERSAR. It did not identify any potential groundwater receptor for off-site groundwater migration. An evaluation of TCE for possible surface water ingestion indicated that levels detected posed a negligible human health risk. Predicted impacts to environmental receptors were also minimal. A Phase II, Stage 3 investigation was conducted in 1992 and addressed areas in the CBP and areas within the ASIP. TCE was detected in the soil and in groundwater. In the vicinity where the former degreasing activities were reportedly conducted (Building 2-30), TCE was identified as the primary groundwater contaminant.

1.3.2 Summary of Remedial Investigations

In 1994, M&E conducted a Phase I RI that concentrated efforts in Former NAD Areas 1 and 2. The results are presented in the *Phase I Remedial Investigation Final Report for the Former Naval Ammunition Depot Areas 1 and 2, Mecklenburg County, Charlotte, North Carolina.* (M&E 1995). The RI concluded that the soil was not impacted; however, the groundwater was contaminated with volatile organic compounds (VOCs), specifically TCE with minor breakdown products. The RI indicated that concentrations of TCE tended to be higher in the bedrock monitoring wells, and were higher in Area 2 than in Area 1 (Figure 1-3). The distribution of TCE ran roughly proximal to Former NAD Buildings 1-30 and 2-30 (Figure 1-4). A qualitative risk evaluation concluded that groundwater would be the most significant exposure pathway but was believed to be incomplete given city-supplied water is use in the area. For the ecological risk, the potential exposure of burrowing animals to metals detected in the soil was not quantified because the metals detected in the soil were believed to occur naturally in the area. The extent of groundwater contamination was not fully defined in the Phase I investigation and a Phase II investigation was recommended.

In 1999, M&E conducted a Phase II RI to delineate the horizontal and vertical extent of contamination, to determine the geologic and hydrogeologic frameworks of shallow and bedrock aquifers, and to conduct a quantitative risk assessment. The results are presented in the *Final Phase II Remedial Investigation Report for the Former Naval Ammunition Depot Areas 1 and 2, Mecklenburg County, Charlotte, North Carolina* (M&E 2000).

During the Phase II RI, three surface geophysical surveys were conducted to map the topography of the unweathered bedrock surface and to identify fractures within the upper section of the bedrock unit. A seismic refraction survey was used to map bedrock surface topography while shear-wave and electromagnetic surveys were conducted to identify fractures present in the bedrock. The refraction survey indicated that a series of northeast-southwest trending ridges and troughs on the bedrock surface exists and that the assumed location of the TCE release is located upon a bedrock topographic high.

Borehole geophysical logging was also performed on three aquifer test boreholes with depths of 70 ft. Fluid temperature, caliper, natural gamma, acoustic televiewer/spectrum, and electromagnetic flowmeter logs were completed for each borehole. The results indicated that the predominant groundwater flow was in the transition zone above fractured, unweathered bedrock with only a small percentage of groundwater storage occurring in the bedrock. As a result, it was concluded that the bulk of the contaminant mass was in the transition zone with minor quantities in the bedrock fractures.

Extensive aquifer testing consisted of three 8-hr step-drawdown/interconnectivity tests, background (static) monitoring, a 72-hr constant rate-pumping test, a recovery test, and several slug tests. The aquifer testing demonstrated that the hydrogeology in the NAD site represents a complex system of interconnected aquifers corresponding to the hydrogeologic zones. The testing revealed interconnectivity between the zones and anisotropy with the transition zone and the bedrock zone. Testing also indicated that the shallow zone and the transition zone were hydraulically interconnected. Groundwater was determined to flow generally in a westerly direction.

Groundwater monitoring wells were also installed and sampled as part of the investigation. A total of 58 groundwater samples were collected and analyzed for VOCs (EPA Method 8260 B) and explosives residue (EPA Method 8330).

The Phase II RI determined that TCE was the most widespread constituent, was detected at the highest concentrations, and that the majority of TCE was detected in the transition zone (Figure 1-6). The horizontal extent of the groundwater contamination was relatively well defined in the area with the exception of the southwestern portion of the plume area near NAD MW-56 and toward Nevada Boulevard (Figure 1-3). Contamination was found to extend vertically to 70 ft in the most impacted portion of the area (NAD MW-21). Hydraulically downgradient of the plume center at NAD MW-45,TCE concentrations were found to be approximately half that observed in NAD MW-19 (located 100 ft from the suspected source of contamination). The vertical extent of contamination downgradient of the suspected source area was not defined to below analytical detection limits. However, a potential receptor survey concluded that groundwater is not used locally for potable purposes, thereby making human exposure unlikely.

The Phase II RI also performed a human health Baseline Risk Assessment (BRA). Carcinogenic risk and the non-carcinogenic hazard index (HI) were estimated based on the reasonable maximum exposure. Only groundwater was evaluated as a potentially complete pathway. Hypothetical future groundwater ingestion by an industrial worker was considered as part of the BRA but was determined to be very unlikely given public water supply in the area. EPA default intake values and published toxicity inputs were used in the calculations. The BRA determined the hypothetical risk for groundwater ingestion was approximately 4E-04. This value exceeded the most commonly used target of 1E-06 but only marginally exceeded the acceptable range for remediation of Superfund sites (1E-06 to 1E-04). The BRA also concluded that the HI exceeded a target of 1 (at 2.6) but was below 10, which has been used for remediation. Furthermore, the BRA concluded that considering the conservative set of assumptions used, the potential risk/hazards calculated were not anticipated to result in adverse human health risks.

While the Phase II RI defined the vertical extent of TCE, the horizontal extent was not completely delineated. Recommendations were made to further define the extent of the TCE plume in the southern and southwestern portion and to begin the feasibility study/remedial design (FS/RD).

1.3.3 Summary of Supplemental Investigation Activities

The supplemental activities conducted, along with the results, are documented in the Final 2003 Letter Report for the Feasibility Study/Remedial Design at the Former Naval Ammunition Depot, Mecklenburg County, Charlotte, North Carolina, September 2003

(SAIC 2003a). The results of the supplemental investigations conducted by SAIC are summarized below.

1.3.3.1 *November 2000*

SAIC was tasked by USACE to implement the Phase II RI recommendations, as well as to collect information to support the development of feasibility and pilot studies. In November 2000, SAIC initiated the FS/RD process at the site. Initial activities included completing the supplemental field investigation effort recommended by the Phase II RI to define the southern and southwestern portions of the TCE plume, to confirm the area of elevated VOC impact near the east end of the Arrowood Building IV, and to collect natural attenuation data for the FS. The field activities included installing 13 new shallow, transition, and deep wells (SAIC-1 through SAIC-13); collecting groundwater samples from the new wells (13) and selected existing wells (28); analyzing all groundwater for VOCs; analyzing groundwater for explosives residue from the new wells and existing wells with previous detections; analyzing groundwater samples from the new wells for natural attenuation parameters; and collecting water level measurements from all the site monitoring wells.

Evaluation of the data collected during the November 2000 field investigation (Table 1-2) indicated that the contaminant concentrations had changed since the Phase II RI, and that the extent of TCE contamination in the northern portion of the TCE plume was smaller than presented in the RI. Water level data also indicated that the potentiometric surface had changed significantly over time, with the groundwater flow direction shifting from west in the Phase II RI (Figure 1-7) to southwest (Figure 1-8). Water level measurements collected in December 2000 indicated that the water table had dropped by more than 20 ft in some of the bedrock wells since last measured in June 1999 (Table 1-3).

SAIC reviewed area climatological data, searched North Carolina Department of Environment and Natural Resources (NCDENR) and Mecklenburg County North Carolina Department of Environmental Protection well installation records, and contacted the Charlotte Municipal Utility Department to determine a possible cause for the significant change in the site conditions. SAIC determined that the Charlotte area had been under drought conditions since 1999, with an annual deficit of 8.18 in. in 1999 and a deficit of 8.35 in. in 2000. Research also revealed that a well field was located less than 150 ft southwest of the Former NAD site focus area (NAD Area 2) on Nevada Boulevard (Figure 1-3). The well field consisted of three, 8-in.-diameter water supply wells that were installed in July 1999 for plant production purposes. According to the boring logs, the wells have an open bore construction to depths ranging from 640 ft below ground surface (BGS) to 750 ft BGS. The wells went on-line in July 2000 and were reported to have a combined flow rate of approximately 0.5 million gallons per day.

With the discovery of the well field and the obvious change in site conditions, a decision was made that further evaluation of the current site conditions was warranted before the FS efforts could proceed. From October 2001 through April 2003 additional delineation efforts were conducted to determine how and to what degree the Former NAD site conditions were altered by the use of the plant production wells. These investigations were conducted in an iterative process with a focus on understanding the current site hydraulic conditions and the horizontal and vertical geometry of the TCE plume. The activities included collecting groundwater samples for VOCs from selected existing site monitoring wells and from the three plant production wells, conducting geophysical surveys, installing three deep bedrock multi-zone FLUTe^{TM} system monitoring wells, and collecting multiple rounds of water level measurements. A description of each of the subsequent investigations is provided in the following sections.

1.3.3.2 April 2001

On April 19, 2001, water samples were collected from the three production wells located at Plant #1 via a surface faucet and analyzed for VOCs. The results indicated that VOCs were present in the groundwater, with TCE concentrations ranging from 25.6 μg/L in WF-2 to 448 μg/L in WF-3. Based on the well installation records provided by the plant production company, WF-3 is the largest production well, located near the plant entrance. According to well construction logs and pumping test data, WF-3 has a total depth of 650 ft BGS, and pumped 300 gallons per minute (gpm), with water-producing zones at 230, 370, and 450 ft BGS.

On April 25, 2001, a complete round of water level measurements was collected at the Former NAD site, and pressure transducers were set in monitoring wells SAIC 04 and SAIC 05. Based on the April 19, sampling results, the well field began shutdown on April 27, 2001, at the request of NCDENR personnel, with complete shutdown on May 6, 2001. The data loggers documented the water table recovery at the Former NAD site of approximately 1.5 ft by May 8, 2001, when the pressure transducers were removed. On May 17, 2001, additional water level measurements were recorded in SAIC-04 and SAIC-05 and indicated that the water table had recovered approximately 5.0 ft.

1.3.3.3 October 2001

Based on decisions made during a meeting held between USACE, NCDENR, SAIC, and Plant Corporate personnel on August 20, 2001, a path forward approach was developed to gain a better understanding of the current Former NAD site conditions to allow an accurate site model to be developed for future FS/RD work. The path forward focused on determining the following:

- Vertical extent of TCE contamination in the vicinity of NAD MW-21, MW-43, and MW-56;
- If there is a hydraulic connection via bedrock fractures between the source area (NAD MW-21) and NAD MW-56;
- Where the TCE concentrations enter in to the plant production wells (fracture interval);
- If the TCE concentrations in select wells have changed along with the water table fluctuations;
- If dense nonaqueous-phase liquid (DNAPL) is present in the groundwater in the vicinity of NAD MW-21; and
- If the site water table conditions have stabilized.

To meet these objectives, another supplemental investigation was conducted from October 2001 through February 2002. The field activities included installation of three 200-ft-deep bedrock coreholes (SAIC-14, SAIC-15, and SAIC-16), conducting geophysical surveys in each of the new coreholes and the three plant production wells, collecting groundwater samples for VOC analysis in 12 existing site wells and from discrete zones in the newly installed coreholes and plant production wells, and collecting water level data from all site monitoring wells. Soil samples were also collected during the installation of the new coreholes and analyzed for VOCs. A test was also conducted to determine if DNAPL was present in the source area by installing a FLUTe™ ribbon at SAIC-14. The results of the investigation are summarized below.

On-site Investigation

Initially, the three deep bedrock coreholes (SAIC-14, SAIC-15, and SAIC-16) were completed to depth (Figure 1-3). Samples of the overburden soil were collected during the installation process directly above the top of bedrock. Immediately following the completion of SAIC-14, a test was conducted to determine if DNAPL was present in the groundwater in the source area. This was accomplished by placing a FLUTe™ ribbon into the corehole. After 4 hr, the colorimetric ribbon was removed and examined for colorimetric changes. The test indicated that DNAPL was not present in SAIC-14.

After completing the coring activities, geophysical surveys were completed in each corehole to identify potential water-bearing fracture zones. Groundwater samples were then collected at discrete intervals identified by the geophysical surveys, using straddle packers, and analyzed for VOCs. Blank FLUTe™ liners were then installed in each corehole to prevent cross-contamination between the fracture zones.

All groundwater samples collected were found to have TCE concentrations above the 2.8-µg/L North Carolina protection standard (Table 1-4). In addition, *cis*-1,2-dichloroethene (DCE); 1,1-DCE; and vinyl chloride, were also detected above their respective North Carolina Administrative Code (NCAC) 2L protection standards. In the three newly installed coreholes, maximum TCE concentrations ranged from 370 µg/L at 193 ft BGS in SAIC-15 to 4,200 µg/L at 168 ft BGS in SAIC-16 (Figure 1-9).

In addition, *cis*-1,2-DCE and TCE were detected in the soil sample from SAIC-15 at a depth of 30 to 31 ft BGS at concentrations of 0.005 J mg/kg and 0.43 J mg/kg, respectively (Table 1-5). However, these concentrations were below the EPA Region 9 risk-based concentrations (RBCs).

Off-site Investigation

Geophysical surveys were also conducted in each of the three plant production wells (WF-1, WF-2, and WF-3). Groundwater samples were then collected from each of the three wells at discrete zones that were selected based on the results of the geophysical survey. TCE was detected in all sampled zones with concentrations ranging from 52 µg/L in WF-1 at a depth of 201 to 218 ft BGS to 290 µg/L in WF-3 at a depth of 309 to 326 ft BGS (Figure 1-10). Other VOCs were also detected, including *cis*-1,2-DCE; 1,1-DCE; 1,2-DCE; 1,2-dichloroethane; and toluene (Table 1-6).

Water Levels

Water level measurements obtained in November 2001 and February 2002 indicated that water table conditions at the site had not stabilized. The February 2002 event showed that in 21 wells, the water levels were still more than 5 ft below the 1999 reported baseline water levels (i.e., before the production wells were installed), with 3 wells remaining dry (NAD MW-18, NAD MW-50, and NAD MW-55; Table 1-3). The precipitation deficit was reported to be only 3.13 in. in 2002.

After evaluating the data and the results of the subsequent investigations, the following conclusions were made regarding the Former NAD site conditions at the end of the October 2001 through February 2002 investigation:

- Operation of the off-site well field changed the plume geometry such that TCE hot spots greater than 2,500 μg/L now exist at depths greater than 100 ft BGS.
- Near the former source area (defined by wells MW-21 and SAIC-14), and towards MW-56 and SAIC-16, the TCE plume with concentrations >500 μg/L extends below a depth of 200 ft.

Borehole geophysics and coring samples indicate a very competent bedrock with a small volume of fractures controlling contaminant migration. The orientation of fractures is very difficult to predict, both horizontally and vertically.

Based on the results of the supplemental investigation, it was determined that a complete plume delineation may not be achievable. Recommendations were made to perform further investigation activities at the site, specifically in the hot spot areas where the vertical extent of the TCE concentrations is greater than 500 μg/L, prior to beginning the FS/RD process. NCDENR Superfund Section personnel concurred with the recommendation to limit the focus of the next phase of work at the site to areas where the vertical extent of TCE concentrations was >500 μg/L. Recommendations were made to extend the depths of coreholes SAIC-14 and -16 to 350 ft with discrete interval groundwater samples to be collected and analyzed for VOCs. Multi-zone sampling systems (FLUTe™) would be installed in SAIC 14, SAIC-15, and SAIC16. Groundwater samples would be collected from selected existing monitoring wells, and water levels would be measured bi-annually. In addition, a detailed receptor survey would be conducted.

1.3.3.4 October 2002 Investigation

From October 2002 to April 2003, focused field investigation activities were performed at the Former NAD site to gain a better understanding of the groundwater plume areas with vertical TCE contamination >500 μg/L (MW-21 and SAIC-14, and MW-56 and SAIC-16) to allow an accurate site model to be developed for future FS/RD work. The details of this field investigation are given in Chapter 3.0 of the 2003 Letter Report (SAIC 2003).

Coring and Discrete Interval Sampling Activities

In October 2002, the blank FLUTe™ liner was removed from SAIC-14 and the borehole deepened by coring to a total depth of 350.7 ft BGS. After the coring was completed, discrete interval groundwater samples were collected for VOC analysis from four intervals using straddle packers. The results are summarized in Table 1-7. After the samples were collected, the blank FLUTe™ liner was successfully reinstalled into the open borehole to minimize cross-contamination.

TCE concentrations ranged from 24,000 μg/L in the groundwater sample collected from the interval near the bottom of the borehole (295.7 to 316.3) to 4,100 μg/L from interval 195.7 to 216.3 (Figure 1-9). The compound *cis*-1,2-DCE was detected in every sample at concentrations ranging from 4,100 to 280 μg/L. Toluene was also detected in three of the four samples at concentrations ranging from 44 to 50 μg/L. Only the TCE and *cis*-1-2-DCE were detected at concentrations above the North Carolina groundwater quality protection standard of 2.8 and 70 μg/L, respectively.

In October 2002, attempts were made to remove the blank FLUTe™ liner from SAIC-16. However, difficulties arose when the FLUTe™ liner became entrapped in the borehole after the borehole wall had collapsed beneath the surface casing at approximately 27 ft BGS. Several attempts were made to remove the liner; however, they were unsuccessful and the decision was made to abandon the borehole and relocate the boring. After boring SAIC-16 was abandoned, a new location was chosen for SAIC-16A (Figure 1-3). The boring was cored to a total depth of 331.60 ft BGS. After the coring was completed, discrete interval groundwater samples were collected from three intervals using straddle packers and analyzed for VOCs. The results are summarized in Table 1-7 and depicted on Figure 1-9.

TCE concentrations were noted to decrease with depth and ranged from 2,100 μg/L in the groundwater sample collected from the interval near the top of the borehole (81.9 to 113.72) to 270 μg/L from interval 282.9 to 314.72. All of the detected compounds are above their respective North Carolina groundwater quality protection standards.

After the borings were cored to their final depths and the groundwater samples were collected, the boring logs and analytical data were evaluated to select the permanent groundwater monitoring intervals for SAIC-14, SAIC-15, and SAIC-16A. In January 2003, the unique multi-zone FLUTe™ sampling systems were manufactured for each of the three coreholes.

Monitoring Well Sampling

A total of 29 existing site monitoring wells were selected for groundwater sampling; however, only 28 wells were sampled as there was no water in monitoring well NAD MW-48. All groundwater samples were sent to an off-site laboratory for VOC analysis. Table 1-7 provides a summary of the results.

The maximum TCE concentration was reported in monitoring well NAD MW-26 at 6,600 μg/L with non-detects (concentrations below the reporting levels) in NAD MW-

46 and SAIC 02. TCE concentrations in all the wells except NAD MW-44, NAD MW-46, SAIC 02, and SAIC 7 exceeded the North Carolina groundwater quality standard of 2.8 μg/L. Other VOCs that exceeded their groundwater quality standards included 1,2-DCE; tetrachloroethene (PCE); and *cis*-1,2-DCE.

A comparison of the current VOC data to the historical data collected (1999 and 2000) indicated that the TCE concentrations in 16 of the sampled monitoring wells decreased with time and showed an increase in concentration over time in 7 monitoring wells. In five of the sampled wells, the concentrations remained relatively unchanged over time.

The most significant decrease occurred in monitoring well NAD MW-22 where the TCE concentration went from 9,900 μg/L in June 1999 to 310 μg/L in October 2002. NAD MW-22 is a bedrock zone well that is located ~200 ft southwest of the source area. The most significant increase occurred in NAD MW-51 where the TCE concentration increased from 340 μg/L in June 1999 to 3,200 μg/L in October 2002. NAD MW-51 is a transition zone well that is located ~400 ft southeast of the source area.

Water Level Measurements

Water level measurements were collected from all 70 existing site monitoring wells in October 2002 and April 2003. The data are summarized in Table 1-3.

The water levels measurements collected in October 2002 indicated that several monitoring wells were still below the June 1999 base level measured prior to the startup of the Plant #1 production wells in July 1999. Nine wells were still >5 ft below the base level (NAD MW-21, NAD MW-31, NAD MW-32, NAD MW-49, NAD MW-51, NAD MW-52, NAD MW-53, NAD MW-54, and NAD MW-56). The measurements also indicated that three wells (NAD MW-48, NAD MW-50, and NAD MW-55) had no measurable water (i.e., were dry).

According to the 2002 Annual Climatological Data Summary for the Charlotte-Douglas International Airport weather monitoring station, the annual precipitation deficit for 2002 was 3.13 in.

The water levels measurements collected in April 2003 indicated that the majority of the wells had recovered to baseline values. Measurements also showed that the wells noted as being dry now contained water. It was also observed that four wells (NAD MW-37, MW-59, MW-60, and MW-65) had water levels that had risen to within <0.35 ft from the top of the casing with the water level in NAD MW-59 measured at the top of the casing.

This excessive rise in the water levels was attributed to the large quantity of precipitation that the Charlotte, North Carolina, area received in 2003. In April 2003, a total of 8.25 in. of precipitation was recorded, which is 5.30 in. greater than the average. From January through June 19, 2003, the Charlotte area received 36.38 in. of precipitation, which is 15.67 in. above the average value.

Receptor Survey

A receptor survey was conducted for a 1-mile radius surrounding the Former NAD site focus area to determine potential receptors of the groundwater contamination. The receptor survey consisted of identifying property owners and the name and size of businesses and/or manufacturers within the radius, as well as their current water supply source. In addition, all existing water wells within the radius, along with their use and capacity, were identified.

The receptor survey indicated the following:

- The area is dominated by commercial and light industrial properties that include warehouses, retail stores, restaurants, hotel/motels, and small private businesses.
- Residential properties are located approximately ¾ miles north of the NAD site focus area.
- The Charlotte Mecklenburg Utility District provides drinking water to the entire area within the 1-mile radius.

Two properties were identified as having wells. However, the wells are no longer in use. One is a residential property, located approximately 1-mile northwest of the Former NAD focus area, that was reported to have a well that was used to supply drinking water. The use of the well was discontinued after October 1999. The other property is located less than 1,500 ft southwest of the Former NAD focus area. This is a commercial property that has three wells. The use of these wells was not listed; however, their use was discontinued in May 2001.

The survey also indicated that 11 properties within the 1-mile radius are listed as contamination sites by the Mecklenburg County Department of Environmental Protection and NCDENR. Four of the properties were investigated for contamination associated with underground storage tanks, with two properties being investigated for VOC contamination. These two properties are located north of Brookford Street less than 1,600 ft north of the boundary of the Former NAD Area 1. Investigation files for the other properties did not list the contaminant or cause for investigation.

1.3.4 Pilot Study and Site-Wide Sampling Event

At the conclusion of the 2002 supplemental investigation effort, recommendations were made to conduct a pilot study to evaluate the use of an electron donor for promoting reductive dechlorination as a remedial approach for the site, and to better understand the hydraulics near NAD MW-21, which has historically contained the highest concentrations of TCE. Injection of a combination bromide tracer and sodium lactate (electron donor) food source was accomplished in October 2003 with subsequent monitoring for 8 months through June 2004 followed by a site-wide sampling event conducted in August and September 2006. The details and results of the pilot study are provided in Chapter 5.0 of this report. The details and results of the 2006 sampling event are provided in the *Site-Wide Groundwater Sampling Report for the Future Remedial Design at the Former Naval Ammunition Depot (NAD), Mecklenburg County, Charlotte, North Carolina* (SAIC 2008). A summary of the 2006 sampling event, along with a discussion of the results, is provided in Appendix A.

2.0 SITE CHARACTERISTICS

Geologic, hydrogeologic, and groundwater geochemical information and data for the Former NAD site were obtained from the RIs and supplemental investigations (Section 1.3) conducted at the site. Each of these characteristics is described in the following sections to provide a brief yet comprehensive overview of the site.

2.1 PHYSIOGRAPHY AND TOPOGRAPHY

Historical and current building activities have impacted the topography of the Former NAD complex including the investigation focus area (NAD Areas 1 and 2). Graded building pads, foundation structures, drainage features, rail lines, and roads are evident across the area. Within the study area, buildings and associated structures, both historical and current, are generally oriented northeast to southwest (Figure 1-3). The developed areas are covered with asphalt, concrete, and buildings. Soil has been cut, filled, and graded, and few natural surface features remain in these areas. The site also has several areas that remain undeveloped and are covered with trees and brush.

Between 1996 and 1997, Norfolk Southern expanded their rail lines causing significant changes to occur to the topography at the site. During construction, approximately 6 to 8 ft of overburden was removed and the area graded to accommodate the new railroad shipping facility operated by Bulkmatic Inc. in Former NAD Area 2 and another railroad shipping facility operated by Roll and Hold in Former NAD Area 1. The rail lines' average grade is 6 ft below the building pads to facilitate loading docks. The construction activities destroyed many of the wells installed in the area during the early investigations, especially the Phase I RI. The removal of the overburden caused the depth to bedrock to be much shallower in the area of NAD MW-21 than over the rest of the site (Figure 1-3).

The landscape is characterized by broad flats and gentle side slopes. Relief at the site is approximately 25 ft with maximum elevation along a low-lying northwest trending ridge in the center of the study area. The ridge is thought to be a result of a subsurface bedrock ridgeform of similar orientation (M&E 2000). This bedrock ridge is well documented in the literature (VERSAR 1993). The apex of both the bedrock and surface ridges forms a line, which separates the ASIP Buildings II and III from Building IV (Figure 1-3). A major portion of the area slopes away from this ridge to the southwest. Drainage around structures in the area has been diverted to the southwest.

2.2 CLIMATE CONDITIONS

Mecklenburg County has a warm, humid climate with a mean annual rainfall of 43 in. The county occupies a moderate plateau ranging in elevation from 520 ft to more than 830 ft. Rainfall is fairly uniformly distributed from December through July. The heaviest rainfall normally occurs in February, March, and July, with March being the wettest month (4.58 in. on the average). The driest months are October and November, with October having a monthly average of 2.51 in. of precipitation. Average daily maximum temperatures in January and July are 52 and 89°F, respectively. The average annual daily maximum temperature is 71°F, with an average minimum temperature of 50°F.

According to the record of climatological observations recorded at the Charlotte-Douglas International Airport weather station, the Charlotte area was in drought conditions and received less precipitation than normal from 1999 through 2002 (http://www.ncdc.noaa.gov/oa/climate/uscrn/index.html). A precipitation deficit of more than 8 in. was reported in 1999 and 2000 and more than 16.5 in. reported in 2001. However, in 2002, a deficit of only 3.13 in. was reported. In 2003, more precipitation was received than normal. A total of 62.63 in. of precipitation was recorded, which is nearly 20 in. above the average. This level of precipitation is very unusual for the area. Only five other years have recorded annual precipitation levels greater than 60 in. for the Charlotte area: 1884, 1886, 1901, 1936, and 1975, with the greatest annual precipitation of 68.44 in. recorded in 1884. According to the National Oceanic and Atmospheric Administration (NOAA), a total of 37.55 in. of precipitation have been recorded for Charlotte through September 2004, indicating that for 2004, the annual precipitation for the area has been in the normal range.

2.3 GEOLOGY

The Former NAD site lies within the central Piedmont of North Carolina, which extends from the northwestern edge of the Kings Mountain and Loundsville belts eastward and southward to the Raleigh and Kiokee metamorphic belts (M&E 2000). Regional geologic features include the Carolina Slate, and the Charlotte, Kings Mountain, and Loundsville shear zones. The eastern edge of the region is defined by a sequence of faults (Jonesborough and Nutbush Creek) and linear features, which include the Raleigh and Eastern Slate belts. The Former NAD site is located within the Charlotte belt (Figure 2-1).

The Charlotte belt occurs near the northern reaches of the central Piedmont. The belt is typically characterized as "dominantly plutonic" with mineralogical compositions ranging from granite to gabbro (M&E 2000). The structure of the Charlotte belt is difficult to determine because of the abundance of post-deformational plutons. In the region southwest of Charlotte, compositional layering and schistosisty are generally steep to vertical and strike northeast; the few folds that have been observed are mostly isoclinal, with nearly vertical axial surfaces and hinges that plunge gently northeast or southwest (Butler 1971).

2.3.1 Soil

The unconsolidated subsurface soils encountered at the Former NAD site are primarily residuum and saprolite material. The general soil zone is classified as Iredell-Mecklenburg. Former NAD Areas 1 and 2 are typically underlain by Iredell fine, sandy loam. The average slope ranges from 0 to 8% over the study area. Slopes range from 2 to 15% for this series. The hydraulic conductivity of these soils ranges from 2.0 to 6.0 in./hr in the 0 to 0.5-ft depth range, and 0.06 to 0.6 in./hr at depth greater than 0.5 ft (M&E 2000).

The residuum consists of moderately well-drained micaceous sandy silts, silty sands, silty clay, and clayey sands that formed from diorite, gabbro, and other rocks having high percentages of ferromagnesium minerals. The residuum is characterized by complete weathering of the parent bedrock, with relative soil densities generally ranging from loose to very firm for granular residuum and firm to stiff for cohesive residuum. Below the residuum is a fine- to medium-grained saprolite composed of weathered biotite, quartz, feldspar, and hornblende. The saprolite is characterized by a soil-like texture but is less weathered than the residuum and shows relict structures of the parent rock.

The residuum encountered at the site is characterized as brown, moist, plastic, sandy clays. The clay contains traces of organic construction materials in areas of fill or disturbance. In undisturbed residual soils, the clay is generally lighter in color, with an increase in mica content. The residuum was found to range in thickness from <4 ft in the central portion of the site where grading activities were conducted during the Norfolk Southern rail line expansion to 25 ft deep in the remaining portions of the area (Figure 2-2). During the Phase II RI, geotechnical analysis of a shallow soil sample, (2 to 4 ft below land surface) collected from NAD MW 0401, determined that the soil consisted of 0.9% gravel, 46.0% sand (mostly medium to fine), and 53.1% fines. Based on a liquid limit of 40, plasticity index of 20, and natural moisture content of 13.6%, the material was classified as a low-plasticity clay (M&E 2000).

The saprolite encountered below the residuum was found to range in thickness across the site from 1 to 15 ft (Figures 2-3 and 2-4). It is characterized by medium-grained interbedded reddish to brown silty sand, clay-rich silts, and silty clays that occur over the bedrock and within fractures in the bedrock. In this zone, the material has weathered to sands, silts, and clays, and contains the structure and composition of the parent material with the sands being derived from quartz-rich layers in the bedrock and the silts and clays from biotite, feldspars, hornblende, and plagioclase. The saprolite was found to occur over the bedrock and within the fractures of the bedrock.

Near the top of the bedrock, the saprolite may become coarser grained with the grains becoming sub-angular. Larger fragments of rock may also be encountered. This zone of partially weathered rock in a matrix of saprolite, along with the upper zone of the fractured bedrock, is referred to as the transition zone.

2.3.2 Bedrock

Regionally, the rocks of the Charlotte Belt consist of massive to weakly foliated granite to granodiorite and earlier formed gneiss. The gneiss unit consists of amphibolites or hornblende gneisses, quartz-biotite, and quartz-microcline gneisses and various types of migmatite marginal to the major plutons. Both the granite and the gneisses are intruded by very late orogenic gabbros consisting of fibrous amphiboles, biotite, and plagioclase. Pegmatites crosscut these gabbros. In addition to the folding and magmatic activity within the belt, a pronounced N 20 W fracture direction is prominent. Gabbro and metagabbro rock of the Mecklenburg-Weddington complex, a member of the Concord Plutonic suite, underlie the Former NAD area. Geophysical data suggest the complex forms a body extending for more than 15 miles east-west and ranging in thickness from 2.2 to 2.8 miles (Wilson 1981).

Based on the environmental investigations conducted at the site, the majority of the bedrock directly underlying the saprolite consists of a fractured, partially weathered rock that ranges in thickness from 0 to 5 ft. This zone of partially weathered bedrock, along with the overlying saprolite, is referred to as the transition zone.

Depth to competent bedrock within the Former NAD site ranges from 4.5 to 31.0 ft below land surface. In the vicinity of the pilot study focus area, approximately 6 to 8 ft of overburden was removed during site grading and construction activities performed by Norfolk Southern in 1996 and 1997, thus causing the depth to bedrock to be much shallower in this area than over the rest of the site. The average depth to bedrock in this area is approximately 6 ft.

At the site, the massive mafic bedrock is typically medium-grained, light-to-dark gray or green gabbro/basalt and amphibolite. According to the borehole logs, the felsic rocks range from a hornblende-biotite granite to a biotite, quartz-rich granodiorite. Feldspar-rich rocks, such as syenite and diorite, are also present. The fractures encountered in the upper portion of the bedrock material were generally found to decrease in density as depth increased. However, at locations that were drilled near the observed lineament trace (SAIC-16 and SAIC-16A), large fracture systems were encountered in the bedrock at relatively shallow depths ranging from 15 to 90 ft.

During the Phase II RI, granodiororite outcrops near the site were investigated and numerous fractures were observed. The predominant orientation of the fractures observed at the site trends to the northeast (M&E 2000). The outcrops identified in the Former NAD area formed a linear feature trending approximately north-south. Many topographical features observed within the Former NAD site and surrounding areas are the result of structural and mechanical processes within the bedrock. During the Phase II RI, M&E identified trace lineaments within the NAD area (Figure 1-3). These lineament traces correlate to the fractures encountered during bedrock coring activities conducted by SAIC, specifically SAIC-16A.

2.4 HYDROGEOLOGY

2.4.1 Groundwater

During the Phase II RI, aquifer testing demonstrated that the hydrogeology in the Former NAD area represents a complex system of interconnected aquifers, corresponding to the hydrogeologic zones: shallow zone, transition zone, and bedrock zone. The shallow zone is characterized by the unconsolidated residuum and the saprolitic soils. The transition zone is identified as the zone of transition along the overburden/bedrock interface. This zone consists of partially weathered parent material and the upper fractured bedrock. The bedrock zone is characterized by the presence of water-bearing fractures within the competent granodiorite. The testing revealed interconnectivity between the zones and anisotropy with the transition zone and the bedrock zone. Testing also indicated that the shallow zone and the transition zone were hydraulically interconnected. The transition zone potentiometric surface and the bedrock zone potentiometric surface from the most recent sampling event (August/September 2006) are represented in Figures 2-5 and 2-6, respectively. The groundwater elevation data for the 2006 sampling event are provided in Table 1-3.The hydraulic conductivity of the saprolite varies greatly based on the percentage of clay and minerals, and the presence of relic secondary features (veins, fractures, and joints). Higher quartz content and more developed fracture patterns enhance hydraulic conductivity. Groundwater in the transition zone is primarily transmitted through the partially weathered rock, whereas groundwater in the crystalline bedrock is transmitted via fractures contained in the bedrock.

The groundwater hydraulics at the Former NAD site are complex and have been altered during the performance of the RI/FS process by both on-site alteration of drainage patterns and off-site pumping (see Chapter 1.0). Data collected during the RI and supplemental investigations, as well as the pilot study (see Chapter 5.0), demonstrate the anisotropic nature of the formation. The groundwater flow direction is predominantly west but there is also a flow component to the south that appears to be associated with the fracture trace lineament (Figure 1-3). The flow in this fracture system may have been enhanced by the artificial increase in the hydraulic gradient that was induced by the three production wells located at Plant #1. Based on reported usage rates, it is estimated that approximately 144 million gallons of water were removed from the aquifer within an area of influence that was calculated to be over 1 mile.

2.4.2 *Surface Water*

The Former NAD site is bisected by a low-lying topographic ridge oriented northwest-southeast. The ridge is probably a result of a subsurface bedrock ridgeform of similar orientation. The apex of both the bedrock and surface ridges forms a line that separates ASIP Buildings II and III from ASIP Building IV. Stormwater runoff on the east side of the ridge flows to a marsh located northeast of Westinghouse Boulevard across from Box USA. The marsh occupies a low-lying area of limited areal extent and drains to the east toward Sugar Creek. Surface water drainage on the west side of the ridge collects in perennial tributaries of Steele Creek. The creek runs parallel to the west side of the area (Nevada Road) and drains towards the south.

2.5 *CONTAMINANT NATURE AND EXTENT*

Based upon the analytical, chemical, and physical findings from the Phase I and Phase II RIs, the supplemental investigations, the pilot study, and the subsequent site-wide groundwater sampling event conducted in 2006 (SAIC 2008), the distribution of TCE in the groundwater can be separated into two distinct plumes based on the hydrogeologic zone (i.e., transition zone and bedrock zone). The TCE plumes were constructed using a data set that included the most current available data for each well. The majority of the data used to define the TCE plume for both the transition and bedrock zones are from the 2006 sampling event. However, not all of the monitoring wells were able to be sampled during this event due to property access agreement limitations and field conditions (SAIC 2008). For the wells that could not be sampled, the most recent data available were included in the data set use to define the TCE plumes. The 2006 data are summarized in Table 2-1 and discussed in Appendix A.

Within the transition zone at the Former NAD site, concentrations of TCE ranged from non-detect to 6,200 μg/L (NAD MW-58) with the plume extending to a depth of ~42 ft BGS. Within the bedrock zone, concentrations of TCE ranged from 2.0 μg/L (SAIC-07 and SAIC-02) to 40,000 μg/L at SAIC-14 with the plume extending to a depth of 305 ft BGS (Figure 2-3).

At the conclusion of the 2002 supplemental investigation effort, a decision was made to focus the remedial action on areas that exhibit TCE concentrations greater than 500 μg/L. Therefore, the 500-μg/L criterion was used in developing the plumes for both the transition zone and the bedrock zone. For the transition zone, the plume was refined by applying the Spatial Analysis and Decision Assistance (SADA) software package [(SADA 2002) see Appendix A]. SADA analysis indicated five separate plumes (hot spot areas) with TCE concentrations exceeding 500 μg/L (Figure 2-7). The following is a list of the individual hot spots along with their associated source (monitoring well with the maximum concentration).

- Hot Spot 1 – NAD MW-58 (2002 data set),
- Hot Spot 2 – VERSAR 17 (2000 data set),
- Hot Spot 3 – NAD MW-49 (2006 data set),
- Hot Spot 4 – NAD MW-42 (2006 data set), and
- Hot Spot 5 – NAD MW-25 (2006 data set).

Unlike the transition zone, a single large TCE plume centered around SAIC-14 was observed for the bedrock zone (Figure 2-8). The plume was generated using the maximum concentrations from all wells from the most current data set (CY 2000 through 2006). Section 2.7 and Appendix A provide the details regarding the groundwater fate and transport modeling performed for this site.

Hydraulic gradient and anistrophy have influence on the plume migration within the Former NAD area. Both the transition and bedrock zones plumes have migrated southwesterly from the suspected source area [Former NAD Building 2-30 (Figure 1-4)] following the potentiometric surface and the bedrock fractures. The bedrock topography also appears to influence the northeasterly migration of the plume.

At the Former NAD site, the TCE was probably released slowly into the environment until processing activities at the facility were discontinued in the 1950s. During the initial phases of the release, TCE may have diffused downward through the porous matrix of the unsaturated zone of the shallow aquifer. During this phase, the migration of the TCE was a function of gravity, the permeability of the porous matrix, the viscosity of TCE, and the interactions of TCE with the porous matrix. The downward migration of TCE as a product-phase or "DNAPL" would have continued until it encountered the shallow water table. At this point (if mass-loading rates were sufficient), the DNAPL moved downward through the aquifer by displacing groundwater from the porous matrix as it advanced and a small percentage of the DNAPL eventually dissolved into the groundwater. Product-phase TCE may have continued diffusing downward through the porous matrix until either loading rates diminished to a point where the remnant DNAPL TCE plume completely dissolved in the groundwater or an impermeable barrier was encountered. Once an impermeable barrier was encountered, product-phase TCE may have pooled at this interface or plume migration may have continued to another permeable matrix through bedrock fractures and fissures.

Product-phase TCE would then have diffused into the fracture system displacing groundwater as it moved and increased in size as it interacted with the groundwater in the bedrock. Migration of the dissolved phase TCE through the bedrock would also be a function of the gravity, hydraulic gradient, and transmissivity with the migration confined to channelized or fracture flow within the virtually impermeable matrix of the massive bedrock.

The results of the Phase I and II RIs and the supplemental investigations support this scenario and indicated that from its point source, the migration of TCE was initially influenced by the hydraulic
gradient and top of bedrock topography, with the TCE plume initially moving southwesterly and moving northeasterly following the bedrock topography and anisotropy. However, the results of the supplemental investigations seem to indicate that the vertical migration of TCE through the bedrock was enhanced by an increase in the hydraulic gradient that was artificially induced by the three production wells located at Plant #1.

2.6 CONCEPTUAL SITE MODEL

The purpose of the CSM is to describe a basic understanding of potential sources, pathways, and possible receptors based upon available site information. Information obtained from the site was used to refine the conceptual model in an iterative process so that subsequent investigations effectively targeted critical needs areas. Through this approach a technically defensible, process-oriented conceptual model has been developed to support the evaluation of risks associated with contaminant fate and transport at the site. A discussion of the pathways is presented below and in Section 2.8.

2.6.1 Potential Sources

During the investigation process employed at the Former NAD site, no remaining specific sources for the TCE groundwater impact have been identified. However, the significant concentrations of TCE in the groundwater near NAD MW-21 and SAIC-14 indicate this area is most likely an initial entry location.

2.6.2 Potential Exposure Pathways

During the Phase II RI, potential exposure pathways were evaluated as part of the Human Health BRA for soil and sediment, groundwater, and surface water (M&E 2000; see Section 2.8). As the entire site vicinity is zoned industrial and no residences are located within 0.5 miles, an industrial scenario was considered for all current exposure pathways. In addition, no change in industrial use is anticipated given the operating history for the last 50 years and surrounding industrial land use.

Consequently, the potential future exposure also considered an industrial scenario. A summary of the potential exposure pathways is provided in the following sections.

2.6.2.1 *Soil and Sediment*

Soil and sediment contact could occur through direct exposure, plant uptake, and animal exposure. No agricultural use or animal subsistence was identified at the site. Direct contact could occur although it is unlikely. However, in the absence of contamination, exposure pathways for soil and sediment are not quantified (M&E 2000).

2.6.2.2 *Groundwater*

As noted in the Phase II RI report and confirmed through the receptor survey conducted as part of the subsequent investigations (SAIC 2002), no residential water supply wells were identified within 1 mile of the site and no potable water wells were identified on-site. However, in 2001, three private commercial water supply wells were identified within 1,500 ft of the site (Plant #1). The use of these wells was discontinued in 2001. The receptor survey conducted in 2002 indicated that city-supplied water exists throughout the area as revealed by information provided by the Charlotte Mecklenburg Utility District and through the Mecklenburg County Well Information System (available at http://maps.co.mecklenburg.nc.us). Given public water supply in the area, current exposure to groundwater via potable use (i.e., drinking water and other domestic use) is not currently considered a complete pathway. However, it is possible that an undocumented well could exist outside the Former NAD site (as was the case for the Plant #1 wells). Therefore, to be conservative, future exposure to groundwater (i.e., industrial/commercial use) is considered to be a complete pathway.

An inspection of buildings within NAD Areas 1 and 2 conducted during the Phase II RI revealed slab construction. In the absence of basements, subsurface vapor accumulation due to groundwater migration was considered to be a complete pathway.

2.6.2.3 *Surface Water*

Surface water in the site area consists of small man-made drainage ditches. These features are non-navigable and unsuitable for recreational purposes. Surface water is similarly not used for potable purposes. No agricultural irrigation is conducted and animal subsistence is not known to exist at the site. Surface water pathways under current and future site uses are considered to be incomplete.

2.7 *CONTAMINANT FATE AND TRANSPORT*

Based on the site characteristics described above and the results of the pilot study (see Chapter 5.0), fate and transport modeling was undertaken to assess whether monitoring of natural attenuation is an appropriate remedy for the dissolved-phase groundwater plume at the site and to support the development of additional, viable remedial alternatives for the site. Appendix A contains the comprehensive fate and transport modeling package. The following discussion will summarize the findings only.

The Analytical Transient 1-, 2-, 3-Dimensional (AT123D) model is an analytical, EPA-approved model typically used to determine mass transport, uniform stationary flow, three-dimensional (3-D) dispersion, first-order decay, and contaminant retardation. The primary purpose of the AT123D modeling for the Former NAD site was to determine the following:

1. How long will it take for the chlorinated volatile organic compounds (CVOCs) (that currently exist at site) to degrade naturally to NCAC 2L standards and how far will the plumes migrate if monitored natural attenuation (MNA) is selected as the remedial alternative?

2. How long will it take for the residual CVOCs (that will exist at the site after implementation of enhanced bioremediation using sodium lactate) to degrade naturally to NCAC 2L standards and also, how far will the residual CVOC plumes migrate if MNA combined with enhanced bioremediation is selected as the remedial alternative?

3. How many events or how long should the sodium lactate injection continue to reduce the concentration of the TCE plumes to below 500 μg/L.

As discussed in Section 2.4, the hydrogeologic zones of the Former NAD site were divided into three zones: shallow, transition, and bedrock. As the shallow zone is not contaminated, it is not a target for remedial action. Therefore, only the transition and bedrock zones were included in the modeling effort. For each zone (transition and bedrock), two scenarios were modeled as presented in Table 2-2. Fate and transport modeling was also performed to predict the time required to reduce the TCE plume concentrations to below 500 μg/L both in transition and bedrock zones using the results of the pilot study and the 2006 site-wide sampling event (Appendix A). For all the modeling efforts, TCE was selected as the surrogate chemical to represent the CVOC group for this analysis.

For the no action/MNA scenario, the results of the fate and transport modeling indicated that the concentrations of TCE would decrease to the NCAC 2L standard of 2.8 μg/L through natural attenuation in 47 years for the transition zone (see Appendix A, Figure A-1) and in 63 years for the bedrock zone (see Appendix A, Figure A-2). The modeling results also indicated that the maximum migration distance for the TCE plume boundary exceeding the NCAL 2L standard would be limited to 400 m (~1,312 ft) from the point of maximum concentration(s) for both the transition and bedrock zones. For the transition zone, the migration distance would be measured from the monitoring well with the maximum concentration (source) in each of the five distinct (hot spots):

- Hot Spot 1 – NAD MW-58,
- Hot Spot 2 – VERSAR 17,
- Hot Spot 3 – NAD MW-49,
- Hot Spot 4 – NAD MW-42, and

- Hot Spot 5 – NAD MW-25.

For the bedrock zone, the migration distance would be measured from the monitoring well SAIC-14.

Fate and transport modeling was also performed based on residual contamination that would be left in the aquifers after implementation of an active treatment (e.g., sodium lactate injection to the core of the plume bounded by 500 μg/L). Results of the modeling indicated that the concentrations of TCE would decrease to the NCAC 2L standard of 2.8 μg/L through natural attenuation in 14 years for the transition zone (see Appendix A Figure A-3) and in 12 years for the bedrock zone (Appendix A, Figure A-4) after completion of the sodium lactate injection to the core of the plume. Modeling results also indicated that the TCE concentration in the groundwater is not expected to exceed its NCAC 2L standard (2.8 μg/L) beyond 400 m (~1,312 ft) downgradient from the existing source(s) in each of the five transition zone plumes or the bedrock plume.

To evaluate the effectiveness of the sodium lactate injection pilot study, groundwater sampling from multiple wells for multiple events (in total, eight events) were performed. The results from these events were analyzed to estimate decay rates by observing the decline of TCE concentrations in the wells that are within the zone of influence of sodium lactate injection. The results of the analysis indicated biodegradation rates of 0.028 day^{-1} in the transition zone and 0.013 day-1 in the bedrock zone (Appendix A). Based on these values, AT123D modeling was performed to predict the time required to reduce the TCE plume concentrations to below 500 μg/L in both the transition and bedrock zones. Results of this modeling indicated that the maximum concentration of TCE will be reduced to 500 μg/L in approximately 6 months. Therefore, a total of four injection events (assuming an injection every other month or 60-day interval) would be required for the transition zone. Similarly, modeling also predicted that it would take approximately 12 months to reduce the TCE concentrations to below 500 μg/L across the site in the bedrock zone. Therefore, seven sodium lactate injection events would be required for the bedrock zone. It was assumed that the effectiveness of sodium lactate would last for at least 60 days from the time of injection.

2.8 BASELINE RISK ASSESSMENT

A human health BRA was conducted as part of the Phase II RI (M&E 2000). In the BRA, surface soil, groundwater, surface water, and sediment data were reviewed to determine chemicals of potential concern (COPCs). Each medium was evaluated for contaminants present with respect to applicable screening criteria. The screening criteria used included RBCs developed by EPA Region III for soil and sediment; federal and North Carolina drinking water standards for groundwater; and North Carolina Surface Water Standards (15A NAC B.0200) and federal standards for surface water. Constituents below screening values were eliminated from further consideration as COPCs. Those constituents that were above the screening values were determined to represent a risk to human health based on the pathway analysis were retained as constituents of concern (COCs). The additional sampling data collected as part of the subsequent sampling efforts, including the pilot study and the

CY 2006 sampling event, were also screened using these criteria. To provide a consistent assessment of the site conditions, the data that were collected as part of the Phase I and II RI's were reevaluated during the FFS to compare the results to EPA Region 9 RBCs, as applicable. A summary of the screening efforts for each medium is provided in the following sections.

2.8.1 *Surface Soil*

Surface soil samples were not collected as part of the Phase I RI. In November 1997, during the Phase II RI, surface soil and sediment samples were collected and analyzed for VOCs, semivolatile organic compounds (SVOCs), and explosives residue (M&E 2000). The data were evaluated using the EPA Region III RBCs for residential and industrial land use and criterion background concentrations. No organic chemicals were detected above the industrial RBCs. One metal (arsenic) was identified above the RBC value. The RI determined that the surface soil quality was marginally affected by commercial/industrial activities in the area, and no surface soil COPCs were identified for inclusion in the FS. No additional surface soil samples were collected during the subsequent supplemental investigations.

As part of the FFS, The Phase II surface soil and sediment data were reevaluated using EPA Region 9 RBCs. The results of this evaluation were the same as those of the RI concluding that arsenic was the only compound detected above EPA Region 9 criteria. The evaluation was therefore in agreement with the conclusions made during the RI.

No COPCs were identified in surface soil using conservative, risk-based screening values; therefore, no complete exposure pathway exists. No COPCs and, therefore, no COCs were identified for inclusion in the FFS for surface soil.

2.8.2 *Subsurface Soil*

Subsurface soil samples collected from 3 to 20 ft BGS were included in the Phase I analysis (M&E 1995). Beryllium was found to exceed the screening criteria but was considered naturally occurring. Metals were also detected but did not exceed the screening criteria. No VOCs were detected. As part of the FFS, the Phase I subsurface soil data were reevaluated using EPA Region 9 RBCs. The results of the evaluation indicated that arsenic was above the industrial RBC screening criteria of 1.6 mg/kg in two of the samples collected. At sampling location NADMWS-0602, arsenic was detected at a concentration of 2.0 mg/kg at a depth of 5 to 7 feet below land surface and at location NADMWS-0701, arsenic was detected at a concentration of 3.0 mg/kg at a depth of 3 to 5 feet below land surface. A review of the site history and the sampling locations revealed that the area where these two points were located had been subsequently graded due to activities to construct rail road tracks in 1997. The Phase II RI report (M&E 2000) noted that during construction activities, several monitoring wells and hydropunch locations were destroyed due to the grading. It was assumed that the soil and respective data are no longer relevant to the evaluation, therefore the conclusions are the same that no COCs were identified for inclusion in the FFS for subsurface soil. Subsurface soils were not investigated at the Former NAD site during the Phase II investigation based on the results of the Phase I RI; however, during the subsequent supplemental investigation conducted by SAIC in October 2001, three subsurface soil samples were collected while installing boreholes SAIC-14, SAIC-15, and SAIC-16 (Table 1-5).

All samples were collected directly above the top of bedrock and analyzed for VOCs. VOCs were not detected in the samples collected from SAIC-14 and SAIC-16. However, *cis*-1,2- DCE was detected at a concentration of 0.005 J mg/kg and TCE was detected at a concentration of 0.43 J mg/L in SAIC-15 at a depth of 30 to 31.0 ft BGS. The concentrations were evaluated using EPA Region 9 RBCs for industrial land use (see Table 1-5). Neither constituent was detected above their respective industrial RBCs value.

No COPCs were identified in the subsurface soil using conservative, risk-based screening values; therefore, no complete exposure pathway exists. No COPCs and, therefore, no COCs were identified for inclusion in the FFS for surface soil.

2.9 SURFACE WATER

2.9.1 Phase I Remedial Investigation

No surface water samples were collected during the Phase I RI.

2.9.1.1 Phase II RI

Nine surface water samples (including three background locations) were collected in November 1997 (M&E 2000). Samples were analyzed for VOCs, SVOCs, explosives residue, and priority pollutant metals. Three samples were collected from the drainage feature located in the west/central portion of NAD Area 1. Three surface water samples were collected in a surface drainage ditch located toward the center of Former NAD Area 2 before the current railroad facility was built. The three background samples were collected from the north and east of the property.

An additional surface water sample was collected in June 1999 at NCDENR's request from a ditch located between NAD MW-21 and NAD MW-23 following the completion of the new rail facility to determine if contaminated groundwater was discharging to the ditch.

Contaminant concentrations detected in this surface water sample were compared to NCAC 2B standards for Class C waters. These standards are based on protection of surface water for secondary recreation, fishing, aquatic life, and wildlife. The federal MCL was used for contaminants for which no NCAC 2B standard was available. The contaminant concentrations were also compared to values obtained from the three background surface water samples.

Most exceedances occurred at SWE04, which is situated in the northern portion of former NAD Area 1 and is upgradient of the NAD source area (M&E 2000). At this location, bis(2-ethylhexyl)phthalate was found to exceed the MCL (there is no NCAC 2B standard) and chromium, copper, lead, nickel, and zinc were found to exceed the

NCAC 2B standards. No chemicals exceeded screening levels immediately upstream or downstream of the sampling locations.

Surface water in the site area consists of small man-made drainage ditches. These features are non-navigable and unsuitable for recreational purposes. Surface water is similarly not used for potable purposes. No agricultural irrigation is conducted and animal subsistence is not known. Surface water pathways under current and future site use are considered to be incomplete. Therefore, no COCs were identified for inclusion in the FFS for surface water.

2.9.2 Groundwater

2.9.2.1 Phase I RI

Groundwater COPCs were identified by comparing the results to the NCAC groundwater quality standards (15A NCAC 02L.0201) and federal drinking water standards MCLs. Both the NCAC 2L and MCLs are based on potable (i.e., drinking water) use. The following COPCs were identified as being present above the screening criteria:

cis-1,2-DCE	PCE
1,2-Dichloroethane	TCE
1,1-DCE	Zinc
Chloroform	

As no state or federal standard was available for 1,3,5-trinitrobenzene; this constituent was also retained as COPCs.

2.9.2.2 Phase II RI

Groundwater samples were collected and analyzed for VOCs and explosives residue. The analytical results were compared to the NCAC 2L groundwater standards and MCLs. Constituents exceeding regulatory levels included CVOCs; most prevalent among these were TCE and *cis*-1,2-DCE. Several VOC and explosives residue compounds were also present at levels above their corresponding regulatory level. However, TCE was determined to be the most widespread constituent and it was found to occur at the highest concentrations.

The following COPCs were identified as being present above the screening values:

Chloroform	TCE
1,2-Dichloroethane	Vinyl Chloride
1,1-DCE	2-Amino-4,6-dinitrotoluene
cis-1,2-DCE	4-Amino-2,6-dinitrotoluene
1,2-Dichloropropane	2,4,6-TNT
Methylene Chloride	Hexahydro-1,3,5-trinitro-1,3,5-triazine
Tetrachloroethene	

During the Phase II investigation, applicable state, county, and local agencies were contacted and a visual survey was performed to identify possible private and/or public water supply wells within a 1-mile radius. The NCDENR Groundwater Section was contacted to determine if the state maintains records of drinking water wells. Some records were found to exist but, because well registration was not required, data were found to be incomplete. To determine if any potable wells were located within a 1-mile radius, a visual drive-through inspection was performed in November 1997. The survey confirmed one well approximately 1 mile north of the site; however, the well was found to be no longer in service. The survey determined that no private or public water supply wells were within a 1-mile radius of the site and that the area is served by municipal water supply (M&E 2000).

Due to the availability of municipal water, current groundwater ingestion was not considered to be a complete pathway. To be conservative, future groundwater ingestion was quantified for an industrial worker. Risk from potential future groundwater ingestion was calculated for all COPCs following standard EPA guidance (1989) and default exposure parameters for an industrial worker.

The total risk for ingestion of groundwater was calculated to be 4.2E-04. This result exceeded the most commonly used target of 1 E-06 but only marginally exceeded the acceptable range for remediation of Superfund sites of 1E-04. The primary contributors to carcinogenic risk were TCE and 1,1-DCE.

The total HI value was calculated to be 2.6 and exceeded the target of 1, but was below a value of 10, which has generally been used for remediating Superfund and state lead sites. The major contributors to the non-carcinogenic HI were TCE and aminodinitrotoluenes.

2.9.2.3 *Supplemental Investigations*

Groundwater samples were collected in 2000, 2001, 2002, 2003, 2004, and 2006 as part of the supplemental site investigations and pilot study. The data for 2000 through 2002 are summarized in Tables 1-2, 1-4, and 1-7. The data for 2004 and 2006 are summarized in Tables 5-1 and 2-1, respectively. These data were compared to their applicable NCAC 2L groundwater standards, MCLs, and Region 9 RBCs.

The following COPCs were identified as being present above the screening criteria:

cis-1,2-DCE[1]	2,4,6-TNT[1]
1,1-DCE[1]	2-Amino-4,6-dinitrotoluene[2]
1,2-Dichloroethane[1]	4-Amino-2,6-dinitrotoluene[2]
1,2-Dichloropropane[1]	Iron[2]
1,1,2-Trichloroethane[1]	2-Butanone
PCE[1]	Manganese[2]
TCE[1]	Sulfate[3]
Vinyl Chloride[1]	Methylene Chloride[1]

1 Many of these constituents were detected during the 2000, 2001, 2004, and 2006 sampling events.

2 These constituents were only detected above their groundwater quality water standards in samples collected in 2000.

3 These constituents were only detected above their groundwater quality water standards in samples collected in 2004.

As noted in the Phase II RI report, and confirmed through the receptor survey conducted as part of the subsequent investigations (SAIC 2003a), no residential water supply wells were identified within 1 mile of the site and no potable water wells were identified on-site. However, in 2001, three private commercial water supply wells were identified within 1,500 ft of the site (Plant #1). The use of these wells was discontinued in 2001. The receptor survey conducted in 2002 indicated that city-supplied water exists throughout the area as revealed by information provided by the Charlotte Mecklenburg Utility District and through the Mecklenburg County Well Information System (available at http://maps.co.mecklenburg.nc.us). Given public water supply in the area, current exposure to groundwater via potable use (i.e., drinking water and other domestic use) is not currently a complete pathway. However, it is possible that an undocumented well could exist outside the Former NAD site (as was the case for the Plant #1 wells). Therefore, to be conservative, future exposure to groundwater (i.e., industrial/commercial use) is considered to be a complete pathway.

2.9.2.4 *Groundwater Summary*

Several COPCs were identified from the Phase I, Phase II, and supplemental sampling results. Although groundwater is not used currently as a source of potable water in this area, based on their prevalence in the groundwater at high concentrations, the following COPCs were considered COCs in groundwater for potential future exposure:

cis-1,2-DCE	1,1,2-trichloroethane;2-butanone
1,1-dichloroethene	PCE
1,2-dichloroethane	TCE
1,2 dichloropropane	vinyl chloride

Sulfate was eliminated as a COC as it was only detected in one sample (2004) above it applicable standard (Table 5-1), while iron and manganese were eliminated as a COCs as these constituents are considered to be naturally occurring. Methylene chloride was detected in 2004; however, it was not detected in the most recent sampling event conducted in 2006. Therefore, it was also eliminated as a COC.

The explosives residue compounds were eliminated as COCs due to low frequency of detection and the range detected. During the supplemental investigation activities conducted in 2000, groundwater verification samples were collected from the wells identified as containing explosives residues compounds (17 monitoring wells) and from the newly installed monitoring wells (11). The results indicated that only three of the explosives residue compounds were detected above the EPA Region 9 RBCs at 2 of the 28 locations (NAD MW-21 and NAD MW-64; Table 1-2). 2,4,6-TNT was detected above the EPA RBC at both of these locations. 2-Amino-4,6-dinitrotoluene and 4-Amino-2,6-dinitrotoluene were detected above their respective RBCs at only one location (NAD MW-64). In addition, the arithmetic mean for each of the detected explosives residue compound was well below its respective RBC (Table 1-2).

3.0 REMEDIAL ACTION OBJECTIVES

RAOs are site-specific goals that define what the remedial action will accomplish and typically serve as the design basis for the remedial alternatives developed for the site. This chapter discusses the RAO established for the Former NAD site and describes the requirements or standards under federal or more stringent state environmental laws that are applicable or relevant and appropriate to the site.

3.1 REMEDIAL ACTION OBJECTIVES

Although several CVOCs were identified as COCs, TCE was detected at much higher concentrations than the other chemicals and will be the model compound for remedial action. As such, the RAOs have been structured around TCE. However, the primary RAO is the restoration of the site groundwater to beneficial use (i.e., NCAC 2L groundwater standards). It is anticipated that with any remedial action, concentrations of all chlorinated compounds will be reduced.

The RAO for the Former NAD site is to actively treat the areas where the TCE concentrations exceed 500 μg/L. The treatment will consist of reducing the TCE concentrations in the groundwater of both the transition and bedrock zones to 500 μg/L via active treatment with the implementation of monitoring natural attenuation to achieve the RG of 2.8 μg/L (NCAC 2L standard), thereby restoring the aquifer to beneficial use.

3.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

CERCLA remedial actions are required to meet federal standards, requirements, criteria, limitations, or more stringent state standards determined to be legally applicable or relevant and appropriate to the circumstances at each site [CERCLA Section 121(d), as cited in EPA 1998]. Regulations that are codified in the NCP govern the identification of, and subsequent compliance with, applicable or relevant and appropriate requirements (ARARs). In the FS, the evaluation of general response actions' (GRAs') compliance with ARARs helps to ensure that the selected remedy will be protective of both human health and the environment.

On-site remedial activities must comply with the substantive requirements of both applicable and relevant and appropriate requirements. In contrast, remedial activities conducted off-site (for example, off-site disposal of excavated soil) must comply with only applicable (as opposed to relevant and appropriate) requirements but must also comply with all administrative requirements, as well as the substantive requirements of those rules.

This section describes types of ARARs for the Former NAD site and chemical-, action-, and location-specific criteria.

3.2.1 *Chemical-Specific Applicable or Relevant and Appropriate Requirements*

Health- and risk-based restrictions on the amounts or concentrations of COCs that may be found in or discharged to environmental media are typically defined as chemical-specific ARARs (EPA 1988). Table 3-1 details the North Carolina and federal groundwater standards for the COPCs identified at the Former NAD site.

3.2.1.1 *Groundwater*

NCAC 2L groundwater standards (Title 15A, Subchapter 2L, Sections .0202) are being used to develop ARARs for the Former NAD site. The NCAC 2L groundwater standards contain more stringent standards than those found in the federal MCLs. However, where there is no NCAC 2L standard published (as is the case for 1,1,2-trichloroethane), the federal MCLs [40 *Code of Federal Regulations* (*CFR*) 141] will be used.

3.2.1.2 *Soil*

No COCs were identified in subsurface or surface soil samples in the Phase I, Phase II, or supplemental investigations.

3.2.1.3 *Surface Water*

No COCs were identified in the surface water in the Phase I, Phase II, or supplemental investigations.

3.2.2 *Potential Action-Specific Applicable or Relevant and Appropriate Requirements*

Action-specific ARARs are activity- and technology-based requirements that are applicable or relevant and appropriate to one or more remedial alternatives (EPA 1988).

3.2.2.1 *Resource Conservation and Recovery Act of 1976*

The active treatment evaluated for remediation of groundwater at this site could involve excavation of soil, in preparation for installation of in-situ treatment technologies. TCE is a contaminant of groundwater across the facility. If the source of the contamination is determined to be Resource Conservation and Recovery Act of 1976 (RCRA)-regulated, then any excavated soil or groundwater contaminated with TCE, although not themselves hazardous wastes, may be considered to contain a listed hazardous waste in accordance with the RCRA "contained-in" policy. Under this policy any actively managed TCE-contaminated soil/groundwater would be considered to "contain" an F001 hazardous waste until such soil/groundwater has been determined to no longer contain spent TCE at concentrations above health-based standards (a "contained-in determination"). For example, a contained-in determination will be requested for excavated soil that does not fail Toxicity Characteristic Leaching Procedure (TCLP) analysis. Any actively managed groundwater, soil debris, or excavated soil having RCRA-listed constituents at concentrations above health-based levels or exhibiting a toxicity characteristic also will be considered a hazardous waste. The NCAC standard, 15A NCAC 13A Section .0106-.0112, [that incorporates the federal requirements (40 *CFR 261.1 through 40 CFR 261.38)* by reference] will be used as the ARAR.

TCE has been detected in groundwater samples across the Former NAD site and is the main COC. Excavated soil generated prior to implementation of in-situ treatment might have detectable concentrations of TCE and have to be managed in accordance with the RCRA contained-in policy. Any excavated soil from site remediation activities would be disposed of at an off-site facility.

Substantive requirements for on-site management of hazardous waste (15A NCAC 13A Sections .0106 through .0112) are relevant and appropriate to excavated soil, including soil that is accumulated on-site pending results of analysis. Groundwater to be sent for off-site treatment and excavated soil containing U228 or F001 waste above remedial levels would be managed as hazardous wastes; RCRA manifesting (15A NCAC 13A Section .0109) and transportation requirements (15A NCAC 13A Section .0108) would apply. Alternative land disposal restriction (LDR) treatment standards (15A NCAC 13A Section .0112) would apply to any excavated soil exhibiting the toxicity characteristic (15A NCAC 13A Section .0106). LDRs, however, would not apply to excavated soil managed within the area of contamination (EPA 1989). Once treated to remove the U228 and/or F001 waste, excavated contaminated soil would no longer be considered to contain U228 and/or F001 hazardous waste, and further compliance with RCRA hazardous waste manifesting and disposal rules would not be necessary unless the media exhibits another characteristic (EPA 1988). Any actively managed (i.e., excavated or extracted) wastes left on-site at the conclusion of remedial actions would be managed in full compliance with all ARARs (EPA 1988).

Treatment of groundwater in mobile treatment units that meet the definition of a wastewater treatment unit under 40 *CFR* 260.10 would not be subject to substantive RCRA standards for on-site treatment according to 15A NCAC 13A Section .0109. RCRA treatment standards would, however, be relevant and appropriate to on-site treatment of any actively managed media that are RCRA-characteristic or RCRA-listed wastes.

3.2.2.2 Ambient Water Quality Criteria for Surface Water

Federal ambient water quality criteria (see chemical-specific criteria, Section 3.2) are relevant and appropriate, and North Carolina water quality criteria are applicable to any alternative that might have the potential to impact the quality of any area surface water. State general water quality criteria (15A NCAC 2B Section .0201) are geared to "maintain, protect, and enhance water quality within the State of North Carolina."

3.2.2.3 Air Quality Standards

Response actions might include technologies that result in releases of VOCs to the air. The federal Clean Air Act of 1970 and NCDENR regulate the construction of new sources and major modifications to existing sources. NCDENR requirements

(NCDENR Environmental Management 2D Section .0400) are potential ARARs for focused alternatives that involve or result in air stripping or vapor extraction. The standard specifies that "no facility or source of air pollution shall cause any ambient air quality standard...to be exceeded or contribute to a violation of any ambient air quality standard...except as allowed by Rules .0531 or .0532" of the NCDENR Environmental Management 15A NCAC 2D Section .0400 regulations. Additionally, NCDENR air quality standards specific to Mecklenburg County and/or promulgated by Mecklenburg County should also be considered as potential ARARs.

3.2.2.4 *Stormwater Management Standards and Sedimentation Control*

Should remedial actions on-site involve storm sewer disturbance via "Dig and Replace," the State Stormwater Management Program would be considered a potential action-specific ARAR. The state program, codified in 15A NCAC 2H Section .1000, affects development activities that require either an Erosion and Sediment Control Plan (for disturbances of one or more acres) or a Coastal Area Management Authority permit in one of the following areas:

- the 20 coastal counties, and/or
- development draining to outstanding resource waters or high quality waters.

Additionally, the substantive standard of Sedimentation Control (15A NCAC 04) is a potential action-specific ARAR as the standards may be relevant to site and/or stormwater conveyance disturbance.

3.2.3 *Location-Specific Applicable or Relevant and Appropriate Requirements*

Damage to unique or sensitive areas, such as floodplains, historic places, wetlands, and fragile ecosystems, is prevented by location-specific ARARs (EPA 1988). Location-specific ARARs may also restrict remediation activities that are potentially harmful because of where they take place (EPA 1988).

Within the investigation area at the Former NAD site, ~75% of the area is covered with building and pavement. The remaining 25% of the site is primarily a grassy area that could provide a nominal foraging habitat for birds, amphibians, and small mammals. Frogs, rodents, stray cats, and rabbits are occasionally observed in these areas. It is unlikely that these areas would provide habitat for the two endangered species in Mecklenburg County, North Carolina: the Carolina Heelsplitter Clam (*Lasmigona decorate)* and Schweinitz's Sunflower (*Helianthus schweinitzii)*. Neither species is expected to be found on-site due to the industrial setting of the area. The Endangered Species Act of 1973 (50 *CFR* 17) was evaluated as a potential ARAR for the site; however, it was found not to apply to the Former NAD site.

The National Register of Historic Places (NRHP) (36 *CFR* 60; National Historic Preservation Act of 1966, 80 Stat. 915, 16 U. S.C. 470, as amended) works through the individual State Historic Preservation Offices (SHPOs). North Carolina's SHPO has a listing of historical areas in Mecklenburg County, North Carolina. The NRHP was evaluated as a potential ARAR for the site; however, it was found not to apply.

Due to the industrial setting of the site, there are no known sensitive areas (i.e., wetlands, floodplains, etc.) to be encountered. However, should the storm sewer and associated drainage ditches be disturbed, the State Stormwater Management Program would be a potential ARAR TBC, as previously mentioned.

3.3 GENERAL RESPONSE ACTIONS

GRAs are broad categories of remedial action that meet the RAOs developed in Section 3.1 for the Former NAD site. The intent of the technology screening is to focus the development of alternatives on those categories of remedial actions that are expected to achieve the RAOs. This focused approach was utilized to eliminate process options/technologies that were considered too impractical to implement based on the Phase I and II RI findings and the results of the sodium lactate injection pilot study (October 2003 to June 2004). For each GRA, potentially applicable technology types and process options are identified. In developing alternatives, combinations of process options may be identified.

An evaluation of groundwater quality was conducted using concentrations observed during the sodium lactate injection study. The summary of this evaluation is presented in Chapter 5.0. In general, in the transition zone, concentrations of TCE and PCE decreased and concentrations of the daughter products *cis*-1,2-DCE and vinyl chloride increased during the injection study as a result of dechlorination of TCE and PCE. In the bedrock zone, the concentrations of TCE had increased immediately after the injection and then began to decrease across the treatment area. The initial increase could have been due to mobilization of isolated residual DNAPL trapped within the bedrock fractures.

Based on the results of the sodium lactate injection pilot study, and recent fate and transport modeling results for the TCE plume both in the transition and bedrock zones, the following GRAs for the Former NAD site were developed (see Table 3-2):

- no action,
- institutional controls,
- in-situ treatment, and
- removal

3.3.1 No Action

The no action alternative is considered in accordance with CERCLA and NCP requirements for comparison with other alternatives. Under this alternative, no remedial action would be implemented at the Former NAD site to reduce contaminant concentrations in the contaminant plume in order to return the impaired groundwater to beneficial use. The groundwater plume would continue to migrate, and institutional controls (such as access controls and restrictions on excavation or groundwater usage) would not be in place to protect human health and the environment. Access to contaminated groundwater would be unrestricted, allowing exposure to contaminated media, and no monitoring of groundwater would be performed.

3.3.2 *Institutional Controls*

Institutional controls are measures taken to minimize the exposure of humans or the environment to the contaminated groundwater and areas affected by it. Such measures include access and use restrictions (for example, restrictions on groundwater use or well drilling) and groundwater monitoring. Groundwater monitoring consists of monitoring environmental media to evaluate the effectiveness of the remedial action, to determine whether adjustments or additional process options are needed, and to determine whether existing or future receptors are threatened. The volume, mobility, and toxicity of contaminants are not reduced through the application of institutional controls. Institutional controls will be evaluated to support both passive and active treatment systems.

3.3.3 *Groundwater In-situ Treatment*

In-situ treatment technologies include a variety of physical, biological, and chemical processes that directly impact the toxicity and/or mobility of the contaminants. In-situ treatments are performed in place, without removal of contaminated groundwater. Effective in-situ treatment limits potential exposure and eliminates the need for off-site disposal.

3.3.3.1 *Passive Treatment Systems*

Passive treatment systems such as MNA will be evaluated during the screening process.

3.3.3.2 *Active Treatment Systems*

Because of the success of the in-situ active treatment systems using sodium lactate injection performed as part of the pilot study (October 2003 to June 2004), no other active remediation system will be evaluated in the screening process.

3.3.4 *Removal*

Removing the groundwater from the subsurface is accomplished by extraction technologies such as vertical or horizontal wells or deep wells. Once removed, the contaminated groundwater can be treated or disposed of on- or off-site.

4.0 *IDENTIFICATION AND SCREENING OF PROCESS OPTIONS*

This chapter provides identification and screening of the process options for remedial alternatives for contaminated groundwater at the Former NAD site. The potentially applicable technology types and process options were identified and evaluated based on information gathered during the Phase I and II RIs, supplemental investigations, and the results of the sodium lactate injection pilot study. Process options that were not technically applicable at the site or for the waste were eliminated from further consideration. The process options that were retained were then screened using the criteria described in the following sections. Process options that passed the initial screening phase were retained for subsequent evaluation as potential remedial actions. These process options are briefly described in the following sections.

4.1 *PROCESS OPTIONS*

4.1.1 *No Action*

The no action process is considered in accordance with CERCLA and NCP requirements as a baseline for comparison with other alternatives. Under this process, no remedial action would be implemented at the Former NAD site to reduce contaminant concentrations in the contaminant plume. The no action option provides no measures to protect human health or the environment, or to maintain or monitor site conditions. No implementation is required. However, the no action alternative is required by NCP for comparison to other alternatives; therefore, this option was retained from the initial screening and carried forward for further evaluation.

4.1.2 *Institutional Controls*

The institutional control technology types evaluated include access and use restrictions and long-term monitoring and maintenance. The objectives of access and use restrictions are to prevent prolonged exposure to contaminants, to control disturbance and development of the site, and to prevent destruction of engineered controls. Institutional controls include fencing, signage, property owner notification, and restrictive covenants on the property deed or easements to the adjacent property. Monitoring and maintenance activities would be conducted to maintain existing engineered controls and barriers and to measure their effectiveness. It should be noted that institutional controls are generally used in conjunction with other actions. Institutional controls were retained as an incidental component of all remedial actions except no action.

Institutional controls will be required during the implementation of remedial alternatives until remedial levels are achieved. As the property is publicly owned, implementation of access and use restrictions on the property may be problematic. To date, rights of entry have been negotiated with the property owners to allow sampling to support investigation activities. Continued rights of entry would be needed with the implementation of any future remedial effort. Institutional control will consist of owner notification in the form of a certified letter to all property owners regarding the groundwater contamination, legal restrictions restricting the use of groundwater for consumption and irrigation, and long-term monitoring.

4.1.3 Monitored Natural Attenuation

Natural attenuation or intrinsic remediation is the reduction in the concentration and mass of a substance in groundwater due to naturally occurring physical, chemical, and biological processes without human intervention. The monitoring process option would consist of long-term monitoring that would monitor environmental media to evaluate the effectiveness of the remedial action, to determine whether adjustments or additional process options are needed, and to determine whether existing or future receptors are threatened. Monitoring could be used with other process options or alone.

The natural attenuation processes include, but are not limited to, dispersion, diffusion, sorption, retardation, chemical degradation, and biodegradation. Dispersion, diffusion, sorption, and retardation are types of non-destructive attenuation mechanisms. Among other physical mechanisms, advective transport is the transport of solutes by the bulk movement of groundwater. Advective transport is the most important process driving dissolved contaminant migration in the subsurface. Solute transport by advection alone yields a sharp concentration front. Immediately ahead of the front, the contaminant concentration is equal to the background concentration. Theoretically, the contaminant concentration at the edge of the front equals its concentration at the point of release. In reality, the front spreads out due to diffusion and dispersion.

Hydrodynamic dispersion is the process whereby a contaminant plume spreads out in directions that are longitudinal and transverse to the direction of plume migration. Dispersion dilutes the concentrations of contaminants and also carries contaminants to previously unaffected portions of the aquifer. Hydrodynamic dispersion results from mechanical mixing caused by varying pore diameters and tortuous flow paths in the subsurface regime. As a result of dispersion, the solute front travels at a rate that is faster than would be predicted solely on the basis of the average linear velocity of the groundwater. The overall result is spreading and mixing of the contaminant plume with uncontaminated groundwater.

Molecular diffusion occurs due to concentration gradients between the contaminant plume and surrounding groundwater. Molecular diffusion is important as an attenuation process only where groundwater velocities are very low.

Most organic contaminants are removed from solution by sorption into the aquifer matrix. Sorption is the physical process whereby contaminants dissolved in the groundwater plume partition from the aqueous phase and adhere to the soil particles that comprise the aquifer matrix. Sorption results in retardation in contaminant migration relative to the average advective groundwater flow velocity. Sorption does not destroy or permanently remove contaminants from the groundwater but only retards their migration. It must be noted that sorption is a reversible process so that some portion of the solute concentration is partitioning to the aquifer matrix, and a portion of the contaminants sorbed to the soils are desorbing and re-entering the solution. As solute concentrations decrease over time, the amount of contaminant that desorbs from the aquifer matrix often increases.

Recharge due to infiltration of precipitation or from surface water entering the groundwater also contributes to natural attenuation of a dissolved contaminant plume. Recharge of the aquifer by these mechanisms contributes to the dilution of the contaminants in the plume by the influx of fresh water. Infiltration of precipitation or surface water also adds electron acceptors such as dissolved oxygen (DO), nitrate, or sulfate to the groundwater system resulting in shifts in the geochemical equilibrium. Such shifts may be favorable for biodegradation of compounds that may be used as electron donors, such as benzene, toluene, ethylbenzene, xylenes or vinyl chloride, but may retard degradation of more oxidized CVOCs.

Many organic compounds are degraded in the subsurface environment by both biotic (biological) and abiotic (non-biological) mechanisms. However, biological mechanisms tend to dominate in most groundwater systems and, therefore, are the primary destructive attenuation mechanism. Biodegradation or decay of dissolved organic compounds induced by microorganisms results in a reduction in contaminant concentration and mass and a slowing of the contaminant front relative to the average groundwater flow velocity.

Biodegradation of organic compounds occurs by one of three mechanisms:

- use of the organic compound as the primary growth substrate,
- use of the organic compound as the electron acceptor, and
- co-metabolism.

Under aerobic conditions (in the presence of molecular oxygen), bacteria couple the oxidation of organic compounds (substrate) with the reduction of oxygen to water. In anaerobic conditions, microorganisms use natural or anthropogenic carbon sources, such as leaked fuel, as the electron donor. Common electron acceptors in anaerobic environments include nitrate, tetravalent manganese, trivalent iron, sulfate, and carbon dioxide. Additionally, microorganisms can use less oxidized chlorinated alkanes or alkenes (such as vinyl chloride) as electron donors and the more highly oxidized chlorinated alkenes (PCE; TCE; and 1,2-DCE) as electron acceptors.

During aerobic degradation, electrons are donated from the organic carbon source, and oxygen is reduced to water resulting in the decrease of DO. In anaerobic systems where nitrate is the electron acceptor, the nitrate ion is reduced to nitrite, nitric oxide, or nitrous oxide, or the ammonium ion and nitrate concentrations decrease. In anaerobic systems, where sulfate is the electron acceptor, the sulfate ion is reduced to H_2S, and sulfate concentrations decrease. In anaerobic systems, where CVOCs are used as electron acceptors, the parent compound is reduced to the less oxidized (less chlorinated) species. As each subsequent electron acceptor is utilized, the Redox potential of the groundwater system is reduced. Table 4-1 shows the typical oxidation-reduction potential (ORP) conditions for groundwater for anaerobic environments utilizing different electron acceptors (Domenico and Schwartz 1990). As such, Redox potential is an indicator of which Redox reactions are being utilized by microorganisms at the site.

Microbial transformations of chlorinated solvents under anaerobic conditions are reductive reactions that involve either hydrogenolysis or dihaloelimination. Hydrogenolysis occurs when a hydrogen atom replaces a chlorine atom. Dihaloelimination involves removal of two adjacent chlorine atoms and formation of a carbon-to-carbon double bond. The most important process for natural biodegradation of the more highly chlorinated species is usually anaerobic reductive dechlorination.

4.1.4 *Bioremediation Using Sodium Lactate*

As discussed in Section 4.1.3, bioremediation involves the use of biologically mediated reactions to break down contaminants. The process may occur under existing conditions (intrinsic bioremediation) or with the addition of oxygen, nutrients, and/or other chemicals. Biodegradation depends upon the existence of microorganisms that will degrade the compound of interest. The potential for degradation of the most common CVOCs has been demonstrated. Specific rates of degradation depend upon many factors, including the contaminants present, the concentration of contaminants, nutrients, and substrates, as well as the extent of contaminant sorption. Degradation requires the presence of primary substrates, nutrients, and appropriate Redox conditions.

Microorganisms generally derive energy from oxidation-reduction (Redox) reactions. An enzyme-mediated oxidation-reduction reaction is the transfer of electrons from electron donors to acceptors. Energy is derived from these reactions when the energy source (electron donor) is oxidized, transferring electrons to an acceptor and releasing energy conserved in the chemical bond. Once the electron donor has been completely oxidized, the compound is no longer a source of energy.

There are three mechanisms used by microorganisms to produce energy: (1) aerobic respiration, (2) anaerobic respiration, and (3) fermentation. Aerobic respiration processes require oxygen. In an aerobic process, oxygen serves as the electron acceptor and is reduced to water. The electron donor is natural or anthropogenic carbon. Anaerobic processes rely on nitrate, iron, sulfate, or carbonate in the absence of oxygen to complete organic compound oxidation. Nitrite is probably the most common alternate electron acceptor, which is converted to more reduced forms of nitrogen. This process is called "denitrification." The Redox potential for the reduction of nitrate to nitrite is lower than the Redox potential for the reduction of oxygen. Growth on nitrate is less efficient than growth on oxygen, and, therefore, nitrate reduction is strongly inhibited by oxygen. Sulfate is used by some bacteria as the electron acceptor to produce hydrogen sulfide. Sulfate-reducing bacteria usually are killed in the presence of oxygen. The Redox potential for the reduction of sulfate is even lower than that for nitrate reduction, and efficiency of growth is also lower. Methanogenic bacteria reduce carbon dioxide to methane. Fermentation is the process of oxidizing some organic compounds in the absence of an added electron acceptor. Under fermentation processes, the organic is partially oxidized and only a small amount of energy is released.

In groundwater, DO concentrations of less than 1.0 mg/L are considered to be anaerobic environments. The Redox potentials for the various anaerobic pathways are +50 to +400 mV for denitrification, -150 to +50 mV for iron reduction, -200 to -150 mV for sulfate reduction, and -250 mV for methanogenesis (Domenico and Schwartz 1990).

Many chlorinated aliphatic compounds are transformed under anaerobic conditions. In the presence of a consortium of microorganisms, these compounds will be mineralized to carbon dioxide, water, and chloride ions. One of the predominant mechanisms for transformation of chlorinated aliphatic compounds is reductive dechlorination. The reductive process is usually through co-metabolism.

The more chlorinated (or oxidized) that a compound is, the more susceptible that compound is to reductive dechlorination. As stated in Section 4.1.3, PCE, TCE, and trichloroethane are susceptible to anaerobic reductive dechlorination. Conversely, 1,2-DCE and vinyl chloride are more readily degraded by aerobic oxidation rather than by reductive dechlorination.

The availability of other electron acceptors in anaerobic systems affects the reductive dechlorination process by competing with the chlorinated compounds for reducing potential. For example, sulfate and nitrate can inhibit the dechlorination because microorganisms will tend to couple half reactions that yield the greatest free energy. Reductive dechlorination rates are highest under the highly reducing conditions associated with methanogenic reactions rather than with denitrifying conditions.

Additions of easily biodegradable organic substrates will enhance the reductive dechlorination of many of the chlorinated aliphatic hydrocarbons. Many organic substrates, such as acetate, butyric acid, lactic acid, methanol, ethanol, vitamin B12, and sucrose, have been shown to be effective in acting as the primary substrate to enhance the anaerobic co-metabolic transformations. However, anaerobic dechlorination reaction rates are slower compared to the possible aerobic transformations of some of the intermediates. Hence, an anaerobic-aerobic sequential transformation will be able to achieve mineralization at a much faster rate than completely anaerobic pathways. If the contamination plume to be remediated is large, multiple anaerobic-aerobic sequencing segments can be implemented to achieve faster cleanup times.

For this site, a pilot study was conducted from October 2003 to July 2004 to determine if bioremediation using sodium lactate could be used as an effective remedy in reducing the TCE groundwater plume (see Chapter 5.0 and Appendix A). The pilot study was highly successful and indicated that the sodium lactate was very effective in that it was able to enhance the biodegradation of TCE and associated breakdown products by providing the needed nourishment under reducing conditions. With the injection of sodium lactate, the aquifer had been pushed into a more strongly reducing environment. Sampling results showed a trend of ORP measurements characteristic of a reducing environment. Nitrate, ferrous iron, and sulfate were monitored to determine the degree of the reducing conditions of the aquifer. Sulfate reduction and methanogenesis indicate that most electron acceptors have been reduced and most of the remaining free electrons are available for the dechlorination process. These conditions are, therefore, optimal for the intended process. As the use of bioremediation using sodium lactate was proven to be effective in reducing the contamination at the Former NAD site, this process option was retained as a remedial technology.

4.1.5 Groundwater Extraction

Groundwater extraction involves the removal of groundwater from the subsurface by extraction technologies such as vertical, horizontal, or deep wells. Once the contaminated groundwater is removed, it can be treated or disposed of on- or off-site. The removal GRA and associated groundwater extraction technologies and process options were not considered further as space limitations and daily site operations preclude an on-site treatment facility. Furthermore, there are no readily available off-site treatment or disposal facilities.

4.2 SCREENING CRITERIA

The process options considered for the Former NAD site were evaluated using three general criteria: effectiveness, implementability, and cost. An explanation of each criterion follows.

4.2.1 Effectiveness

This criterion evaluates the extent to which a technology would reduce overall risk to human health and the environment. It also considers the degree to which the action provides sufficient long-term controls and reliability to prevent exposures that exceed levels protective of human and environmental receptors. Factors considered include performance characteristics and the ability to reduce contaminant concentrations.

4.2.2 Implementability

This criterion evaluates the technical and administrative factors affecting implementation of a technology and considers the availability of services and materials required during implementation. Technical factors assessed include ease and reliability of construction and operations and adequacy of monitoring systems to detect failures. Technical feasibility considers the performance history of the technologies in direct applications or the expected performance for similar applications. Administrative factors include ease of obtaining permits, enforcing deed restrictions, or maintaining long-term control of the site.

4.2.3 Cost

Relative cost-effectiveness is evaluated for each technology to facilitate comparison among them. Detailed cost estimates are not prepared at this screening stage. Typical cost-estimating contingencies are excluded from the relative costs.

4.3 EVALUATION AND SELECTION OF REPRESENTATIVE PROCESS OPTIONS

In this section, the process options are evaluated more closely to determine which can be developed into remedial alternatives. This evaluation selects one or more process options to represent each technology type so an estimated cost can be developed for each alternative. The process option that appears to offer the best blend of effectiveness, implementability, and cost is carried forward for the development of alternatives. In some cases, process options in the same technology type are significantly different, and the analysis of one option may not accurately represent the other. In such a case, two or more process options in a technology type may be carried forward. Because the selected process options represent a technology type, options not carried forward may be reevaluated in the Proposed Plan, the Record of Decision (ROD), or the RD process. A re-evaluation of technology types will be performed if new contaminant data are identified or if new advances in a technology's performance related to the contaminant types at the Former NAD site are achieved. This section presents the effectiveness, implementability, and relative cost evaluations for the technologies and provides a discussion of the selection of representative process options retained after the initial screening.

4.3.1 No Action

Evaluation of the no action process option is required by NCP as a baseline for comparison to other alternatives. The no action process option does not initiate action or assume continued access or use restrictions or media monitoring, it assumes that present security measures limiting access and use are not maintained, and it excludes short- and long-term monitoring. No implementation is required.

4.3.1.1 Effectiveness

There is no reduction in toxicity, mobility, or volume of the TCE in groundwater as a result of implementing the no action process option. Without groundwater use restrictions, groundwater could be used as a source of drinking water, which would pose an unacceptable risk to hypothetical future receptors. No action, in and of itself, will not achieve the RAO to reduce contaminant concentrations in groundwater to below NCAC 2L standards.

4.3.1.2 Implementability

No implementation is required.

4.3.1.3 Cost

There are no costs involved. The no action process will be retained as required by the NCP.

4.3.2 Institutional Controls

The institutional control technology types evaluated include access and use restrictions, property owner notification, and long-term monitoring and maintenance. The process options from these technology types can be used only in combination with other technologies to reduce the risk of exposure to contaminants.

4.3.2.1 Access and Use Restrictions

The objectives of access and use restrictions are to prevent prolonged exposure to contaminants, to control disturbance and development of the site, and to prevent destruction of engineered controls. Potential process options include:

- Administrative controls—Administrative measures such as controlled site entry, access controls, security patrols, and use of personal protective equipment (PPE) can protect receptors from unacceptable exposure to contamination.
- Restrictions—Use could be restricted by issuing codes, deeds, or zoning, which designate land/groundwater use privileges. Restrictions would prohibit certain activities on the site such as installing drilling drinking water and irrigation wells.

Effectiveness

Access and use restrictions, by themselves, would not be effective in meeting the Former NAD site RAOs but could be used in support of other process options to achieve these objectives. If properly maintained, access and use restrictions would protect against direct contact with contaminated media. Administrative controls would provide for using proper PPE when sampling contaminated groundwater. Restrictions to restrict groundwater use would be legally enforceable; however, these institutional controls alone would not reduce the volume, toxicity, or mobility of the contaminated groundwater.

Implementability

Because public properties are involved within the site boundary, access and use restrictions would not be easily implemented and maintained in the future.

Cost

Access and use restrictions would be low cost compared to other process options; however, such controls may reach a moderate cost if implemented for an extended period of time.

4.3.2.2 Monitoring and Maintenance

Monitoring and maintenance activities would be conducted to maintain existing engineered controls and barriers and to measure their effectiveness. Monitoring and maintenance could be used with other process options or alone. Monitoring and maintenance process options consist of long-term monitoring and physical maintenance.

- Long-term monitoring—This process option consists of monitoring to evaluate the effectiveness of the remedial action, to determine whether adjustments or additional process options are needed, and to determine whether existing or future receptors are threatened. Capital costs would be low because many groundwater monitoring wells are already installed at the site, and additional wells could be easily installed, if required. However, sampling and analysis could be costly over a long period.

- Physical Maintenance—Physical surveillance would involve visually or physically inspecting engineered structures and identifying the need for maintenance actions. Visual and physical inspection of monitoring equipment or engineered remedial action components would detect physical changes, such as unwanted vegetation or clogging of equipment that could lead to the failure or unsatisfactory performance of a component. Repairs or revised maintenance activities could be implemented as a result of these inspections. Maintenance includes both corrective actions and preventative actions. Physical maintenance would apply to any monitoring or treatment systems left in place for the long-term.

Effectiveness

Long-term monitoring would be viable to determine the effectiveness of remedial actions. By itself, it does not contribute to reductions in risk or contaminant levels. Physical surveillance combined with maintenance would be effective for extending the useful life of monitoring equipment or engineered controls, such as fencing, and ensuring that remedial actions continue to meet performance objectives.

Implementability

All long-term monitoring and physical maintenance process options are readily implementable at the Former NAD site. The site is readily accessible for surveillance and maintenance; groundwater monitoring wells are in place at the site. Additional monitoring wells may be required to augment the groundwater monitoring well network.

Cost

Annual costs associated with monitoring would be low, but total costs could become significant over the long-term. Typically, surveillance and maintenance costs are low unless replacement of a system or structure is required.

4.3.3 Monitored Natural Attenuation

MNA would involve long-term monitoring of groundwater quality to observe the decrease in concentrations of COCs and to verify that RGs have been met. During the MNA period, contaminant concentrations in groundwater would decline as a result of advection, dispersion, biodegradation, and volatilization. Advection, dispersion, and volatilization would be relatively slow attenuation processes due to the limited rate of groundwater movement.

During the natural attenuation period, CVOCs in groundwater would be degraded through anaerobic biological decay. Biodegradation of chlorinated solvents, such as TCE, is generally dominated by reductive dechlorination occurring under anaerobic conditions. The primary biotransformation pathway for chlorinated solvents is as follows:

PCE → TCE → cis-1,2-DCE → vinyl chloride → ethane.

4.3.3.1 *Effectiveness*

MNA can be effective in achieving the RGs, particularly if naturally occurring biodegradation is already taking place. Groundwater monitoring would be included as an institutional action. The purpose of groundwater monitoring would be to show that natural attenuation was decreasing the TCE and its daughter products (e.g., DCE, vinyl chloride, etc.) contamination as predicted. Monitoring would allow assessment of contaminant migration and would be an important part of preventing potential unacceptable exposures. Modeling has indicated that TCE and its daughter products in groundwater within the transition zone would naturally attenuate to NCAC 2L standards in 47 years from CY 2006, and in the bedrock zone it would take 63 years from CY 2006 to naturally attenuate the CVOCs. No increased risks are anticipated for potential receptors with implementation of MNA, and residual risk following implementation of this process option would be no different from the baseline because there are no groundwater receptors based on current or future land use.

The MNA process option can achieve the RGs alone, but it can be combined with the action process option. When combined with the action process options, RGs will be achieved in a less amount of time based on the effectiveness of the treatment.

4.3.3.2 *Implementability*

MNA could be readily implemented. It is a proven alternative that has been implemented at other federal facility sites where the groundwater has been contaminated and a reductive dechlorination environment exists. The equipment involved with monitoring the contaminated groundwater is widely available and routinely used in investigating environmental conditions in groundwater. The proposed monitoring program and analytical suite of analyses are well understood and routinely employed at a number of sites and investigations.

Only a few (~ten) additional groundwater monitoring wells will be installed. Sufficient space exists above or around the contaminant zones to temporarily accommodate all the equipment required to sample the proposed groundwater monitoring network.

4.3.3.3 *Cost*

The capital costs associated with MNA would be low, but total costs could become significant over the long-term.

4.3.4 *Bioremediation Using Sodium Lactate*

This option involves expansion of the sodium lactate injection pilot program. A series of injections (e.g., every 2 months) is necessary to maintain the reductive dechlorination conditions (anaerobic) over time until remedial levels are reached. This requirement necessitates the use of permanent injection wells, a header and feed system, and a sodium lactate mixing system. The highly soluble food-grade sodium lactate comes in a 60% solution. Sodium lactate solution with sodium lactate concentrations of approximately 1.0% will be injected into the transition zone, as well as into the bedrock zone, groundwater contaminated with TCE concentrations greater than 500 μg/L. The rate of injection would be approximately 1.5 gpm in the transition zone and 6.0 gpm in the bedrock zone. Injection would be continued for 2 days. Injection points would be installed within the transition and bedrock aquifer zones.

Groundwater samples would be collected from existing monitoring wells and/or injection wells before each injection event. The groundwater samples would be analyzed for VOCs and geochemical indicators.

4.3.4.1 Effectiveness

Sodium lactate injection has already been proven to be highly effective at this site for treating TCE in groundwater through the pilot study performed by SAIC in CY 2003 through 2004 (see Chapter 5.0). Long-term monitoring would be needed to evaluate the long-term effectiveness of the sodium lactate injections.

4.3.4.2 Implementability

Bioremediation could be readily implemented over most of the site and is a proven remedial technology that has been implemented at this site. The injectant (i.e., sodium lactate) is commercially available in the quantities required for implementation of this process option. Only a few additional groundwater monitoring wells (~ten) will be installed. However, several injection wells (~85) would have to be installed. Sufficient space exists to accommodate the installation of the monitoring wells; however, access to some of the treatment areas where the injection wells will be located may be limited based on the location of buildings and the active railroad spur.

The equipment and procedures required to install additional groundwater monitoring and injection wells are conventional and routinely used in environmental investigation and monitoring applications. Sufficient space exists above or around the contaminant zones to temporarily accommodate all the equipment required to install, develop, and sample the proposed groundwater monitoring network.

The equipment involved with monitoring the contaminated groundwater is widely available and routinely used in investigating environmental conditions in groundwater. The proposed monitoring program and analytical suite of analyses are well understood and routinely employed at a number of sites and investigations.

4.3.4.3 Cost

The capital cost for this process option is high due to the installation of the injection well network and the cost of the injection program; however, the operation and maintenance (O&M) cost is relatively low as the monitoring would be conducted over a relatively short period.

4.4 SUMMARY OF REPRESENTATIVE PROCESS OPTIONS

Based on the criteria of effectiveness, implementability, and cost, representative process options were selected for each technology type or group of technology types. The representative process options provide a basis for developing alternatives in the FFS. However, the specific process option used to implement the remedial action could change and may not be selected until the post-ROD phase. In some cases, more than one process option may be selected to represent a technology type. This type of selection may be made if two or more processes are sufficiently different in their performance such that one would not adequately represent the other.

The representative process options are used to further develop and compare alternatives in later chapters. The process options selected as representative are considered to represent similar performance and costs to those that are actually implemented as remedial actions. These process options form the technological components of the alternatives.

The two process options considered to achieve the RGs for the TCE plume at the Former NAD site are MNA and bioremediation using sodium lactate (Table 4-2). Institutional controls were not retained as a primary process option but will be used in combination with other process options to reduce risk.

5.0 PILOT STUDY

5.1 INTRODUCTION

Prior to writing the FS to address the CVOC impacts at the Former NAD site, a pilot study was conducted to evaluate the use of an electron donor (sodium lactate) for promoting reductive dechlorination as a remedial approach in both the transition and bedrock zones at the Former NAD site and to better understand the site hydraulic conditions. The pilot study focused on the area that has historically contained the highest concentrations of TCE and is the suspected source area (NAD MW-21/SAIC-14) (Figure 5-1). The scope and objectives of the pilot study are discussed in detail in *Addendum #3 to the Sampling and Analysis Plan for the Feasibility Study/Remedial Design at the Former Naval Ammunition Depot, Mecklenburg County, Charlotte, North Carolina* (SAIC 2003b). The pilot study consisted of an initial injection of a bromide tracer followed by a continuous injection of sodium lactate solution (food source) over a 3-day period and an 8-month monitoring period. Testing for anaerobic *Dehalococcoides* organisms was also conducted. A summary of the pilot study activities and a discussion of the results are provided in the following sections. The analytical data are summarized in tabular form in Appendix C with the validated laboratory analytical data sheets for the pilot study presented in Appendix D.

5.1.1 Injection and Monitoring Well Installation

Prior to implementing the treatment activities, one additional injection well (SAIC-17) and four additional monitoring wells (SAIC-18C, SAIC-19B, SAIC-20, and SAIC-21) were installed in the transition and bedrock zones at the Former NAD site in September and October 2003. All wells were completed as flush mounts. The boring logs and well construction diagrams are presented in Appendix B.

5.1.1.1 Transition Zone Wells

For the pilot study, one injection well was planned for the transition zone and two transition zone wells were planned for monitoring activities. The location of these transition zone wells was critical to the injection and monitoring program. Their proposed locations were determined using the groundwater flow direction and by predicting the range of distances the bromide would travel using a calculated area of influence based on the assumed transition zone injection rates of 1 to 2 gpm and aquifer properties reported in the Phase II RI (M&E 2000). The model predicted that in the transition zone, the bromide tracer would travel a minimum of 54 ft and a maximum of 73 ft (Appendix A, Table A-5).

As shown in Figure 5-1, well SAIC-17 was installed in the transition zone adjacent to monitoring wells NAD MW-21 and SAIC-14. In this area, the transition zone was encountered at a shallower depth than the predicted depth of 15 to 20 ft; therefore, the well was set at a depth of 10.7 ft BGS. This well was constructed with a 2-in. stainless steel riser and a 5.0-ft screen. SAIC-17 was initially installed as an injection well; however, attempts to deploy the injectate (sodium lactate) into this well failed and it was used as a monitoring point (see Section 5.1.3 for a discussion of the injection program). As an injection well, the riser casing was temporarily extended approximately 5 ft above the ground surface to allow the injection system to be attached. Once the injection program was completed, the riser casing was adjusted so that the well could be completed as a flush-mount well.

Two new transition zone wells, SAIC-18C and SAIC-19B, were installed as monitoring wells to assist in the evaluation of the sodium lactate and bromide distribution (Figure 5-1). During the installation of the monitoring wells at locations SAIC-18 and SAIC-19, boreholes were attempted at several locations before they were completed with monitoring wells. At location SAIC-18, three locations (SAIC-18, SAIC-18A, and SAIC-18B) were drilled before enough water was encountered to install the well. The transition zone at this location was also encountered at a much shallower depth than the predicted depth of 15 to 20 ft BGS. Therefore, SAIC-18C was only installed to a depth of 13.90 ft BGS and was constructed with a 2.0-in. polyvinyl chloride (PVC) riser and a 5.0-ft. screen. Although this well was originally planned as a monitoring point, it was used as an injection well for the transition zone after the injection failed in SAIC-17. At location SAIC-19, two locations (SAIC-19 and SAIC-19A) were drilled before the well was finally set to a total depth of 20.14 ft BGS at location SAIC-19B. This well was constructed with a 2.0-in. PVC riser and a 10-ft screen.

The wells were advanced to the transition zone by initially using a 4.25-in., hollow-stem auger to drill through the unconsolidated overburden, saprolite, and into the upper fractured bedrock to the top of competent bedrock. If the augers encountered refusal while drilling through the fractured bedrock, a 4-in. air hammer was used to advance the boring until the top of the competent bedrock was encountered. The boring logs, along with the well construction diagrams, for each newly installed well are included in Appendix B.

5.1.1.2 Bedrock Zone Wells

For the pilot study, two bedrock zone wells were planned for monitoring activities. The location and monitoring depth of these bedrock zone wells was critical to the monitoring program. At the time of the pilot study, no bedrock zone wells were located downgradient of the projected flow path within the focus area; therefore, two new bedrock wells (SAIC-20 and SAIC-21) were installed (Figure 5-1). The locations of the two bedrock wells were determined using the same methodology employed to locate the transition zone wells. The model predicted that in the bedrock the tracer would travel a minimum of 177 ft and a maximum of 354 ft (Appendix A, Table A-5).These predicted travel lengths were based on a combination of injection and 6 months of advective transport. The large variation in travel distance in the bedrock is due to the variation in the effective porosity, which is based on the estimated fractures in the associated bedrock. Bedrock zone wells SAIC-20 and SAIC-21 were installed into the bedrock with a total depth of 100.4 and 105.7 ft BGS, respectively. Both wells were constructed with a 2.0-in. PVC riser, with SAIC-20 having a 20-ft screen and SAIC-21 having a 10-ft screen.

A 6.25-in.-diameter hollow-stem auger and a 6-in.-diameter air hammer were used to advance the two borings to a depth of 5 ft below the top of competent bedrock.

Steel surface casing, measuring 4.25 in., was then inserted into the boring and grouted in place. No sooner than 48 hr after grouting, a core rig was used to HQ (3.77 in.) wireline core the borehole into the bedrock to total depth. The diameter of the borehole created by the coring was a nominal 3.7-in., which is smaller than the standard borehole size (6 in.) for a 2-in.-diameter well. However, by coring the borehole SAIC was able to accurately describe the lithology of the bedrock and assisted in locating the water-bearing fracture zones that ultimately determined the specific depth of each bedrock. The monitoring well was constructed after all drilling activities were completed. The boring logs, along with the well construction diagrams, for each newly installed well are included in Appendix B.

5.1.2 Baseline Sampling

A baseline sampling event was conducted from October 17 through October 22, 2003, to establish baseline conditions prior to beginning the injection program. After the new injection and monitoring wells were installed, but prior to beginning the injection program, a total of 21 selected monitoring points, including 14 monitoring wells and the 7 separate sampling zones in the multi-port FLUTe™ well SAIC-14, were sampled for VOCs, chemical oxygen demand (COD), methane, potassium, sodium, bromide, and natural attenuation parameters including alkalinity, nitrate, nitrite, sulfate, nitrogen, ethane, and ethane. Field measurements for conductivity, ORP, DO, temperature, pH, turbidity, and bromide were also collected. The analytical data are summarized in tabular format by well and presented in Appendix C. In addition, water level measurements were collected from each of the wells. The points that were initially monitored included:

SAIC-14 – Zones 1 through 7
SAIC-17
SAIC-18C
SAIC-19B
SAIC-20
SAIC-21
NAD MW-18
NAD MW-19
NAD MW-20
NAD MW-21
NAD MW-22
NAD MW-23
NAD MW-30
NAD MW-31
NAD MW-32

5.1.3 Injection Program

The injection program began on October 22, 2003. Some difficulties were encountered during the initial phase (due to site hydrogeologic conditions) that warranted changes to the planned injection program. Originally, the program planned to use SAIC-17 as the injection well for the transition zone and NAD MW-21 would be used as the injection well for the bedrock zone. However, SAIC-17 would not take water at the required flow rate and the injection program for the transition zone was completed in SAIC-18C.

During the initial phase of the bedrock zone injection program, it became apparent that the pressures induced in NAD MW-21 from the injection process were impacting the multi-port FLUTe™ liner system of SAIC-14. The close proximity of NAD MW-21 to SAIC-14 created concern as to whether proper injection pressures could be maintained while also keeping the proper head requirements in the FLUTe™ liner that are necessary to keep the liner firmly seated against the borehole walls. Therefore, the injection program for the bedrock zone was modified and the injection was completed in SAIC-20.

After adjustments to the system were made, the injection program continued. All injection activities, including multiple rounds of water level measurements within the focus area, installation of the bromide probe/data logger in SAIC-19, and injection system breakdown were completed by October 27, 2004. A brief description of the completed injection program activities is provided below.

5.1.3.1 *Bromide Tracer*

A sodium bromide (NaBr) tracer and sodium lactate were injected into the transition zone through SAIC-18C. In the bedrock, potassium bromide (KBr) was injected into NAD MW-21 and sodium lactate was injected in SAIC-20. In the transition zone, NaBr was in front of the sodium lactate push, as planned (Figure 5-2), but in the bedrock, the large mound created by the sodium lactate injection in SAIC-20 actually pushed the KBr upgradient of the point at which it was injected (Figure 5-3). Approximately 80 gal of NaBr (~concentration of 7,700 μg/L) and water were injected in the transition zone and approximately 150 gal of KBr (~concentration of 7,700 μg/L) and water were injected into the bedrock zone.

5.1.3.2 *Sodium Lactate Injection in the Transition Zone*

Sodium lactate solution was injected into the transition zone at an average rate 1.2 gpm for 55.5 hr. Approximately 4000 gal of solution were injected in the transition zone. Approximately 60% of the solution was injected at 0.6% sodium lactate concentration by volume. For the remaining 40% solution, the sodium lactate concentration by volume was increased to 0.9%. An approximate 80-ft radius of influence was observed by measuring water levels (see Appendix C, Table C-34) during the test in the transition zone (Figure 5-2).

5.1.3.3 *Sodium Lactate Injection in the Bedrock Zone*

Sodium lactate solution was injected into the bedrock zone at a rate of approximately 5 gpm for 55.5 hr. Approximately 16,650 gal of sodium lactate solution was injected. Tables C-35 and C-36, Appendix C, show changes in groundwater levels during the test. Approximately 60% of the solution was injected at 0.6% sodium lactate concentration by volume. For the remaining 40% solution, the sodium lactate concentration by volume was increased to 0.9%. In the north-south direction, the "radius" of influence in the bedrock was approximately 400 ft (Figure 5-3). In the east-west direction, the "radius" of influence was approximately 60 ft. Influence from injection in the bedrock was controlled by a fracture that runs north-south in relation to SAIC-20. This fracture acted as a conduit for a majority of the injected water, with much smaller effects being seen in the east-west and vertical directions.

5.1.4 *Monitoring Program*

Monitoring for the bromide tracer, sodium lactate, and changes in the groundwater chemistry were conducted over an 8-month period. The first four events were conducted bi-weekly (Event 1 through Event 4) followed by two monthly events (Events 5 and 6), concluding with two bimonthly monitoring events (Event 7 and 8).

The monitoring events included:

Event 1 – November 12 - 14, 2003
Event 2 – November 24 - 26, 2003
Event 3 – December 9 - 11, 2003
Event 4 – December 19 - 21, 2003
Event 5 – January 20 - 23, 2004
Event 6 – February 19 - 22, 2004
Event 7 – April 12 - 15, 2004
Event 8 – June 24 - 28, 2004

Initially, the monitoring network consisted of only the 21 monitoring points that were included in the baseline sampling event. However, after it was observed that the radius of influence was greater in the bedrock than predicted, the monitoring area was expanded and multi-port FLUTe^{TM} wells SAIC-16A (6 separate sampling zones) and SAIC-15 (5 separate sampling zones) were added to the monitoring program for a total of 32 monitoring points. Water level measurements were collected from each monitoring point in the focus area at the beginning of each event. Water-gauging activities were also expanded beyond the original 21 monitoring points to include several wells outside of the focus area.

During the monitoring program, the distribution of the sodium lactate (electron donor) was assessed using the COD parameter as a surrogate. Samples were also collected for bromide (potassium and sodium), VOCs, natural attenuation parameters, and organic acids. Field measurement parameters including ferrous iron and carbon dioxide conductivity, ORP, DO, temperature, pH, turbidity, and bromide were also collected (see Appendix C, Tables C-32 and C-33). Data were also downloaded from the bromide probe/data logger installed in SAIC-19 (see Appendix C, Table C-37).

Initially, select wells were screened for the bromide tracer with a field probe and were analyzed for COD as an indicator parameter for the sodium lactate distribution. Wells where bromide was detected and elevated COD values and reduced ORP conditions (increase in levels) were present were sampled for VOCs and natural attenuation parameters. Once reducing conditions were exhibited, wells were sampled for lactate breakdown products (organic acids) that include acetic acid, lactic acid, butanoic acid, propanoic acid, ethane, ethane, and methane (see Appendix C, Tables C-32 and C-33).

During the monitoring program it was evident, through the evaluation of the COD results, that the distribution of the sodium lactate did not progress very rapidly in the transition zone (Figures 5-4 and 5-5). However, in the bedrock zone, the distribution was over a much greater area due to the nature of the fractured bedrock (Figures 5-5 through 5-8). Reducing conditions were apparent by Event 4 and analysis for organic acids, ethane, ethane, and methane were added to the monitoring program. During Event 3, a Gene-Trac analysis for the presence of *Dehalococcoides* organisms was included.

5.2 *RESULTS OF THE PILOT STUDY*

The analytical data collected during the pilot study are summarized in tabular format and depicted on concentration versus time graphs by well in Appendix C. The validated analytical data sheets are included in Appendix D. A summary of the results from the final sampling event conducted in June 2004 (Event 8) is provided on Table 5-1. The discussion of the pilot study results focuses on data collected from specific wells that are representative of the conditions observed in the transition and bedrock zones. The representative transition zone wells include SAIC-17, SAIC-18C (injection well), and SAIC-19B. The representative bedrock zone wells include SAIC-21, NAD MW-23, and SAIC-20 (injection well). Multi-port wells SAIC-16A and SAIC-14 were also chosen for discussion. Figures 5-9 and 5-10 show the site plan with well locations along with radial diagrams generated by the SEQUENCE program that depicts the degradation of the CVOCs. The radial diagrams plot TCE; *cis*-1,2 DCE; *trans*-1,2 DCE; vinyl chloride; and PCE concentration variations with time. The time correlates to sampling events conducted during the following months after the initial sodium lactate injection. A discussion of the results is provided in the following sections.

5.2.1 *Gen-Trac* **Dehalococcoides** *Test*

Dehalococcoides organisms are the only microorganisms proven to possess the necessary enzymes for the complete dechlorination of PCE or TCE to ethane. The presence of *Dehalococcoides* genetic material has been positively correlated to complete dechlorination of chlorinated ethenes at contaminated sites. To determine if biological processes were present at the Former NAD site and could be effective in promoting anaerobic biodegradation of the CVOCs present in the aquifer, Gene-Trac testing was conducted.

On December 9, 2003, during monitoring Event 3, a 1-L sample of groundwater was collected from monitoring zone 7 (297 to 307 ft BGS) of the multi-port FLUTe™ well SAIC-14 and sent to SiREM laboratory for Gene-Trac assay analysis.

This test determines the presence of *Dehalococcoides* deoxyribonucleic acid (DNA) with results presented as either detected or not detected based on interpretation of an electronic image of DNA gel. Detects (gel bands) were then quantified using densitometry software and assigned a "band intensity percentage" using the relative intensity of the strongest bands obtained to the intensity of the positive control reaction. This value is in turn used to assign a test intensity score.

The *Dehalococcoides* test intensity is a quantitative assessment of band intensity as a percentage of the test to the positive control reaction. This value provides a semi-quantitative assessment of the amount of *Dehalococcoides* genetic material present in the sample. While band intensity may reflect actual concentration of the target organism, Gene-Trac is a semi-quantitative method and is only recommended to determine the presence or absence of *Dehalococcoides* genetic material in the sample. A score of 4 indicates a very high band intensity. High intensity scores with multiple primer sets provide the most conclusive results.

The test indicated a positive intensity of 161% with an intensity score of 4 out of 4 and revealed that organisms belonging to the *Dehalococcoides* group were present in three of the three test sets. The results of the test are provided in Appendix C. This positive test result provides strong evidence that the *Dehalococcoides* organisms are present in the aquifer at the Former NAD site and may facilitate complete dechlorination of chloroethene compounds if the appropriate geochemical conditions are present.

5.2.2 Transition Zone

As shown in Figure 5-9, at SAIC-18C (injection well), TCE concentrations prior to injection were above ~5 μg/L. By Event 4, TCE and associated breakdown products were reduced to non-detects. A conversion of TCE mass to daughter products is not depicted by the diagram and is likely a result of injection taking place at this well.

SAIC-17 is slightly upgradient of the injection point; however, effects of the injection were evident. As shown in the radial diagram, TCE mass from the baseline event shifted to *cis*-1,2 DCE by Event 8. Likewise, a reduction in TCE concentration is evident by the second sampling event approximately 1.5 months after injection.

Perhaps the most accurate representation of the reductive dechlorination in the transition zone is evidenced by the radial diagram shown for SAIC-19B. From the baseline event and just after injection (Event 2), PCE concentrations decreased slightly as TCE increased. By Event 4, PCE and TCE had significantly reduced with most of the mass appearing to go to *cis*-1,2 DCE. At Event 8, PCE, TCE, and daughter products are reduced to approximately ~0 μg/L.

5.2.3 Bedrock Zone

Although NAD MW-23 was located ~200 ft upgradient from the injection point (SAIC-20), effects of the sodium lactate injection is evident (Figure 5-10). By Event 2, a reduction in PCE concentrations and slight increase in TCE concentrations had occurred. This indicates that the sodium lactate is causing the reductive environment already at this point to become more reducing. NAD MW-23 was not sampled during Event 4; however, by Event 8 a noticeable reduction in PCE, TCE, and daughter products is evident.

Results at SAIC-20 (injection well) and SAIC-21 (approximately 125 ft from the injection point) are similar. Significant reduction of PCE and TCE followed by an increase in associated breakdown products by Event 8 is evident.

Multi-port well SAIC-14 is also indicative of reducing conditions occurring approximately 100 ft upgradient of the injection well. Results shown in the radial diagram are from Port 2, which is located in the interval of 109 to 114 ft BGS. By Event 8, most of the mass resides in *cis*-1,2 DCE and vinyl chloride.

Multi-port well SAIC-16A is located approximately 500 ft downgradient of the injection well SAIC-20. Here, as in SAIC-14, the sampling interval was from Port 2 approximately 83 to 103 ft BGS. Results are similar to other wells, in that, by Event 8

TCE concentrations are reduced and associated daughter product concentrations have increased.

5.3 *CONCLUSIONS*

The pilot study has demonstrated that at the Former NAD site:

- Sodium lactate (electron donor) can be effectively distributed through the aquifer in both the transition and bedrock zones;
- Areas that received the electron donor show significant dechlorination;
- The reductive properties of the aquifer can be increased by enhancing the microbial activity of the detected *Dehalococcoides* population with the injection of an electron donor (food source); and
- Enhanced bioremediation using sodium lactate is an effective and appropriate remedial technology for promoting anaerobic biodegradation and reduction of the CVOC contamination present in the aquifer.

6.0 DEVELOPMENT AND DESCRIPTION OF ALTERNATIVES

6.1 INTRODUCTION

This chapter presents the development and description of remedial alternatives assembled from combinations of technologies and associated process options carried forward from the technology screening.

The CERCLA remedial alternative selection process (i.e., the FS, Proposed Plan, and ROD) is used to identify and plan the implementation of CERCLA remedial actions that eliminate, reduce, or control risks to human health and the environment (40 *CFR* 300). The purpose of the FFS, as defined in NCP, is to develop a range of possible remedies that protect human health and the environment, maintain protection over time, and minimize untreated waste. Criteria for identifying possible applicable technologies to achieve these goals are provided in EPA guidance (EPA 1988) and in NCP.

NCP defines the following preferences in developing remedial action alternatives:

- Use of treatment to address the principal threats posed by a site, wherever practical.
- Use of engineering controls (e.g., containment) for waste that poses a relatively low, long-term threat and for which treatment is not practical.
- Implementation of a combination of actions, as appropriate, to achieve protection of human health and the environment.
- Use of institutional controls (e.g., drinking water supply controls and deed restrictions) to supplement engineering controls for short- and long-term management to prevent or limit exposures to hazardous substances.
- Selection of an innovative technology when the technology offers the potential for comparable or better treatment performance or implementability, fewer adverse impacts than other technologies, or lower costs than demonstrated technologies for similar levels of performance.
- Restoration of environmental media, such as groundwater, to their beneficial uses whenever practical and within a reasonable timeframe. When restoration of groundwater to beneficial uses is not practical, EPA expects to prevent further migration of the contaminant plume, prevent human and environmental exposures to contaminated groundwater, and evaluate further risk reduction.

EPA guidance (EPA 1988) establishes an approach to developing appropriate remedial action alternatives. In implementing this approach, the scope, characteristics, and complexity of the specific conditions at the site were considered to develop a range of alternatives that would protect human health and the environment. Protection may be achieved by eliminating, reducing, or controlling risks posed by each pathway at the site.

The purpose of the range of remedial alternatives is to present the decision-makers with several technical and economic options to achieve the RAOs. Regulatory preferences and considerations were also a factor in development of the remedial alternatives.

The process options carried forward from the screening of technologies were combined to form preliminary remedial alternatives. The remedial action alternatives developed in this FFS are based on the data available from the Phase I and II RIs, the supplemental investigations, the sodium lactate injection pilot study results presented in the previous chapter, and the results of fate and transport modeling presented in the earlier chapters. Uncertainties in the assumptions regarding the nature and extent of contaminated media used to develop remedial action alternatives could significantly impact effectiveness, implementability, and cost. The remedial action alternatives developed for the Former NAD site to meet the RGs are shown below:

- Alternative 1 – "No Action";
- Alternative 2 – "Monitored Natural Attenuation";
- Alternative 3 – "Enhanced Bioremediation Using Sodium Lactate Injection."

6.2 REMEDIAL ALTERNATIVES

The following sections briefly describe each alternative. A summary of the remedial actions alternatives is shown in Table 6-1.

6.2.1 Alternative 1 – "No Action"

The no action alternative is considered in accordance with CERCLA and NCP requirements for comparison with other alternatives. Under this alternative, no remedial action would be implemented at the Former NAD site to reduce contaminant concentrations in the contaminant plume to return the impaired groundwater to beneficial use. Access to contaminated groundwater would be unrestricted, allowing exposure to contaminated media, and no monitoring of groundwater would be performed.

The no action alternative provides no measures to protect human health or the environment, or to maintain or monitor site conditions. The no action alternative would not meet the RAO of attempting to achieve the NCAC 2L criteria for CVOCs in groundwater at the Former NAD site. Although the no action alternative would be the lowest cost and the easiest to implement, unacceptable risk from exposure to contaminated groundwater may be realized if the site were available for uncontrolled use. However, consideration of the no action alternative is required by NCP as a baseline for comparison, and, therefore, this alternative was retained from the initial screening and carried forward for detailed analysis in Chapter 7.0.

6.2.2 Alternative 2 – "Monitored Natural Attenuation"

Alternative 2 would be groundwater monitoring and natural attenuation involving the implementation of institutional controls, such as restricting groundwater access and property owner notification. Restrictions limiting the use of groundwater for consumption and irrigation would be implemented as well as notifying property owners in the form of a certified letter regarding groundwater contamination.

Groundwater monitoring would be included as an institutional action. The purpose of groundwater monitoring would be to show that natural attenuation was decreasing the CVOCs contamination as predicted. Analytical results would be evaluated after each monitoring event to verify that concentrations

of CVOCs are decreasing and that the RG is ultimately achieved. Long-term monitoring would allow assessment of contaminant migration and would be an important part of preventing potential unacceptable exposures.

Modeling has indicated that CVOCs in the transition zone groundwater would naturally attenuate to the NCAC 2L standards within 47 years (see Appendix A, Figure A-1); whereas, in the bedrock zone groundwater, it would take approximately 63 years (see Appendix A, Figure A-2) for the CVOCs to be reduced to the NCAC 2L standards. Therefore, the transition zone groundwater would be monitored for 47 years and the bedrock zone groundwater would be monitored for 63 years or until such time as the transition zone and bedrock zone groundwater at the site meets the NCAC 2L standards. Reviews of the data will be conducted to determine how rapidly the aquifer is attenuating residual contaminants or to determine if remedial measures should be undertaken.

Transition Zone Groundwater Monitoring. Groundwater monitoring (baseline event) would begin at the start of the implementation of this alternative. Then, following the current NCDENR Division of Water Quality policy, groundwater monitoring would be performed quarterly for the first 12 quarters (3 years). USACE may then seek authorization from NCDENR to reduce the sampling frequency of the groundwater monitoring network to a semiannual basis for the subsequent four events (2 years). Upon completion of semiannual sampling, USACE may seek authorization from NCDENR to reduce the sampling frequency to an annual basis thereafter. Note that in the event that a COC is consistently below its corresponding remediation goal (NCAC 2L standards) for four consecutive quarterly monitoring events (1 year) at a particular groundwater monitoring well, USACE may seek authorization from NCDENR to reduce groundwater monitoring for that specific contaminant to annual monitoring for that particular groundwater monitoring well. However, in the event that the contaminant is detected above the RG during annual sampling of the groundwater monitoring well, quarterly groundwater monitoring for the contaminant must be re-initiated at that groundwater monitoring well. Lastly, all monitoring wells must be sampled for all COCs in anticipation of, and in support of, the 5-year reviews to be conducted for the site. Upon achieving the specified RGs at all groundwater monitoring wells in the monitoring network (defined by the Division of Water Quality as occurring when a COC is consistently below it corresponding remediation goal for four consecutive quarterly monitoring events), USACE shall seek written approval from NCDENR to discontinue the groundwater monitoring program. Upon written approval from NCDENR, USACE may discontinue the groundwater monitoring program.

Groundwater samples would be collected from the 11 existing transition zone monitoring wells located within the site boundary and 4 newly installed transition zone monitoring wells that would be installed to depths of approximately 25 ft BGS. These monitoring wells would include NAD MW-25, NAD MW-27, NAD MW-31, NAD MW-33, NAD MW-48, NAD MW-49, NAD MW-50, NAD MW -58, NAD MW-52, NAD MW-64, and VERSAR 17. The locations of the four new groundwater monitoring wells (SAIC-22 through SAIC-25) are shown in Figure 6-1. They would be installed to depths of approximately 25 ft and would augment the groundwater monitoring network.

Groundwater would be analyzed for all COCs (VOCs) and natural attenuation parameters [anions (chloride, fluoride, bromide, sulfate, nitrite, and nitrate), alkalinity, sulfide, methane, phosphates, carbon dioxide, total organic carbon, and iron]. The following field parameters also to be measured include: turbidity, ferrous iron, Redox, DO, pH, temperature, and specific conductivity. A report would be issued after each groundwater sampling event presenting the results of the groundwater monitoring, evaluating the performance of MNA, and updating the natural attenuation model. A final report would be submitted upon completion of the confirmatory sampling event. All monitoring wells would be abandoned by removing the surface completion and grouting to the ground surface, following confirmatory sampling and approval of the final report.

Bedrock Zone Groundwater Monitoring. Groundwater monitoring (baseline event) would begin at the start of the implementation of this alternative and be performed following the monitoring program discussed in detail for the transition zone. Groundwater samples would be collected from the ten existing bedrock monitoring wells located within the site boundary and five newly installed bedrock monitoring wells that would be installed to depths of 250 ft BGS. These monitoring wells would include NAD MW-21, NAD MW-22, NAD MW-26, NAD MW-28, NAD MW-29, NAD MW-51, the three multi-port wells (SAIC-14, SAIC-15 and SAIC-16A), and VERSAR 20. The locations of the five new groundwater monitoring wells (SAIC-27 through SAIC-31) are shown in Figure 6-2. Groundwater would be analyzed for all COCs (VOCs) and natural attenuation parameters [anions (chloride, fluoride, bromide, sulfate, nitrite, and nitrate), alkalinity, sulfide, methane, phosphates, carbon dioxide, total organic carbon, and iron]. The following field parameters also to be measured include: turbidity, ferrous iron, Redox, DO, pH, temperature, and specific conductivity. A report would be issued after each groundwater sampling event presenting the results of the groundwater monitoring, evaluating the performance of MNA, and updating the natural attenuation model. A final report would be submitted upon completion of the confirmatory sampling event. All monitoring wells would be abandoned by removing the surface completion, and grouting to the ground surface, following confirmatory sampling and approval of the final report.

6.2.2.1 Evaluation

MNA can be effective in achieving the RGs, particularly if naturally occurring biodegradation is already taking place. At the Former NAD site, conditions in the aquifer are anaerobic. Therefore, conditions are favorable for intrinsic reductive dechlorination of the TCE. Conditions are also favorable for the intrinsic remediation of TCE daughter products.

MNA could be readily implemented. It is a proven alternative that has been implemented at other federal facility sites where the groundwater has been contaminated. The equipment involved with monitoring the contaminated groundwater is widely available and routinely used in investigating environmental conditions in groundwater. The proposed monitoring program and analytical suite of analyses are well understood and routinely employed at a number of sites and investigations.

6.2.3 *Alternative 3 – "Enhanced Bioremediation Using Sodium Lactate Injection"*

At the Former NAD site, a sodium lactate injection pilot test program was conducted from October 2003 to June 2004. The results of the pilot test, presented in Chapter 5.0, proved that the sodium lactate could be effectively distributed through the aquifer and be effective in promoting reductive dechlorination at the site. The Pilot Test indicated that a highly anaerobic condition within the treatment area was produced by the electron donor, thereby degrading the PCE and TCE within the treatment zone at a much faster rate than in the natural conditions (e.g., orders of magnitude faster degradation).

Therefore, Alternative 3 would use a combination of enhanced bioremediation and MNA to achieve the remedial levels in groundwater at the Former NAD site. The plume area with contamination greater than 500 μg/L will be treated using sodium lactate injection. The residual contamination within the treatment areas and the contamination located outside of the radius of influence of the horizontal injection wells will attenuate naturally following the treatment period. Contamination levels would be monitored to ensure natural attenuation of contamination to below remedial levels. Modeling predicted that natural attenuation would degrade contaminants in approximately 14 years in the transition zone and 12 years in the bedrock zone following the completion of the sodium lactate injection program.

Transition Zone. Based on the analysis of results from the sodium lactate injection pilot study, the enhanced degradation rate of TCE in the transition zone is estimated to be 0.028 day^{-1} (see Appendix A, Table A-2a). Therefore, four injection events will be required in the transition zone to reduce the TCE concentrations to below 500 μg/L. Groundwater modeling using the results of the pilot test (see Appendix A) has indicated that to capture the 500-μg/L plume boundary, the sodium lactate injection system would need to be comprised of a network of 54 injection wells. The injection system will include associated piping between the injection wells, and the distribution pump that delivers the sodium lactate solution to the injection wells through the piping. Before each injection event, all the injection wells, along with the 15 monitoring wells (discussed under MNA), will be sampled for the parameters necessary to evaluate the distribution of the sodium lactate and the effect on the aquifer characteristics, including chlorinated solvent concentrations. Injection will occur every 2 months over a 6-month period for a total of four injections. Injection through each well will be at the rate of 1.5 gpm for 48 hr with 1% sodium lactate solution. CVOCs and other geochemical parameters will be monitored before each injection.

The enhanced bioremediation system will be monitored through a network of monitoring and injection wells to evaluate the operating conditions of the system. Samples will be collected for two types of data: field parameters and fixed-base laboratory chemical analysis. Field parameters will include, pH, specific conductivity, temperature, ferrous iron, carbon dioxide, alkalinity, DO, ORP, and static water level. Laboratory analyses will include COD and VOCs. Following active treatment, groundwater monitoring will be performed following the program detailed in Alternative 2 – "Monitored Natural Attenuation." However, the monitoring period will be limited to a shorter period of time (see Appendix A, Figure A-3). It should be noted that if contaminant rebound occurs, then it may be necessary to re-initiate active treatment.

Bedrock Zone. Based on the analysis of results from the sodium lactate injection pilot study, the enhanced degradation rate of TCE in the bedrock zone is estimated to be 0.013 day^{-1} (see Appendix A Table A-2a) Therefore, it will require seven injection events in the bedrock zone to reduce the TCE concentrations to below 500 μg/L. Groundwater modeling using the results of the pilot study (see Appendix A) has indicated that in order to capture the 500-μg/L plume boundary, the sodium lactate injection system would need to be comprised of a network of 31 injection wells. The injection system will include associated piping between the injection wells and the distribution pump that delivers the sodium lactate solution to the injection wells through the piping.

Before each injection event, all the injection wells, along with the 15 monitoring wells (discussed under MNA), would be sampled for the parameters necessary to evaluate the distribution of the sodium lactate and the effect on the aquifer characteristics, including chlorinated solvent concentrations. Injection will occur every 2 months up to 12 months for a total of seven injections. Injection through each well will be at the rate of 6 gpm for 48 hr with 1% sodium lactate solution. CVOCs and other geochemical parameters will be monitored before each injection.

The enhanced bioremediation system will be monitored through a network of monitoring and injection wells to evaluate the operating conditions of the system. Samples will be collected for two types of data: field parameters and fixed-base laboratory chemical analysis. Field parameters will include, pH, specific conductivity, temperature, ferrous iron, carbon dioxide, alkalinity, DO, ORP, and static water level. Laboratory analyses will include COD and VOCs. Following active treatment, groundwater monitoring will be performed following the program detailed in Alternative 2 – "Monitored Natural Attenuation." However, the monitoring period will be limited to a shorter period of time (see Appendix A, Figure A-4). It should be noted that if contaminant rebound occurs, then it may be necessary to re-initiate active treatment.

7.0 DETAILED ANALYSIS OF ALTERNATIVES

This chapter evaluates the remedial alternatives retained in Section 6.2 to address contaminated groundwater at the Former NAD site. These three alternatives include:

- Alternative 1 – "No Action";
- Alternative 2 – "Monitored Natural Attenuation"; and
- Alternative 3 – "Enhanced Bioremediation Using Sodium Lactate Injection".

NCP requires that potential remedial alternatives undergo detailed analysis using relevant evaluation criteria. The results of the detailed analysis are then arrayed to compare alternatives and to highlight key advantages, disadvantages, and trade-offs among the alternatives. The evaluation criteria, individual alternative analysis, and comparative alternative analysis are presented in the following sections.

7.1 EVALUATION CRITERIA FOR ANALYSIS

NCP identifies nine CERCLA evaluation criteria to be applied during the detailed analysis. Furthermore, this FFS incorporates National Environmental Policy Act values into the evaluation. These criteria fall into three groups: (1) threshold criteria, (2) primary balancing criteria, and (3) modifying criteria.

7.1.1 Threshold Criteria

All action alternatives must meet the two CERCLA threshold criteria for further consideration:

- overall protection of human health and the environment, and
- compliance with ARARs.

These criteria are the basis for statutory findings that must be documented in the ROD.

7.1.2 Primary Balancing Criteria

The primary balancing criteria consider the performance of the alternatives and verify that they could be realistically implemented:

- long-term effectiveness and permanence;
- reduction of contaminant toxicity, mobility, and volume through treatment;
- short-term effectiveness;
- implementability; and
- cost.

The evaluation details the ability of alternatives to meet these criteria and provides sufficient detail to enable decision makers to understand the significant aspects of each alternative and any associated uncertainties.

7.1.3 *Modifying Criteria*

The final criteria focus on the viability of the preferred alternative:

- state acceptance, and
- community acceptance.

CERCLA-modifying criteria (state agency concurrence and community acceptance) are not addressed in this FFS as these criteria rely on stakeholder participation and feedback to the Proposed Plan. The Proposed Plan, to be issued by USACE, will document the evaluation of alternatives and present the preferred alternative. The Proposed Plan will be available for public review and comment subsequent to regulatory agency concurrence. The ROD will present the selected remedy and address public comments on the Proposed Plan and any other components of the Administrative Record.

7.2 *OVERVIEW OF THE EVALUATION CRITERIA*

7.2.1 *Criterion 1: Overall Protection of Human Health and the Environment*

Each alternative's ability to protect human health and the environment is assessed along with its ability to comply with the project-specific RAO detailed in Chapter 3.0. All alternatives, except the no action alternative, must satisfy this criterion. The scope of the criterion is broad and reflects assessments discussed under other evaluation criteria, especially long-term effectiveness and permanence and short-term effectiveness. This criterion focuses on how site risks associated with each exposure pathway would be eliminated, reduced, or mitigated through treatment, engineering controls, or institutional controls. It also covers impacts to the site resulting from implementation of the remedial action.

7.2.2 *Criterion 2: Compliance with Applicable or Relevant and Appropriate Requirements*

Each alternative is assessed to address compliance with federal and state environmental requirements that are either legally applicable or relevant and appropriate. In certain cases, regulatory standards may not address the action or the COCs. In such cases, non-promulgated advisories, criteria, or guidance developed by EPA, other federal agencies, or states can be identified as potential to-be-considered (TBC) guidance.

7.2.3 *Criterion 3: Long-Term Effectiveness and Permanence*

Each alternative is assessed to determine its ability to achieve overall reduction in risk to human health and the environment and to provide sufficient long-term controls and reliability. This criterion focuses on the degree to which the alternative provides sufficient engineering, operational, and institutional controls; the reliability of those controls to maintain exposures to human and environmental receptors within protective levels; and the uncertainties associated with the alternative over the long-term. For this FFS, long-term effectiveness and permanence are evaluated under the following categories:

- magnitude of residual risk and uncertainties,
- adequacy and reliability of controls,
- long-term environmental effects,
- socioeconomics and land use, and
- irreversible and irretrievable commitment of resources.

7.2.4 Criterion 4: Reduction of Toxicity, Mobility, or Volume Through Treatment

Each alternative is assessed to determine the extent to which it can effectively and permanently fix, transform, or reduce the volume of waste material and contaminated media. The evaluation also considers the amount of material treated; the magnitude, significance, and irreversibility of the given reduction; and the nature and quantity of treatment residuals.

7.2.5 Criterion 5: Short-Term Effectiveness

This criterion addresses the effects on human health and the environment posed by the construction and implementation of the alternative. Potential impacts are examined, as well as appropriate mitigative measures for maintaining protectiveness for the community, workers, environmental receptors, and potentially sensitive resources.

7.2.6 Criterion 6: Implementability

This criterion evaluates the technical and administrative factors affecting implementation of an alternative. In addition, the availability of needed services and materials is also evaluated. Administrative feasibility addresses the need for coordination with other offices and agencies to include obtaining permits and approval from regulatory agencies. Evaluation of the availability of services and materials includes the availability of necessary facilities, equipment, technologies, and specialists, and the effect of reasonable deviations on implementability. Technical feasibility considers difficulties and uncertainties associated with construction and operation of a given technology, the reliability of the technology, the ease of undertaking additional future remedial action, the ability to monitor effectiveness or remedial action, and the potential risk of exposure from an undetected release.

7.2.7 Criterion 7: Cost

Comparisons among alternatives include cost estimates developed to support the detailed analysis based on feasibility-level scoping. The estimates have an accuracy of +50 to -30% (EPA 1988). The cost estimates for this FFS are based on the expected scopes of work and assumptions provided in the detailed description of alternatives. Only unescalated costs are presented in this FFS because of scheduling uncertainties. No direct costs are associated with the no action alternative. Costs are presented as capital costs (direct and indirect) and O&M costs:

- Capital costs include expenditures required to initiate and perform a remedial action, mainly design and construction costs. Capital costs consist of direct and indirect costs. Direct costs include construction (material, labor, and equipment), service equipment, buildings, and utilities. Indirect costs include such elements as Title I and Title II engineering, Title III inspection, project integration, project administration, and management.
- Operations costs include transportation fees, tipping fees, waste handling, facility maintenance, and monitoring. Maintenance costs are long-term costs that accrue following completion of remedial actions.

7.2.8 Criterion 8: State Acceptance

This FFS does not evaluate against this modifying criterion. This modifying criteria will be addressed in the ROD following review of this document and the Proposed Plan by regulatory agencies and the public.

7.2.9 Criterion 9: Community Acceptance

This FFS does not evaluate against this modifying criterion. This modifying criterion will be addressed in the ROD following review of this document and the Proposed Plan by regulatory agencies and the public.

7.3 INDIVIDUAL ANALYSIS OF ALTERNATIVES

7.3.1 Alternative 1 – "No Action"

The first retained remedial alternative is the no action alternative. Evaluation of the no action alternative is required under NCP to provide a comparative baseline for the other alternatives.

Under this alternative, active remedial measures would not be implemented at the Former NAD site and contaminated groundwater would remain. Monitoring would not be implemented for the groundwater. No corrective measures would be taken to reduce contaminant concentrations in order to return the impaired groundwater to beneficial use.

7.3.1.1 *Overall Protection of Human Health and the Environment*

The no action alternative would not be protective of human health or the environment. There are no current groundwater receptors; however, a future exposure pathway includes ingestion of groundwater. The no action alternative would not eliminate potential future routes for human exposure nor would it involve treatment to reduce the inherent risk associated with contaminated groundwater at the site. Under the no action alternative, no restrictions or controls would be placed on the use of groundwater at the site. Without institutional controls, there is a possibility of groundwater ingestion by a future hypothetical resident. The no action alternative would not be protective of the environment because migration of contaminated groundwater would continue to occur.

7.3.1.2 *Compliance with ARARs*

Because the no action alternative does not trigger action- or location-specific ARARs, only the chemical-specific ARARs are considered for the no action alternative. With the no action alternative, the concentrations in groundwater would remain above the NCAC 2L standards, and although natural attenuation would occur, the aquifer would not comply with requirements of NCAC 2L to reduce contaminant concentrations in the resource groundwater to meet the drinking water standards.

7.3.1.3 *Long-Term Effectiveness and Permanence*

The no action alternative would not remove, isolate, or treat contaminated media at the Former NAD site. Contaminants in groundwater would not be addressed by this alternative. Accordingly, the residual risks presented by the affected media would be equivalent to the current levels of risks presented by the site.

The no action alternative would have no long-term effectiveness or permanence. Risks would essentially remain the same because no controls would be implemented to prevent potential exposure to the groundwater, there would be no treatment of the groundwater contaminants, and there would be no confirmation of any long-term reduction of contamination through natural attenuation.

7.3.1.4 *Reduction in Toxicity, Mobility, or Volume*

The no action alternative does not reduce the toxicity, mobility, or volume of contaminated groundwater at the site. The exceedancs of NCAC 2L standards will continue, as no action will be taken to reduce or isolate contamination in the groundwater. However, modeling has predicted that the present concentration of CVOCs in transition zone groundwater would require approximately 47 years to naturally attenuate to below remedial levels and for the CVOCs in the groundwater of the bedrock zone, it would take approximately 63 years to naturally attenuate to below remedial levels. Therefore, there would be a gradual decrease in the volume or mass of contamination. Under no action, however, no monitoring would be performed to evaluate such decreases or mobility (further migration). Some future impact/unknown factor at the site could potentially increase the toxicity, mobility, or volume of contamination at the site. The no action alternative does not meet EPA's statutory preference for treatment.

7.3.1.5 *Short-Term Effectiveness*

Risk, or potential risk, to both human and ecological receptors remains unchanged under the no action alternative. The no action alternative would not remove, isolate, or treat contaminated groundwater at the Former NAD site.

There are no risks to remedial workers from implementation of the no action alternative. No new risks to the community (maintenance workers or recreational users) result from this alternative.

7.3.1.6 *Implementability*

The No action alternative does not involve any construction and, therefore, could be implemented immediately. Issues concerning the availability of services, equipment, space, utilities, or manpower are not relevant for this alternative, and coordination with other agencies or permits is not required.

7.3.1.7 *Cost*

Indirect costs for pre-construction activities and construction costs do not apply to the no action alternative. Long-term O&M activities are not conducted under the no action alternative, and, therefore, these cost elements are not applicable. There are no costs associated with the no action alternative.

7.3.2 *Alternative 2 – "Monitored Natural Attenuation"*

7.3.2.1 *Overall Protection of Human Health and the Environment*

This alternative is similar to the no action alternative in that no active remedial action would be implemented to reduce the contaminants to below remedial levels; however, legal controls preventing the use of groundwater for drinking or irrigation would be implemented to eliminate potential contact (i.e., risk) from the groundwater. The overall protection of human health and the environment for this alternative is dependent, therefore, on the establishment and maintenance of institutional controls on-site. This alternative would provide protection of human health through warning signs and legal controls placed on the use of groundwater. Monitoring and reporting established for the alternative would confirm natural attenuation of the CVOCs and the 5-year reviews would confirm that institutional controls were in place, and that the CVOC contamination is being reduced through natural attenuation without migrating beyond the predicted boundary. Human health and the environment would be protected over the short-term because no major physical installation/implementation would be required. It should be noted that groundwater is currently not used either on- or off-site; the groundwater aquifer is not used as a source for drinking or irrigation; and adjacent properties are on potable water supply. Therefore, it is unlikely that human health and the environment would be impacted.

7.3.2.2 *Compliance with ARARs*

The applicable chemical-specific ARARs for this alternative are discussed in Chapter 3.0. These federally enforceable standards would be protective of a potential future resident who could be exposed to the COCs through the ingestion pathway. Legal controls implemented under this alternative would prevent future ingestion of contaminated drinking water, and long-term monitoring would demonstrate when the aquifer was restored to unrestricted potable use standards. Under the natural attenuation alternative, it would take up to 63 years to attain the ARARs for CVOCs.

The natural attenuation alternative would comply with ARARs but not in a short timeframe. The concentration of groundwater would remain above NCAC 2L standards until complete restoration of the aquifer had been achieved, predicted by modeling to require 63 years.

There are no action- or location-specific ARARs associated with this alternative.

7.3.2.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of natural attenuation would be dependent on the establishment and maintenance of institutional controls on-site and the decrease with time in CVOCs. The magnitude of the residual risk would remain the same as no action; however, institutional controls would be established to eliminate potential exposure to humans and the environment, thereby significantly reducing the potential risk. Some uncertainty is associated with the modeling of natural attenuation and fate and transport of the contaminants. As discussed in the contaminant nature and extent (Section 2.5) and modeling (Section 2.6) sections, the site conditions are highly conducive to reductive dechlorination; therefore, the biological degradation is expected to be quite effective in reducing the contaminant mass. The long-term reliability of the alternative in protecting human health and the environment would be dependent on maintaining the institutional controls. The short- and the long-term monitoring and reporting would confirm natural attenuation of the COCs to their respective remedial levels and the maintenance of the institutional controls.

7.3.2.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

This alternative does not meet the statutory preference for employing treatment technologies that permanently reduce the toxicity, mobility, or volume of the contaminants. There would be no immediate reduction in toxicity, mobility, or volume of the contaminants as a result of implementing this alternative because active treatment would not be employed. Modeling has predicted that the aquifer will be restored to below remedial levels for all the CVOCs in the transition zone in ~47 years and in the bedrock zone in ~63 years. Groundwater monitoring in the transition zone and bedrock zone following NCDENR Division of Water Quality policy (detailed in Section 6.2.2) would be used to confirm the continued decrease in toxicity, mobility, and volume in groundwater contaminants. Because no treatment technologies would be employed, no treatment residuals would be generated.

7.3.2.5 *Short-Term Effectiveness*

Risks, or potential risks, would not be reduced in the short-term by this alternative. MNA would have no short-term effectiveness as a stand-alone remedial alternative. Short-term impacts would be minimal. Impacts to the environment or community would not be expected to occur from implementation of this action. According to the modeling results, it would take approximately 47 years for the CVOC plumes to meet NCAC 2L standards in the transition zone and approximately 63 years for the CVOC plumes to meet NCAL 2L standards.

Workers and the community would have limited exposure to contaminated groundwater during the groundwater sampling activities resulting in the potential for few short-term risks. Health and safety controls in accordance with Occupational

Safety and Health Act (OSHA) requirements would be implemented to mitigate, prevent, and limit potential exposure of workers during these activities.

7.3.2.6 *Implementability*

MNA is readily implementable because no active remedial actions would be taken that would require any construction. Materials, equipment, and labor for groundwater sampling are readily available. Some uncertainty is associated with the modeling of the potential for natural attenuation and contaminant fate and transport. As discussed previously, site conditions are conducive to reductive dechlorination; therefore, the biological degradation is active.

It is also believed that limiting the use of the groundwater for drinking water and irrigation use over a long period of time (e.g., 63 years) is implementable. Groundwater monitoring and subsequent reporting are easily feasible.

7.3.2.7 *Cost*

There is low capital cost as there will be the need for installing only nine additional monitoring wells (four in the transition zone and five in the bedrock zone). For the transition zone, O&M costs would include quarterly, semiannual, and annual sampling, followed by confirmatory sampling at the rate defined in NCDENR Division of Water Quality policy (see Section 6.2.2) at all monitoring wells (total of ~47 years). Samples would be analyzed and validated. O&M costs would also include quarterly, semiannual, and annual reports, 5-year reviews, a confirmation report, and monitoring well abandonment.

For the bedrock zone, O&M costs would include the same monitoring schedule as the transition zone; however, monitoring would continue over a longer period of time (~63 years). Samples would be analyzed and validated. O&M costs would also include quarterly, semiannual, and annual reports, 5-year reviews, a confirmation report, and monitoring well abandonment.

The capital costs for Alternative 2 would be approximately $336,195 and the O&M cost would be $6,227,047. The total cost for Alternative 2 would be approximately $6,563,242. Detailed costs for this alternative are presented in Appendix E.

7.3.3 *Alternative 3 – "Enhanced Bioremediation Using Sodium Lactate Injection"*

7.3.3.1 *Overall Protection of Human Health and the Environment*

Treatment of the source areas by the injection of sodium lactate into both the transition and bedrock zones will reduce the concentrations of CVOCs and daughter products in groundwater to below 500 µg/L and subsequent MNA will reduce the concentration to below the NCAC 2L standards. This in-situ alternative would be protective of human health and the environment. The risks from the high concentrations of CVOCs would be reduced by enhanced bioremediation and through natural attenuation. The CVOC plumes in the transition zone groundwater would be treated to below remedial levels in approximately 14 years after the completion of the sodium lactate injection; whereas, the CVOC plumes in the bedrock zone groundwater would be treated to below remedial levels in approximately 12 years after completion of the sodium lactate injection. Upon completion of the treatment, risks to human health and the environment would be eliminated from this area because the contaminants in groundwater would have been degraded to non-chlorinated and non-hazardous constituents. Upon achieving remedial levels, contaminants would no longer be present in groundwater; therefore, the alternative would have long-term effectiveness.

The remedial levels would be achieved in 14 years in the transition zone and 12 years in the bedrock zone from the start of the sodium lactate injection system. The establishment of institutional controls similar to those in Alternative 2 would prevent exposure to groundwater during the performance of this alternative. Engineering controls established during the installation of the injection system and additional monitoring wells would mitigate any potential exposures to humans and the environment.

7.3.4 *Compliance with Applicable or Relevant and Appropriate Requirements*

The applicable chemical-specific ARARs for this alternative are discussed in Chapter 3.0. These federally enforceable standards would be protective of a potential future resident who could be exposed to the COCs through the ingestion pathway. Legal controls implemented under this alternative would prevent future ingestion of contaminated drinking water, and long-term monitoring would demonstrate when the aquifer was restored to NCAC 2L unrestricted potable use standards. This alternative would meet the intent of chemical-specific ARARs requirements in that sodium lactate injections would result in a reduction of concentrations of contaminants.

On-site activities that would be implemented under this alternative would trigger other action-specific ARARs. This alternative would include injection of sodium lactate treatment solutions into the groundwater. Subsurface emplacement of liquids is regulated by federal and state underground injection control (UIC) programs (see Chapter 3.0). Substantive provisions of the UIC regulations that are applicable to remedial actions involving injection of fluids include requirements for well construction, design of the well casing, well operation, and monitoring. UIC administrative requirements such as permits, inventory records, and reporting requirements would not be applicable to on-site injection wells; however, full administrative requirements would apply to any injection wells on the easement. Because spent TCE from the site is a RCRA F001 listed waste, ARARs would include management of any TCE-contaminated soil from drilling activities as RCRA hazardous (in accordance with the RCRA "contained-in" policy) until the results of TCLP analyses were received. With the concurrence of the state regulatory agency, any TCE-contaminated soil or any well development or purge water from monitoring that did not fail the TCLP for TCE would be determined to no longer contain an F001 waste (i.e., a RCRA "contained-in" determination). Administrative, as well as substantive, RCRA Subpart C requirements would apply to any hazardous waste transported off-site for disposal. In the unlikely event of off-site volatile organic or particulate emissions resulting from remediation activities, such emissions would be subject to the substantive requirements of North Carolina air emissions standards. It is expected that all action-specific ARARs would be attained under this alternative. Implementation of this alternative would be in compliance with ARARs.

7.3.4.1 *Long-Term Effectiveness and Permanence*

This alternative would provide long-term effectiveness and permanence. CVOCs in groundwater would be biologically degraded to ethane or ethene under reductive dechlorination conditions within 14 years in the transition zone and 12 years in the bedrock zone of the sodium lactate injection. Monitoring following NCDENR Division of Water Quality policy (see Section 6.2.2) would confirm that contaminants have been degraded and that no rebound effect has occurred in the aquifer. However, additional injection events might be necessary if a rebound is occurring.

7.3.4.2 *Reduction of Toxicity, Mobility, or Volume through Treatment*

This alternative would meet the statutory preference for employing treatment technology. This treatment alternative would effectively reduce the toxicity and volume of the CVOCs in groundwater to below remedial levels in a relatively reasonable period of time (~14 years from the time of injection for the transition zone and ~12 years from the time of injection in the bedrock). The toxicity and volume of the contaminants would gradually be decreased through biological degradation under reductive dechlorination conditions in ~14 years for the transition zone and ~12 years for the bedrock zone. TCE and *cis*-1,2-DCE would be biologically degraded to ethane or ethene. Although mobility of the contaminants would not be reduced through this alternative, modeling has indicated that the contaminants are not expected to migrate any significant distance beyond their current locations.

7.3.4.3 *Short-Term Effectiveness*

A sodium lactate injection program was conducted as a pilot study for enhancing reductive dechlorination in the groundwater from October 2003 to June 2004. The results of the pilot study indicated that a single injection of sodium lactate was able to transform the transition zone and the bedrock zone groundwater within the radius of influence from a mildly reducing condition to a strongly reducing environment with significant decreases in TCE and PCE (Chapter 5.0). Because the sodium lactate injection alternative is an expansion of the sodium lactate pilot test, exposure of workers and the community to contaminated groundwater during implementation would be minimal. Implementation of health and safety procedures, as required by OSHA, would limit exposure to groundwater during injection of sodium lactate and groundwater monitoring activities. The transition and bedrock zones aquifers would be restored in approximately 14 and 12 years after injection, respectively.

7.3.4.4 *Implementability*

The sodium lactate injection program alternative can be readily implemented. Materials, labor, and equipment are readily available. Also, MNA required for the residual contamination would be readily implementable. Materials, equipment, and labor for groundwater sampling are readily available. Some, uncertainty is associated with the modeling of the potential for natural attenuation and contaminant fate and transport. As discussed previously, the site conditions are conducive to reductive dechlorination; therefore, the biological degradation is active.

7.3.4.5 Cost

This alternative is the continuation of the pilot study sodium lactate injection program; however, additional capital costs for the installation of 85 injection wells (54 in the transition zone and 31 in the bedrock zone) and 9 new monitoring wells (4 in the transition zone and 5 in the bedrock zone) will be needed. The capital cost for the sodium lactate injection system would be approximately, $4,562,346.

O&M costs would include four sodium lactate injection events (conducted over a 6-month period) in the transition zone at the rate of 1.5 gpm for 2 days with 1% sodium lactate solution for 24 hr/day, seven sodium lactate injection events (conducted over a 1-year period) in the bedrock zone at the rate of 6 gpm for 2 days with 1% sodium lactate solution for 24 hr/day, and sampling and reporting the performance of the enhanced bioremediation system.

O&M costs would also include quarterly, semiannual, and annual sampling, followed by confirmatory sampling at the rate defined in NCDENR Division of Water Quality policy (see Section 6.2.2). Samples would be analyzed and validated. Quarterly, semiannual, and annual reports, 5-year reviews, a confirmation report, and monitoring well abandonment are also included in the O&M costs.

The capital costs for Alternative 3 would be approximately $4,555,321 and the O&M costs would be $2,568,755. The total cost for Alternative 3 would be approximately $7,124,076. Detailed costs for this alternative are presented in Appendix E.

7.4 COMPARATIVE EVALUATION OF ALTERNATIVES

This section provides a brief comparative analysis of the alternatives with respect to the assessment criteria. The preferred alternative is identified from this evaluation. The comparative analysis identifies the advantages and disadvantages of the alternatives relative to each other. A summary of the comparative analysis of alternatives for groundwater is presented in Table 7-1. Each of the seven criteria is discussed below.

7.4.1 Overall Protection of Human Health and the Environment

Alternative 1, no action, offers no overall protection of human health and the environment because there would be no reduction in risk to human health or the environment. Under the no action alternative, no institutional controls would be put in place, and no monitoring information would be available to the public that might prevent an off-site resident from installing a well for drinking water or irrigation, thereby potentially exposing the resident to site COCs in groundwater. There would also be no restoration of the aquifer and, thus, no protection of the environment. The remaining alternatives provide varying degrees of overall protection of human health and the environment based primarily on the time to achieve remedial levels and the level of uncertainty associated with the performance of the alternatives. Short-term effectiveness of Alternatives 2 and 3 and its influence on the protection of human health and the environment were deemed equal because engineering controls and implementation of health and safety procedures would be used to mitigate them during the performance of each alternative.

Alternative 2 would provide a greater degree of protection of potential receptors than Alternative 1, but slightly less than that provided by Alternatives 3. As with Alternative 3, institutional controls would be used to reduce potential exposures (ingestion pathway) to off- and on-site groundwater contamination through the life of the alternative, which is expected to be 63 years. The groundwater sampling and reporting program of Alternative 2 would provide a check and confirm that the institutional controls were being maintained; however, because of the extended length of the alternative (63 years), slightly less protection would be provided by this alternative.

Alternatives 3 would provide the highest overall protection of human health and the environment. Groundwater in the highly contaminated area would be actively treated and the risk to human health and the environment would be significantly reduced within ~1 year and completely eliminated within 14 years in the transition zone and 12 years in the bedrock zone. The exposure to groundwater contamination both on- and off-site would be controlled through the use of similar institutional controls as discussed under Alternative 2. However, the life of this alternative (~14 years) is significantly shorter than Alternative 2 (~63 years).

Therefore, the alternatives were ranked in the following order:

- Alternative 1 – (3)
- Alternative 2 – (2)
- Alternative 3 – (1)

7.4.2 *Compliance with Applicable or Relevant and Appropriate Requirements*

The no action alternative will not address contaminants that exceed the NCAC 2L standards. Therefore, the no action alternative does not comply with the primary chemical-specific ARAR for the site.

Alternative 2 is expected to be in compliance with the primary chemical-specific ARARs for the target area within approximately 47 years in the transition zone and 63 years in the bedrock zone. Alternative 3 is an active remedial effort aimed at reducing the high concentrations of TCE and daughter products to 500 μg/L within ~1 year, followed by MNA for the residual contamination to chemical-specific ARAR for the site within another 14 years for the transition zone and 12 years for the bedrock zone. The primary differences in achieving ARARs among Alternatives 2 and 3 are based on the type of the alternative and the time that each alternative would take to achieve the remedial levels.

Therefore, the alternatives were ranked in the following order:

- Alternative 1 – (3)
- Alternative 2 – (2)
- Alternative 3 – (1)

7.4.3 *Long-Term Effectiveness and Permanence*

Alternative 1, no action, would have no long-term effectiveness or permanence because the risk to human health and the environment would not be reduced. Contaminants would remain in the groundwater, and no institutional controls would be implemented to control exposure from the potential use of groundwater for drinking water or irrigation. Long-term effectiveness and permanence would be increased in Alternatives 2 and 3 through the establishment of institutional controls both on- and off-site and a measured reduction in risk with time. Alternative 2 would use passive technologies and institutional controls to reduce the risk over a long time (approximately 63 years). Alternative 3 would have long-term effectiveness and permanence because the risk to human health and the environment would be essentially eliminated by the active treatment and passive treatment of contaminants in groundwater to below remedial levels within 14 years in the transition zone and 12 years in the bedrock zone after injection.

Therefore, the alternatives were ranked in the following order:

- Alternative 1 – (3)
- Alternative 2 – (2)
- Alternative 3 – (1)

7.4.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

None of the alternatives would reduce the mobility of the contaminants in groundwater. Alternative 1, no action, and Alternative 2, MNA, would provide the lowest degree of reduction of toxicity and volume through treatment because no treatment would be implemented. Alternatives 1 and 2 would have essentially the same reduction in toxicity and volume; however, Alternative 2 differs from the no action alternative in that groundwater monitoring would confirm the reduction of toxicity and volume over the long treatment period. Alternative 3 would reduce the toxicity and volume through treatment. This alternative would employ active treatment technology that would reduce the CVOC concentrations within the highly contaminated area in ~1 year and through MNA to below the remedial levels across the site within 14 years.

Therefore, the alternatives were ranked in the following order:

- Alternative 1 – (3)
- Alternative 2 – (2)
- Alternative 3 – (1)

7.4.5 *Short-Term Effectiveness*

Alternative 1, no action, would have a high level of short-term effectiveness because no action would be implemented, so there would be no possibility of exposure of workers, the community, or the environment. Of the remaining alternatives, none would include aspects that would impact short-term effectiveness that standard engineering controls or implementation of health and safety procedures (as required by OSHA) would not mitigate or eliminate during implementation. In addition, groundwater monitoring is part of all the alternatives except no action; therefore, potential exposure to human health and the environment from performance of groundwater monitoring was considered to be equal across the alternatives, so the alternative comparison is based on only potential release to the environment during the physical installation of the alternative. However, Alternative 2 would have the lowest potential for exposure to workers, the community, and the environment because implementation of this alternative would only require installation of 9 additional wells as compared to Alternative 3, which would require installation of 9 additional monitoring wells (4 in the transition zone, 5 in the bedrock zone), along with 85 injection wells (54 in the transition zone and 31 in the bedrock zone).

Therefore, the alternatives were ranked in the following order:

- Alternative 1 – (1)
- Alternative 2 – (2)
- Alternative 3 – (3)

7.4.6 *Implementability*

All the alternatives are implementable, with Alternative 1 having the highest implementability because no action would be taken. Materials, equipment, and labor are available for implementing the remaining alternatives. Alternatives 2 and 3 are proven technologies for the treatment of CVOCs in groundwater; therefore, site-specific conditions as well as implementation of institutional controls required would have the most impact on the implementability of these two alternatives.

The institutional controls for Alternatives 2 and 3 are considered to be equal and implementable. The same level of institutional control (deed restrictions, rights of entry, etc.) would be required for Alternatives 2 and 3; however, the length of time the institutional controls would have to be maintained would vary. Alternative 2, natural attenuation, would require approximately 63 years to reach the remedial levels, while Alternative 3 would be essentially complete in 14 years. Some uncertainty would be associated with the implementation of institutional controls on the property.

The implementation of Alternatives 2 and 3 would require standard construction technology; therefore, their construction implementability, presented in decreasing order, varies based on the level of construction. Alternative 2, natural attenuation, is considered more easily implementable than Alternative 3 because it would require the installation of only 10 monitoring wells and establishment of a groundwater sampling and reporting program; whereas, Alternative 3 would require installation of 85 injection wells along with 10 monitoring wells, and bi-monthly injections for 6 months (for a total of four injections) in the transition zone and 12 months (for a total of seven injections) in the bedrock zone.

Therefore, the alternatives were ranked for implementability in the following order:

- Alternative 1 – (1)
- Alternative 2 – (2)
- Alternative 3 – (3)

7.4.7 *Cost*

Alternative 1 would have no costs because no action would be taken. Alternative 3, enhanced bioremediation using sodium lactate injection with MNA, would have the highest costs at $7,036,490 and Alternative 2, MNA with institutional controls, would have a lower cost of $6,529,520 (see Appendix E).

Based on total costs the alternatives were ranked as follows:

- Alternative 1 – $0 (1)
- Alternative 2 – $6,563,242 (2)
- Alternative 3 – $7,124,076 (3)

8.0 RECOMMENDATIONS

This chapter presents the selection of a remedial alternative based on the results of the Pilot Study presented in Chapter 5.0 and the comparative analysis presented in Chapter 7.0. The selected alternative for groundwater is Alternative 3, "Enhanced Bioremediation Using Sodium Lactate Injection." This alternative was selected because this remedial technology was proven to be effective in promoting biodegradation and reducing the CVOC contamination present in the aquifer at the Former NAD Site. This alternative was also selected because it would achieve the RG levels in a reasonable amount of time and provide the highest overall protection of human health and the environment.

Alternative 3 will use a combination of enhanced bioremediation (sodium lactate injection) and MNA to reduce the concentration of the contamination to below the NCAC 2L standards. With this alternative, groundwater in the highly contaminated areas would be actively treated and the risk to human health and the environment would be significantly reduced within approximately 1 year. Modeling estimated that the CVOC plume in the transition zone groundwater would attenuate to below remedial levels in approximately 14 years after the completion of the sodium lactate injection, whereas the CVOC plume in the bedrock zone groundwater would attenuate to below remedial levels in approximately 12 years after completion of the sodium lactate injection. Contamination levels would be monitored to ensure natural attenuation of contamination to below the remedial levels.

This in-situ alternative would be protective of human health and the environment, and upon completion of this alternative, risks to human health and the environment would be eliminated. The cost to implement Alternative 3 would be higher than the other alternatives as the treatment technology would require the installation of injection wells along with bi-monthly injections of sodium lactate for a 1-year period. This alternative would cost $7.12M but through the injection of the sodium lactate, the RG would be reached in substantially less amount of time than Alternatives 1 and 2.

9.0 REFERENCES

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FIGURES

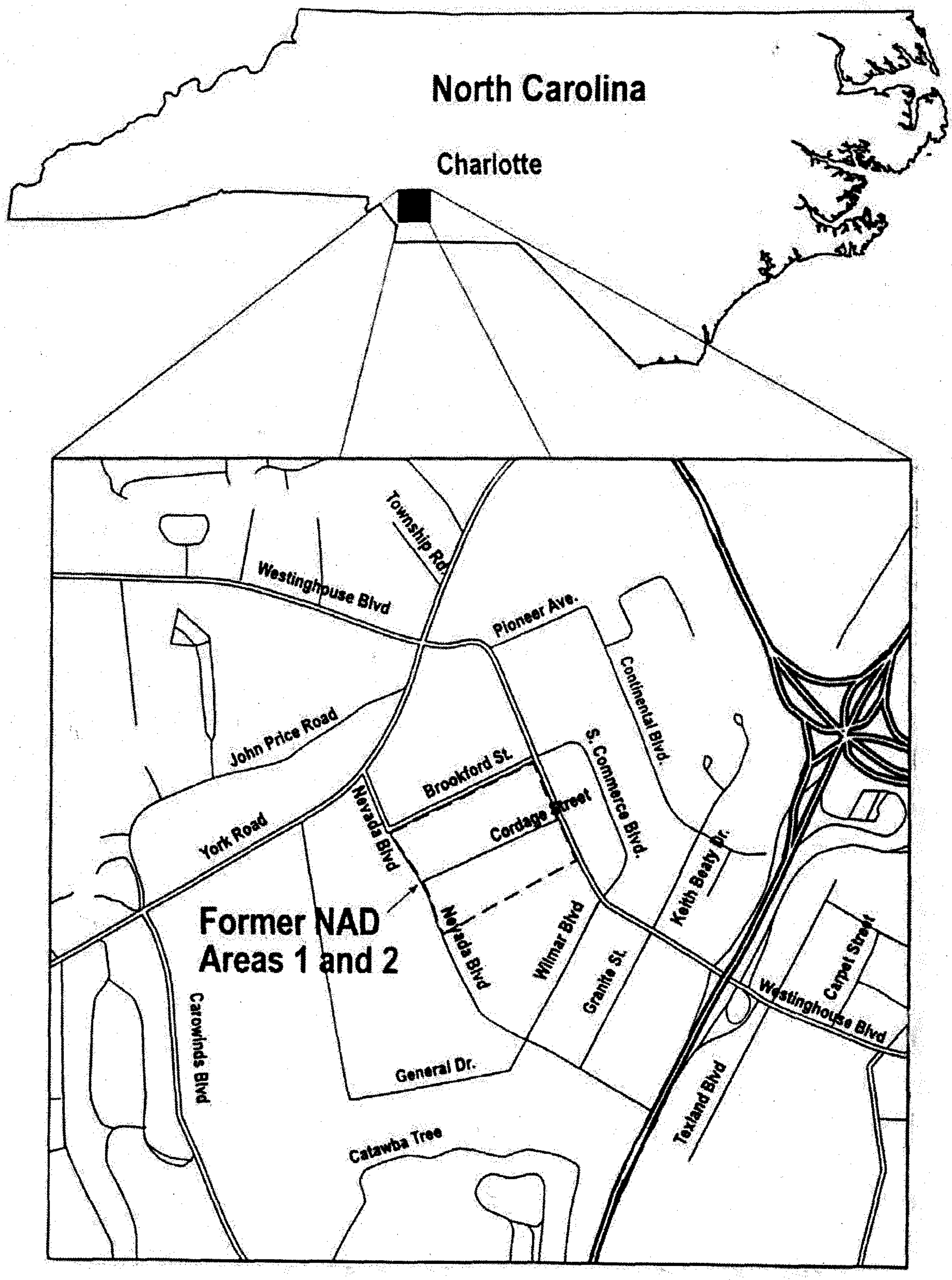


Figure 1-1. Area Location Map for the Former NAD Site, Charlotte, North Carolina

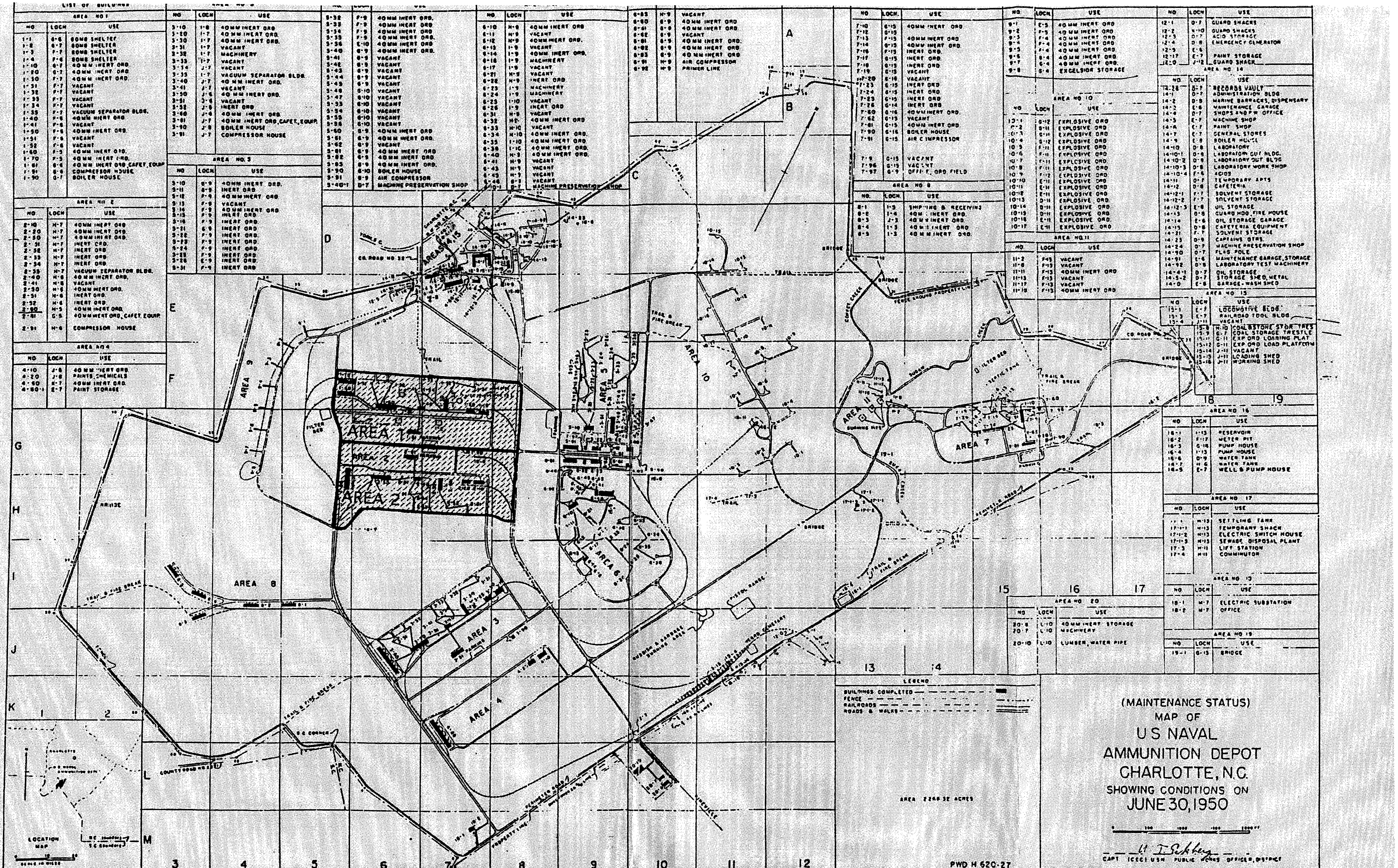


Figure 1-2. U. S. Naval Ammunition Depot Complex, June 30, 1950

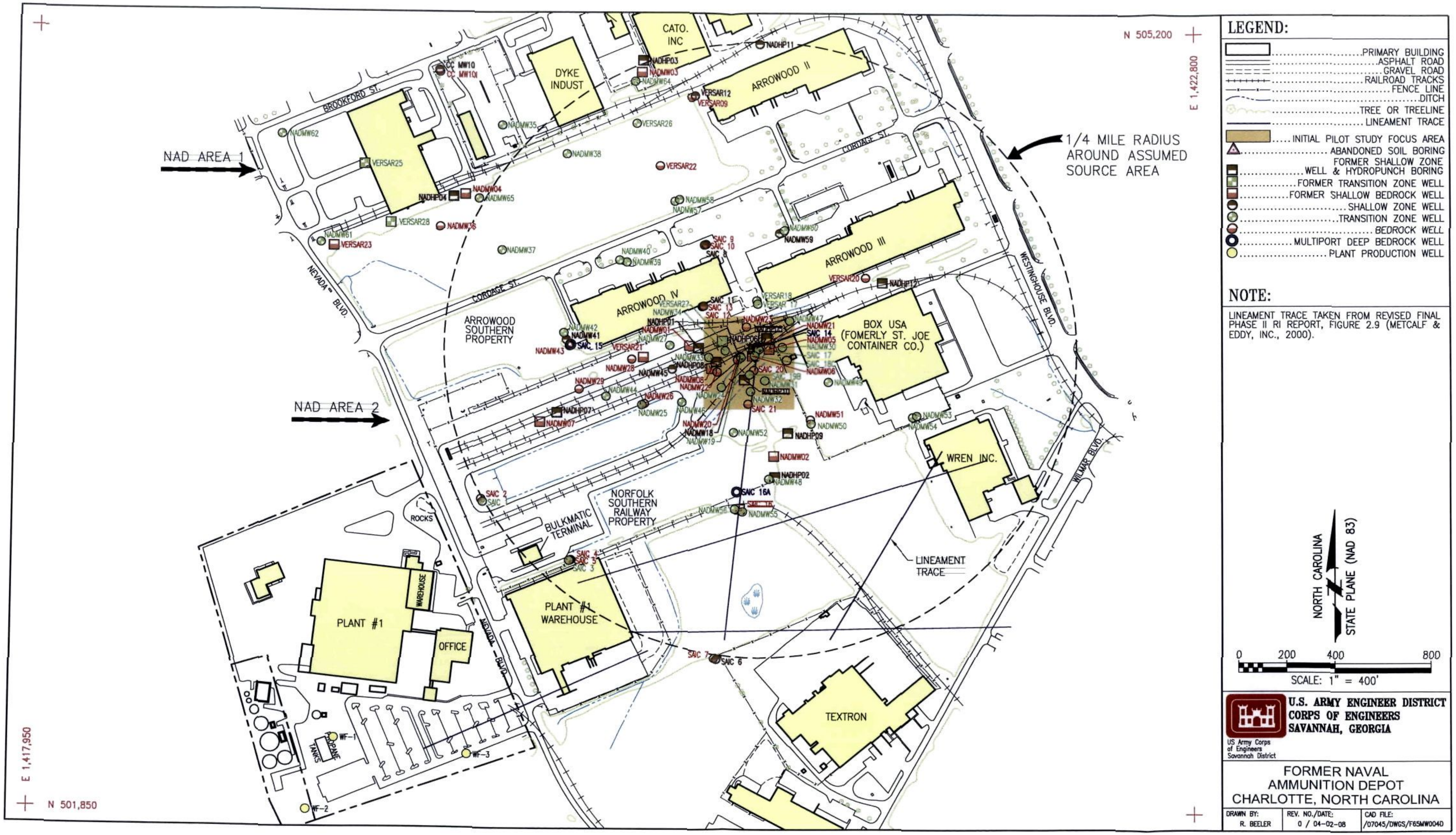


Fig. 1-3. Site Map of the Former NAD Site, Charlotte, North Carolina

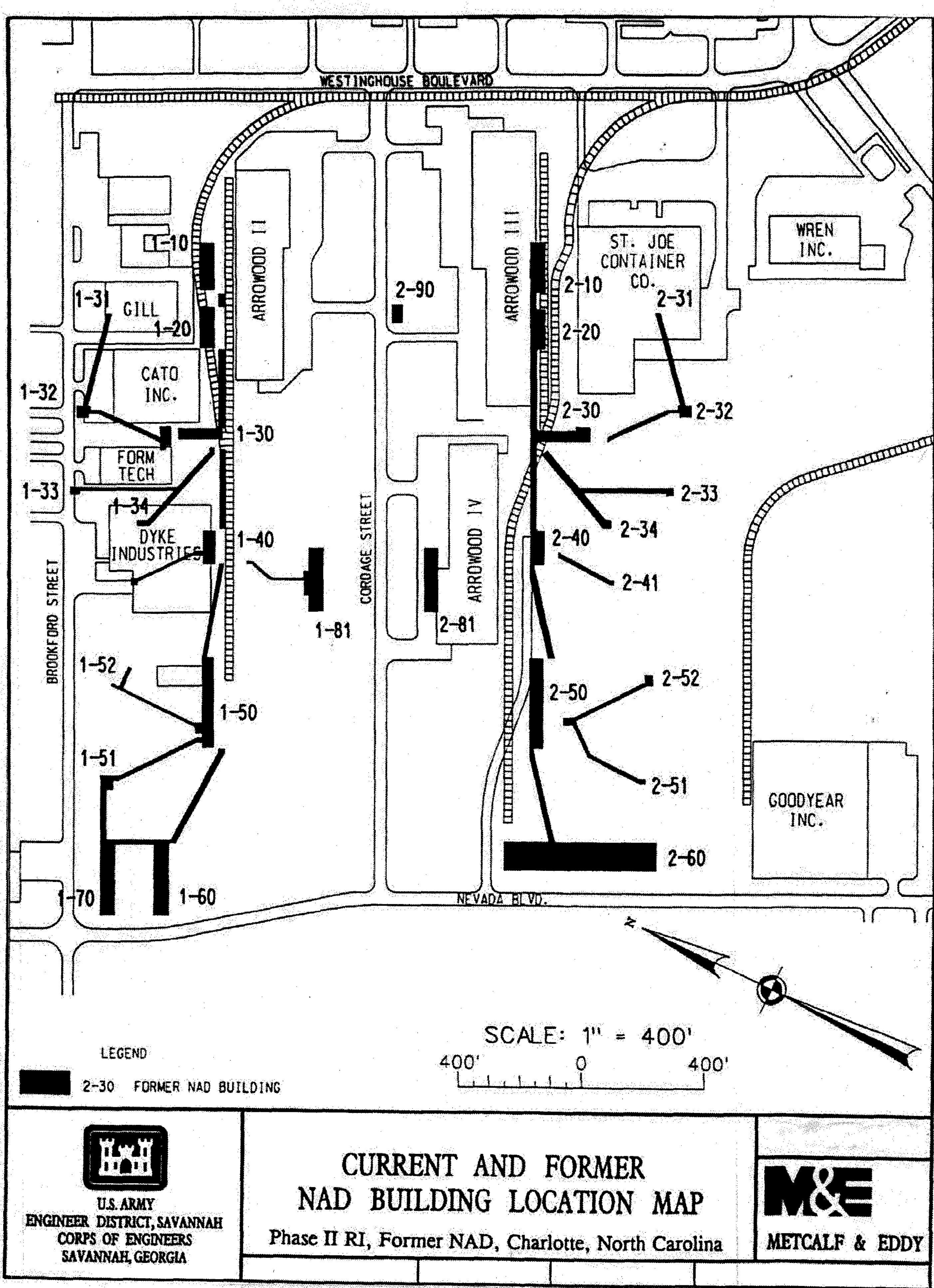
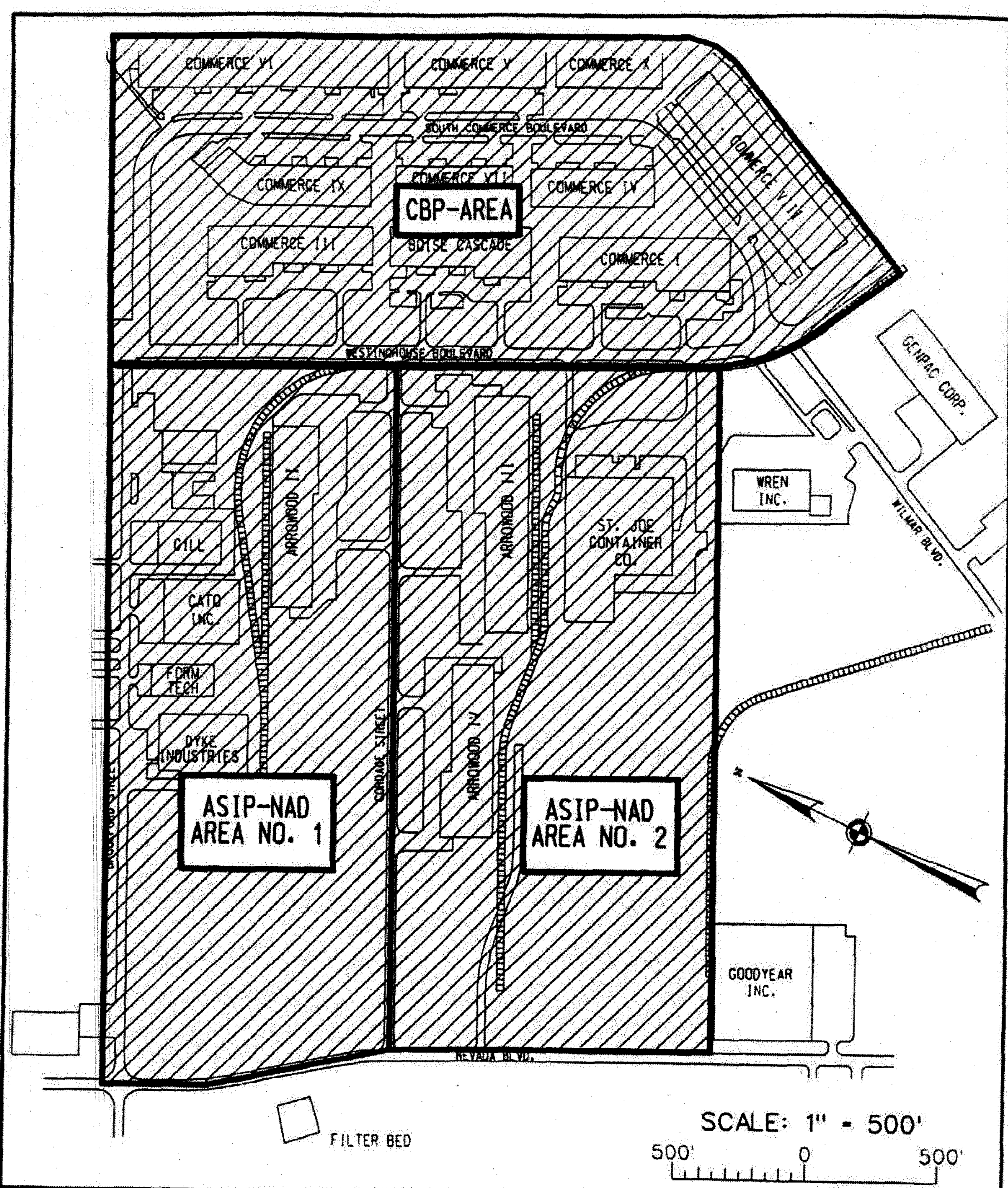


Figure 1-4. Current and Former NAD Buildings Location Map
(Source: Phase II RI, M&E 2000)



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U.S. ARMY
ENGINEER DISTRICT, SAVANNAH
CORPS OF ENGINEERS
SAVANNAH, GEORGIA

SITE MAP
INVESTIGATION AREAS

M&E
METCALF & EDDY

Figure 1-5. Previous Investigation Areas
(Source: Phase II RI, M&E)

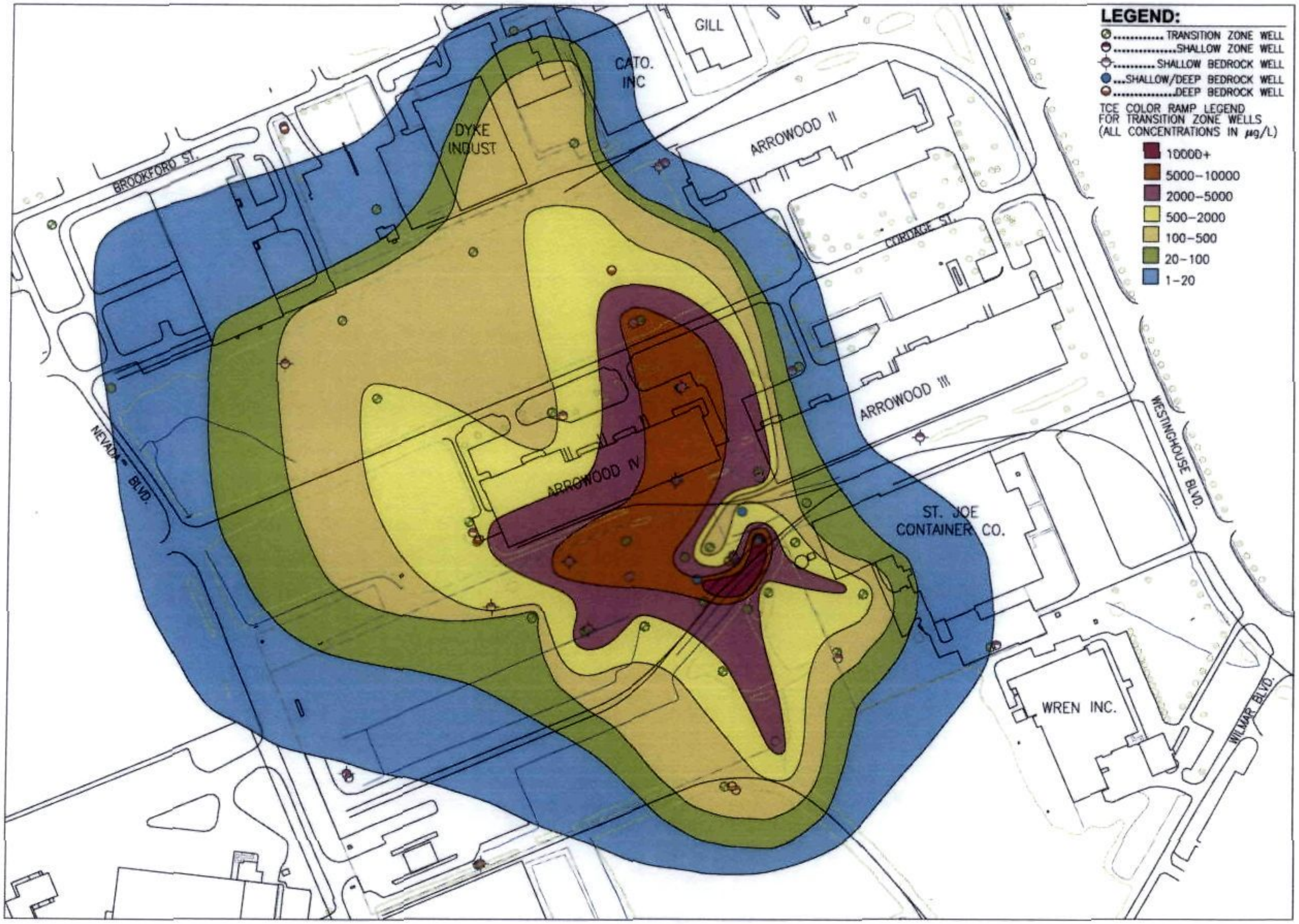


Figure 1-6. Trichloroethene in the Transition Zone Groundwater, June 9, 1999
(Source: Phase II RI, M&E 2000)

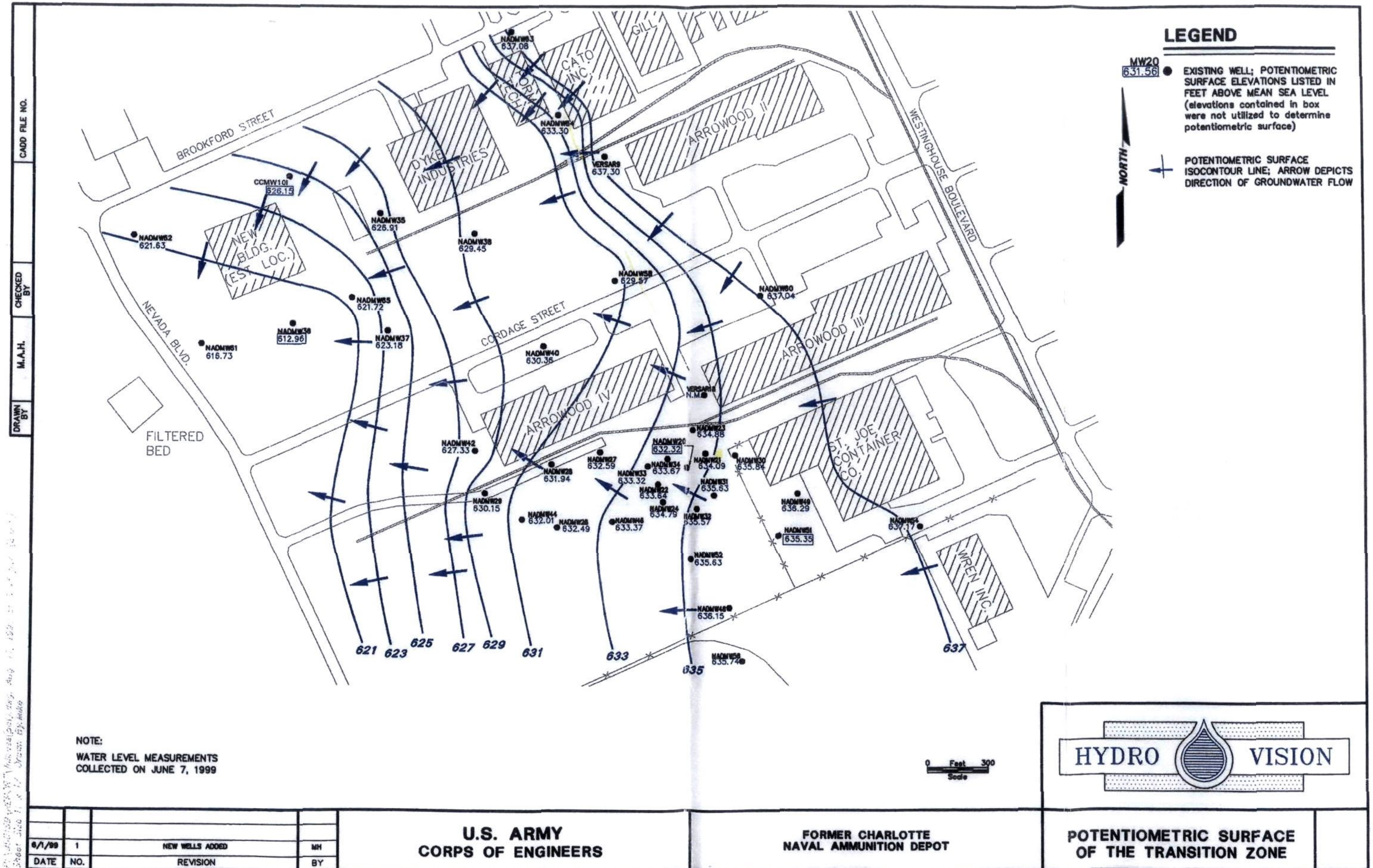


Figure 1-7. Potentiometric Surface of the Transition Zone, June 1999
(Source: Phase II RI, M&E 2000)

Figure 1-8. Potentiometric Surface of the Transition Zone, December 2000

On-Site Deep Boring TCE Concentrations (ug/L)

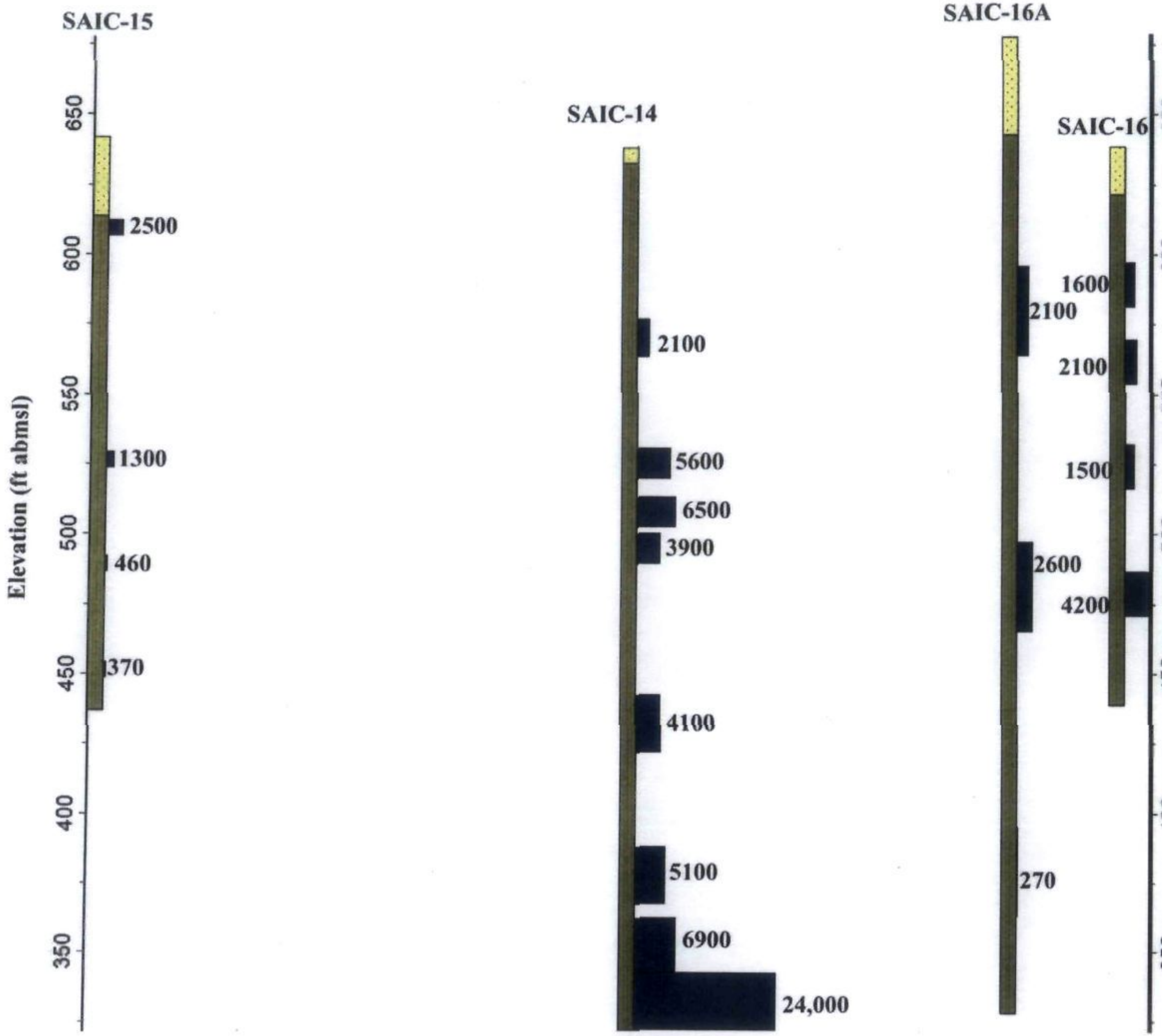


Figure 1-9. TCE Concentrations in SAIC-14, SAIC-15, SAIC-16, and SAIC-16A

Off-Site Production Well TCE Concentrations (ug/L)

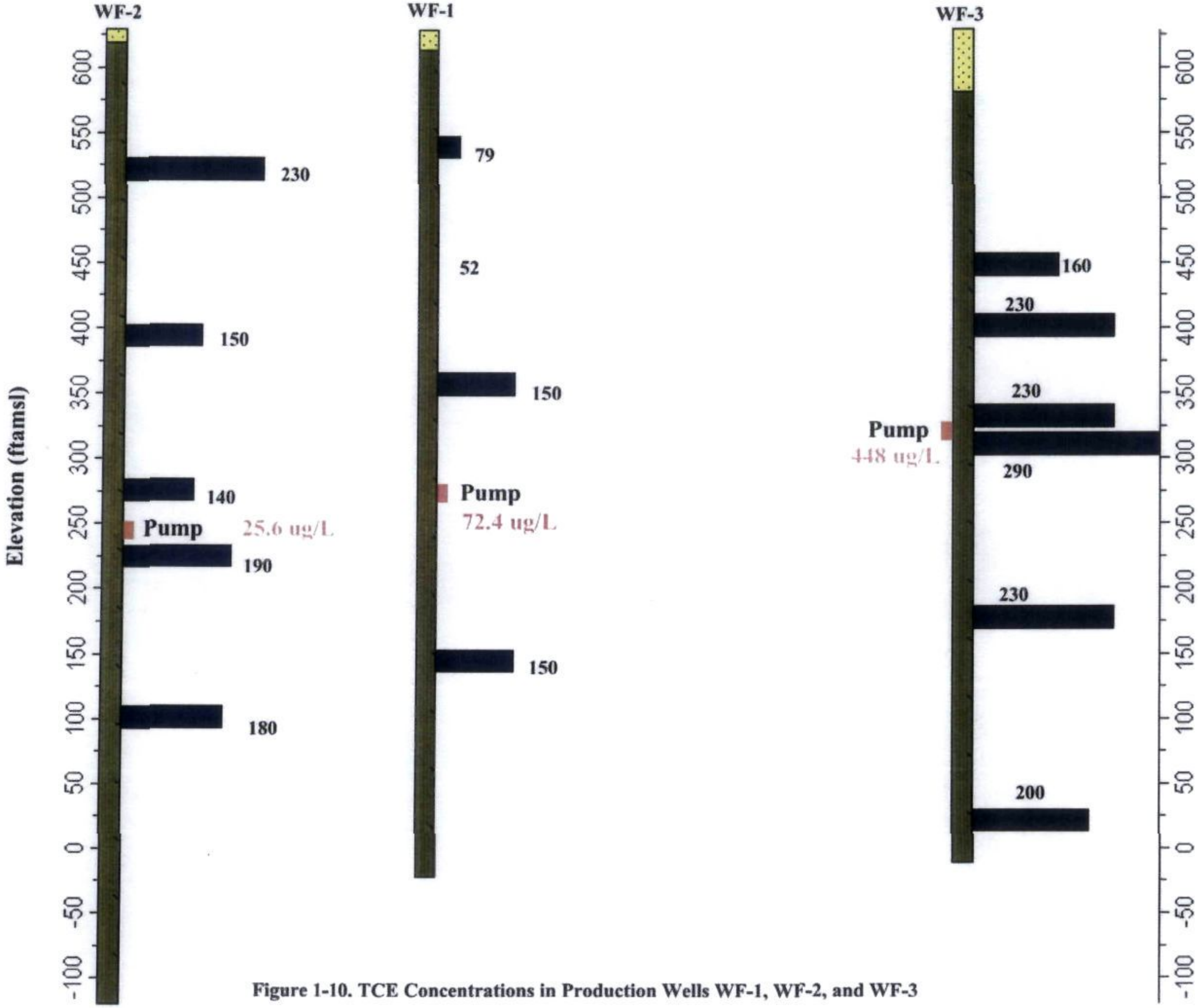
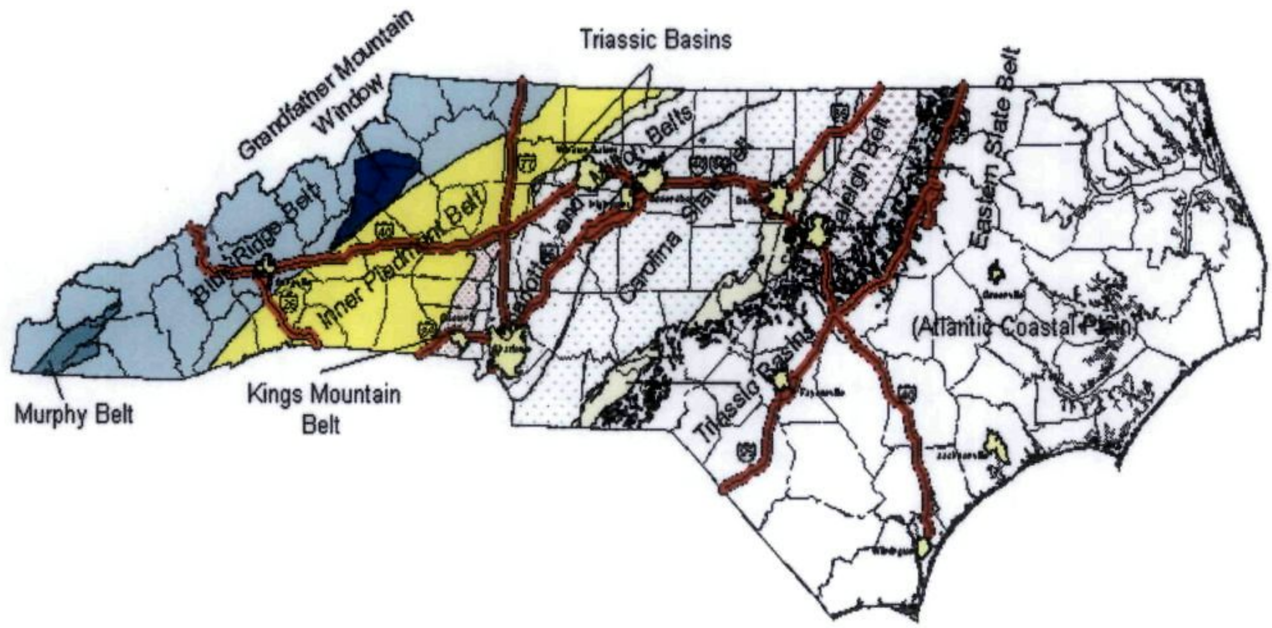


Figure 1-10. TCE Concentrations in Production Wells WF-1, WF-2, and WF-3

Well Sampled on 04/01

Figure 2-1

Map of North Carolina's Geologic Belts and Associated Interstate System



Source: North Carolina Department of Transportation, Geographic Information Systems Geologic History, http://www.ncdot.org/planning/tpb/gis/geology

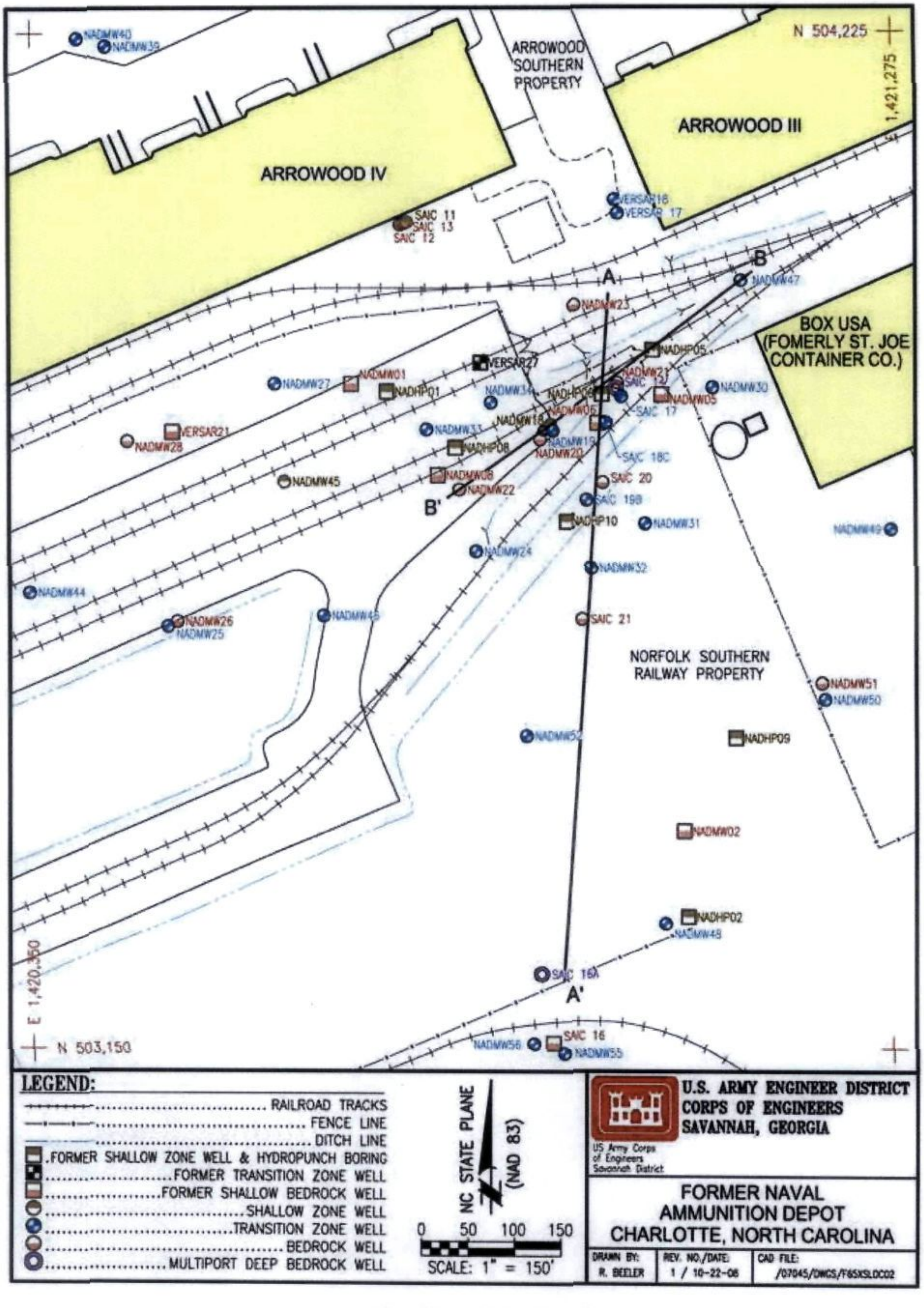


Figure 2-2. Cross Section Location

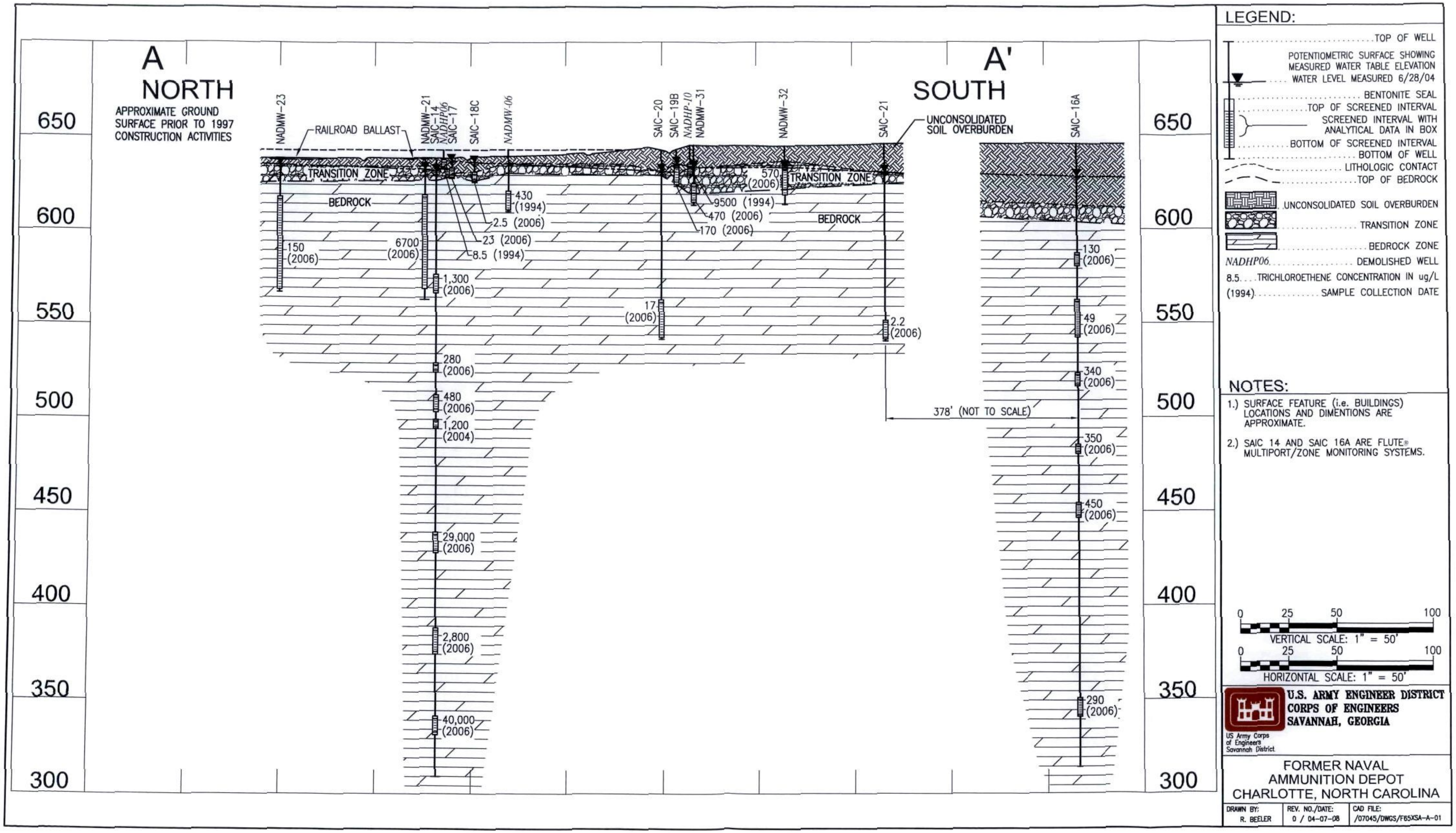


Figure 2-3. Cross-Section A-A'

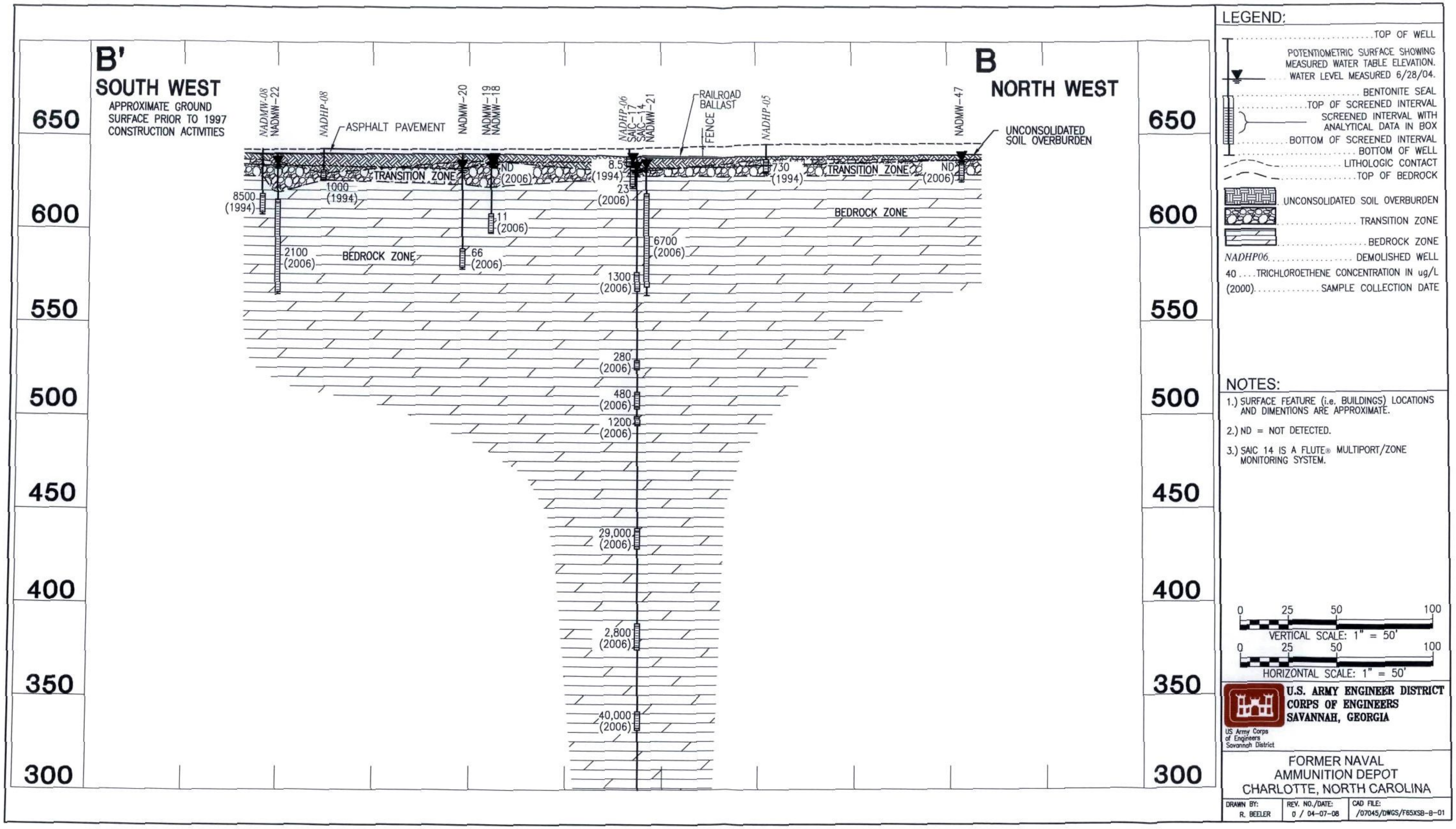


Figure 2-4. Cross-Section B-B'

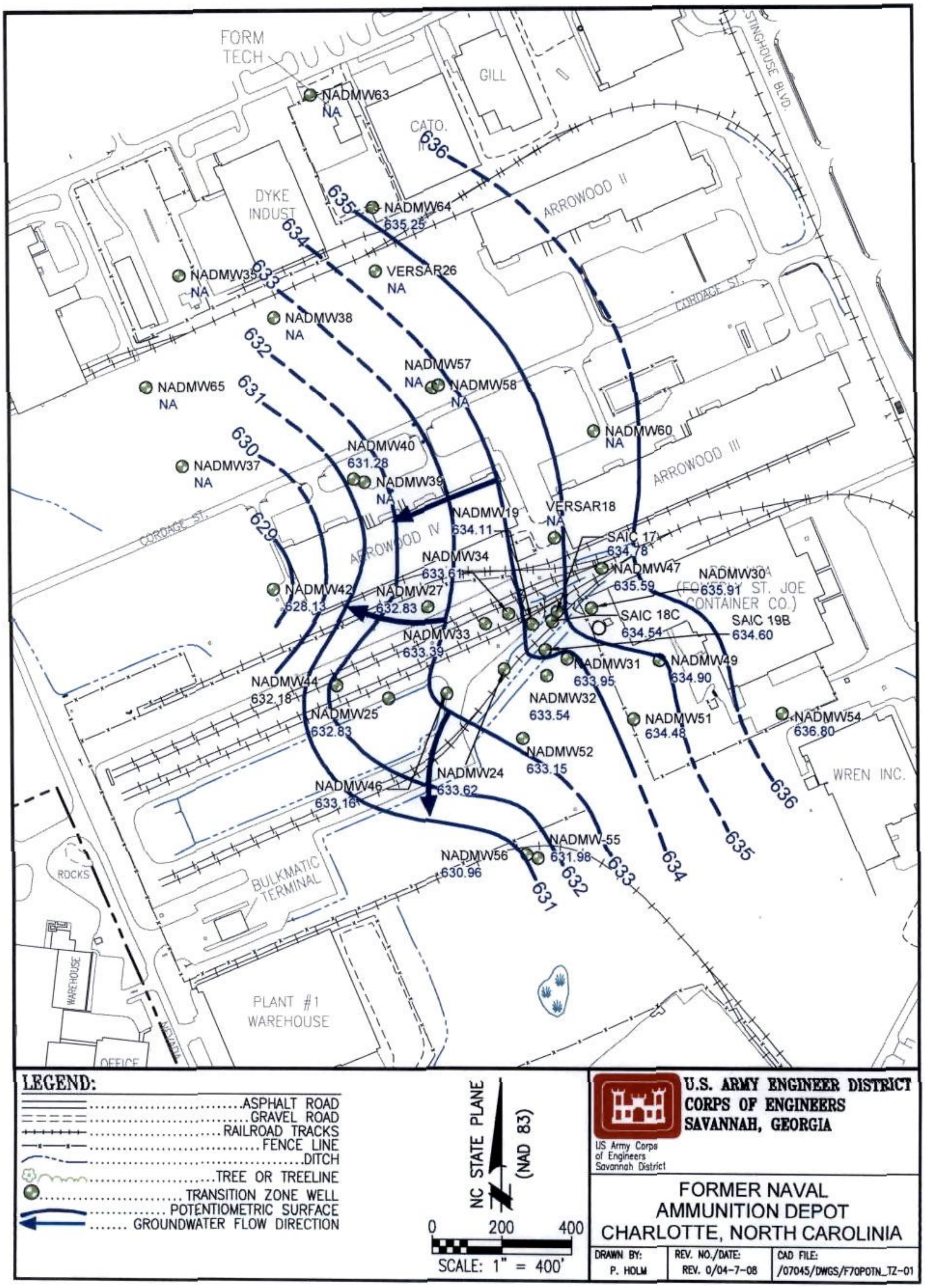


Figure 2-5. Potentiometric Surface in the Transition Zone, September 2006

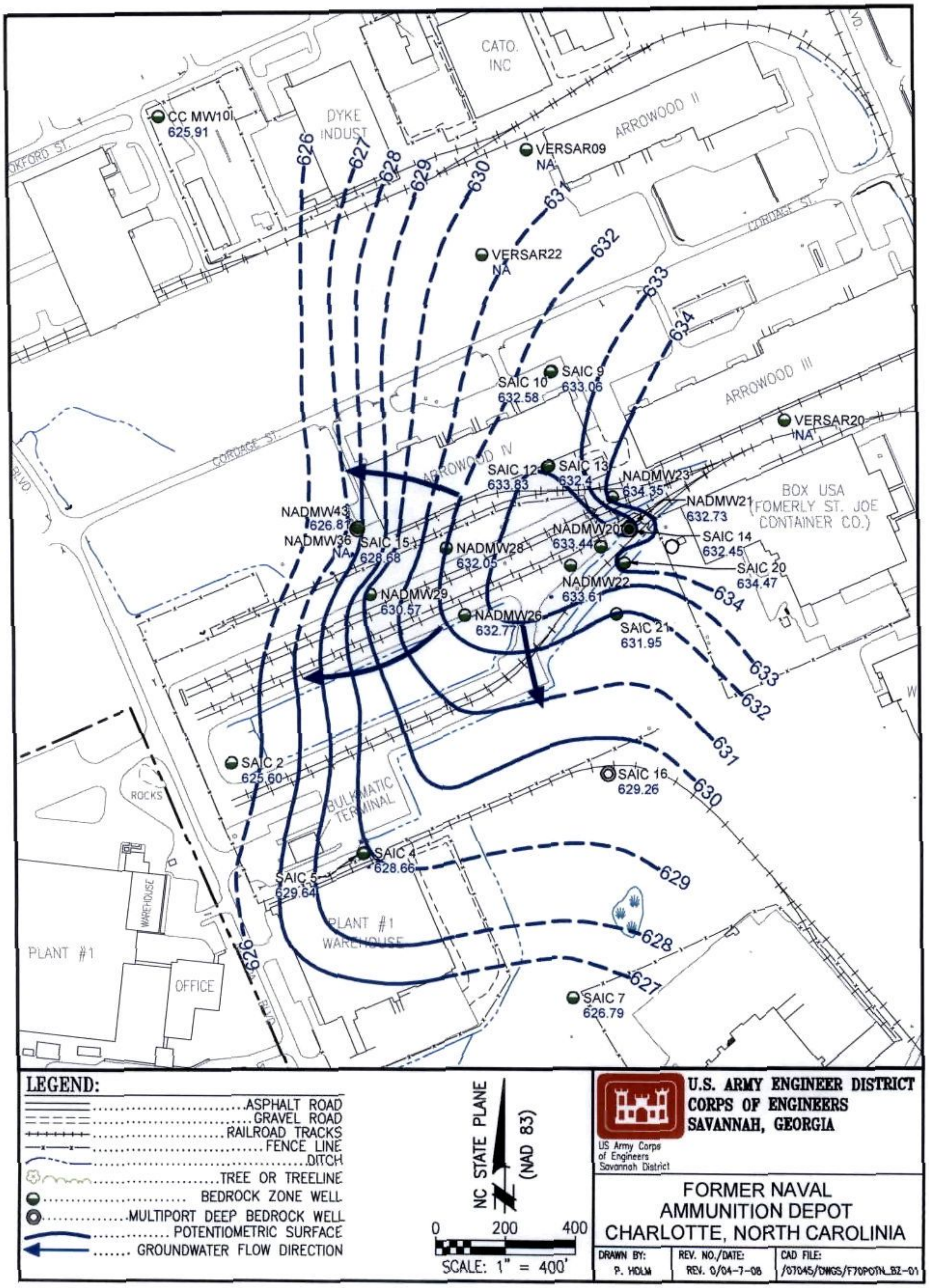


Figure 2-6. Potentiometric Surface in the Bedrock Zone, September 2006

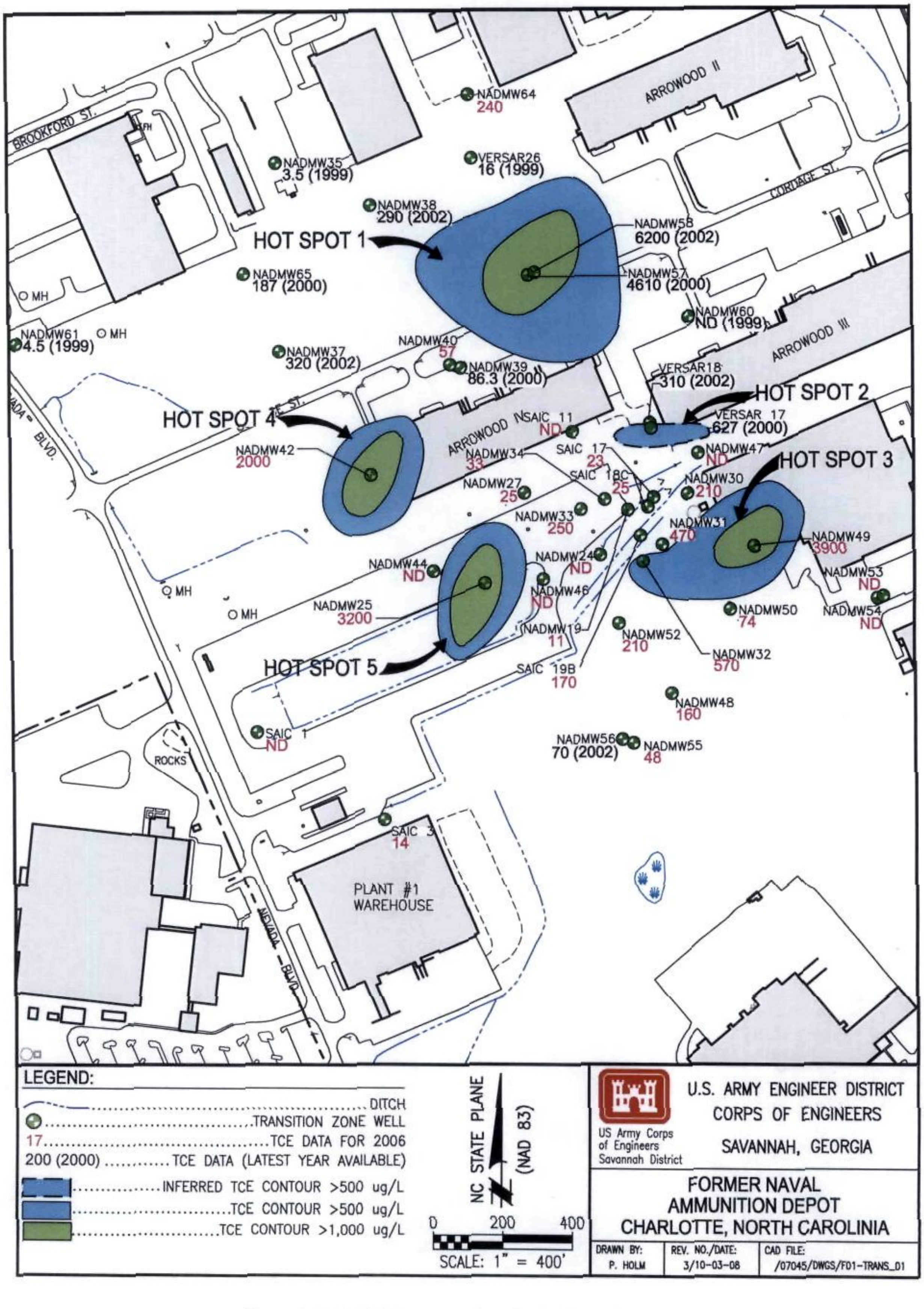


Figure 2-7. TCE Concentrations in the Transition Zone

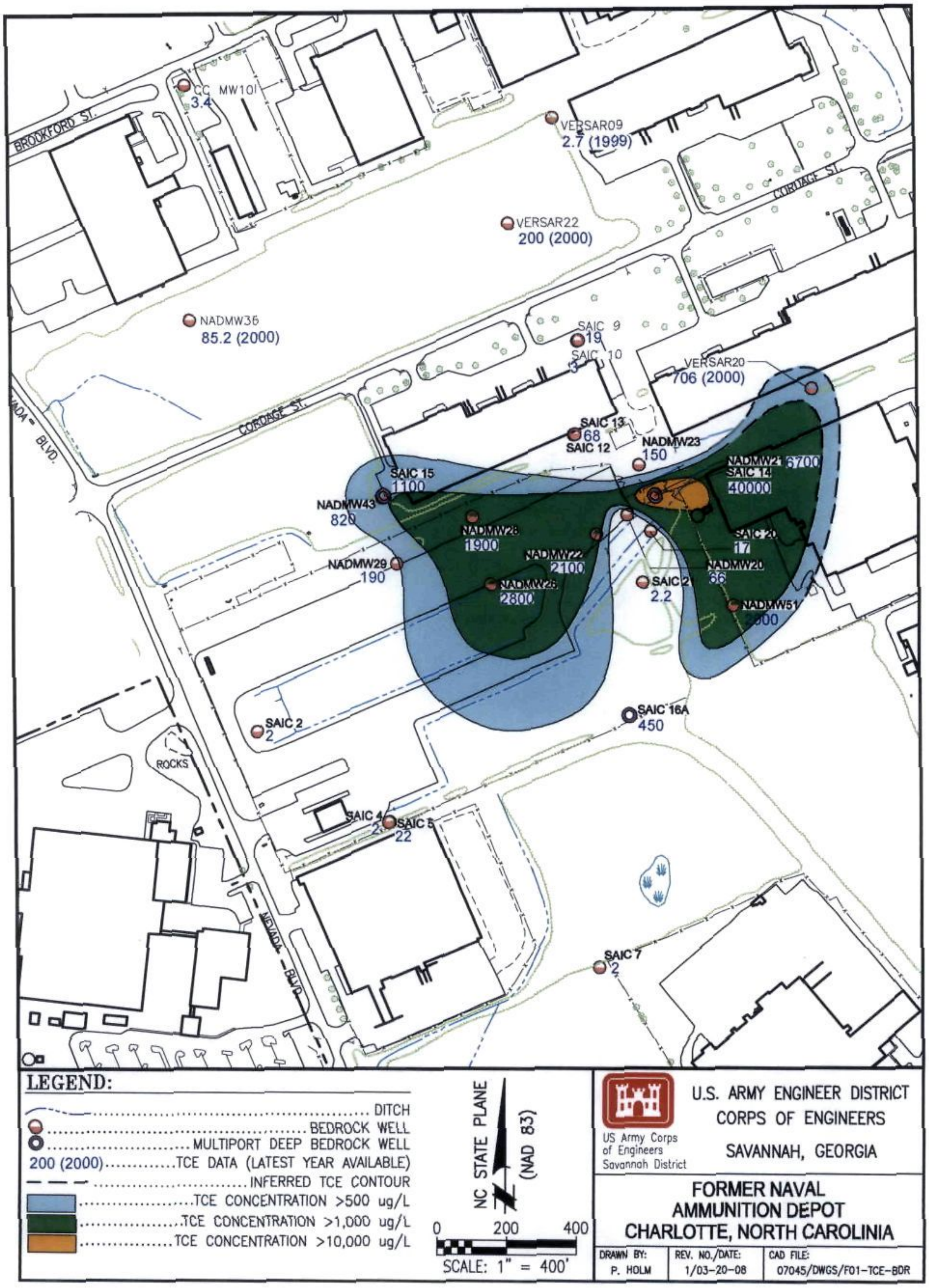


Figure 2-8. TCE Concentrations in the Bedrock Zone

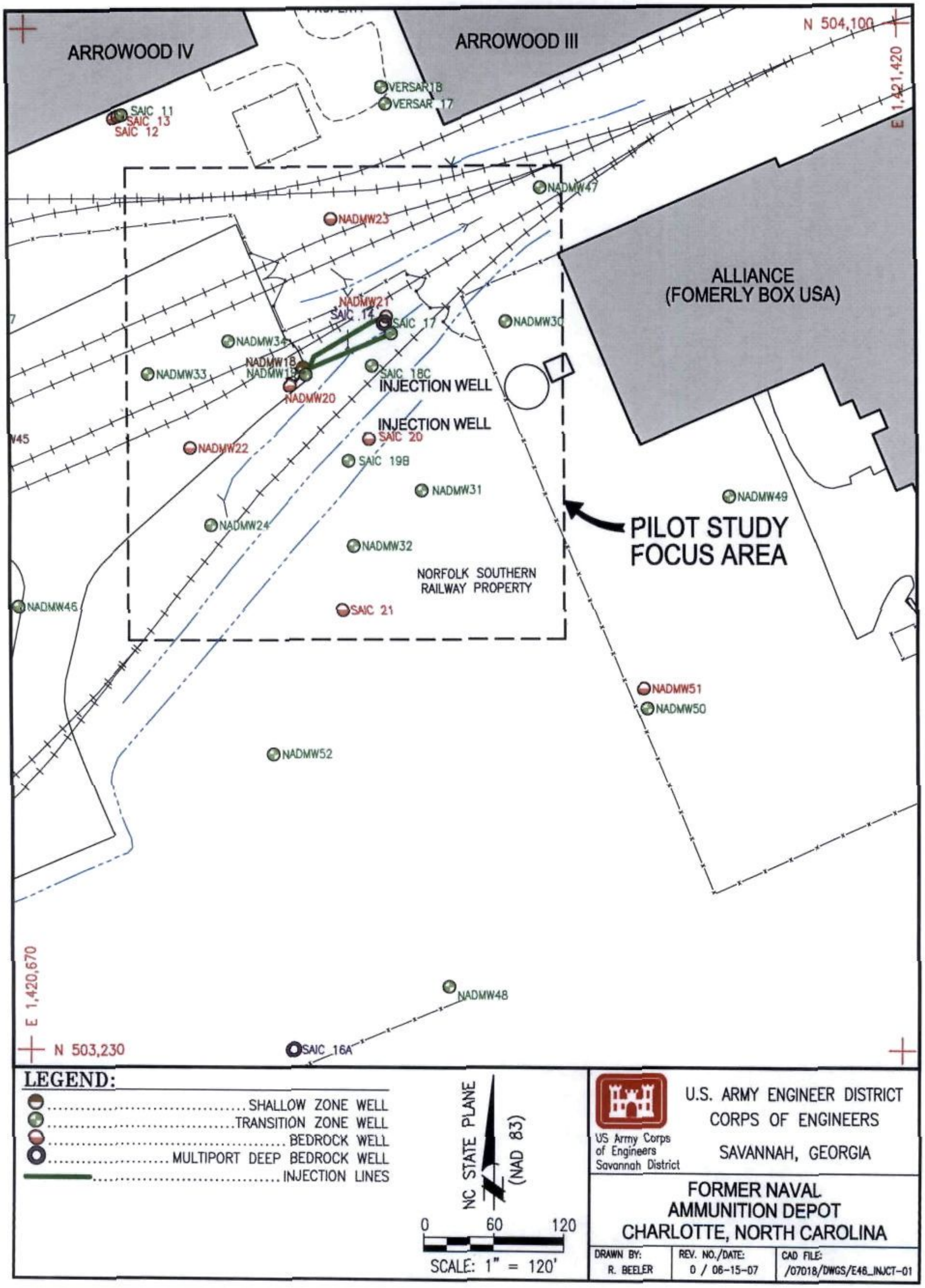


Figure 5-1. Initial Pilot Study Focus Area at the Former NAD Site

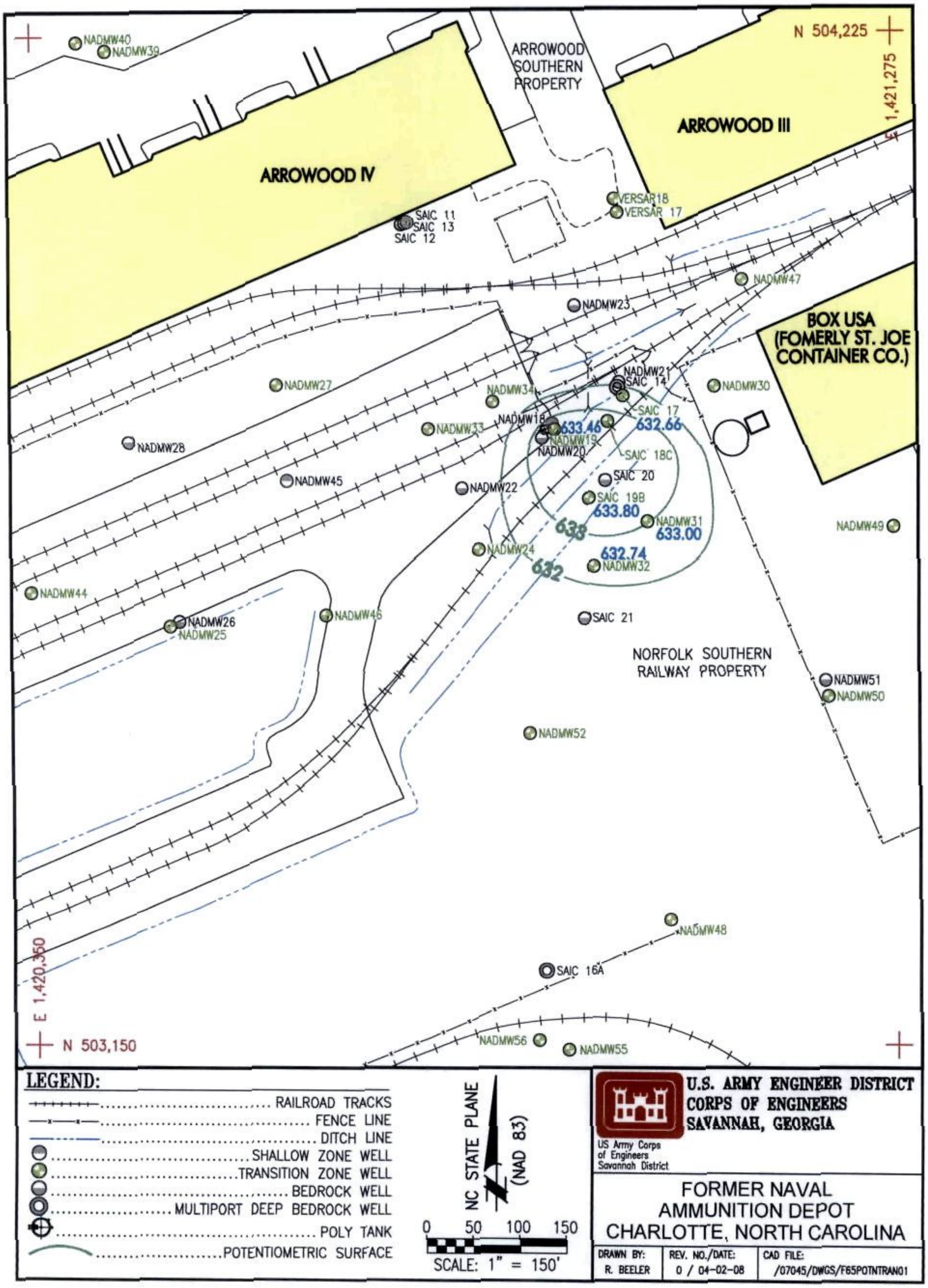


Figure 5-2. Maximum Observed Influence in the Transition Zone During Injection at the Former NAD Site

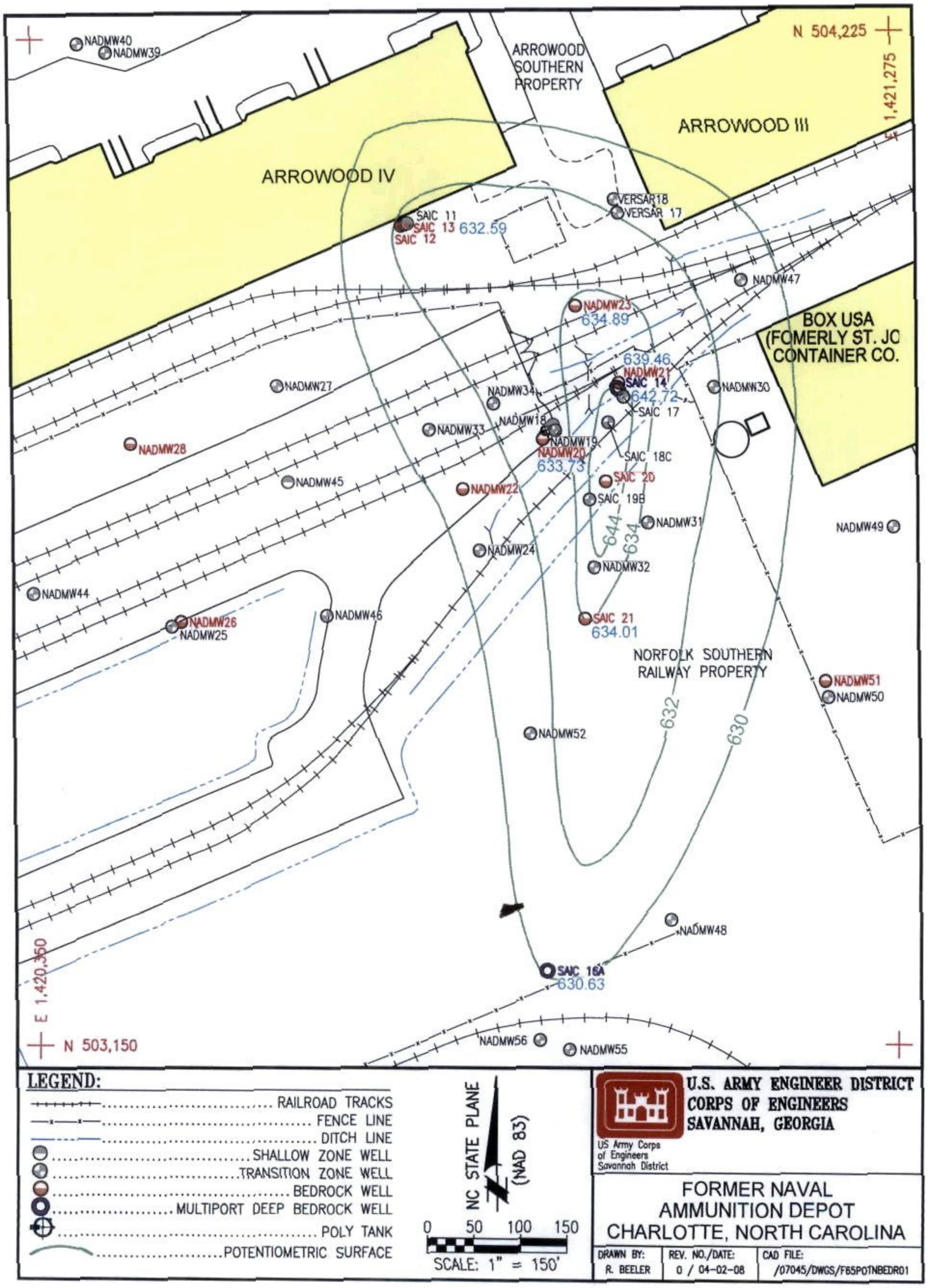


Figure 5-3. Maximum Observed Influence in the Bedrock Zone During Injection at the Former NAD Site

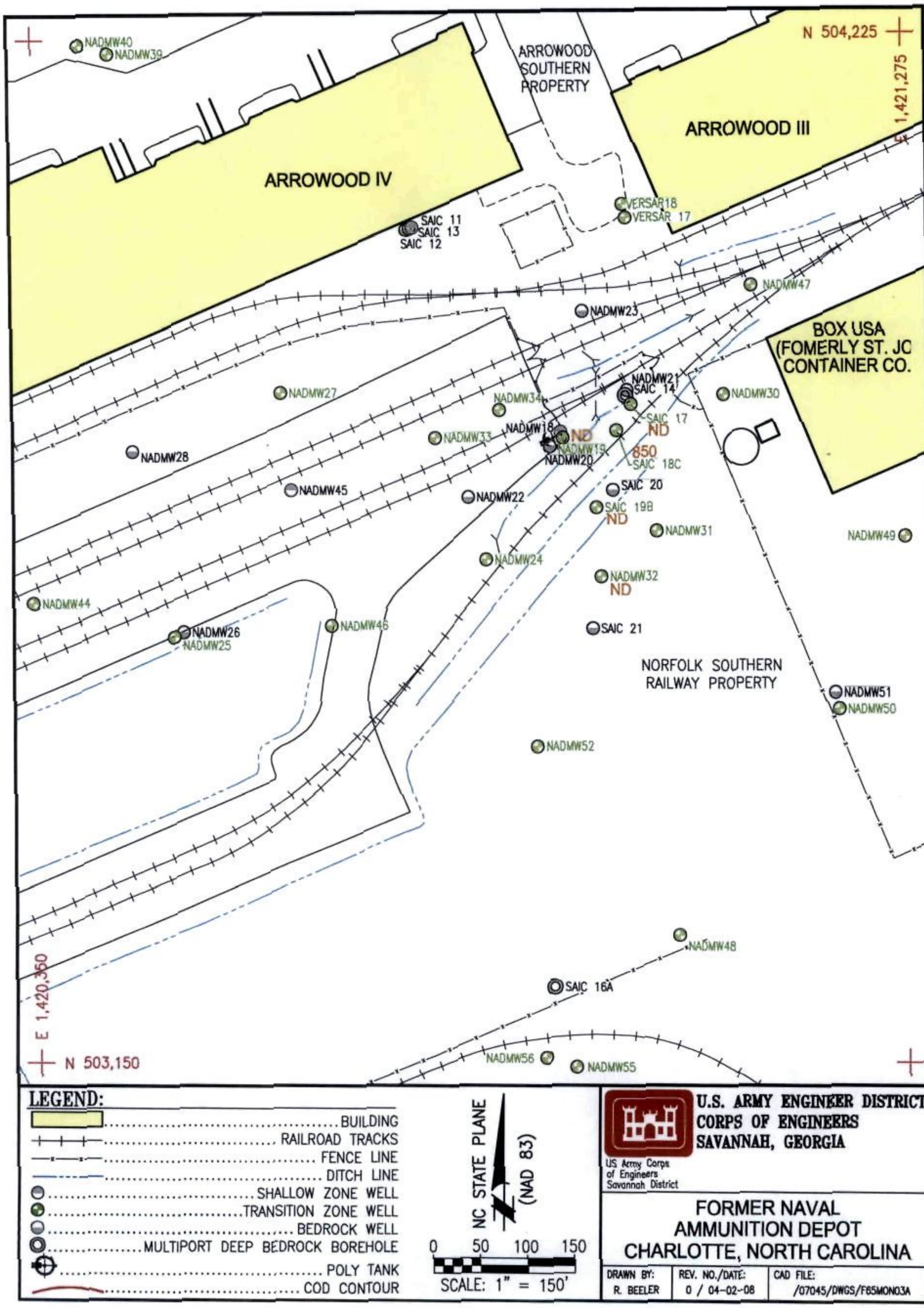


Figure 5-4. Transition Zone COD Isoconcentration Map - Monitoring Event 3, December 10, 2004

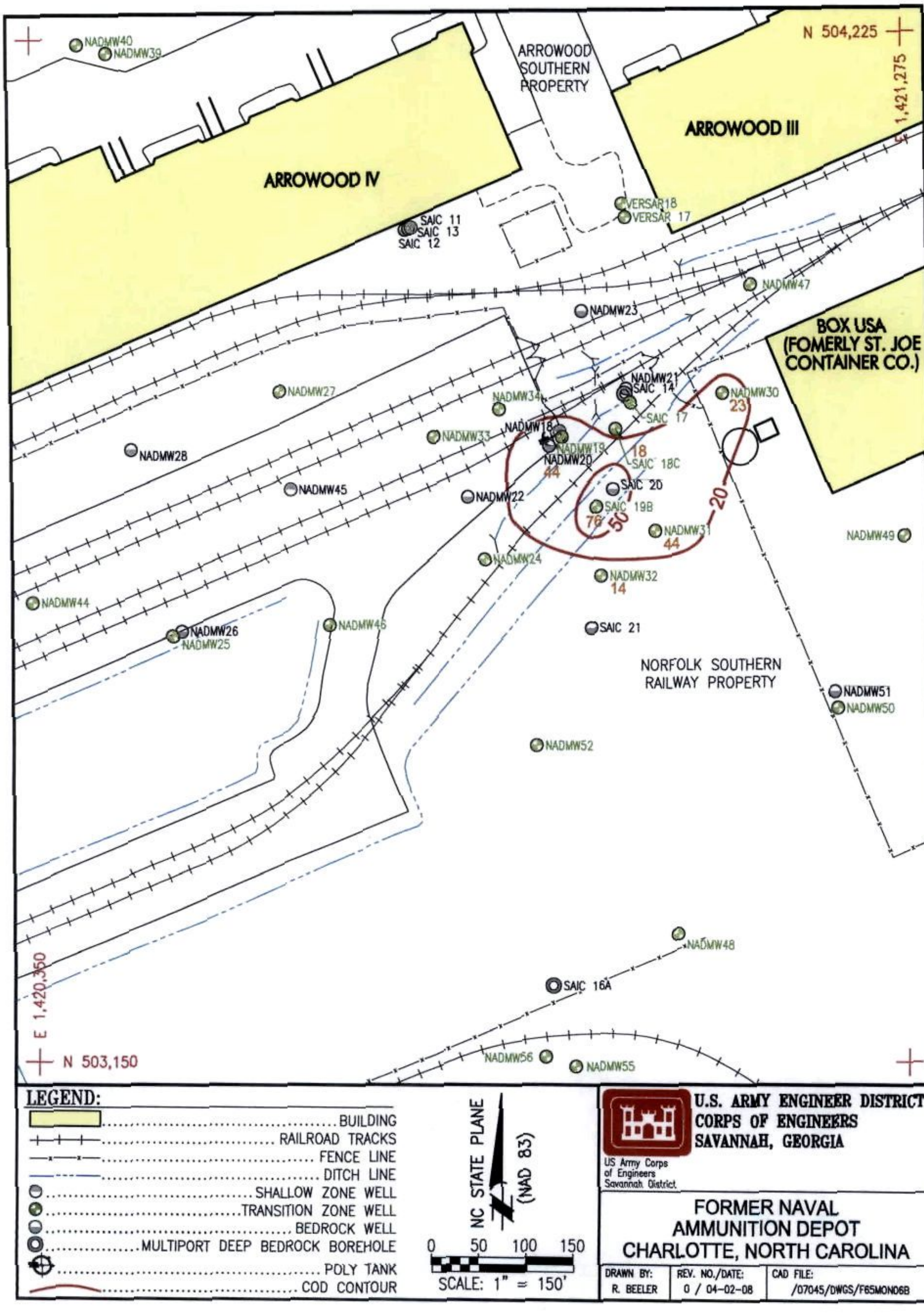


Figure 5-5. Transition Zone COD Isoconcentration Map - Monitoring Event 6, February 20, 2004

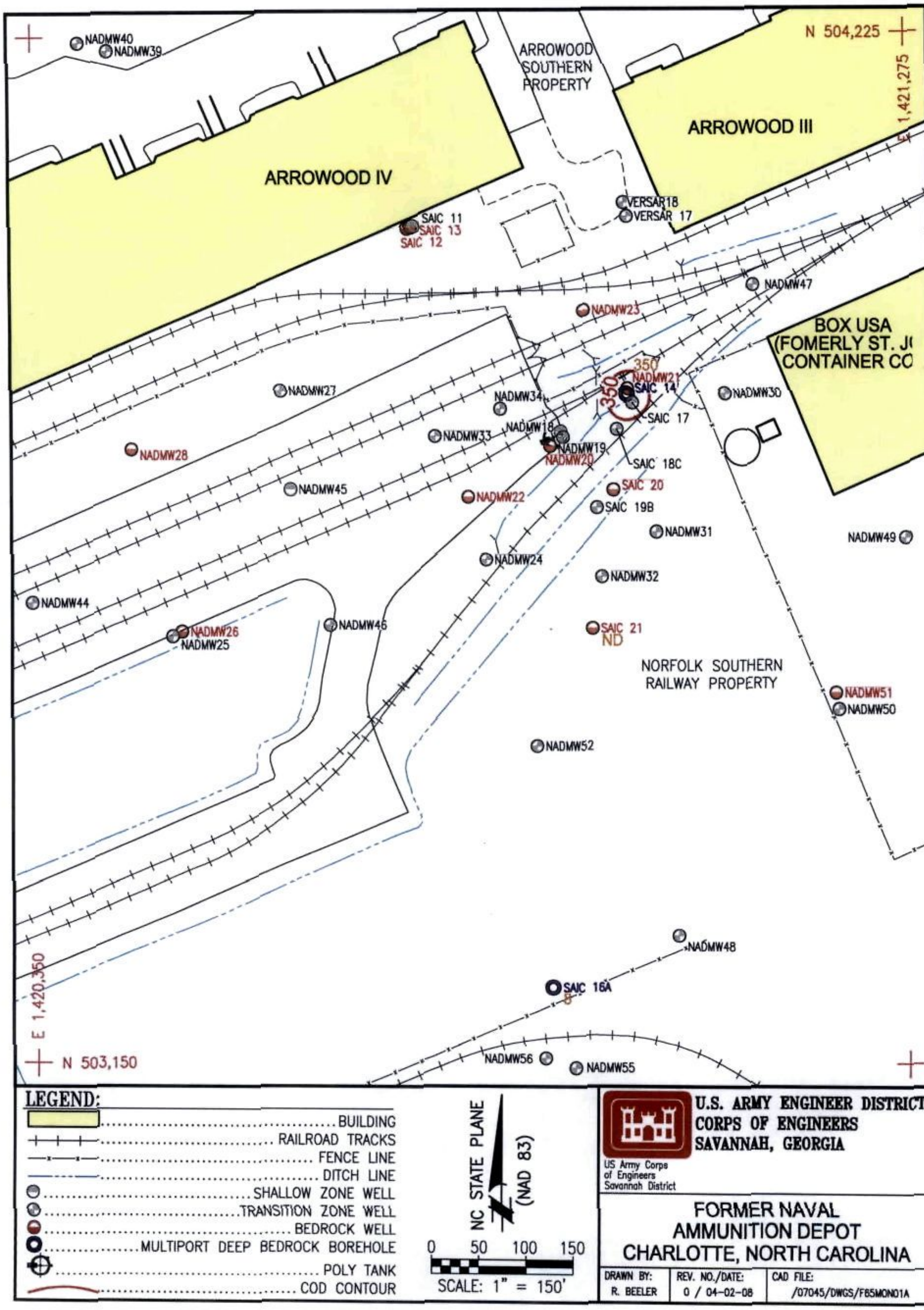


Figure 5-6. Bedrock Zone COD Isoconcentration Map - Monitoring Event 1, November 13, 2003

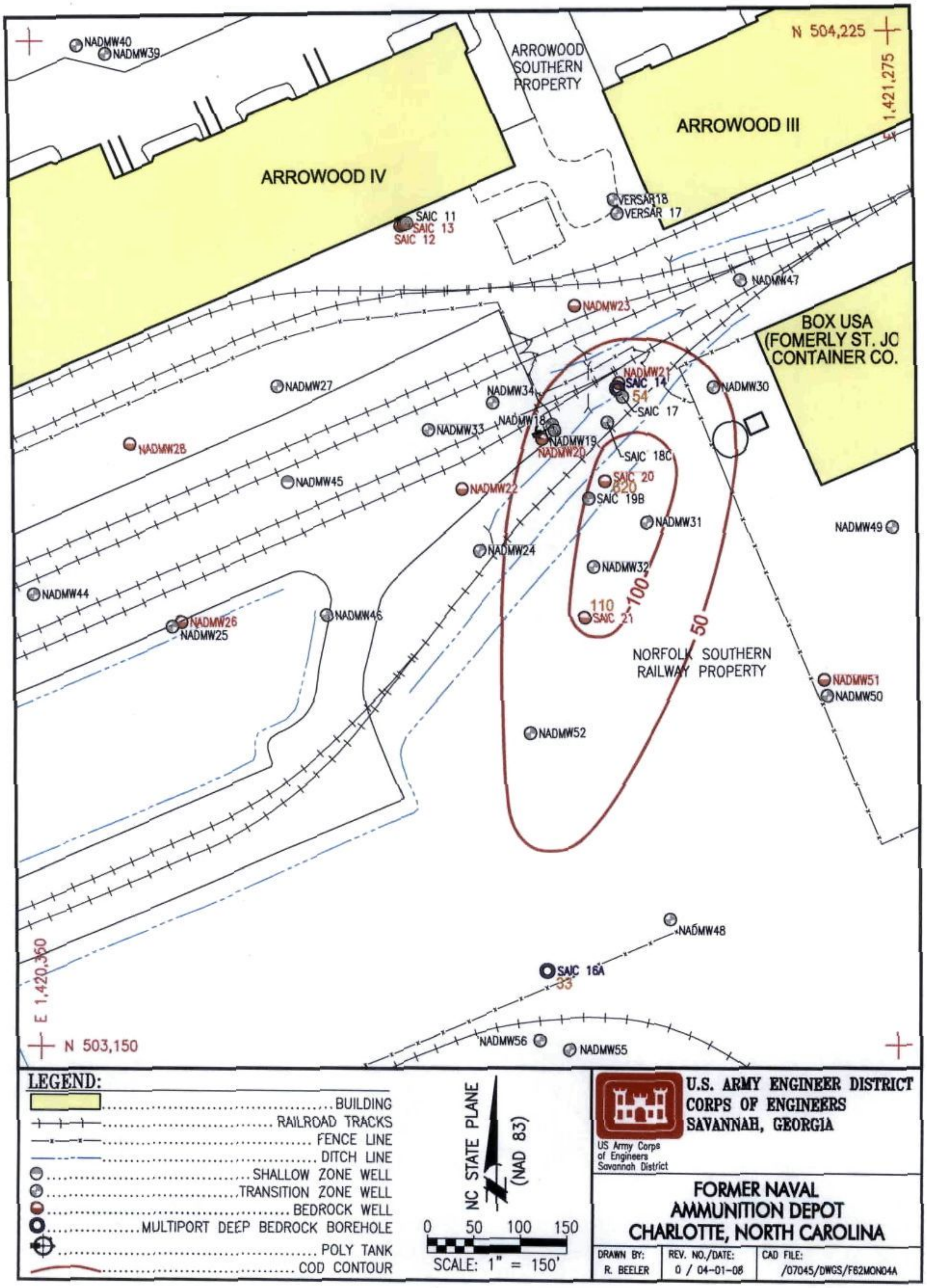


Figure 5-7. Bedrock Zone COD Isoconcentration Map - Monitoring Event 4, December 10, 2003

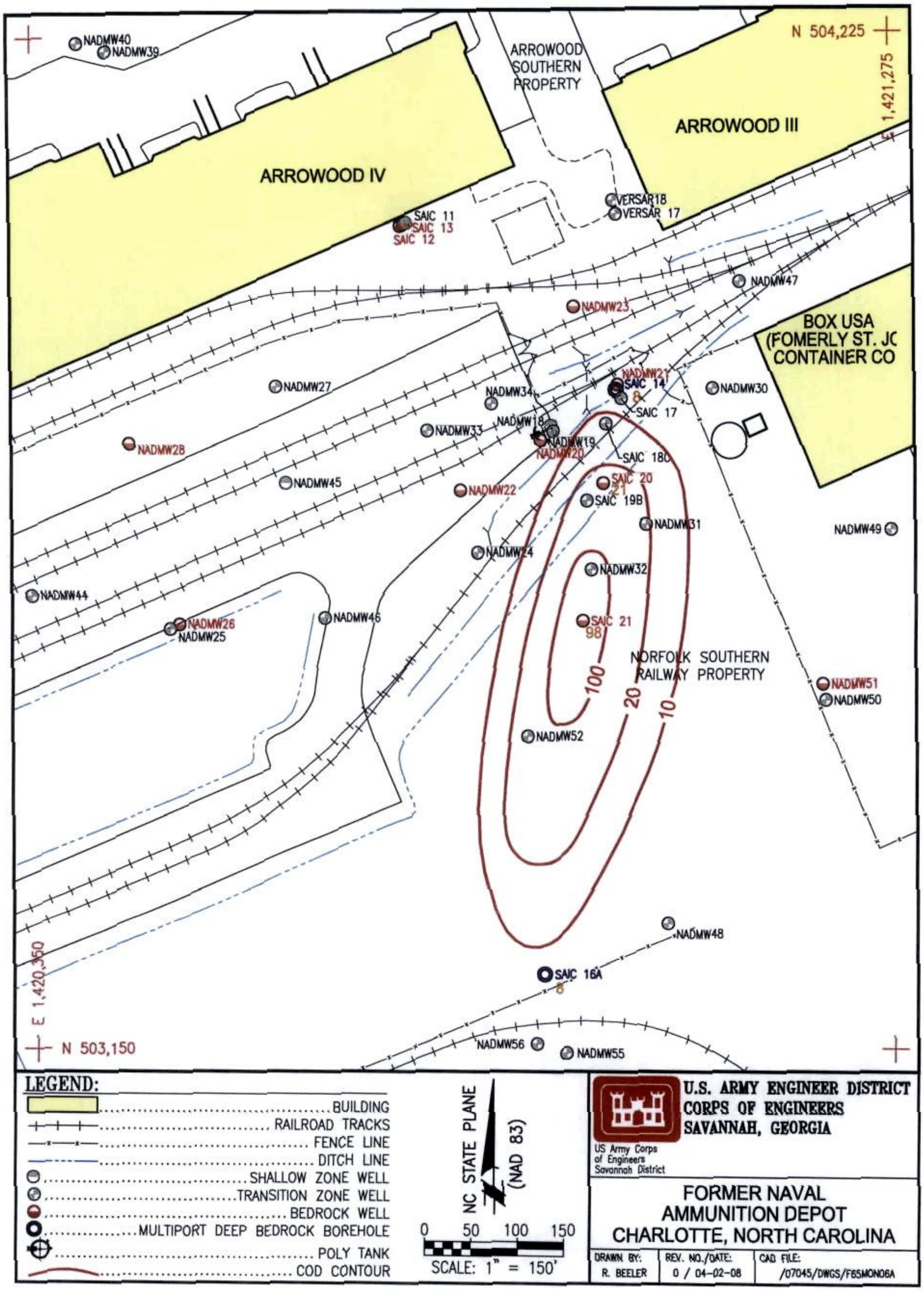


Figure 5-8. Bedrock Zone COD Isoconcentration Map - Monitoring Event 6, February 20, 2004

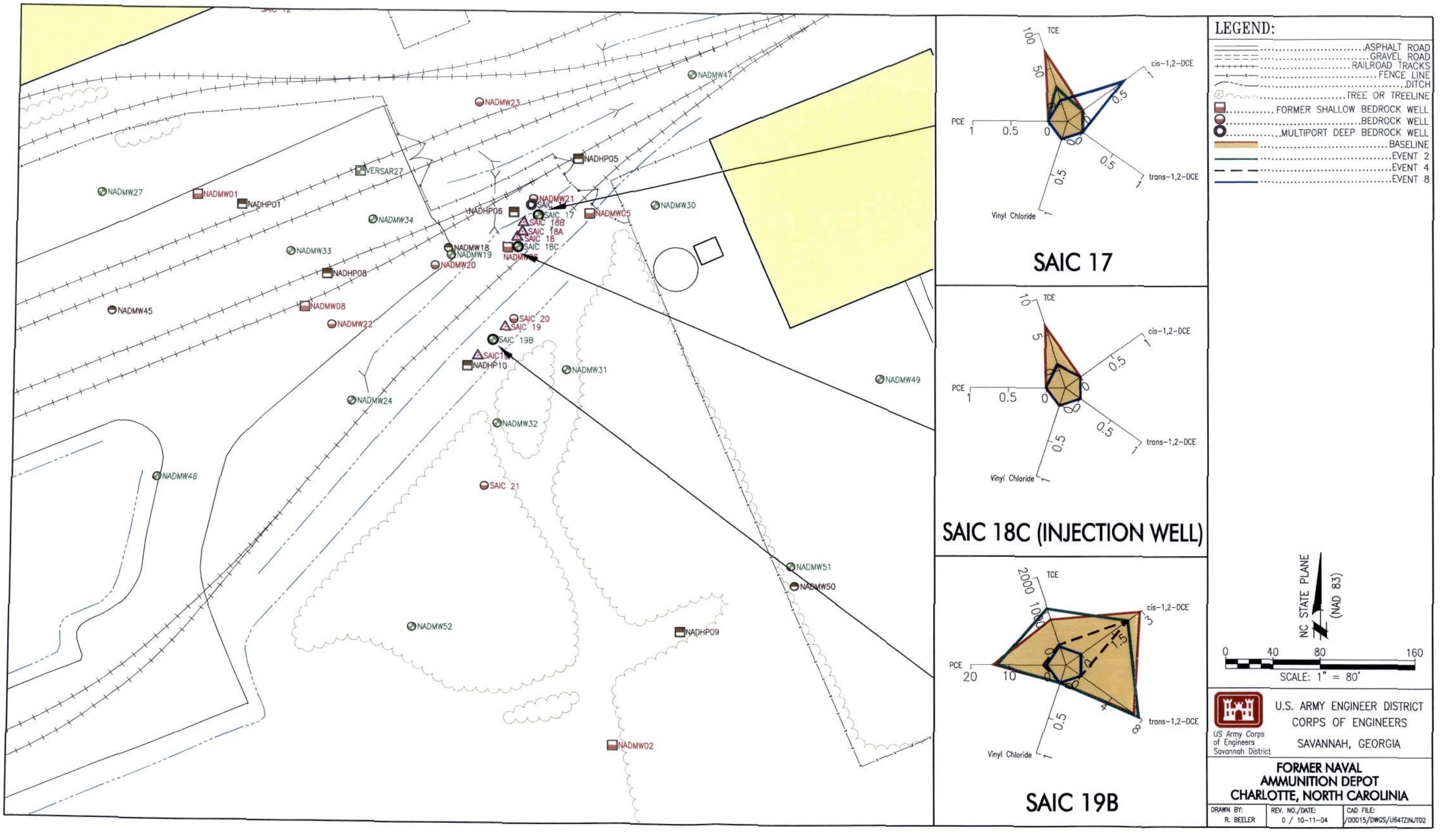


Figure 5-9. Transition Zone Radial Diagram Using SEQUENCE to Assess Effects of Sodium Lactate Injection

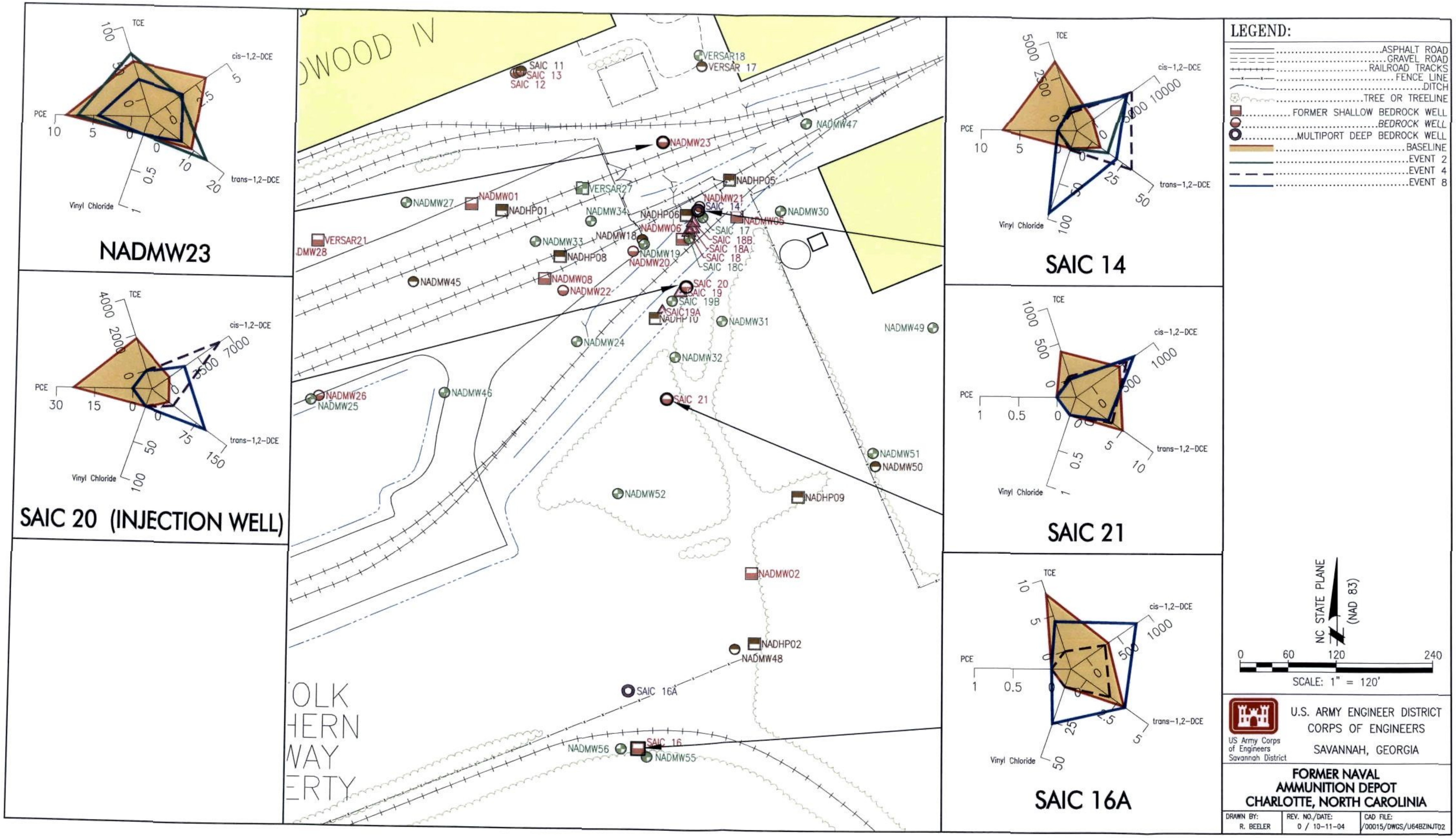


Figure 5-10. Bedrock Zone Radial Diagram Using SEQUENCE to Assess Effects of Sodium Lactate Injection

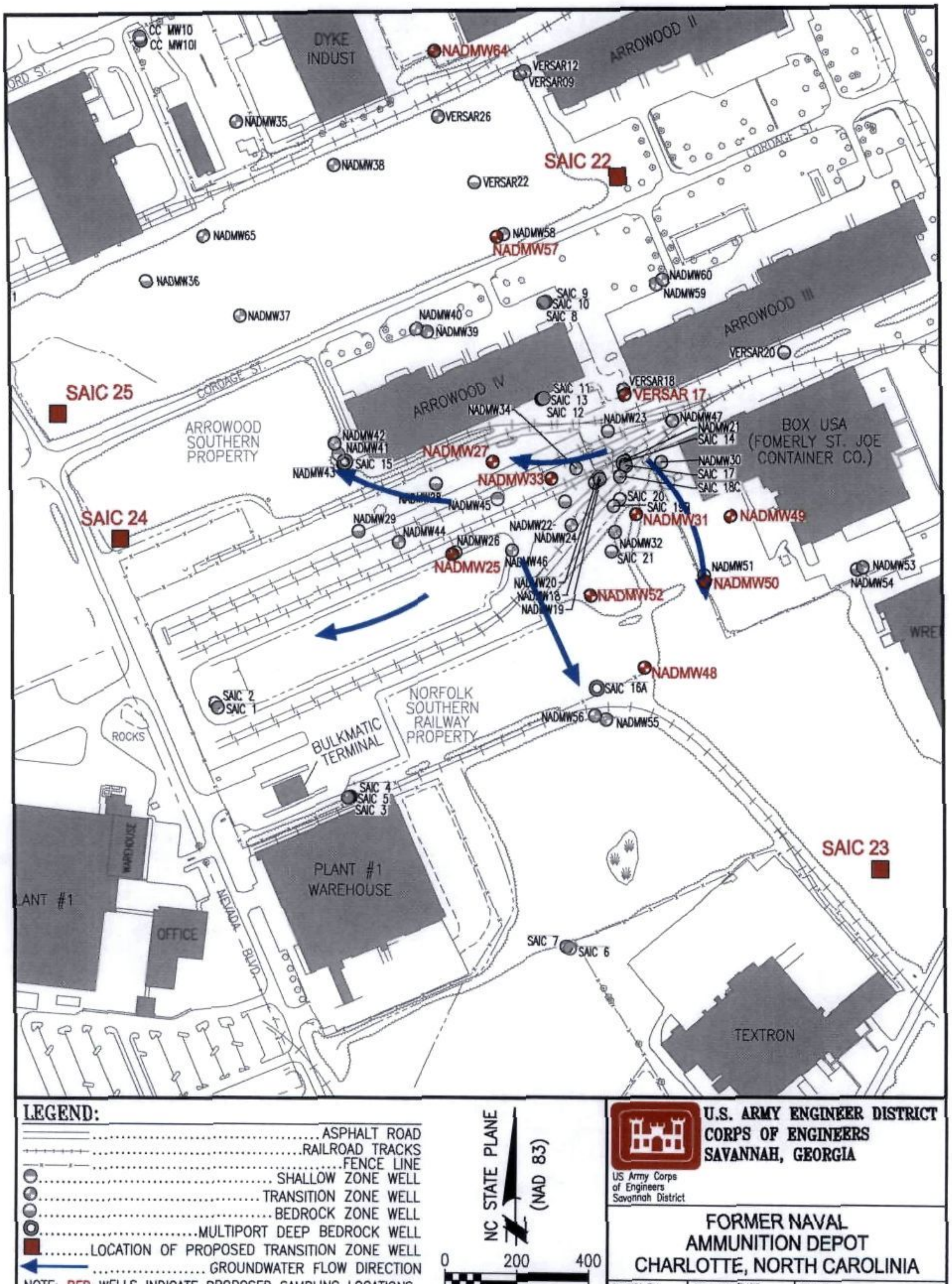


Figure 6-1. Location of Proposed Monitoring Wells and Sampling Locations for the Transition Zone

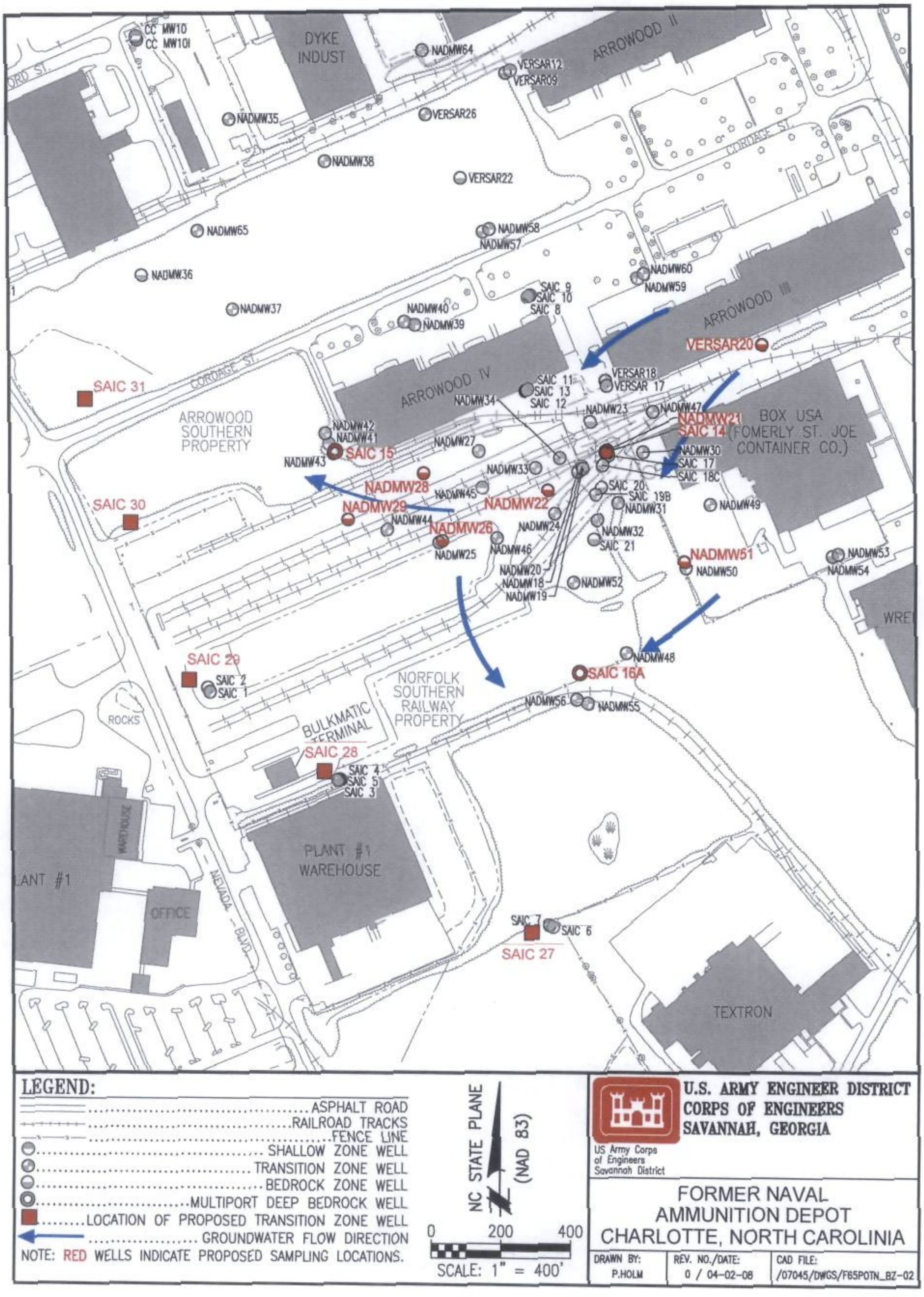


Figure 6-2. Location of Proposed Monitoring Wells and Sampling Locations for the Bedrock Zone

TABLES

Table 1-1
Environmental Site Investigation History
Former Naval Ammunition Depot, Charlotte, North Carolina

Date	Description
June 1989	S&ME conducted a Phase II Environmental Site Evaluation
December 1989	Dames & Moore conducted a limited surface and subsurface site investigation of Commerce Business Park Buildings I, VIII, IX, and X
February 1990	VERSAR, Inc., conducted a Phase I property transfer assessment
June/July 1990	VERSAR, Inc., conducted a Phase II, Stage 1 Field Investigation
November 1990	VERSAR, Inc., conducted a Phase II, Stage 2 Field Investigation
September 1992	VERSAR, Inc., conducted a Phase II, Stage 3 Field Investigation
June 1994	M&E received NTP from USACE to perform a Phase I RI at the Former NAD site
December 1994	M&E completed collection of field data for the Phase I RI
April 1995	The Phase I RI Report was completed
May 1996	M&E received NTP from USACE to perform a Phase II RI at the Former NAD Areas 1 and 2
June 1999	Process plant (Plant #1) located on adjacent property (Nevada Boulevard) installed three, 8-in.-diameter water supply wells for plant production purposes
March 2000	SAIC received NTP from USACE to perform a FS/RD at the Former NAD Areas 1 and 2
July 2000	Plant #1 began using the three production wells
October 2000	The revised Final Phase II RI was completed. Results indicated groundwater at the site was impacted with TCE
December 2000	SAIC completed the field investigation for the FS/RD
March 2001	Results of the FS/RD investigation indicated that site conditions had changed significantly since the Phase II RI. Specifically, the water table had dropped more than 20 ft in some bedrock wells, and the groundwater flow direction shifted from west to southwest
March 2001	An investigation to determine the cause of the change in the site conditions revealed that Plant #1, located less than 150 ft southwest of the Former NAD site (NAD Area 2), on Nevada Boulevard, had installed three production wells. According to Plant #1 personnel, these wells were reported to have a usage rate of 0.5 million gallons per day
April 2001	Water samples collected from the three production wells on April 19, 2001, were analyzed for VOCs. The results indicated that TCE was present at concentrations ranging from 448 µg/L in the largest production well, WF 3, to 25.6 µg/L in WF2
April 2001	A complete round of water level measurements was collected in monitoring wells at the Former NAD site. In addition, pressure transducers were installed in SAIC 04 and SAIC 05
April 27, 2001	Plant #1 began limited shutdown of the three production wells

Table 1-1
Environmental Site Investigation History
Former Naval Ammunition Depot, Charlotte, North Carolina

Date	Description
May 6, 2001	Plant #1 completed shutdown of the three production wells. It was estimated that during the 11-month usage period, approximately 144 million gallons of water were used/removed from the aquifer
May 8, 2001	Pressure transducers were removed from SAIC 04 and SAIC 05
May 17, 2001	Additional water level measurements were recorded in SAIC 04 and SAIC 05. Data indicated water table recovery of approximately 5.0 ft
August 20, 2001	A meeting was held with USACE, NCDENR, Corporate Plant #1, and SAIC personnel to discuss the "path forward" approach for the investigation at the Former NAD site
September 2001	Based on the team meeting, the project objectives were defined
October 2001 to February 2002	SAIC performed supplemental field investigation activities
April 9, 2002	A regulatory presentation was held in Charlotte, North Carolina. Recommendations made included limiting the focus of the RI/FS to TCE >500 µg/L, monitoring the groundwater levels at the site on a routine basis, sampling groundwater from selected existing monitoring wells for VOCs, conducting a detailed receptor survey, extending the depths of SAIC-14 and SAIC-16, and that the pilot study should evaluate a cost-effective approach for addressing localized areas with TCE concentrations greater than 2,500 µg/L
October 2002	Coreholes were deepened and discrete interval groundwater samples were collected
January 2003	FLUTe™ sampling port intervals were chosen
February 28, 2003	The path forward approach was discussed during a site visit. A general approach for conducting a pilot study was developed that included injection of a combination bromide tracer and lactate (electron donor) food source. It was agreed that the purpose of the study would be to evaluate the potential of biostimulation as a remedial approach for the site and to better understand the hydraulics near NAD MW-21
April 2003	FLUTe™ installation was completed
July 2003	A project team meeting was held to discuss results of the latest field activities and to present an overview of the planned pilot study. During the meeting is was agreed that with the current site condition, a complete delineation of the dissolved-phase VOCs in the fractured bedrock is not achievable and that efforts should focus on reducing the TCE concentrations in the suspected source area. Recommendations were made to conduct the study on the area surrounding NAD MW-21/SAIC-14 to evaluate the use of an electron donor (sodium lactate) for promoting reductive dechlorination. The study will also provide data for travel times and distribution rates (horizontally and vertically) for the transition and bedrock zones and will determine if reductive dechlorination will proceed beyond *cis*-1,2-dichloroethene without bioaugmentation. The data will then be modeled to develop a site-specific remedial approach for areas where TCE concentrations exceed 500 µg/L
September 2003	Final 2003 letter report submitted by SAIC. The report detailed the field investigation activities conducted from October 2002 through April 2003 and provided a summary of all current field activities, as well as a brief summary of historical investigations conducted by SAIC and previous subcontractors at the Former NAD site

Table 1-1
Environmental Site Investigation History
Former Naval Ammunition Depot, Charlotte, North Carolina

Date	Description
September 2003	The Pilot Study Sampling and Analysis Plan was completed
October 2003	Injection and observation monitoring wells were installed and baseline sampling activities were conducted at the Former NAD site in preparation for the pilot study. Pilot study activities were initiated with the injection of sodium lactate and a bromide tracer in both the transition and bedrock zones
November 2003 to June 2004	Pilot study monitoring activities were conducted. Eight monitoring events consisting of collecting groundwater samples and water level measurements were completed
August to September 2006	Site-wide groundwater sampling event. Groundwater samples were collected from a total of 54 groundwater monitoring wells and 18 discrete sampling ports from the 3 FLUTe™ monitoring systems for VOC analysis

FLUTe = Flexible Liner Underground Technologies™.
FS = Feasibility study.
M&E = Metcalf and Eddy, Inc.
NAD = Naval Ammunition Depot.
NCDENR = North Carolina Department of Environment and Natural Resources.
NTP = Notice to Proceed.
RD = Remedial design.
RI = Remedial investigation.
S&ME = Soil & Material Engineers, Inc.
SAIC = Science Applications International Corporation.
TCE = Trichloroethene.
USACE = U. S. Army Corps of Engineers.
VOC = Volatile organic compound.

Table 1-2. Summary of 2000 Groundwater Data for the Former NAD Site (Detected Analytes Only)

Chemical	Units	Freq. of Detection	Non-detects		Mean[a]	Detected			Freq. > GWQS[b]	EPA MCL[c]	Freq. > MCL[c]	EPA RBC[d]	Freq. > RBC[d]
			Minimum	Maximum		Minimum	Maximum	GWQS[b]					
Anions													
Chloride	mg/L	11 / 11			8.43	4	15.2	250	0 / 11				
Nitrate	mg/L	6 / 11	0.1	0.1	0.418	0.146	2.27	10	0 / 6				
Nitrite	mg/L	1 / 11	0.02	0.1	0.0518	0.11	0.11	1	0 / 1				
Sulfate	mg/L	11 / 11			49.1	11.9	111	250	0 / 11				
Explosive Organics													
1,3,5-Trinitrobenzene	µg/L	3 / 28	0.1	0.1	0.588	3.4	6.5	--	--	--	--	1100	0 / 3
1,3-Dinitrobenzene	µg/L	1 / 28	0.1	0.1	0.0582	0.28	0.28	--	--	--	--	3.6	0 / 1
2,4,6-Trinitrotoluene	µg/L	4 / 28	0.1	0.1	0.58	0.24	**5.7**	--	--	--	--	**2.2**	**3 / 4**
2,4-Dinitrotoluene	µg/L	2 / 28	0.1	0.1	0.0743	0.38	0.4	--	--	--	--	73	0 / 2
2-Amino-4,6-dinitrotoluene	µg/L	5 / 28	0.1	0.1	1.08	1.6	**14.2**	--	--	--	--	**7.3**	**1 / 5**
4-Amino-2,6-Dinitrotoluene	µg/L	8 / 28	0.1	0.1	0.9	0.11	**11**	--	--	--	--	**7.3**	**1 / 8**
Organic Gases													
Methane	µg/L	6 / 11	50,000	50,000	24,818	11,700	45,100	--	--	--	--	--	--
Inorganics													
Iron	µg/L	7 / 11	2.37	4.28	1361	**358**	**6,650**	**300**	**7 / 7**				
Manganese	µg/L	11 / 11			190	5.64	**486**	**50**	**9 / 11**				
Volatile Organics													
1,1,1-Trichloroethane	µg/L	7 / 39	1	50	2.63	0.5	20.2	200	0 / 7				
1,1,2-Trichloroethane	µg/L	11 / 39	1	50	2.63	0.38	2.4	--	--	5	0 / 11		
1,1-Dichloroethane	µg/L	17 / 39	1	50	3.53	0.39	25.6	70	0 / 17				
1,1-Dichloroethene	µg/L	23 / 39	1	50	6.8	0.11	**50.6**	**7**	**7 / 23**				
1,2-Dichloroethane	µg/L	14 / 39	1	5	3.06	0.17	**27.1**	**0.38**	**13 / 14**				
1,2-Dichloropropane	µg/L	7 / 39	1	50	1.73	0.2	**7.8**	**0.51**	**6 / 7**				
Acetone	µg/L	8 / 39	10	500	25.4	2.7	17.2	700	0 / 8				
Benzene	µg/L	6 / 39	1	50	2.52	0.19	0.59	1	0 / 6				

Table 1-2. Summary of 2000 Groundwater Data for the Former NAD Site (Detected Analytes Only)

Chemical	Units	Freq. of Detection	Non-detects		Mean[a]	Detected			Freq. > GWQS[b]	EPA MCL[c]	Freq. > MCL[c]	EPA RBC[d]	Freq. > RBC[d]
			Minimum	Maximum		Minimum	Maximum	GWQS[b]					
Carbon Disulfide	µg/L	1 / 39	5	250	12.7	4.5	4.5	700	0 / 1				
Chlorobenzene	µg/L	1 / 39	1	50	2.56	1.4	1.4	50	0 / 1				
Chloroform	µg/L	13 / 39	1	50	2.69	0.21	5.2	70	0 / 13				
Ethylbenzene	µg/L	4 / 39	1	50	2.49	0.057	0.084	550	0 / 4				
Methylene Chloride	µg/L	1 / 39	5	250	12.7	1.7	1.7	4.6	0 / 1				
Tetrachloroethene	µg/L	18 / 39	1	50	5.43	0.43	**57.6**	**0.7**	**15 / 18**				
Toluene	µg/L	11 / 39	1	50	2.49	0.26	1.8	1,000	0 / 11				
Trichloroethene	µg/L	36 / 39	1	1	1,364	0.38	**14,100**	**2.8**	**31 / 36**				
Vinyl Chloride	µg/L	5 / 39	1	50	3.48	**0.42**	**23.4**	**0.015**	**5 / 5**				
Xylenes, Total	µg/L	4 / 39	3	150	7.5	0.3	0.52	530	0 / 4				
cis-1,2-Dichloroethene	µg/L	32 / 39	2	2	16.0	0.15	**161**	**70**	**2/32**				

[a]Summary statistics are shown to 3 significant digits or the nearest integer, as a proxy.

[b]North Carolina Administrative Code (NCAC) Groundwater Quality Standards (GWQS), Chapter 15A NCAC 02L.0202, April 1, 2005, site applicable or relevant and appropriate requirement (ARAR).

[c]U. S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) federal drinking water standards. Used as site ARAR if NCAC 2L GWQS not available.

[d]EPA Region 9 risk-based concentrations (RBC) for tap water, April 14, 2004. Used as guidance if NCAC 2L GWQS not avaliable.

Detected concentrations, criteria, and frequencies of detection are shown in **bold** if criteria are exceeded.

NAD = Naval Ammunition Depot.

-- = Criteria not available.

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
CC MW-10	S	S	632.7	?	?	? to 20	20.0	01-Sept-06	626.36
								09-Apr-03	628.81
								17-Oct-02	627.39
								06-Nov-01	622.70
								13-Dec-00	621.97
								07-Jun-99	626.14
CC MW-10I	T	B	632.8	?	n/a	? to 62.2	62.2	01-Sept-06	625.91
								09-Apr-03	628.04
								17-Oct-02	626.74
								06-Nov-01	622.29
								13-Dec-00	621.86
								07-Jun-99	626.15
NAD HP-11	S	S	?	?	9.5	3.9 to 8.9	9.5	01-Sept-06	N/A
								09-Apr-03	642.04
								17-Oct-02	639.38
								06-Nov-01	636.39
								06-Dec-00	No Access
NAD MW-18	S	S	640.1	3.0	?	1.5 to 6.5	6.9	01-Sept-06	634.23
								26-Jun-04	636.10
								23-Oct-03	634.03
								09-Apr-03	636.52
								17-Oct-02	634.94
								06-Nov-01	Dry
								07-Dec-00	633.79
								07-Jun-99	635.11
NAD MW-19	T	T	640	6.0	19.0	31.8 to 41.8	42.3	01-Sept-06	634.11
								26-Jun-04	635.71
								23-Oct-03	633.66
								09-Apr-03	636.18
								17-Oct-02	634.17
								06-Nov-01	625.63
								06-Dec-00	626.50
								07-Jun-99	635.12
NAD MW-20	B	B	640.3	6.0	16.0	51.2 to 61.2	62.0	01-Sept-06	633.44
								26-Jun-04	632.94
								23-Oct-03	632.61
								09-Apr-03	633.41
								22-Oct-02	628.89
								08-Nov-01	622.19
								07-Dec-00	616.43
								07-Jun-99	632.32
NAD MW-21	T	B	638.5	8.0	19.5	19.5 to 69.5	70.0	01-Sept-06	632.73
								26-Jun-04	632.50
								23-Oct-03	631.77
								09-Apr-03	634.73

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								17-Oct-02	627.43
								06-Nov-01	624.68
								15-Dec-00	616.37
								07-Jun-99	634.09
NAD MW-22	T	B	640	2.8	22.0	24.5 to 74.5	75.0	01-Sept-06	633.61
								26-Jun-04	634.23
								23-Oct-03	633.39
								09-Apr-03	635.62
								22-Oct-02	632.35
								06-Nov-01	627.48
								08-Dec-00	628.80
								07-Jun-99	633.64
NAD MW-23	T	B	638.7	?	12.3	20.5 to 70.5	71.0	01-Sept-06	634.35
								13-Apr-04	634.99
								23-Oct-03	633.88
								09-Apr-03	636.11
								22-Oct-02	634.22
								06-Nov-01	626.97
								08-Dec-00	626.86
								07-Jun-99	634.88
NAD MW-24	T	T	638.4	9.8	16.5	6.5 to 16.5	19.5	01-Sept-06	633.62
								28-Jun-04	634.39
								09-Apr-03	635.61
								22-Oct-02	633.06
								06-Nov-01	624.61
								06-Dec-00	624.86
								07-Jun-99	634.79
NAD MW-25	S	T	639.9	?	12.0	9.0 to 19.0	19.5	01-Sept-06	632.83
								28-Jun-04	633.11
								09-Apr-03	634.33
								22-Oct-02	630.32
								06-Nov-01	626.47
								06-Dec-00	627.92
								07-Jun-99	632.81
NAD MW-26	T	B	640	9.5	16.0	30.0 to 40.0	42.0	01-Sept-06	632.77
								28-Jun-04	632.77
								09-Apr-03	634.20
								21-Oct-02	630.37
								08-Nov-01	626.54
								06-Dec-00	627.97
								07-Jun-99	632.49
NAD MW-27	T	T	640.1	?	19.5	15.5 to 25.5	29.5	01-Sept-06	632.83
								09-Apr-03	635.11
								21-Oct-02	631.87
								01-Nov-01	628.03

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								06-Dec-00	629.19
								07-Jun-99	632.59
NAD MW-28	T	B	636.9	?	13.0	30.0 to 40.0	41.0	01-Sept-06	632.05
								09-Apr-03	633.23
								21-Oct-02	631.13
								01-Nov-01	627.38
								06-Dec-00	628.72
								07-Jun-99	**631.94**
NAD MW-29	T	B	639.5	?	16.0	30.0 to 40.0	41.5	01-Sept-06	630.57
								28-Jun-04	631.00
								09-Apr-03	631.71
								21-Oct-02	630.59
								07-Nov-01	625.96
								06-Dec-00	624.56
								07-Jun-99	630.15
NAD MW-30	T	T	648.6	16.0	26.0	20.4 to 30.4	32.0	02-Sept-06	635.91
								25-Jun-04	635.03
								09-Apr-03	635.81
								23-Oct-02	631.44
								01-Nov-01	no access
								06-Dec-00	626.08
								07-Jun-99	635.84
NAD MW-31	T	T	645.9	?	26.0	20.0 to 30.0	31.5	01-Sept-06	633.95
								27-Jun-04	633.31
								09-Apr-03	634.48
								23-Oct-02	628.68
								07-Nov-01	623.14
								06-Dec-00	622.40
								07-Jun-99	635.63
NAD MW-32	T	T	645.6	10.0	23.0	9.0 to 29.0	31.0	01-Sept-06	633.54
								26-Jun-04	633.21
								09-Apr-03	634.58
								23-Oct-02	628.56
								07-Nov-01	622.38
								06-Dec-00	620.82
								07-Jun-99	635.57
NAD MW-33	T	T	639.7	?	5.0	4.0 to 24.0	25.0	01-Sept-06	633.39
								28-Jun-04	634.26
								09-Apr-03	635.58
								18-Oct-02	632.24
								01-Nov-01	627.94
								14-Dec-00	629.24
								07-Jun-99	633.32
NAD MW-34	T	T	640.2	4.5	7.5	4.0 to 14.0	24.5	01-Sept-06	633.61
								28-Jun-04	634.59
								09-Apr-03	635.89

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								18-Oct-02	632.65
								01-Nov-01	627.67
								14-Dec-00	628.97
								07-Jun-99	633.67
NAD MW-35	T	T	634.05	?	25.5	21.6 to 36.6	37.0	01-Sept-06	N/A
								09-Apr-03	628.86
								18-Oct-02	625.97
								01-Nov-01	623.23
								14-Dec-00	619.81
								07-Jun-99	626.91
NAD MW-36	T	B	622.5	6.0	14.0	12.0 to 22.0	23.7	01-Sept-06	N/A
								09-Apr-03	620.77
								18-Oct-02	617.77
								01-Nov-01	614.59
								12-Dec-00	604.14
								07-Jun-99	612.96
NAD MW-37	T	T	626.2	?	12.0	9.2 to 19.2	21.2	01-Sept-06	N/A
								09-Apr-03	625.79
								18-Oct-02	623.83
								01-Nov-01	620.88
								14-Dec-00	618.26
								07-Jun-99	623.18
NAD MW-38	T	T	634.2	?	16.3	14.5 to 24.5	26.0	01-Sept-06	N/A
								09-Apr-03	632.76
								18-Oct-02	630.60
								01-Nov-01	626.04
								13-Dec-00	626.04
								07-Jun-99	629.45
NAD MW-39	S	T	637.7	14.5		10.0 to 20.0	21.0	01-Sept-06	N/A
								09-Apr-03	632.74
								17-Oct-02	630.42
								06-Nov-01	627.58
								13-Dec-00	628.06
								07-Jun-99	631.31
NAD MW-40	T	T	638.4	?	25.0	23.0 to 33.0	33.8	31-Aug-06	631.28
								09-Apr-03	634.28
								18-Oct-02	N/A
								01-Nov-01	627.87
								11-Dec-00	627.55
								07-Jun-99	630.36
NAD MW-41	S	S	641.9	?	?	8.0 to 18.0	19.0	01-Sept-06	628.67
								28-Jun-04	629.41
								09-Apr-03	633.68
								18-Oct-02	628.51
								08-Nov-01	627.23

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								11-Dec-00	627.84
								07-Jun-99	630.04
NAD MW-42	T	T	641.2	?	22.5	20.5 to 30.5	31.0	01-Sept-06	628.13
								28-Jun-04	628.43
								09-Apr-03	628.83
								18-Oct-02	627.85
								08-Nov-01	624.47
								11-Dec-00	620.70
								07-Jun-99	627.33
NAD MW-43	B	B	641.08	?	23.0	70.5 to 80.5	81.1	01-Sept-06	626.81
								28-Jun-04	627.32
								09-Apr-03	629.01
								21-Oct-02	624.99
								08-Nov-01	621.62
								11-Dec-00	610.08
								07-Jun-99	626.58
NAD MW-44	T	T	640.3	?	12.0	10.0 to 20.0	20.8	01-Sept-06	632.18
								28-Jun-04	631.98
								09-Apr-03	633.24
								21-Oct-02	632.67
								01-Nov-01	627.66
								11-Dec-00	628.70
								07-Jun-99	632.01
NAD MW-45	S	S	640.3	?	9.3	4.0 to 9.0	9.3	01-Sept-06	636.63
								09-Apr-03	637.51
								21-Oct-02	636.43
								01-Nov-01	635.37
								07-Dec-00	634.37
								07-Jun-99	634.83
NAD MW-46	T	T	640.2	?	9.0	7.0 to 17.0	23.6	01-Sept-06	633.16
								28-Jun-04	634.35
								09-Apr-03	631.35
								21-Oct-02	634.89
								01-Nov-01	626.31
								17-Dec-00	627.64
								07-Jun-99	633.37
NAD MW-47	S	T	639.5	5.0	12.5	3.0 to 13.0	14.0	01-Sept-06	635.59
								28-Jun-04	636.42
								09-Apr-03	637.39
								21-Oct-02	633.42
								01-Nov-01	627.09
								17-Dec-00	628.64
								07-Jun-99	636.00
NAD MW-48	T	T	647.2	13.0	23.5	12.0 to 22.0	23.5	01-Sept-06	632.47
								28-Jun-04	630.31

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								09-Apr-03	631.88
								21-Oct-02	Dry
								01-Nov-01	Dry
								17-Dec-00	Dry
								07-Jun-99	636.15
NAD MW-49	T	T	647.6	17.5	22.0	19.0 to 29.0	31.0	01-Sept-06	634.90
								25-Jun-04	633.00
								09-Apr-03	632.59
								23-Oct-02	627.67
								01-Nov-01	No Access
								17-Dec-00	625.23
								07-Jun-99	636.29
NAD MW-50	S	T	648.5	?		9.8 to 19.8	20.0	01-Sept-06	634.43
								25-Jun-04	632.20
								09-Apr-03	631.70
								23-Oct-02	Dry
								01-Nov-01	No Access
								17-Dec-00	628.69
								07-Jun-99	636.31
NAD MW-51	T	B	648.6	23.0	26.0	20.0 to 30.0	33.5	01-Sept-06	634.48
								25-Jun-04	632.21
								09-Apr-03	631.82
								23-Oct-02	626.07
								01-Nov-01	No Access
								17-Dec-00	622.75
								07-Jun-99	635.35
NAD MW-52	T	T	644.3	20.0	26.0	19.5 to 29.5	33.0	01-Sept-06	633.15
								21-Oct-02	625.84
								07-Nov-01	620.42
								08-Dec-00	617.73
								07-Jun-99	635.63
NAD MW-53	S	T	643.9	13.0	19.0	10.0 to 20.0	21.0	01-Sept-06	637.11
								09-Apr-03	633.09
								21-Oct-02	628.97
								01-Nov-01	No Access
								08-Dec-00	627.77
								07-Jun-99	636.40
NAD MW-54	T	T	643.5	?	20.0	18.0 to 28.0	30.0	01-Sept-06	636.80
								25-Jun-04	634.82
								09-Apr-03	632.79
								21-Oct-02	628.93
								01-Nov-01	No Access
								08-Dec-00	627.71
								07-Jun-99	637.17
NAD MW-55	S	T	638.9	12?	18.0	7.0 to 17.0	18.4	01-Sept-06	631.89

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								09-Apr-03	631.89
								21-Oct-02	Dry
								01-Nov-01	Dry
								08-Dec-00	Dry
								07-Jun-99	635.76
NAD MW-56	T	T	638.6	8.0	20.5	17.0 to 27.0	27.6	01-Sept-06	630.96
								09-Apr-03	631.57
								17-Oct-02	620.96
								08-Nov-01	616.19
								08-Dec-00	610.88
								07-Jun-99	635.74
NAD MW-57	S	T	644	?	19.5	9.0 to 19.0	19.5	01-Sept-06	N/A
								09-Apr-03	634.83
								17-Oct-02	631.78
								01-Nov-01	628.35
								12-Dec-00	629.51
								07-Jun-99	632.30
NAD MW-58	T	T	644.4	4.0	18.0	16.0 to 26.0	29.2	01-Sept-06	N/A
								09-Apr-03	634.86
								21-Oct-02	631.73
								01-Nov-01	628.60
								12-Dec-00	629.55
								07-Jun-99	629.57
NAD MW-59	S	S	640.7	10.0	14.0	4.0 to 14.0	14.3	01-Sept-06	N/A
								09-Apr-03	640.71
								21-Oct-02	638.24
								01-Nov-01	632.87
								12-Dec-00	636.05
								07-Jun-99	637.04
NAD MW-60	T	T	641.3	8.0	14.0	11.8 to 21.8	22.8	01-Sept-06	N/A
								09-Apr-03	640.91
								21-Oct-02	638.05
								01-Nov-01	632.77
								12-Dec-00	635.95
								07-Jun-99	637.04
NAD MW-61	T	T	623.3	?	17.0	14.0 to 24.0	24.4	01-Sept-06	N/A
								09-Apr-03	618.20
								21-Oct-02	616.99
								01-Nov-01	615.20
								12-Dec-00	608.63
								07-Jun-99	616.73
NAD MW-62	T	T	628.9	?	20.0	17.0 to 27.0	28.3	01-Sept-06	N/A
								09-Apr-03	623.46
								21-Oct-02	622.42
								01-Nov-01	618.47

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								12-Dec-00	617.18
								07-Jun-99	621.63
NAD MW-63	T	T	646.8	10.0	15.0	12.5 to 22.5	23.5	01-Sept-06	N/A
								09-Apr-03	639.46
								21-Oct-02	635.09
								01-Nov-01	632.66
								12-Dec-00	633.37
								07-Jun-99	637.08
NAD MW-64	T	T	646.01	14.0	21.0	18.0 to 28.0	29.0	01-Sept-06	635.25
								09-Apr-03	637.88
								21-Oct-02	633.55
								01-Nov-01	630.73
								13-Dec-00	631.52
								07-Jun-99	633.30
NAD MW-65	T	T	625.5	17.0	31.0	27.0 to 37.0	38.1	01-Sept-06	N/A
								09-Apr-03	624.96
								21-Oct-02	621.64
								01-Nov-01	619.85
								12-Dec-00	616.21
								07-Jun-99	621.72
SAIC-1	S	T	640.3	28.5	?	19.7 to 29.1	30.0	30-Aug-06	625.59
								28-Jun-04	626.17
								09-Apr-03	627.22
								21-Oct-02	624.94
								01-Nov-01	621.61
								15-Dec-00	621.87
SAIC-2	B	B	640.3	28.0	29.5	41.8 to 51.3	52.0	30-Aug-06	625.60
								28-Jun-04	626.34
								09-Apr-03	627.85
								17-Oct-02	624.65
								08-Nov-01	621.32
								15-Dec-00	614.70
SAIC-3	S	T	641.7	26.0	?	17.7 to 27.6	28.5	30-Aug-06	629.51
								28-Jun-04	629.50
								09-Apr-03	630.05
								17-Oct-02	622.54
								06-Nov-01	616.70
								06-Dec-00	Dry
SAIC-4	B	B	641.7	?	25.5	50.0 to 59.5	60.4	30-Aug-06	628.66
								28-Jun-04	629.98
								09-Apr-03	629.92
								17-Oct-02	621.55
								01-Nov-01	616.80

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								08-May-01	606.97
								19-Dec-00	609.01
SAIC-5	B	B	641.7	?	24.5	64.3 to 73.7	75.0	30-Aug-06	629.64
								28-Jun-04	629.67
								09-Apr-03	630.03
								20-Oct-02	623.08
								07-Nov-01	617.23
								17-May-01	609.02
								08-May-01	606.90
								19-Dec-00	608.85
SAIC-6	S	S	639.8	23.0	27.8	19.0 to 28.5	29.4	30-Aug-06	631.46
								09-Apr-03	630.29
								20-Oct-02	625.92
								01-Nov-01	617.97
								18-Dec-00	621.67
SAIC-7	B	B	639.8	21.0	24.0	40.0 to 59.5	61.0	30-Aug-06	626.79
								09-Apr-03	625.65
								17-Oct-02	618.70
								01-Nov-01	614.77
								19-Dec-00	580.38
SAIC-8	S	S	637.6	?	?	5.1 to 14.5	15.3	30-Aug-06	632.85
								09-Apr-03	635.99
								17-Oct-02	632.72
								01-Nov-01	628.61
								14-Dec-00	629.86
SAIC-9	B	B	637.7	12.0	14.7	25.1 to 40.2	40.4	30-Aug-06	633.06
								09-Apr-03	635.95
								17-Oct-02	632.58
								01-Nov-01	628.54
								20-Dec-00	629.56
SAIC-10	B	B	637.6	16.0	18.5	53.8 to 68.6	70.2	30-Aug-06	632.58
								09-Apr-03	635.91
								17-Oct-02	632.13
								01-Nov-01	628.60
								20-Dec-00	629.05
SAIC-11	S	S	641.9	13.5	?	4.4 to 14.4	14.9	30-Aug-06	633.95
								28-Jun-04	634.61
								09-Apr-03	636.41
								17-Oct-02	632.70
								01-Nov-01	628.58
								19-Dec-00	629.73
SAIC-12	B	B	641.9	13.5	15.0	25.5 to 35.0	36.5	30-Aug-06	633.83
								28-Jun-04	634.29
								09-Apr-03	636.01

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								17-Oct-02	632.40
								01-Nov-01	628.31
								19-Dec-00	629.43
SAIC-13	B	B	641.9	13.5	16.0	44.5 to 54.5	55.2	30-Aug-06	632.40
								28-Jun-04	632.99
								09-Apr-03	635.10
								17-Oct-02	631.70
								01-Nov-01	627.99
								19-Dec-00	627.06
SAIC-14[c]		MP	638.6	4.5	10.8		350.7		n/a
Port 1		B				62.0 to 72.0		25-Jun-04	631.28
Port 2		B				109.0 to 114.0		25-Jun-04	631.52
Port 3		B				126.0 to 135.0		25-Jun-04	631.30
Port 4		B				139.0 to 144.0		25-Jun-04	631.23
Port 5		B				199.0 to 210.0		25-Jun-04	631.52
Port 6		B				250.0 to 264.0		25-Jun-04	631.55
Port 7		B				297.0 to 307.0		25-Jun-04	631.48
SAIC-15[c]		MP	641.9	30.0	31.0		204.8		N/A
Port 1		B				31.0 to 39.0		28-Jun-04	628.45
Port 2		B				60.0 to 67.0		28-Jun-04	627.20
Port 3		B				112.0 to 120.0		28-Jun-04	626.37
Port 4		B				149.0 to 155.0		28-Jun-04	626.39
Port 5		B				188.0 to 204.8		28-Jun-04	626.42
SAIC-16A[c]		MP	647.3	34.5	43.3		331.6		N/A
Port 1		B				58.0 to 65.0		25-Jun-04	629.04
Port 2		B				83.0 to 103.0		25-Jun-04	627.98
Port 3		B				122.0 to 129.0		25-Jun-04	627.97
Port 4		B				160.0 to 165.0		25-Jun-04	628.08
Port 5		B				191.0 to 199.0		25-Jun-04	628.34
Port 6		B				295.0 to 305.0		25-Jun-04	628.14
SAIC-17	T	T	638.3	8.0	10.0	5.13 to 10.13	10.7	31-Aug-06	634.78

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								26-Jun-04	636.89
								23-Oct-03	633.73
SAIC-18C	T	T	639.1	8.0	13.0	8.08 to 13.08	13.9	31-Aug-06	634.54
								25-Jun-04	636.12
								23-Oct-03	634.03
SAIC-19B	T	T	642.8	12.0	18.5	8.50 to 18.50	20.1	31-Aug-06	634.60
								28-Jun-04	635.25
								23-Oct-03	633.71
								23-Oct-03	633.71
SAIC-20	B	B	642.5	11.5	13.5	79.57 to 99.57	100.4	03-Sept-06	634.47
								28-Jun-04	631.34
								23-Oct-03	630.97
SAIC-21	B	B	645.6	15.5	21.5	93.88 to 103.88	105.7	31-Aug-06	631.95
								26-Jun-04	630.53
								23-Oct-03	630.41
VERSAR 09	T	B	?	?	N/A	? to 38	38.0	31-Aug-06	N/A
								09-Apr-03	640.95
								21-Oct-02	636.86
								01-Nov-01	634.24
								12-Dec-00	No Access
								08-Jun-99	637.30
VERSAR 12	S	S	?	?	N/A	? to 20	20.0	31-Aug-06	N/A
								09-Apr-03	640.63
								21-Oct-02	636.57
								01-Nov-01	632.96
								12-Dec-00	635.49
								07-Jun-99	637.35
VERSAR 17	S	T	?	?	N/A	? to 15	15.0	31-Aug-06	N/A
								28-Jun-04	636.68
								13-Apr-04	635.20
								09-Apr-03	637.95
								21-Oct-02	633.98
								01-Nov-01	Dry
								15-Dec-00	630.03
								07-Jun-99	635.65
VERSAR 18	T	T	?	?	N/A	? to 33	33.0	31-Aug-06	N/A
								28-Jun-04	636.79
								09-Apr-03	637.95
								21-Oct-02	634.05
								01-Nov-01	628.18
								15-Dec-00	630.04
								07-Jun-99	635.80
VERSAR 20	B	B	?	?	N/A	23.8 to 33.8	33.8	31-Aug-06	N/A
								28-Jun-04	639.92
								09-Apr-03	638.55

Table 1-3
Groundwater Elevation and Monitoring Well Construction Summary

Well ID	Original Well Type[a]	Revised Well Type[b]	Ground Surface Elevation	Top of Transition Zone (ft BGS)	Top of Bedrock (ft BGS)	Screen Interval (ft BGS)	Total Depth[d] (ft BGS)	Sample Date	Groundwater Elevation (AMSL)
								21-Oct-02	637.75
								01-Nov-01	635.18
								08-Dec-00	636.00
								07-Jun-99	638.24
VERSAR 22	B	B	?	?	?	40.0 to 50.0	50.0	31-Aug-06	N/A
								09-Apr-03	633.90
								21-Oct-02	630.66
								01-Nov-01	628.96
								15-Dec-00	629.45
								07-Jun-99	631.76
VERSAR 26	n/a	T	?	?	N/A	6.3 to 21.3	?	31-Aug-06	N/A
								09-Apr-03	636.40
								17-Oct-02	632.21
								25-Apr-01	Dry
								06-Dec-00	N/A
								07-Jun-99	N/A

[a] The original well type as classified by Metcalf and Eddy (M&E) in the Phase I and II Remedial Investigation (RI).

[b] Science Applications International Corporation (SAIC) reclassified the well types based on supplemental investigation findings to define the hydrogeologic framework more accurately. These revised well types were used in the current site evaluation and to prepare the potentiometric maps.

[c] Multi-port wells (FLUTe™ Systems). Water level measurements are provided for the most recent sampling event for each zone.

[d] Bottom of the borehole as reported on the well construction diagrams.

Data collected in June 1999 were collected by M&E and taken from the Phase II RI Report. All other data were collected by SAIC.

? = Value unknown/not available.
AMSL = Above mean sea level.
B = Bedrock Zone well.
BGS = Below ground surface.
ID = Identifier.
MP = Muli-port FLUTe™ well.
N/A = Not available.
S = Shallow zone well.
T = Transition zone well.

Table 1-4
Summary of 2001 Groundwater Data for the Former NAD Site (Detected Analytes Only)

Chemical	Units	Freq. of Detection	Non-detects		Mean [a]	Detected		GWQS [b]	Freq. > GWQS [b]
			Minimum	Maximum		Minimum	Maximum		
Volatile Organics									
1,1-Dichloroethane	µg/L	1/24	1	400	15.0	15.0	15.0	700	0/1
1,1-Dichloroethene	µg/L	2/24	1	400	**14.0**	**12**	**16**	**7**	**4/5**
Chloroform	µg/L	1/24	1	400	15.0	15	15	**70**	0 / 1
Toluene	µg/L	1/24	1	400	120.0	120	120	1,000	0/1
Trichloroethene	µg/L	23/24	1	1	**2,401**	**68**	**6,500**	**2.8**	**23/23**
Vinyl Chloride	µg/L	2/24	1	**400**	**12.0**	**12**	**12**	**0.015**	**2/2**
cis-1,2-Dichloroethene	µg/L	7/24	1	**400**	**48.3**	**1.4**	**120**	**0.19**	**7/24**

[a]Summary statistics are shown to 3 significant digits or the nearest integer.
[b]North Carolina Administrative Code (NCAC) Groundwater Quality Standards (GWQS), Chapter 15A NCAC 02L.0202, April 1, 2005, site applicable or relevant and appropriate requirement.
Detected concentrations, criteria, and frequencies of detection are shown in **bold** if criteria are exceeded.
NAD = Naval Ammunition Depot.

Table 1-5
Summary of Detected Soil Analytical Data

Sample Station	Date Collected	Depth (ft BGS)	Analyte (mg/kg)	
			TCE	*cis*-1,2-Dichloroethene
EPA Region 9 RBC[a]			6.5	150
SAIC-14	25-Oct-01	5.0 to 5.3	ND	ND
SAIC-15	25-Oct-01	30.0 to 31.0	0.43 J	0.005 J
SAIC-16	25-Oct-01	15.0 to 17.0	ND	ND

[a]U. S. Environmental Protection Agency (EPA) Region 9 risk-based concentration (RBC) for an industrial worker, published April 2004.
BGS = Below ground surface.
ND = Not detected.
TCE = Trichloroethene.

Table 1-6
Summary of Groundwater Data for the Plant #1 Production Wells – January 2002 (Detected Analytes Only)

Chemical	Units	Freq. Of Detection	Non-detects Minimum	Non-detects Maximum	Mean[a]	Detected Minimum	Detected Maximum	GWQS[b]	Freq. > GWQS[b]
Volatile Organics									
1,1-Dichloroethene	µg/L	4 / 15	5	10	4.11	5.3	**7.8**	**7**	**2 / 4**
1,2-Dichloroethane	µg/L	3 / 15	5	10	**3.69**	**5.4**	**6.5**	**0.38**	**3 / 3**
Toluene	µg/L	2 / 15	5	10	3.88	5.2	13	1,000	0 / 2
Trichloroethene	µg/L	15 / 15	--	--	**177.4**	**52**	**290**	**2.8**	**15 / 15**
cis-1,2-Dichloroethene	µg/L	15 / 15	--	--	**202**	**87**	**310**	**70**	**15 / 15**

[a] Summary statistics are shown to 3 significant digits or the nearest integer.

[b] North Carolina Administrative Code (NCAC) Groundwater Quality Standards (GWQS), Chapter 15A NCAC 02L.0202, April 1, 2005, site applicable or relevant and appropriate requirement.

-- = Criteria not available.

Detected concentrations, criteria, and frequencies of detection are shown in **bold** if criteria are exceeded.

Table 1-7
Summary of 2002 Groundwater Data for the Former NAD Site
(Detected Analytes Only)

Chemical	Units	Freq. of Detection	Non-detects		Mean[a]	Detected			Freq. > GWQS[b]
			Minimum	Maximum		Minimum	Maximum	GWQS[b]	
Volatile Organics									
1,1,1-Trichloroethane	µg/L	1 / 35	1	200	21.4	10	10	200	0 / 1
1,1-Dichloroethane	µg/L	1 / 35	1	200	21.2	1.4	1.4	70	0 / 1
1,1-Dichloroethene	µg/L	2 / 35	1	200	**21.4**	1.8	**9.5**	**7**	**1 / 2**
1,2-Dichloroethane	µg/L	2 / 35	1	200	**21.3**	**1**	**2.4**	**0.38**	**2 / 2**
Chloroform	µg/L	1 / 35	1	200	21.6	18	18	70	0 / 1
Tetrachloroethene	µg/L	1 / 35	1	200	**21.5**	**12**	**12**	**0.7**	**1 / 1**
Toluene	µg/L	3 / 35	1	200	24.2	44	71	1,000	0 / 3
Trichloroethene	µg/L	33 / 35	1	1	**2319**	1.1	**24,000**	**2.8**	**31 / 33**
cis-1,2-Dichloroethene	µg/L	14 / 35	1	200	**177**	1.3	**4,100**	**70**	**5 / 14**

[a]Summary statistics are shown to 3 significant digits or the nearest integer.

[b]North Carolina Administrative Code (NCAC) Groundwater Quality Standards (GWQS), Chapter 15A NCAC 02L.0202, April 1, 2005, site applicable or relevant and appropriate requirement.

Detected concentrations, criteria, and frequencies of detection are shown in **bold** if criteria are exceeded.

NAD = Naval Ammunition Depot.

Table 2-1
Summary of the 2006 Groundwater Data for the Former NAD Site
(Detected Analytes Only)

Chemical	Units	Freq. of Detection	Non-detects Minimum	Non-detects Maximum	Mean[a]	Detected Minimum	Detected Maximum	GWQS[b]	Freq. > GWQS[b]	EPA MCL[c]	Freq. > MCL[c]
Volatile Organics											
1,1,1-Trichloroethane	µg/L	8/72	2	20	5.1	1.6	12	200	0/8		
1,1,2-Trichloroethane	µg/L	14/72	1	100	2.03	0.71	**7.5**	--	--	**5**	**1/14**
1,1-Dichloroethane	µg/L	25/72	3	30	3.01	1.1	5.8	70	0/25		
1,1-Dichloroethene	µg/L	33/72	2	20	**10.6**	0.83	**42**	**7**	**17/33**		
1,2-Dichloroethane	µg/L	14/72	1	100	**1.72**	**0.6**	**5.6**	**0.38**	**14/14**		
1,2-Dichloropropane	µg/L	6/72	2	20	**0.78**	**0.58**	**0.97**	**0.51**	**6/6**		
Acetone	µg/L	3/72	10	100	15.67	10	21	700	0 / 3		
2-Butanone	µg/L	2/72	5	50	**5.75**	5.3	6.2	4.20	**2/2**		
Chloroform	µg/L	6/72	2	20	1.55	0.82	2.7	70	0 / 6		
Tetrachloroethene	µg/L	15/72	2	20	**13.01**	**0.9**	**55**	**0.7**	**15/15**		
Toluene	µg/L	12 / 72	2	20	7.11	1.1	22	1,000	0 / 12		
Trichloroethene	µg/L	57/72	2	2	**1884.41**	1.3	**40,000**	**2.8**	**53/57**		
Vinyl Chloride	µg/L	22/72	5	50	**598.18**	**5.8**	**4,500**	**0.015**	**22/22**		
cis-1,2-Dichloroethene	µg/L	55/72	1	10	**1806.43**	**0.54**	**28,000**	**70**	**24/55**		
trans-1,2-Dichloroethene	µg/L	17/72	3	30	14.84	1.2	56	100	0/17		

[a] Summary statistics are shown to 3 significant digits or the nearest integer.

[b] North Carolina Administrative Code (NCAC) Groundwater Quality Standards (GWQS), Chapter 15A NCAC 02L.0202, April 1, 2005, site applicable or relevant and appropriate requirement (ARAR).

[c] U. S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) federal drinking water standards. Used as site ARAR if NCAC 2L GWQS not available.

Detected concentrations, criteria, and frequencies of detection are shown in **bold** if criteria are exceeded.

-- = Criteria not available.

NAD = Naval Ammunition Depot.

Table 2-2
Modeling Scenario Summary

No.	Modeled Scenario	Hydrogeologic Zone	Distance the Plume will Migrate Before Reaching the NCAC 2L Standard of 2.8 μg/L (ft)	Time it will take to Reach the NCAC 2L Standard of 2.8 μg/L (years)
1	No Action/MNA	Transition	1,312	47
		Bedrock	1,312	63
2	TCE Plumes Reduced to 500 μg/L with Active Treatment (enhanced bioremediation using sodium lactate) Followed by MNA	Transition	1,312	14
		Bedrock	1,312	12

MNA = Monitored natural attenuation.

NCAC = North Carolina Administrative Code.

TCE = Trichloroethene.

Table 3-1
North Carolina and Federal Groundwater Standards

COPCs Identified for the Former NAD site FFS	NC GWQS Standard[a] (µg/L)	Federal MCL[b] (µg/L)
1,1,2-Trichloroethane	--	5
1,1-Dichloroethene	7	
1,2-Dichloroethane	0.38	
1,2-Dichloropropane	0.56	
2-Butanone	4.20	
Tetrachloroethene	0.7	
Trichloroethene	2.8	
Vinyl Chloride	0.015	
cis-1,2-Dichloroethene	70	

[a] North Carolina Administrative Code (NCAC) Groundwater Quality Standards (GWQS), Chapter 15A NCAC 02L.0202, April 1, 2005, site applicable or relevant and appropriate requirement (ARAR).

[b] U. S. Environmental Protection Agency maximum contaminant level (MCL) federal drinking water standard. Used as ARAR where the NCAC 2L standard is not available.

COPC = Contaminant of potential concern.

FFS = Focused feasibility study.

NC = North Carolina.

Table 3-2
General Response Actions, Technology Types, and Process Options for the Former NAD Site

General Response Action	Remedial Technology Type	Process Options
No Action	None – No Action	No Action
Institutional Controls	Access and Use Restrictions	Administrative Controls
		Deed Restrictions
		Physical Barriers
	Monitoring and Maintenance	Long-term Monitoring
		Physical Surveillance and Maintenance
In-Situ Treatment	Biological Treatment	Monitored Natural Attenuation
		Bioaugmentation
Removal	Groundwater Extraction	Well Points
		Deep Wells

NAD = Naval Ammunition Depot.

Table 4-1
Oxidation-Reduction Potentials for Various Redox Reaction Pairs in Aerobic/Anaerobic Environments

Selected Redox Pairs	Standard Redox Potentials (mV) for Redox Pairs
Aerobic Respiration (O_2/H_2O)	+820
Nitrate Reduction (NO_3/N_2)	+430
Fe-Reduction ($Fe(OH_3/Fe(II))$)	+50
Sulfate Reduction (SO_4/HS)	-210
Methanogenesis (CO_2/CH_4)	-250

Redox = Oxidation-reduction.

Table 4-2
Summary of Preliminary Screening of Process

Alternative	Effectiveness	Implementable	Approximate Costs	Comments
No Action	Not effective	Easily implementable as no activities would be conducted	None	Retained as required by NCP
Monitored Natural Attenuation	This option would eventually attain the RG for TCE	Easily implementable. A monitoring well network is already in place. Additional monitoring wells could be easily installed	Moderate to high	Retained. Can achieve the RG
Bioremediation Using Sodium Lactate	This option was proven to be successful in reducing the CVOCs at this site during the pilot study that was conducted in 2003 and 2004	Implementable over most of the site. Injection of sodium lactate is reasonably well established and would require installation of a number of injection wells, but relies upon standard, proven techniques	High	Retained. Can achieve the RG

CVOC = Chlorinated volatile organic compound.

NCP = National Oil and Hazardous Substances Pollution Contingency Plan (e.g., National Contingency Plan).

RG = Remedial goal.

TCE = Trichloroethene.

Table 5-1
Summary of the June 2004 Groundwater Data for the Former NAD Site
(Detected Analytes Only)

Chemical	Units	Freq. of Detection	Non-detects		Mean[a]	Detected		GWQS[b]	Freq. > GWQS[b]	EPA MCL[c]	Freq. > MCL[c]	EPA RBC[d]	Freq. > RBC[d]
			Minimum	Maximum		Minimum	Maximum						
Anions													
Nitrate	mg/L	7 / 8	0.1	0.1	1.02	0.15	2.2	10	0 / 7				
Sulfate	mg/L	8 / 8			**136**	59	**330**	**250**	**1 / 8**				
Gasoline Organics													
Ethane	µg/L	19 / 27	0.005	0.005	0.254	0.01	2.1	--	--	--	--		
Ethene	µg/L	26 / 27	0.005	0.005	5.01	0.0052	36	--	--	--	--		
Methane	µg/L	27 / 27			1246	0.16	6,900	--	--	--	--		
General Chemistry													
Chemical Oxygen Demand	mg/L	10 / 27	5	5	11.5	6	110	--	--	--	--		
Volatile Organics													
1,1,1-Trichloroethane	µg/L	6 / 27	1	1	2.76	2.3	45	200	0 / 6				
1,1,2-Trichloroethane	µg/L	5 / 27	1	1	1.14	1.1	**12**	--	--	**5**	**1 / 5**		
1,1-Dichloroethane	µg/L	19 / 27	1	1	1.99	0.59	9.7	70	0 / 19				
1,1-Dichloroethene	µg/L	22 / 27	1	1	**15.6**	2.1	**100**	**7**	**12 / 22**				
1,2-Dichloroethane	µg/L	10 / 27	1	1	**1.63**	**1.5**	**6.4**	**0.38**	**10 / 10**				
1,2-Dichloropropane	µg/L	5 / 27	1	1	**0.704**	**0.72**	**3.9**	**0.51**	**5 / 5**				
4-Methyl-2-pentanone	µg/L	2 / 27	10	10	6.11	19	21	--	--	--	--	6,300	0/0
Acetone	µg/L	2 / 27	10	10	6	13	24	700	0 / 2				
Chlorobenzene	µg/L	3 / 27	1	1	0.722	1.9	3.6	50	0 / 3				
Chloroform	µg/L	7 / 27	1	1	0.852	0.85	5.6	70	0 / 7				
Methylene Chloride	µg/L	1 / 27	5	5	2.64	**6.3**	**6.3**	4.6	**1 / 1**				
Tetrachloroethene	µg/L	7 / 27	1	1	**5.33**	**3.9**	**79**	**0.7**	**7 / 7**				
Toluene	µg/L	13 / 27	1	1	64.3	0.97	610	1,000	0 / 13				
Trichloroethene	µg/L	26 / 27	1	1	**7,715**	0.72	**120,000**	**2.8**	**23 / 26**				
Vinyl Chloride	µg/L	14 / 27	1	1	**281**	**1.1**	**3,300**	**0.015**	**14 / 14**				
cis-1,2-Dichloroethene	µg/L	25 / 27	1	1	**3,166**	**0.67**	**22,000**	**70**	**16 / 25**				

[a] Summary statistics are shown to 3 significant digits or the nearest integer.

[b] North Carolina Administrative Code (NCAC) Groundwater Quality Standards (GWQS), Chapter 15A NCAC 02L.0202, April 1, 2005, site applicable or relevant and appropriate requirement (ARAR).

[c] U. S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) federal drinking water standards. Used as site ARAR if NCAC 2L GWQS not available.

[d] EPA Region 9 risk-based concentrations (RBCs) for tap water, April 14, 2004. Used as guidance if NCAC 2L GWQS not available.

Detected concentrations, criteria, and frequencies of detection are shown in **bold** if criteria are exceeded.

-- = Criteria not available.

NAD = Naval Ammunition Depot.

Table 6-1
Summary of Remedial Action Alternatives

Remedial Alternative	Active Treatment Activities	Groundwater Monitoring Required During Treatment	Long-Term Groundwater Monitoring Required
No Action		NA	NA
Monitored Natural Attenuation	Installation of 9 additional groundwater monitoring wells	NA	Baseline sampling would be conducted for all wells to be monitored in the transition and bedrock zones (30 wells). For the transition zone, a total of 15 wells would be monitored and results reported following the current NCDENR Division of Water Quality policy that includes provisions for 12 quarterly sampling events, 4 semiannual sampling events, annual sampling events, 5-year reviews, and quarterly confirmation sampling. For the transition zone, monitoring would continue for approximately 47 years. For the bedrock zone, a total of 15 wells would be monitored following the NCDENR Division of Water Quality monitoring and reporting policy and would continue for approximately 63 years
Enhanced Bioremediation Using Sodium Lactate Injection	Installation of 9 additional groundwater monitoring wells, 85 injection wells, and injection of sodium lactate	Performance monitoring of the injection wells (85 wells) and monitoring wells (30 wells) during treatment operations that will include baseline sampling and injection event sampling (4 events for the transition zone and 7 events for the bedrock zone) for VOCs and natural attenuation parameters. The monitoring would occur over a 1-year period	Monitoring 30 wells (15 transition zone wells and 15 bedrock zone wells) following the NCDENR Division of Water Quality monitoring and reporting policy for approximately 14 years

NA = Not applicable.

NCDENR = North Carolina Department of Environment and Natural Resources.

VOC = Volatile organic compound.

Table 7-1
Comparative Analysis of Remedial Alternatives

Remedial Alternative	Protection of Human Health and Environment	Compliance with ARARs	Long-term Effectiveness and Permanence	Reduction in Toxicity, Mobility, and Volume	Short-term Effectiveness	Implementability	Cost
No Action	Not protective	Does not comply with ARARs	TCE would naturally attenuate in ~63 years (passive technology)	Toxicity and mass of TCE would be reduced through natural attenuation	Effective because no action would be implemented	Easily implementable – no activities conducted	$0
Monitored Natural Attenuation	Protective of human health and the environment through institutional controls	Complies with ARARs in the long-term	Effective in the long-term. TCE would naturally attenuate in ~63 years	Toxicity and mass of TCE would be reduced through natural attenuation	Effective in the short-term, as Health and Safety procedures will be implemented to reduce risk	Easily implementable. Would require the installation of 10 additional monitoring wells and monitoring over a 63-year period Installation of monitoring wells would require a minor degree of coordination with property owners	$6,529,520
Enhanced Bioremediation Using Sodium Lactate	Protective of human health and the environment through institutional controls and active treatment of contaminated groundwater	Complies with ARARs	Effective in the long-term. Permanently biodegrades TCE through active technologies TCE concentrations reduced to the NCAC 2L standards in 14 years after the sodium lactate injection program is completed	Toxicity and mass of TCE reduced through biodegradation processes	Effective in the short-term, as Health and Safety procedures will be implemented to reduce risk Would reduce the CVOC concentrations within the highly contaminated areas in approximately 1 year and through MNA to below the remedial levels across the site within 14 years	Implementable Treatment vendors and equipment readily available Installation of 85 injection wells and 10 monitoring wells would require coordination with property owners with some disruption to ongoing operations	$7,036,490

ARAR = Applicable or relevant and appropriate requirement.

NCAC = North Carolina Administrative Code.

TCE = Trichloroethene.

Appendices

APPENDIX A
FATE AND TRANSPORT MODELING

CONTENTS

TABLES

FIGURES

ACRONYMS

3-D	three dimensions
AT123D	Analytical Transient 1-, 2-, 3-Dimensional model
BGS	below ground surface
COC	chemical of concern
CVOC	chlorinated volatile organic compound
CY	calendar year
DCE	dichloroethene
DNAPL	dense, nonaqueous-phase liquid
F&T	fate and transport
FFS	Focused Feasibility Study
gpm	gallons per minute
MNA	monitored natural attenuation
NAD	Naval Ammunition Depot
NCAC	North Carolina Administrative Code
PCE	tetrachloroethene
psi	pounds per square inch
ROI	radius of influence
SADA	Spatial Analysis and Decision Assistance
TCE	trichloroethene
VC	vinyl chloride
VOC	volatile organic compound

A.1 FATE AND TRANSPORT MODELING

A1.1 INTRODUCTION

Monitored natural attenuation (MNA) is an appropriate remedial approach only where it can be demonstrated capable of achieving a site's remedial objectives within a reasonable timeframe. To determine whether MNA is an appropriate remedy for groundwater at a given site, fate and transport (F&T) modeling is performed to show that contaminants present in groundwater can be effectively remediated by natural attenuation processes. The following discussion summarizes the modeling performed for evaluating natural attenuation as a remedial alternative for the contaminated groundwater at the Former Naval Ammunition Depot (NAD) site in Charlotte, North Carolina. F&T modeling was also performed to support the evaluation of other feasible remedial alternatives presented in the Focused Feasibility Study (FFS) Report.

Initial F&T modeling conducted in 2004 was based on the available data set that consisted of data collected over a period of time from calendar year (CY) 2000 to CY 2004. The CY 2004 data were limited to a small area and, in defining the boundary of the contaminated plume area, the older set of data (mainly CY 2000) had the most influence. After the initial modeling effort was completed, recommendations were made to collect a comprehensive set of groundwater data to confirm the plume geometry and verify the results of the model. In August and September 2006, a sampling event was conducted to provide comprehensive groundwater analytical results for the monitoring wells located on the NAD site (SAIC 2008). These data were used to update the contaminant plume and verify and update the F&T model completed in CY 2005. Earlier, field tests were conducted to assess hydraulic conditions and to estimate hydraulic parameters of the aquifer, and the results of these tests were considered in developing mathematical (i.e., analytical, semi-analytical, or numerical) models to simulate groundwater flow and contaminant transport through the aquifer. It should be noted that the models were developed as screening tools using an analytical approach and, as such, they were not calibrated rigorously to site-wide conditions. The resulting models were used for certain components of the assessment.

A1.2 MODELING APPROACH

The modeling approach can be outlined as follows:

1. Develop the conceptual model for each distinct flow path, including contaminated soil, the groundwater plume, the flow path direction and characteristics, and the receptor location.

2. Identify the chemicals of concern (COCs) and select a surrogate chemical to represent the chemical group with conservatism. At the Former NAD site, the chlorinated volatile organic compounds (CVOCs) [e.g., tetrachloroethene (PCE); trichloroethene (TCE); *cis*-1,2-dichloroethene (DCE); *trans*-1,2-DCE; and vinyl chloride (VC)] were identified as the COCs in groundwater. A surrogate chemical was selected from the CVOCs detected at this site to limit the number of simulations. The selection of the surrogate chemical considered several chemical characteristics that included: (1) solubility in water, (2) mobility, (3) prevalence, and (4) degradation. TCE was the most prevalent chemical at the site (i.e., greatest mass) and has a high solubility in water and a low degradation rate; therefore, it was selected as the surrogate chemical representing the CVOCs for modeling.

3. Perform TCE trend analysis on the groundwater analytical data to determine the appropriate attenuation rate to be used for the MNA evaluation.

4. Perform saturated flow and contaminant transport modeling using the Analytical Transient 1-, 2-, 3-Dimensional (AT123D) model to predict the maximum concentrations of the selected COC at the receptor location using the existing groundwater plumes in the transition zone, as well as in the bedrock zone. This step required calibration of the models such that existing groundwater concentrations in the aquifers could be reasonably reproduced.

5. Using the results from Step 4, estimate the time necessary for TCE to be below the North Carolina Administrative Code (NCAC) 2L standards. Similarly, estimate the downgradient distance before TCE is reduced to its NCAC 2L standard.

6. Use the sodium lactate pilot test data to develop the enhanced biodegradation rates for TCE in both the groundwater zones (e.g., transition and bedrock zones).

7. Perform Step 4 with the enhanced biodegradation rates (developed in Step 6) and estimate the times necessary to reduce the maximum concentrations at the sources (both in the transition and bedrock zones) to below 500 µg/L.

8. Using the results from Step 7, calculate the number of sodium lactate injection events necessary for the sodium lactate with MNA alternative to be effective.

A1.3 MODEL SELECTED

AT123D is a well known and commonly used analytical groundwater pollutant F&T model. This model was developed by Yeh (1981) and has been updated by GSC. It computes the spatial-temporal concentration distribution of chemicals in the aquifer system and predicts the transient spread of a chemical plume through a groundwater aquifer. The F&T processes accounted for in AT123D are advection, dispersion, adsorption/retardation, and decay. This model can be used as a tool for estimating the dissolved concentration of a chemical in three dimensions (3-D) in groundwater resulting from a mass release (either continuous, instant, or depleting source) over a source area (i.e., point, line, area, or volume source).

A1.4 PARAMETERS

The hydrogeologic modeling parameters used in the modeling are based on findings from previous investigations (USACE 2000). The parameters are selected such that they are representative values and account for the variability in the hydraulic system and the most likely conditions within that variability. The hydrogeologic input parameters are presented in Table A-1.

The chemical-specific model parameters include the organic carbon partition coefficient, the soil-water distribution coefficient, diffusion coefficients in water, and the first-order decay constant. These are literature-based parameters and a conservative approach was always utilized for selecting the values of these parameters. The input parameters are presented in Table A-1.

A1.5 INITIAL MODEL APPLICATION AND RESULTS

The AT123D models were developed by calibrating the selected COC plumes both in the transition zone and in the bedrock zone groundwater. For a given COC, the AT123D model was used to compare the current dissolved-phase plume configuration of the COC with modeled values. The hydraulic conductivity value discussed above was combined with other aquifer and contaminant transport properties to develop the modeling runs of the COC. AT123D modeling was performed separately for the transition zone and the bedrock zone. In the following paragraphs, discussions of AT123D simulations of TCE in both the transition and bedrock zones to support the no action, MNA, and sodium lactate injection with MNA alternatives are provided.

A1.5.1 Trichloroethene in the Transition Zone Supporting the No Action and Monitored Natural Attenuation Alternatives

A near steady-state source was assumed for conservatism. In addition, five distinct plumes (hot spots) were observed in the transition zone. However, only one model representing the plume with the highest mass and concentration was developed. For this plume, the source size and loading were characterized through calibration. A continuous loading in the past was considered to create a plume similar to that observed in 2000 through 2004. (As discussed previously, the initial plumes were generated using data from CY 2000 through CY 2004; in general, most of the data were from CY 2000. Had there been data from all the monitoring wells in CY 2004, the shape of the plumes could have been different.) Thereafter, the model was run to assess natural attenuation. The breakthrough curves for multiple locations were predicted and compared to NCAC 2L standards for the assessment. Figure A-1 shows the results of this analysis. As shown in this figure, the concentrations of TCE would be reduced below NCAC 2L standards at all the wells in about 45 years from 2004.

A1.5.2 Trichloroethene in the Bedrock Zone Supporting the No Action and Monitored Natural Attenuation Alternatives

A near steady-state source was assumed for conservatism. Unlike the transition zone, a single large plume centered around SAIC 14 was observed. Therefore, only one AT123D model was developed and run to address the plume. The source size and loading were characterized through calibration. A continuous loading in the past was considered to create a plume similar to that observed in 2004. The 2004 plume was generated using the maximum concentrations from all wells collected during sampling events from CY 2000 through CY 2004. Thereafter, the model was run to assess natural attenuation. The breakthrough curves for multiple locations were predicted and compared to NCAC 2L standards for the assessment. Figure A-2 shows the results of this analysis. As shown in this figure, the concentrations of TCE would be reduced below NCAC 2L standards at all the wells in about 70 years from 2004.

A1.5.3 Trichloroethene in the Transition Zone Supporting the Sodium Lactate Injection with Monitored Natural Attenuation Alternative

To simulate this scenario, the AT123D no action model with revised source size and loading was utilized. All of the calibrated parameters from the previous model (i.e., no action model), except source loading and source size, were used in this simulation. Regarding the source loading, it was assumed that a certain mass in the source existed after the sodium lactate injection such that the concentrations around the source area were reduced to 500 μg/L. Lateral migrations to the receptors were performed using the AT123D model. The results of the modeling are presented in Figure A-3. As can be seen from this figure, the concentrations of TCE in the transition zone will be reduced to its NCAC 2L standard (2.8 μg/L) within 13 years due to natural attenuation after source reduction to 500 μg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 400 m (~1,312 ft) from the source (point of the maximum concentration) in each of the five identified transition zone plumes (hot spots) before being reduced to its NCAC 2L standard through natural attenuation.

A1.5.4 Trichloroethene in the Bedrock Zone Supporting the Sodium Lactate Injection with Monitored Natural Attenuation Alternative

To simulate this scenario, the AT123D no action model for the bedrock zone with revised source size and loading was utilized. All of the calibrated parameters from the previous model (i.e., no action model), except source loading and source size, were used in this simulation. Regarding the source loading, it was assumed that a certain mass in the source existed after the sodium lactate injection such that the concentrations around the source area were reduced to 500 μg/L. Lateral migrations to the receptors were performed using the AT123D model. The results of the modeling are presented in Figure A-4. As can be seen from this figure, the concentrations of TCE in the bedrock zone will be reduced to its NCAC 2L standard (2.8 μg/L) within 14 years due to natural attenuation after source reduction to 500 μg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 400 m (~1,312 ft) from the source or point of the maximum concentration (i.e., SAIC 14) in the bedrock zone plume before being reduced to its NCAC 2L standard through natural attenuation.

A1.5.5 Developing Sodium Lactate Injection Events based on Pilot Test Data

Concentrations versus time curves (see Appendix C) were developed for all of the monitoring wells within the zone of influence of the pilot test injection wells. An average time period of 60 days for the effectiveness of sodium lactate was identified through visual inspection of these plots. Assuming a first-order decay, the decay constants for each curve for this time period were estimated. The contributions due to dispersion and advection into these decay constants were subtracted to obtain the enhanced biodegradation rates. AT123D simulations were performed using these enhanced biodegradation rates. Results of these simulations indicated that TCE will be reduced to 500 μg/L within 1 year in the bedrock zone and within 6 months in the transition zone. However, because the time period for the effectiveness of sodium lactate after injection is only 60 days, four injection events in the transition zone and seven injection events in the bedrock zone will be required under the sodium lactate injection with MNA alternative.

A1.6 UPDATE AND CONFIRMATION OF THE FATE AND TRANSPORT MODEL

In September 2006, an additional sampling event was conducted at the Former NAD site to collect groundwater analytical data from the monitoring wells utilized in the Pilot Study. The purpose of the 2006 sampling event was to determine: (1) if the TCE plume geometry had changed, (2) if the F&T modeling results are still correct, and (3) if contaminant rebound is occurring.

A1.6.1 Plume Geometry

The CY 2006 sampling event was conducted to provide comprehensive groundwater analytical results for the monitoring wells located on the NAD site. Prior to the CY 2006 sampling, the CY 2004 data were the most recent; however, the CY 2004 data were limited to a small area defining the plume boundaries. Therefore, the older data (mainly CY 2000 data) along with the CY 2004 data were used to construct plume maps (Figures A-5 and A-6). The purpose of the CY 2006 sampling was to determine if the TCE plume geometry in the bedrock and transition zones had changed since the CY 2000 through CY 2004 sampling events. This evaluation was conducted to confirm that the plume sizes would have been significantly reduced since the CY 2000 sampling event (especially in the transition zone).

When the transition zone plume based on the CY 2000 through CY 2004 data (Figure A-5) is compared to the plume generated with the CY 2006 data (Figure A-7), it is obvious that the plume geometry has changed. The TCE plume has been significantly reduced and now more accurately resembles the hot spot areas identified by the Spatial Analysis and Decision Assistance (SADA) model (Section A2.3). Although there is some uncertainty associated with the plume size because data could not be obtained from wells in the northern portion of the site, the plume has reduced in size and there has been a significant loss of mass. A similar change in the plume geometry is also observed for the bedrock zone (Figure A-8).

A1.6.2 Fate and Transport Model

The data collected from the CY 2006 sampling event were used to update and validate the F&T model discussed in Section A1.5. The F&T model initially developed in the FFS was developed with data collected over a period of time (CY 2000 through CY 2004) instead of from a comprehensive event, and recommendations were made to update the model with data collected from a comprehensive event and confirm the results prior to completing this FFS.

To evaluate the F&T model discussed in Section A1.5, the following tasks were completed:

1. Revise concentration trends using the new data from CY 2006.

2. Develop the natural attenuation rate for each monitoring location using concentration trend results.

3. Rerun the AT123D model using the revised attenuation rates to confirm the previous results for the dissolved-phase plume.

4. Compare the attenuation rates with those developed earlier after the injection of sodium lactate.

5. Evaluate if there is a continuing source of dense, nonaqueous-phase liquid (DNAPL) present in the bedrock zone.

Decreasing concentrations of contaminants in the monitoring wells within the contaminant plume area are the first line of evidence for natural attenuation and indicate the effectiveness of natural attenuation in controlling the spread of the plume. Therefore, groundwater data over time were evaluated for all the monitoring wells exceeding North Carolina groundwater criteria for TCE (Tables A-2a and A-2b). First-order attenuation rates were then estimated from the concentration-over-time data for the monitoring wells showing decreasing trends. With the exception of only a few wells, generally decreasing trends were observed in most of the wells. For these wells, a first-order decay rate was estimated using the following equations:

$$C = C_o \times e^{-\lambda t},$$

where

C = biodegraded contaminant concentration,
Co = initial contaminant concentration,
λ = rate of degradation/attenuation,
t = time elapsed between initial and degraded concentration.

The above equation can be expressed as:

$$\lambda = \frac{-\ln(C/C_o)}{t}.$$

The degradation/attenuation rates of the volatile organic compounds (VOCs) in the plume are cumulative effects of biodegradation, dispersion and diffusion, advection, and sorption. Attenuation rates for TCE were updated using the CY 2006 data and compared to the attenuation rates developed for the modeling in Section A1.5. The comparison indicates that the attenuation rates for TCE were greater in CY 2004, at the end of the Pilot Study, than they are now. The CY 2006 data show that since the single sodium lactate injection event conducted in October 2003, the attenuation rates have significantly decreased over time, indicating that a sufficient amount of sodium lactate was not injected into the aquifer for complete degradation of the VOCs. As a result, the groundwater system has returned back to the original geochemical environment showing slow attenuation. The changes in attenuation rates are attributed to the sodium lactate injection indicating that the degradation/dechlorination rate of dissolved-phase TCE can be enhanced by injecting sodium lactate into the groundwater system.

A1.6.3 Confirmation of Previous Modeling Results

The AT123D models discussed in Section A1.5 were rerun using the revised attenuation rates determined based on the CY 2006 analytical data (Tables A-2a and A-2b). Based on this evaluation, the results of the models were confirmed for the dissolved-phase TCE plumes for both the transition and bedrock zones. Table A-3 provides a comparison of the previous modeling results and the updated model.

A1.6.4 Contaminant Rebound

Another uncertainty is the potential for contaminant rebound. Any enhanced remediation technique offers the potential for rebound. With sodium lactate, rebound would typically occur when not all of the contaminant is treated due to inadequate distribution within the aquifer and all of the sodium lactate is expended. Residual contamination would then diffuse out of un-remediated zones. As with the sodium lactate persistence rates, rebound characteristics are highly variable, site specific, and difficult to predict. Therefore, the site-wide sampling event conducted from August 29, 2006, through September 3, 2006, included collecting groundwater samples from the monitoring wells utilized in the Pilot Study with all samples analyzed for VOCs (Figures A-7 and A-8). For consistency, the eight wells that were used to evaluate the results of the Pilot Study (see Section 5) were selected for the contaminant rebound evaluation.

For the transition zone, three wells were selected: SAIC 17, SAIC 18C, and SAIC 19B. A review of the data for these wells (Table A-4) indicates that the sodium lactate injection was effective in reducing the TCE concentrations; however, contaminant rebound is also present. At SAIC 19B, effects of the sodium lactate injection are evident. The baseline concentration of 790 µg/L (October 2003) was reduced to a concentration of 29 µg/L (June 2004). However, the results of the CY 2006 sampling event show an increase in the TCE concentration with a result of 170 µg/L. Although the concentration is below the initial baseline values, the concentration is increasing. Similar behavior is also observed in SAIC 18C and SAIC 17, although only slightly.

For the bedrock zone, five wells were selected: SAIC 20; SAIC 21; NAD MW-23; SAIC 14, Zone 2; and SAIC 16A, Zone 2. In addition, NAD MW-21 and SAIC 14, Zone 7 were included because these wells are located in the source area. A review of the data in Table A-4 for these wells also indicates that the sodium lactate injection was effective in reducing the TCE concentrations and that contaminant rebound is occurring in all of the wells except for SAIC 21. In this well, TCE concentrations have been reduced from an initial baseline concentration of 390 µg/L in October 2003 to a concentration of 2.2 µg/L in CY 2006. At locations SAIC 20 and SAIC 14, Zone 2, TCE concentrations were significantly decreased immediately following the sodium lactate injections; however, the concentrations are beginning to rebound slightly. At locations NAD MW-21 and SAIC 14, Zone 7 (source area) and SAIC 16A, Zone 2, a complete rebound of the TCE concentration to above pre-injection levels has occurred.

Due to the limited volume of sodium lactate injected and the injection interval, the rebounded TCE (especially in the vicinity of NAD MW-21 and SAIC 14) likely is the result of the following:

- downward flux of dissolved-phase TCE,
- the presence of DNAPL in the bedrock matrix, and
- the flux of TCE from cross- and upgradient sources not treated by the initial injection zone of influence.

A1.6.5 Dense, Nonaqueous-Phase Liquid Evaluation

In 2001, immediately following the completion of SAIC 14, a test was conducted to determine if DNAPL was present in the groundwater in the source area. This was accomplished by placing a FLUTe™ ribbon into the corehole. After 4 hr, the colorimetric ribbon was removed and examined for colorimetric changes. The test indicated that DNAPL was not present in SAIC-14. However, highly contaminated groundwater samples were encountered in bedrock at monitoring well SAIC-14. Notably, TCE was detected at concentrations up to 160,000 μ/L in 2003 or approximately 15% of the water-solubility limit for TCE. Therefore, based on TCE dissolved-phase concentrations in the range of 1 to 10% or greater of the solubility, DNAPL is considered likely present at this site.

The presence of DNAPLs can also be determined by evaluating the increasing/fluctuating trends in the concentration of parent compounds (i.e., TCE) detected in this plume. In general, concentration trends in the vicinity of SAIC-14 decreased following the Pilot Study; however, this well demonstrates an overall increasing trend. In fact, at SAIC 14, Zone 7 [the 297- to 307-ft below ground surface (BGS) source area], a complete rebound of the TCE concentration to above pre-injection levels has occurred. The persistence of high concentrations suggests that residual sources may still be in place in the subsurface near these investigation areas. These potential DNAPLs provide a continuing source of contamination as they diffuse back out into the groundwater.

In summary, TCE DNAPL is suspected in the vicinity of SAIC-14 based on its: (1) presence at high concentrations, (2) increasing concentration trends, (3) persistence in the environment even though disposal activities ceased approximately 20 years ago, and (4) contaminant rebound after the Pilot Study.

A1.6.6 Dense, Nonaqueous-Phase Liquid Monitored Natural Attenuation Evaluation

Assuming the presence of DNAPL, a different modeling approach is conducted to evaluate natural attenuation. First, the TCE DNAPL mass at the source area was estimated by calculating the volume of residuum and bedrock that are presumed to be occupied by DNAPL, calculating the volume of pore space within the occupied volume, and assigning a fraction of the pore space volume that was assumed to retain DNAPL. The resulting volume of DNAPL is multiplied by the density of the compound (TCE) to determine the mass, thus:

DNAPL Volume = Area of the rock matrix where DNAPL is present,
× thickness of the rock matrix with DNAPL,
× porosity of the rock matrix,
× residual DNAPL saturation.

and

DNAPL Mass = DNAPL Volume × density of the DNAPL constituent (i.e., TCE)

Areas presumed to be occupied by DNAPL are based on plume drawings on which estimated DNAPL plumes are identified as areas with concentrations of TCE greater than 11 mg/L (i.e., SAIC 14 and NAD MW 21). The thickness of DNAPL was estimated from the vertical profile of the concentration observed in the Science Applications International Corporation multi-port wells. The bedrock porosity of 0.0043 and a residual saturation of 0.10 were assumed for the Former NAD site.

An updated calculation of the depletion rate and times was developed. First, an initial depletion rate (α) was calculated as:

$$\alpha = \frac{QCo}{M}$$

where

- Q = volumetric groundwater flux through the DNAPL source;
- C_o = concentration at time, t = 0 (i.e., currently observed maximum concentration at the DNAPL source area);
- M = calculated mass.

Then, the mass loading was calculated using the following equation:

$$\sum_i Mj = \sum_i QC_O \exp(-\alpha tj)$$

The calculated mass loadings were then applied to the AT123D model, which computes the spatial-temporal concentration distribution of chemicals in the aquifer system and predicts the transient spread of a chemical plume through a groundwater aquifer. An assumption was made that releases from the primary DNAPL source zone began approximately 20 years ago. The loading rates were slightly revised to match the predicted groundwater concentrations with the measured analytical data.

The AT123D transport model was developed using the available site-specific range of data and TCE concentrations. For the bedrock plume material, the U. S. Environmental Protection Agency default bulk density of 1,500 kg/m^3 was assumed. The effective porosity was assumed to be 0.0043. The fraction organic carbon content was set to be 0.002. Other site- and constituent-specific parameters are provided in Table A-1.

If the model-predicted results did not match the site plume behavior, then the initial depletion rate (α) and QC_o were revised to predict the contaminant plume behavior based on the observed data. Assuming a DNAPL source is present in the bedrock, the model predicts that it will take over 1,000 years for TCE to naturally attenuate to a concentration below the NCAC 2L standard.

A1.7 LIMITATIONS/ASSUMPTIONS

Listed below are important assumptions used in this analysis.

- The use of K_d and R_d to describe the reaction term of the transport equation assumes that an equilibrium relationship exists between the solid- and solution-phase concentrations and that the relationship is linear and reversible.

- An average attenuation rate for TCE was used for the MNA analysis that was based on historical groundwater analytical data (CY 2000 through CY 2004).

- An attenuation rate used in the sodium lactate analysis was based on the groundwater analytical data collected immediately following the Pilot Study injection.

- Flow and transport are not affected by density variations.

- The aquifer is homogenous and isotropic.

- A near steady-state contaminant-loading source to the aquifer is assumed for lateral transport.

The inherent uncertainties associated with using these assumptions must be recognized. K_d values for organic constituents are highly sensitive to organic carbon contents. Therefore, it is important that the values be measured or estimated under conditions that will represent as closely as possible those of the contaminant plume. It is also important to note that the contaminant plume will change over time and be affected by multiple solutes that are present at the site. Projected organic concentrations in the aquifer are uncertain because of the lack of site-specific data on constituent decay. Use of literature values (particularly K_d values) may produce either over- or underestimation of the constituents' concentrations in the aquifer. Deviations from assumed literature values may significantly affect contaminant fate predictions.

The effects of heterogeneity, anisotropy, and spatial distribution of fractures are not addressed in these simulations. The present modeling study using AT123D does not address the effects of flow and contaminant transport across interfaces in a sharply varying heterogeneous medium.

A.2 GROUNDWATER MODELING TO SUPPORT THE DESIGN OF THE SODIUM LACTATE INJECTION SYSTEM

A2.1 INTRODUCTION

As discussed previously, although several CVOCs were identified as COCs in the groundwater of the aquifers below the Former NAD site, TCE was chosen as the surrogate chemical representing all of the observed CVOCs because it is the primary COC and also the most prevalent contaminant at this site. It is expected that by addressing TCE, the rest of the CVOCs will be addressed. Therefore, plumes of TCE in the groundwater were delineated, and attempts were made to remediate (clean up) the groundwater using an injection system. Earlier, field observations (measurements) were conducted to characterize the plume, to assess hydraulic conditions, and to estimate hydraulic parameters of the aquifer. In this study, attempts are made to augment the characterization and to design the system. First, the observed data were evaluated for the augmentation. Second, the observed data and the resulting evaluation were used to develop a groundwater flow model. The injection system was designed using the model. Note that the model was developed as a screening tool and that the design should be interpreted with caution.

A2.2 SEQUENCE

A Pilot Study was conducted at the site in 2003 and 2004 to assess the applicability of enhanced bioremediation (sodium lactate injection) as a remedial alternative for the CVOC plumes observed in the transition zone and the bedrock zone. Observed data from the Pilot Study and the sampling event conducted in CY 2006 were analyzed using SEQUENCE to help the assessment.

A2.2.1 Description

SEQUENCE is a tool that provides an innovative approach for visualizing the effects of natural attenuation based on a modified radial diagram that may be used to simultaneously show spatial and temporal trends for multiple organic contaminants on the site map. Therefore, it was used to develop radial diagrams for selected wells both in the transition zone and bedrock zone at the Former NAD site. Figures A-9 and A-10 show the site plan with well locations along with radial diagrams for both the transition zone and the bedrock zone, respectively, generated by the SEQUENCE program depicting the degradation of the CVOCs. The radial diagrams plot TCE; *cis*-1,2-DCE; 1,1-DCE; PCE; and VC concentration changes over time. The time correlates to sampling events conducted during the Pilot Study and for CY 2006. A discussion of the results is provided in the following sections.

A2.2.2 Application to the Transition Zone Plume

Figure A-9 shows the impact of the sodium lactate injection on the TCE plume in the transition zone. Three monitoring wells and four monitoring events were selected to develop radial diagrams of the CVOCs and they were placed on a site map to show the impact. As explained earlier, these diagrams on the map show the spatial and temporal trends for priority contaminants in the plume.

The wells selected were SAIC 17, SAIC 18C, and SAIC 19B. Sodium lactate was injected in SAIC 18C and the response of the injection was monitored at these wells. The CVOCs evaluated include TCE; *cis*-1,1-DCE; PCE; and VC and show the reductive dechlorination of PCE and TCE. The events selected were the baseline event, Event 2, Event 4, and CY 2006. For each well, a radial diagram was developed using SEQUENCE and the diagram was placed on the site map.

At SAIC 17, the effects of the sodium lactate injection are evident. The radial diagram shows that after the initial injection, the TCE concentrations were reduced to levels well below the 2003 baseline concentrations (i.e., prior to the sodium lactate injection). However, as discussed in Section A.1.6.4, the 2006 sampling event showed an increase in the TCE concentrations, thus indicating that contaminant rebound is occurring. The radial diagram also shows that the TCE daughter products (e.g., *cis*-1,2-DCE; 1,1-DCE; and VC) are continuously increasing thereby indicating reductive dechlorination is occurring in this transition zone well. Similar behavior is also observed in SAIC 18C and SAIC 19B.

A2.2.3 Application to the Bedrock Zone Plume

Figure A-10 shows the impact of the sodium lactate injection on the TCE plume in the bedrock zone. Five monitoring wells and four monitoring events were selected to develop the CVOC radial diagrams that were placed on a site map to show the impact. Within the study area at the site, two multi-port monitoring wells (FLUTe™ systems) are present: SAIC 14 and SAIC 16A. Analytical results from Zone 2 were selected for presentation on the radial diagrams because the zones represent the trends observed in the bedrock wells.

The wells selected were NAD MW23; SAIC 14, Zone 2 (109 to 114 ft BGS); SAIC 16A, Zone 2 (83 to 103 ft BGS); SAIC 20; and SAIC 21. Sodium lactate was injected into SAIC 20 and the response of the injection was monitored at these wells. The contaminants selected for the CVOC diagrams were PCE; TCE; *cis*-1,2-DCE; *trans*-1,2-DCE; and VC to evaluate the reductive dechlorination of PCE and TCE. The events selected were the baseline event, Event 2, Event 8, and the 2006 sampling event. For each well, a radial diagram was developed using SEQUENCE and the diagram was placed on the site map.

During the Pilot Study, it was observed (Chapter 5.0 of the FFS) that although NAD MW23 is located ~200 ft upgradient from the injection point (SAIC 20), the effects of the sodium lactate injection were evident. The results of the CY 2006 sampling event shown on Figure A-10 indicate a complete rebound of all of the CVOC concentrations. Similar behavior is observed in SAIC 16, Zone 2. Results at SAIC 14, Zone 2; SAIC 20; and SAIC 21 indicate a similar trend with a slight increase in TCE concentrations from Event 8 to CY 2006, although much below the baseline concentrations. However, VC is continuously increasing in all these wells, thus indicating reductive dechlorination is occurring.

The data analysis indicates that a reductive geochemical environment is present in the aquifer and the reductive properties can be increased by enhancing the microbial activity of the *Dehalococcoides* population with the injection of an electron donor. Therefore, enhanced natural attenuation using sodium lactate is an effective technology for remediation of the CVOC contamination present in the groundwater at the Former NAD site.

A2.3 SPATIAL ANALYSIS AND DECISION ASSISTANCE

The extents of the plume in the transition and bedrock zones were delineated using SADA to design an injection system for remediating the areas with TCE concentrations >500 μg/L (hot spot or sources of the plume) through sodium lactate injection.

A2.3.1 Description

SADA addresses common environmental assessment issues by integrating and streamlining methods from multiple fields, as follows.

- data exploration and visualization,
- geographic information system,
- statistical analysis,
- human health risk assessment,
- ecological risk assessment,
- data screening and decision criteria,
- geospatial interpolation,
- uncertainty analysis,
- decision analysis, and
- sample design.

While SADA was developed within the context of environmental analysis, many of its processes were broadly constructed to deal with a wide array of problems concerning spatially distributed information.

A2.3.2 Application to the Transition Zone Plume

Figure A-11 shows the locations of monitoring wells on a site map for the study area. Data from these locations were used for characterizing contaminant concentrations. An attempt was made to delineate hot spots in the transition zone plume through the characterization of the TCE concentrations in the plume. In addition, the figure shows the domain selected for the characterization. A source model was set up for the domain. Observed data for the domain were compiled, and the contaminant concentration in every cell of the domain was predicted using geospatial interpolation. Observed data were available at scattered locations in the domain, and the interpolation was expected to smooth the predicted concentrations over the domain. The complete characterization involved geospatial interpolation of the data within the domain, a visual inspection of the results of the interpolation, and an analysis (post-processing) of the interpolation.

Figure A-12 shows the flood contour of the plume in two dimensions on a planer area of the domain. The contour was developed through geospatial interpolation. The nearest neighbor technique was used for the interpolation. This technique provided adequate contrast in concentration and ease in source delineation through visual inspection. The figure shows uncertainty directions in the characterization of the plume and uncertain (arbitrary) boundaries used for the characterization. The uncertainty is due to data limitation beyond these boundaries.

A2.4 MODFLOW/MODPATH

A 3-D model to simulate groundwater flow was developed using the MODFLOW (McDonald and Harbaugh 1988) simulator under the Groundwater Vistas (ESI 1999) environment. The flow of groundwater particles through the model was tracked using the MODPATH (Pollock 1989) simulator under the same environment. The particle tracks simulated by the model were used to delineate the capture zone of an injection well and, hence, to estimate the number of wells if the injection system for remediating the hot spots in the plume.

A2.4.1 Description

MODFLOW is a 3-D finite-difference groundwater simulator. It has a modular structure that allows it to be easily modified to adapt the code for a particular application. It simulates steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can be unconfined, potentially unconfined, or confined. It can simulate groundwater flow under stress (e.g., well, recharge, evapotranspiration, drain, and river). It can incorporate anisotropy (restricted to having the principal directions aligned with the grid axes) and heterogeneity in hydraulic conductivity and storage coefficient in a layer. It can also incorporate specified head and/or specified flux boundaries.

MODPATH is a particle-tracking simulator. It was designed to work with the MODFLOW simulator. MODPATH uses the output from steady or transient MODFLOW simulations to compute paths for imaginary "particles" of groundwater flowing through the groundwater system. In addition, MODPATH tracks the transport (travel) time of the particles moving through the system. MODPATH may be used to perform a wide range of analyses by carefully defining the starting locations of particles. Such analyses include delineating the capture zone, flow nets, recharge areas, and others.

A2.4.2 Model Set Up and Calibration for Steady Condition

The groundwater flow model for steady condition was developed in multiple steps. First, the domain of the model was set up in 3-D. Horizontally, the area of the model was extended sufficiently away from the center of the plume to reduce the impact of the boundary conditions on and around the center (Figure A-13). An area covering 2,397 by 2,288 ft was considered. Vertically, the model was extended from the ground surface through the transition zone and into a depth of 320 ft in the bedrock zone. The bottom elevation of the model in the bedrock zone was estimated using available data. The model was assumed to be an anisotropic, homogeneous flow system under steady-state within a zone. Two layers were considered. Layer 1, the top layer, represented the transition zone. The layer was considered an unconfined aquifer and its saturated thickness was observed to depend on the water table elevation and the bottom elevation of the transition zone. Layer 2, the bottom layer, represented the bedrock zone. The layer was considered a confined aquifer and its saturated thickness was observed to depend on the bottom elevations of the transition and bedrock zones. Second, the domain was set to boundary conditions. The observed groundwater level was contoured over the area of the model. Regional groundwater flow was assessed along the southwest to west direction. The contoured values at the boundaries were used to set constant-head boundary conditions throughout the entire boundaries of Layers 1 and 2. Third, the model was calibrated to the observed groundwater level data. The parameters of the model, including the boundary conditions, were adjusted through the calibration. Figure A-14 shows the results of the calibration. The model was assumed to be suitable for the design of the injection system.

A2.4.3 Model Set Up and Calibration for Transient Condition

The groundwater flow model for the transient condition was developed by updating the model for the steady condition in multiple steps. First, the model for the steady condition was updated to three layers, discretizing Layer 2 for the bedrock zone with a thickness of about 320 ft into two layers: the upper layer (i.e., the new Layer 2) with a thicknesses of 55 ft and the bottom layer (i.e., the new Layer 3) with a thickness of 265 ft. Layer 2 was introduced to focus on the upper part of the bedrock zone. Second, the resulting model was updated for the transient condition. The specific yield of Layer 1 was estimated by calibrating to the maximum mounding observed at SAIC 19B due to injection at SAIC 18C during the Pilot Study. An injection rate of 1.2 gallons per minute (gpm) over 2 days was considered to simulate the mound. The specific yield was estimated as 0.025, noting the maximum mounding as 0.2 ft. Similarly, the storage coefficients of Layers 2 and 3 were estimated by calibrating to the maximum mounding observed at SAIC 21 due to injection at SAIC 20 during the Pilot Study. An injection rate of 5 gpm over 2 days was considered to simulate the mound. The storage coefficient was estimated as 4E-6, noting the maximum mounding as 1.5 ft.

A2.4.4 Injection System for the Transition Zone Plume

An injection system for the transition zone plume was designed in multiple steps. First, the treatment area was estimated as 14.1 acres based on the five TCE plumes (hot spots) bounded by 500 μg/L that were developed by SADA (Figure A-11). Second, an injection scenario was conceptualized considering the Pilot Study and the capture area for the scenario was estimated. The scenario conceptualized considered an injection well at SAIC 18C injecting sodium lactate solution into the transition zone plume at an injection rate of 1.5 gpm for 2 days followed by 58 days of transport under ambient (natural) groundwater conditions. The capture area for this scenario was estimated to be 0.26 acre (Figure A-15). Third, the number of wells required for the injection system to capture the treatment area was estimated to be 14.1/0.26 or 54.2. Therefore, the injection system was expected to include 54 wells.

A2.4.5 Injection System for the Bedrock Zone Plume

An injection system for the bedrock zone plume was designed in multiple steps. First, the treatment area was estimated to be 32 acres based on the TCE plumes bounded by 500 μg/L. Second, an injection scenario was conceptualized considering the Pilot Study and the capture area for the scenario was estimated. The scenario conceptualized considered an injection well at SAIC 20 injecting sodium lactate solution into the bedrock zone plume at an injection rate of 6 gpm for 2 days followed by 58 days of transport under ambient groundwater condition. The capture area for the scenario was estimated to be 1.05 acres (Figure A-16). Third, the number of wells needed to cover the treatment area was estimated to be 32.3/1.05 or 31. Therefore, the injection system was expected to include 31 wells.

A2.5 CONCLUSION

In this FFS, the following conclusions were drawn.

1. Radial diagrams suggested that sodium lactate injection is suitable for reductive dechlorination of the TCE plume. In addition, the diagrams suggested that sodium lactate contributed to the reduction over 60 days since the injection.

2. Data analysis suggested the observed data to be limited for delineation of the transition zone plume. A need for additional sampling was observed to address the limitation. A need for accurate delineation of the plume(s) was observed for efficient design of the injection system for the bedrock zone plume.

3. Mathematical modeling suggested a need for an injection system with 54 wells for remediating the transition zone plume. In contrast, the modeling suggested a need for an injection system with 31 wells for remediating the bedrock zone plume.

A.3 MODELING TO SUPPORT THE DESIGN OF THE BROMIDE TRACER TEST

The distance that the bromide tracer would travel in the bedrock zone and the transition zone during the Pilot Study was estimated by calculating the flow velocities under ambient conditions and the radius of influence (ROI) and height of mounding during the injection. The following sections present the predicted travel distance results for the bedrock and transition zones.

A3.1 BEDROCK ZONE

Hydraulic conductivity (K), hydraulic gradient (I), effective porosity (n_e), and groundwater flow velocity (Vs) were used to calculate the distance that the tracer would travel (X) in the bedrock zone under ambient conditions.

Hydraulic conductivity values reported in Table 4-3 of the *Revised Final Phase II Remedial Investigation Report* (USACE 2000) were used as a basis to estimate the flow rates for the bromide tracer injected into the bedrock. Using these values, a geometric mean hydraulic conductivity value of 3.24E-4 was calculated for the bedrock. This K value was found to correspond with the upper end of published ranges for fractured bedrock (Domenico and Schwartz 1990). A hydraulic gradient (I) of 0.007 was estimated using the available potentiometric surface maps created for the Former NAD site (SAIC 2003).

A range of effective porosity (n_e) calculations was used in calculating flow velocity at the site, thereby creating a range of flow velocities. First, the effective porosity of NAD MW21 was calculated using the formula n_e=2b/B where n_e is the effective porosity, 2b is the average fracture aperature, and B is the average fracture spacing (Solomon et al. 1992). Fracture aperature and spacing were found in the acoustic televiewer logs presented in the Final Phase II Report (USACE 2000). The average fracture spacing was 20 ft and the average fracture aperature was 1.03 in., thus resulting in an effective porosity of 0.0043 for the lower bound of the range. To estimate the upper bound of the range, an effective porosity of 0.01 was used in the calculation. This value is associated with fractured crystalline bedrock and was taken from Table 2.2 of *Physical and Chemical Hydrogeology* (Domenico and Schwartz 1990). Therefore, the resulting velocities for the bedrock were calculated to range from 5.27E-04 cm/sec or 1.5 ft/day (using the lower bound range of effective porosity) to 2.27E-04 cm/sec or 0.64 ft/day (using the upper bound range of effective porosity).

Based on these estimated flow velocities, it was determined that under ambient conditions, the tracer would travel a minimum distance of 112 ft and a maximum distance of 263 ft in the bedrock during the 175-day (6-month) monitoring period (Table A-5).

For the tracer test, a conservative tracer (bromide) will be injected over a 5-day period with monitoring to occur over a 6-month (175-day) period. During the injection phase, the injected solution will create a mounding effect on top of the water table that will extend the delivery of the solution in a radial pattern around the injection point. This ROI caused by injection was calculated to more closely estimate the distance an injected solution would travel during the 6-month monitoring phase of the Pilot Study. The height of the mound above the water table surface was also calculated to estimate the force [pounds per square inch (psi)] required to pump the tracer into the bedrock zone.

Assuming confined conditions, the ROI (R) and height of mounding (s_w) were calculated for the bedrock zone using the following equation (Bear 1979):

$$R = 3000 s_w K^{1/2};\ s_w (Q_w/2\pi T)\ln(R/r_w)$$

where

R = ROI,
K = hydraulic conductivity,
sw = height of mound (draw down),
Qw = volumetric flow (injection) rate,
T = transmissivity,
rw = radius of injection well.

The equations were solved simultaneously by the trial and error method with the ROI and mound height calculated to 3- and 4-gpm injection rates. The range of distances the conservative tracer will travel during the monitoring period was then predicted by adding the travel distance determined under ambient conditions (X) to the calculated ROI (R). Given the ranges estimated for X, the tracer is estimated to travel a minimum of 177 ft and a maximum of 354 ft for the bedrock zone (Table A-5).

A3.2 TRANSITION ZONE

As discussed for the bedrock zone, hydraulic conductivity (K), hydraulic gradient (I), effective porosity (n_e), and groundwater flow velocity (Vs) were used to calculate the distance the tracer would travel (X) in the transition zone under ambient conditions.

A geometric mean hydraulic conductivity value of 4.6E-4 cm/sec was estimated from slug test values for NAD MW18, NAD MW 24, and NAD MW 31 reported in the Final Phase II RI Report (USACE 2000). A hydraulic gradient (I) of 0.006 was estimated using the available potentiometric surface maps created for the Former NAD site (SAIC 2003). The effective porosity (n_e) of 0.10 was determined considering the values reported in Table 6-2 of the Final Phase II RI Report (USACE 2000). Therefore, groundwater flow velocity was estimated as 2.6E-5 cm/sec or 0.078 ft/day. Considering a 6-month (175-day) monitoring period, it was determined that under ambient conditions, the tracer would travel a distance of 14 ft in the transition zone (Table A-5).

As previously discussed for the bedrock zone, a conservative tracer (bromide) will be injected over a 5-day period with monitoring to occur over a 6-month (175-day) period. During the injection phase, the injected solution will create a mounding effect on top of the water table that will extend the delivery of the solution in a radial pattern around the injection point. This ROI caused by injection was calculated to more closely estimate the distance an injected solution would travel during the 6-month monitoring phase of the Pilot Study. The height of the mound above the water table surface was also calculated to estimate the force (psi) required to pump the tracer into the transition zone.

ROI (R) and height of mounding (s_w) were calculated for the transition zone using Dupuit assumptions (Bear 1979):

$$R = 3000 s_w K^{1/2}; \quad s_w = (1/(H_o+h))*(Q_w/2\pi K)\ln(R/r_w)$$

where

R	=	ROI,
K	=	hydraulic conductivity,
sw	=	height of mound (draw down),
Qw	=	volumetric flow (injection) rate,
Ho	=	initial aquifer thickness,
h	=	height of the water column in the pumping/injection well,
rw	=	radius of injection well.

The equations were solved simultaneously by the trial and error method with the ROI and mound height calculated for 1- and 2-gpm injection rates. The distance the conservative tracer will travel during the monitoring period was then predicted by adding the travel distance determined under ambient conditions (X) to the calculated ROI (R). Given the estimated value for X, the tracer is estimated to travel a minimum of 54 ft and a maximum of 73 ft for the transition zone (Table A-5).

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TABLES

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Table A-1. Parameters for AT123D Modeling at the Former NAD Site

Parameter	Symbol	Unit	Transition Zone Value	Transition Zone Source	Bedrock Zone Value	Bedrock Zone Source
Source Area Length	L	m	5.00	a	10.00	a
Source Area Width	W	m	3.00	a	4.00	a
Source Area Depth	D	m	2.00	a	2.00	a
Soil Bulk Density	ρ	kg/m^3	1500.00	b	1500.00	b
Effective Porosity	n_e	unitless	0.025	c	0.0043	c
Hydraulic Conductivity	K	m/hr	0.10	d	0.0742	d
Hydraulic Gradient	I	unitless	8.80E-03	c	7.00E-03	c
Water Density	ρ_w	kg/m^3	1000.00	d	1000.00	d
Dispersivity (Longitudinal)	α_L	m	15.00	a	18.00	a
Dispersivity (Transverse)	α_T	m	5.00	a	6.00	a
Dispersivity (Vertical)	α_V	m	1.50	a	1.80	a
Fraction of Organic Carbon	f_{oc}	unitless	2.00E-03	b	2.00E-03	b
Molecular Diffusion Coefficient	D_w	m^2/hr	3.27E-06	e	3.27E-06	e
Biodegradation Rate	λ	1/hr	4.00E-05	a	4.00E-05	a
Distribution Coefficient	K_d	m^3/kg	1.88E-04	f	1.88E-04	f

a. Calibrated.
b. U. S. Environmental Protection Agency default.
c. Site-specific data analysis.
d. Site-specific.
e. USEPA 1996.
f. Estimated value based on partition coefficient (Koc) as Kd = foc x Koc.
AT123D = Analytical Transient 1-, 2-, 3-Dimensional model.
NAD = Naval Ammunition Depot.

Table A-2a. Summary of Natural Attenuation Rates

Station	Type	Depth Interval (ft)	Baseline Concentration of TCE (µg/L)	Duration of Enhanced Degradation (day)	TCE Concentration after Enhanced Degradation (µg/L)	First-Order Degradation Rate after the Injection (1/d)	First-Order Degradation Rate up to CY 2006 (1/d)	Peak Concentration After Injection (µg/L)	Concentration at Event 8 (µg/L)	Concentration in 2006 (µg/L)
SAIC-20	Injection well (Bedrock)	80 – 100	1,800	61	13	8.08E-02	1.29E-03	29	2.6	17.0
SAIC-19B	Transition MW	9 – 19	790	60	77	3.88E-02	7.60E-04	1,100	29	170
SAIC-14	Multi-port MW	62 – 72	3,300	60	2,300	6.02E-03	8.30E-04	7,500	1,800	1,300
	(Bedrock)	109 – 114	3,600	60	23	8.42E-02	increasing	320	250	280
		126 – 135	12,000	60	410	5.63E-02	7.50E-04	1,200	65	480
		139 – 144	27,000	60	620	6.29E-02	9.50E-04	6,100	390	1,200
		199 – 210	6,000				3.80E-04	160,000	120,000	29,000
		250 – 264	4,700				2.34E-03	110,000	64,000	8,300
		297 – 307	19,000				increasing	29,000	14,000	40,000
NAD MW-20	Bedrock MW	51 – 61	82	251	62	1.11E-03	9.85E-04	62	62	66
NAD MW-21	Bedrock MW	20 – 70	5,600	251	2,800	2.76E-03	1.52E-04	7,600	2,800	6,700
SAIC-21	Bedrock MW	94 – 104	390	60	45	3.60E-02	2.85E-03	45	2.3	2.2
NAD MW-23	Transition MW	21 – 71	52	252	27	2.60E-03	increasing	63	27	150
SAIC-16A	Multi-port MW	58 – 65	110	91	4.1	3.61E-02	increasing	270	260	130
	(Bedrock)	83 – 103	8	58	1	3.59E-02	increasing	4.4	4.2	49
		122 – 129	680	91	17	4.05E-02	increasing	740	350	340
		160 – 165	480	91	1.6	6.27E-02	increasing	480	270	350
		191 – 199	1,100	48	760	7.70E-03	6.62E-04	1,100	770	450
		295 – 305	140	48	56	1.91E-02	increasing	180	130	290
SAIC-18C	Injection well (TZ)	8 – 13	6.2	62	0.880	3.15E-02	increasing	1.9	0.72	2.50
SAIC-17	Transition MW	5 – 10	73	36	23	3.21E-02	3.55E-04	23	4.8	23.0
NAD MW-19	Transition MW	32 – 42	17	27	13	9.94E-03	1.64E-03	14	10	11
NAD MW-31	Transition MW	20 – 30	910				0.00123	2,200	2,000	470
NAD MW-32	Transition MW	9 – 29	560	176	220	5.31E-03	increasing	300	300	570

CY = Calendar year.
TCE = Trichloroethene.

Table A-2b. Summary of Natural Attenuation Rates for Remaining Wells

Station	First-Order Degradation Rate up to CY 2006 (1/day)	Last Observed Concentration Prior to CY 2006 (μg/L)	Month and Year of Observation	Concentration in 2006 (μg/L)
SAIC-13	6.40E-04	258	Dec-00	68
SAIC-12	1.10E-03	289	Dec-00	32
SAIC-10	4.60E-04	49.1	Dec-00	19
SAIC-15 (1)	2.75E-03	140	Oct-03	7.9
SAIC-15 (2)	increasing	750	Oct-03	1,100
SAIC-15 (3)	increasing	15	Oct-03	580
SAIC-15 (4)	increasing	17	Oct-03	420
SAIC-15 (5)	increasing	42	Oct-03	70
SAIC-09	5.69E-04	9.8	Dec-00	3
SAIC-05	1.10E-04	41	Oct-02	22
NAD MW-22	increasing	440	Jun-04	2,100
NAD MW-25	increasing	2,330	Dec-00	3,200
NAD MW-26	6.10E-04	6,600	Oct-02	2,800
NAD MW-27	3.30E-03	2,800	Oct-02	25
NAD MW-28	4.11E-04	3,400	Oct-02	1,900
NAD MW-29	2.02E-03	3,300	Oct-02	190
NAD MW-30	5.66E-04	330	Jun-04	210
NAD MW-33	1.06E-03	790	Oct-02	250
NAD MW-34	0.00102	140	Oct-02	33
NAD MW-37	NA	320	Oct-02	NA
NAD MW-38	NA	290	Oct-02	NA
NAD MW-40	8.00E-04	304	Dec-00	57
NAD MW-41	0.00245	300	Nov-01	3
NAD MW-42	increasing	1,700	Nov-01	2,000
NAD MW-43	0.00066	3,600	Oct-02	820
NAD MW-45	0.000913	8.8	Dec-00	1.3
NAD MW-49	increasing	1,900	Oct-02	3,900
NAD MW-51	0.00033	3,200	Oct-02	2,000
NAD MW-52	0.00119	1,300	Oct-02	210
NAD MW-56	NA	70	Oct-02	NA
NAD MW-58	NA	6,200	Oct-02	NA
NAD MW-64	0.000062	273	Dec-00	240

CY = Calendar year.
NA = Not applicable.

Table A-3. Comparison of Modeled Times to Reach MCLs for the Dissolved-Phase TCE Plume

Plumes	COC	Time to MCL (year)	
		Previous Model	Revised Model
Model Supporting No Action and MNA for the Dissolved-Phase Plume			
Transition Zone	TCE (dissolved phase)	45	47
Bedrock Zone	TCE (dissolved phase)	70	63
Model Supporting the Sodium Lactate Injection to 500 µg/L			
Transition Zone	TCE (dissolved phase)	0.5	0.5
Bedrock Zone	TCE (dissolved phase)	1	1
Model Supporting MNA to 2.8 µg/L Following the Sodium Lactate Injection to 500 µg/L			
Transition Zone	TCE (dissolved phase)	13	14
Bedrock Zone	TCE (dissolved phase)	14	12

COC = Chemical of concern.
MCL = Maximum contaminant level.
MNA = Monitored natural attenuation.
TCE = Trichloroethene.

Table A-4. Summary of TCE Concentrations in the Groundwater at the Former NAD Site

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
CCMW-10	Shallow Zone	? – 20	06/07/99	<0.17
			09/01/06	<2.0
CCMW-10I	Bedrock Zone	? – 62.5	06/07/99	**6.4**
			12/13/00	1.7 =
			09/01/06	**3.4 =**
NAD HP-11[b]	Shallow Zone	3.9 – 8.9	06/07/99	<0.17
NAD MW-18	Shallow Zone	1.5 – 6.5	06/07/99	**330**
			06/27/04	<1.0
			08/30/06	<2.0
NAD MW-19	Transition Zone	31.8 – 41.8	06/07/99	**1,600**
			12/07/00	**294 =**
			10/22/02	**40 =**
			10/17/03	**17 J**
			12/20/03	**13 =**
			04/15/04	**14 =**
			06/26/04	**10 =**
			08/29/06	**11 =**
NAD MW-20	Bedrock Zone	51.2 – 61.2	06/07/99	**920 =**
			12/07/00	<1.0
			11/08/01	**370 =**
			10/22/02	**190 =**
			10/19/03	**82 =**
			06/26/04	**62 =**
			08/29/06	**66 =**
NAD MW-21	Bedrock Zone	19.5 – 69.5	06/07/99	**61, 000**
		30[c]	12/15/00	**14,100 =**
		45[c]	12/18/00	**7,160 =**
		68[c]	12/19/00	**3,590 =**
		19.5 – 69.5	10/19/03	**5,600 =**
		19.5 – 69.5	11/25/03	**7,600 =**
		19.5 – 69.5	06/26/04	**2,800 J**
		19.5 – 69.5	09/02/06	**6,700 =**
NAD MW-22	Bedrock Zone	24.5 – 74.5	06/07/99	**9,900**
			12/08/00	**1,110 =**
			10/20/02	**310 J**
			10/18/03	**130 =**
			06/27/04	**440 =**
			09/02/06	**2,100 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
NAD MW-23	Bedrock Zone	20.5 – 70.5	06/07/99	**560**
			12/08/00	**160 =**
			10/22/02	**7.6 =**
			10/19/03	**52 =**
			11/25/03	**63 =**
			06/27/04	**27 J**
			09/03/06	**150 =**
NAD MW-24	Transition Zone	6.5 – 16.5	06/07/99	**4,300**
			12/06/00	**2,930 =**
			10/20/02	**4.7 =**
			09/02/06	<2.0
NAD MW-25	Transition Zone	9.0 – 19.0	06/07/99	**2,900**
			12/06/00	**2,330 =**
			09/01/06	**3,200 =**
NAD MW-26	Bedrock Zone	30.0 – 40.0	06/07/99	**4,100**
			10/21/02	**6,600 J**
			09/01/06	**2,800 =**
NAD MW-27	Transition Zone	15.5 – 25.5	06/07/99	**5,500**
			10/18/02	**2,800 =**
			09/03/06	**25 =**
NAD MW-28	Bedrock Zone	30.0 – 40.0	06/07/99	**6,600**
			10/21/02	**3,400 J**
			09/03/06	**1,900 =**
NAD MW-29	Bedrock Zone	30.0 – 40.0	06/07/99	**1,200**
			10/21/02	**3,300 J**
			09/03/06	**190 =**
NAD MW-30	Transition Zone	20.4 – 30.4	06/07/99	**590**
			10/23/02	**160 J**
			10/21/03	**210 J**
			02/20/04	**250 =**
			04/15/04	**450 =**
			06/25/04	**330 =**
			09/02/06	**210 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
NAD MW-31	Transition Zone	20.0 – 30.0	06/07/99	**270**
			11/07/01	**7,600 =**
			10/23/02	**1,300 J**
			10/23/03	**910 =**
			01/22/04	**1,200 =**
			04/15/04	**2,200 =**
			06/27/04	**2,000 J**
			08/30/06	**470 =**
NAD MW-32	Transition Zone	9.0 – 29.0	06/07/99	**2,500**
			11/07/01	**680 =**
			10/23/02	**55 J**
			10/22/03	**560 =**
			04/15/04	**220 =**
			06/27/04	**300 =**
			08/30/06	**570 =**
NAD MW-33	Transition Zone	4.0 – 24.0	06/07/99	**3,700**
			12/14/00	**2,520 =**
			10/18/02	**790 =**
			09/02/06	**250 =**
NAD MW-34	Transition Zone	4.0 – 14.0	06/07/99	**490**
			10/18/02	**140 =**
			09/02/06	**33 =**
NAD MW-35[b]	Transition Zone	21.6 – 26.6	06/07/99	**3.5 J**
NAD MW-36[b]	Bedrock Zone	12.0 – 22.0	06/07/99	**30**
			12/12/00	**85.2 =**
NAD MW-37[b]	Transition Zone	9.2 – 12.2	06/07/99	**840**
			12/14/00	**1,030 J**
			10/18/02	**320 =**
NAD MW-38[b]	Transition Zone	14.5 – 24.5	06/07/99	**300**
			12/13/00	**436 =**
			10/18/02	**290 J**
NAD MW-39[b]	Transition Zone	10.0 – 20.0	06/07/99	**32**
			12/11/00	**86.3 =**
NAD MW-40	Transition Zone	23.0 – 33.0	06/07/99	**380**
			12/11/00	**304 =**
			08/31/06	**57 =**
NAD MW-41	Shallow Zone	8.0 – 18.0	06/07/99	**61**
			12/11/00	**380 =**
			11/08/01	**300 =**
			09/01/06	**2.8 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
NAD MW-42	Transition Zone	20.5 – 30.5	06/07/99	**1,200**
			11/08/01	**1,700 J**
			09/01/06	**2,000 =**
NAD MW-43	Bedrock Zone	70.5 – 80.5	06/07/99	**920**
			12/11/00	**2,960 =**
			11/08/01	**2,800 =**
			10/21/02	**3,600 J**
			09/01/06	**820 =**
NAD MW-44	Transition Zone	10.0 – 20.0	06/07/99	**60**
			10/21/02	1.7 J
			09/03/06	<2.0
NAD MW-45	Shallow Zone	4.0 – 9.0	06/07/99	**4.6**
			12/07/00	**8.8 =**
			09/02/06	1.3 J
NAD MW-46	Transition Zone	7.0 – 17.0	06/07/99	**600**
			10/21/02	<1.0
			09/03/06	<2.0
NAD MW-47	Transition Zone	3.0 – 13.0	06/07/99	**61**
			09/03/06	<2.0
NAD MW-48	Transition Zone	12.0 – 22.0	06/07/99	**2,200**
			08/30/06	**160 =**
NAD MW-49	Transition Zone	19.0 – 29.0	06/07/99	**1,600**
			10/23/02	**1,900 J**
			09/02/06	**3,900 J**
NAD MW-50	Transition Zone	9.8 – 19.8	06/07/99	**3.8**
			08/31/06	**74 =**
NAD MW-51	Bedrock Zone	20.0 – 30.0	06/07/99	**340**
			10/23/02	**3,200 J**
			08/31/06	**2,000 =**
NAD MW-52	Transition Zone	19.5 – 29.5	06/07/99	**670**
			12/08/00	**2,340 =**
			11/07/01	**1,900 =**
			10/21/02	**1,300 J**
			8/31/06	**210 =**
NAD MW-53	Transition Zone	10.0 – 20.0	06/07/99	<0.17
			8/31/06	<2.0
NAD MW-54	Transition Zone	18.0 – 28.0	06/07/99	2.1
			08/31/06	<2.0
NAD MW-55	Transition Zone	7.0 – 17.0	06/07/99	**610**
			09/03/06	**48 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
NAD MW-56[b]	Transition Zone	17.0 – 27.0	06/07/99	**140**
			11/08/01	**72 =**
			10/17/02	**70 =**
NAD MW-57[b]	Transition Zone	9.0 – 19.0	06/07/99	**3,800**
			12/12/00	**4,610 =**
NAD MW-58[b]	Transition Zone	16.0 – 26.0	06/07/99	**5,600**
			12/12/00	**4,140 =**
			10/21/02	**6,200 =**
NAD MW-59[b]	Shallow Zone	4.0 – 14.0	06/07/99	0.18
NAD MW-60[b]	Transition Zone	11.8 – 21.8	06/07/99	<0.17
NAD MW-61[b]	Transition Zone	14.0 – 24.0	06/07/99	**4.5 J**
NAD MW-62[b]	Transition Zone	17.0 – 27.0	06/07/99	0.30
NAD MW-63[b]	Transition Zone	12.5 – 22-5	06/07/99	0.21 J
NAD MW-64	Transition Zone	18.0 – 28.0	06/07/99	**280**
			12/13/00	**273 =**
			09/01/06	**240 =**
NAD MW-65[b]	Transition Zone	27.0 – 37.0	06/07/99	**380**
			12/12/00	**187 =**
VERSAR-09[b]	Bedrock Zone	? – 38	12/05/94	**16**
			06/07/99	2.7 J
VERSAR-12[b]	Shallow Zone	? – 20	12/05/94	1.2
			06/07/99	1.1
VERSAR-17[b]	Transition Zone	? – 15	06/07/99	**390**
			12/15/00	**627 J**
VERSAR-18[b]	Transition Zone	? – 33	06/07/99	**2,500**
			10/21/02	**310 J**
VERSAR-20[b]	Bedrock Zone	23.8 – 33.8	12/08/00	**706 =**
VERSAR-22[b]	Bedrock Zone	40.0 – 50.0	12/05/94	**77**
			06/07/99	**200**
			12/13/00	**200 =**
VERSAR-26[b]	Transition Zone	6.3 – 21.3	12/05/94	**29**
			06/07/99	**16**
SAIC 01	Transition Zone	19.7 – 29.1	12/15/00	<1.0
			08/30/06	<2.0
SAIC 02	Bedrock Zone	41.8 – 51.3	12/15/00	0.68 J
			11/08/01	<1.0
			10/20/02	<1.0
			08/30/06	<2.0
SAIC 03	Transition Zone	17.7 – 27.6	08/31/06	**14 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
SAIC 04	Bedrock Zone	50.0 – 60.0	12/19/00	**11.4 =**
			09/03/06	<2.0
SAIC 05	Bedrock Zone	64.3 – 73.3	12/19/00	**15.1 =**
			11/07/01	**68 =**
			10/20/02	**41 =**
			8/31/06	**22 =**
SAIC 06	Shallow Zone	19.0 – 29.0	12/18/00	<1.0
			09/02/06	<2.0
SAIC 07	Bedrock Zone	40.0 – 60.0	12/19/00	1.7 =
			10/17/02	1.1 =
			09/2/06	<2.0
SAIC 08	Shallow Zone	5.1 – 15.1	12/14/00	1.1 =
			08/31/06	<2.0
SAIC 09	Bedrock Zone	25.1 – 40.1	12/20/00	**9.8 =**
			08/31/06	**3 =**
SAIC 10	Bedrock Zone	53.8 – 68.8	12/20/00	**49.1 =**
			08/31/06	**19 =**
SAIC 11	Shallow Zone	4.4 – 14.4	12/19/00	0.38 J
			08/31/06	<2.0
SAIC 12	Bedrock Zone	25.5 – 35.0	12/19/00	**289 =**
			08/31/06	**32 =**
SAIC 13	Bedrock Zone	44.5 – 54.5	12/19/00	**258 =**
			08/31/06	**68 =**
SAIC 14 – Interval 1	Multi-port Bedrock Zone	62 – 72	10/20/03	**3,300 =**
			11/24/03	**7,500 =**
			12/19/03	**2,300 J**
			01/21/04	**1,900 =**
			02/20/04	**1,200 =**
			04/14/04	**1,800 =**
			06/26/04	**1,800 J**
			09/01/06	**1,300 =**
SAIC 14 – Interval 2	Multi-port Bedrock Zone	109 – 114	10/20/03	**3,600 =**
			11/24/03	**320 =**
			12/19/03	**23 =**
			01/21/04	**22 =**
			02/20/04	**29 =**
			04/14/04	**81 =**
			06/26/04	**250 J**
			09/01/06	**280 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
SAIC 14 – Interval 3	Multi-port Bedrock Zone	126 – 135	10/20/03	**12,000 =**
			11/24/03	**1,200 =**
			12/19/03	**410 J**
			01/21/04	**360 J**
			02/20/04	**65 =**
			04/14/04	**120 =**
			06/26/04	**65 J**
			09/01/06	**480 =**
SAIC 14 – Interval 4	Multi-port Bedrock Zone	139 – 144	10/20/03	**27,000 J**
			11/24/03	**6,100 =**
			12/19/03	**620 J**
			01/21/04	**1,100 J**
			02/20/04	**390 =**
			04/14/04	**790 J**
			06/26/04	**390 J**
			09/01/06	**1,200 =**
SAIC 14 – Interval 5	Multi-port Bedrock Zone	199 – 210	10/20/03	**6,000 =**
			11/24/03	**120,000 =**
			12/19/03	**160,000 =**
			01/21/04	**97,000 =**
			02/20/04	**18,000 J**
			04/14/04	**84,000 =**
			06/26/04	**120,000 =**
			09/01/06	**29,000 =**
SAIC 14 – Interval 6	Multi-port Bedrock Zone	250 – 264	10/20/03	**4,700 =**
			11/24/03	**110,000 J**
			12/19/03	**85,000 J**
			01/21/04	**20,000 =**
			02/20/04	**34,000 =**
			04/14/04	**57,000 J**
			06/26/04	**64,000 J**
			09/01/06	**2,800 =**
SAIC 14 – Interval 7	Multi-port Bedrock Zone	297 – 307	10/20/03	**19,000 J**
			11/24/03	**22,000 J**
			12/19/03	**16,000 J**
			01/21/04	**29,000 J**
			02/20/04	**14,000 J**
			04/14/04	**13,000 =**
			06/26/04	**14,000 J**
			09/01/06	**40,000 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (μg/L)
SAIC 15 – Interval 1	Multi-port Bedrock Zone	31 – 39	10/23/03	**140 =**
			09/01/06	**7.9 =**
SAIC 15 – Interval 2	Multi-port Bedrock Zone	60 – 67	10/23/03	**750 =**
			09/01/06	**1,100 =**
SAIC 15 – Interval 3	Multi-port Bedrock Zone	112 – 120	10/23/03	**15 =**
			09/01/06	**580 =**
SAIC 15 – Interval 4	Multi-port Bedrock Zone	149 – 155	10/23/03	**17 =**
			09/01/06	**420 =**
SAIC 15 – Interval 5	Multi-port Bedrock Zone	188 – 204.8	10/23/03	**42 =**
			09/01/06	**70 =**
SAIC 16A – Interval 1	Multi-port Bedrock Zone	58 – 65	10/22/03	**110 =**
			12/09/03	**65 =**
			12/19/03	**72 J**
			01/21/04	**4.1 =**
			02/20/04	**92 =**
			04/13/04	**270 =**
			06/25/04	**260 =**
			09/01/06	**130 =**
SAIC 16A – Interval 2	Multi-port Bedrock Zone	83 – 103	10/22/03	**8 =**
			12/19/03	<1.0
			01/21/04	**3.1 =**
			02/20/04	**4.1 J**
			04/13/04	**4.4 =**
			06/25/04	**4.2 =**
			09/01/06	**49 =**
SAIC 16A – Interval 3	Multi-port Bedrock Zone	122 – 129	10/22/03	**680 =**
			12/19/03	**240 J**
			01/21/04	**17 =**
			02/20/04	**310 =**
			04/13/04	**740 =**
			06/25/04	**350 =**
			09/01/06	**340 =**
SAIC 16A – Interval 4	Multi-port Bedrock Zone	160 – 165	10/22/03	**480 J**
			12/19/03	**40 J**
			01/21/04	**1.6 =**
			02/20/04	**150 =**
			04/13/04	**480 =**
			06/25/04	**270 =**
			09/01/06	**350 =**

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
SAIC 16A – Interval 5	Multi-port Bedrock Zone	191 – 199	10/22/03	**1,100** =
			12/19/03	**760 J**
			01/21/04	**1,000** =
			02/20/04	**460** =
			04/13/04	**1,100** =
			06/25/04	**770** =
			09/01/06	**450** =
SAIC 16A – Interval 6	Multi-port Bedrock Zone	295 – 305	10/22/03	**140** =
			12/19/03	**56** =
			01/21/04	**160** =
			02/20/04	**100** =
			04/13/04	**180** =
			06/25/04	**130** =
			09/01/06	**290** =
SAIC 17	Transition Zone	5.13 – 10.13	10/20/03	**73 J**
			11/25/03	**23** =
			06/26/04	**4.8** =
			09/02/06	**23** =
SAIC 18C[d]	Transition Zone	8.08 – 13.08	10/19/03	**6.2** =
			12/20/03	0.88 J
			01/22/04	1.9 =
			06/25/04	0.72 J
			09/02/06	2.5 =
SAIC 19B	Transition Zone	8.50 – 18.50	10/21/03	**790** =
			11/25/03	**1,100** =
			12/20/03	**77** =
			01/22/04	**410** =
			04/14/04	**19** =
			06/28/04	**29 J**
			09/03/06	**170** =
SAIC-20[2]	Bedrock Zone	79.57 – 99.57	10/21/03	**1,800** =
			12/21/03	**13** =
			01/22/04	**29** =
			02/21/04	**7** =
			04/14/04	**5.9** =
			06/28/04	2.6 =
			09/03/06	**17** =

Table A-4. Summary of TCE Concentrations in Groundwater at the Former NAD Site (continued)

Well ID	Well Type	Screen Interval	Date Sampled	TCE Results[a] (µg/L)
SAIC-21	Bedrock Zone	93.88 – 103.88	10/22/03	**390 =**
			12/21/03	**45 =**
			01/22/04	**8.4 =**
			02/21/04	**4.9 =**
			04/15/04	**3.6 J**
			06/27/04	2.3 =
			08/30/06	2.2 =

[a] Data reported for December 1994 and June 1999 were collected by Metcalf & Eddy, Inc., and were taken from the Phase II Remedial Investigation Report (USACE 2000). All other data were collected by Science Applications International Corporation.
[b] Monitoring well was not sampled during the 2006 sampling event because there was either no property access agreement or the well was inaccessible.
[c] Monitoring well NAD MW-21 contains a 50-ft screen. During the 2000 sampling event, samples were collected at selected zones within the screened interval by positioning the sampling pump at the desired location.
[d] Sodium lactate injection well.
NAD = Naval Ammunition Depot.
TCE = Trichloroethene.
< = Not detected at the indicated method detection limit.
? = Borehole logs unavailable. The length of the screen is unknown.
Data Qualifiers:
J = Concentration reported is an estimated value.
"=" = Analyte detected at the concentration reported.
Bold values exceed the North Carolina Groundwater Quality Standard of 2.8 µg/L for TCE.
Shaded cells represent the TCE results for the current sampling event conducted from August 29 through September 3, 2006.

Table A-5. Travel Distance for Tracer Test

Zone	Ambient Condition Travel Distance Range (X) (ft)	Injection Rate (Q) (gpm)	Height of Mound (s_w) (ft)	Radius of Influence (R) (ft)	Predicted Travel Distance during the Pilot Study (R) (ft)
Bedrock	112 – 263	3	11.91	64.35	177 – 327
Bedrock	112 – 263	4	16.75	90.50	203 – 354
Transition	14	1	6.30	40.0	54
Transition	14	2	9.30	59.0	73

gpm = Gallons per minute.

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FIGURES

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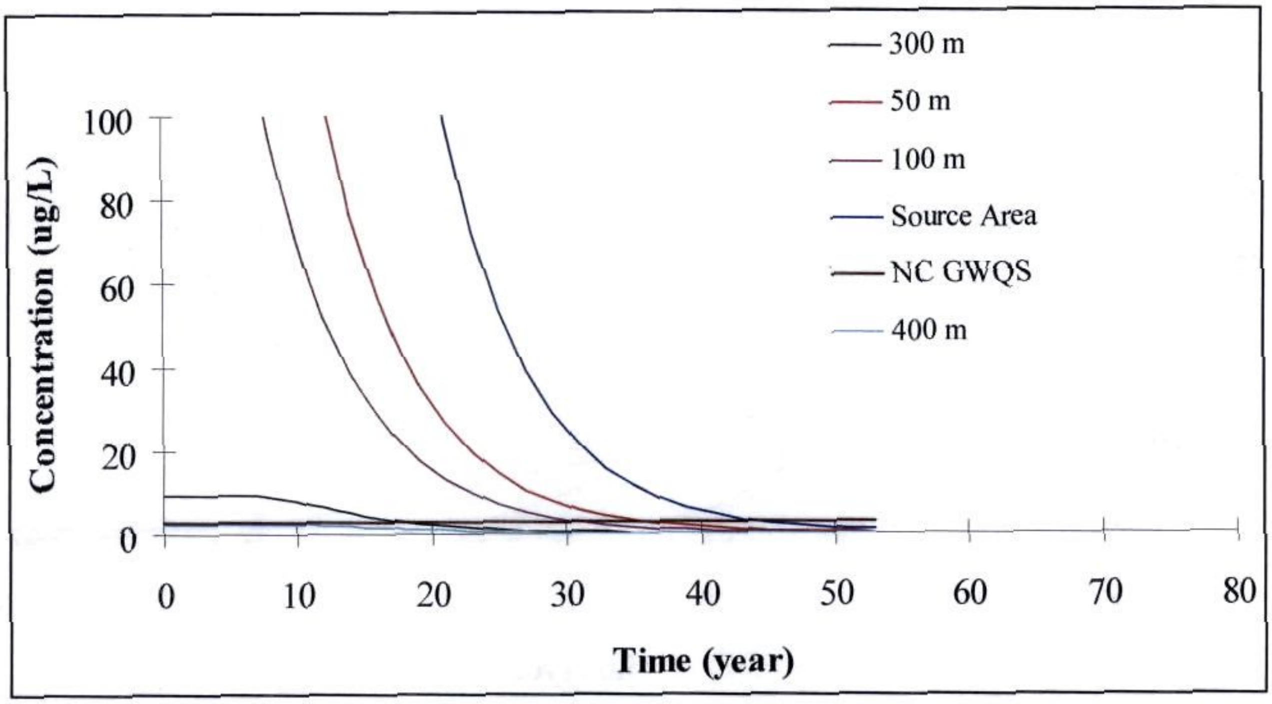

Figure A-1 (Zoomed). AT123D-Modeled Future Concentration of TCE in the Transition Zone Groundwater at the NAD Site Without any Source Reduction

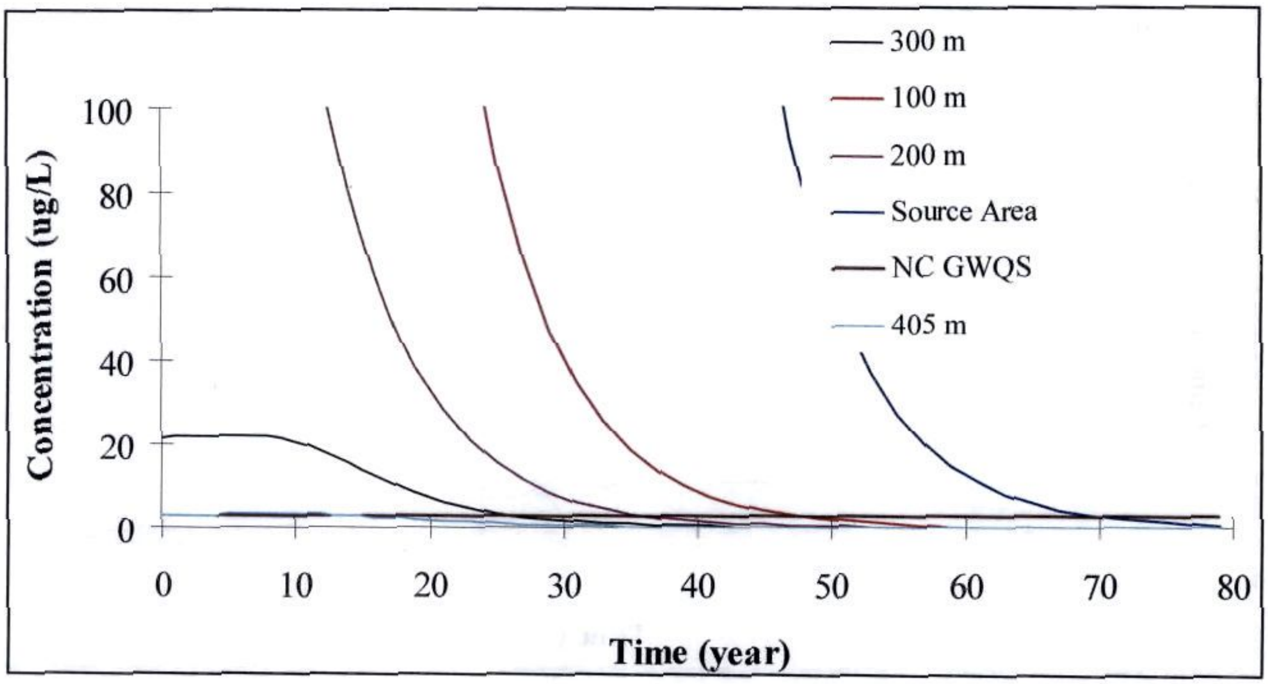

Figure A-2 (Zoomed). AT123D-Modeled Future Concentration of TCE in the Bedrock Zone Groundwater at the NAD Site Without any Source Reduction

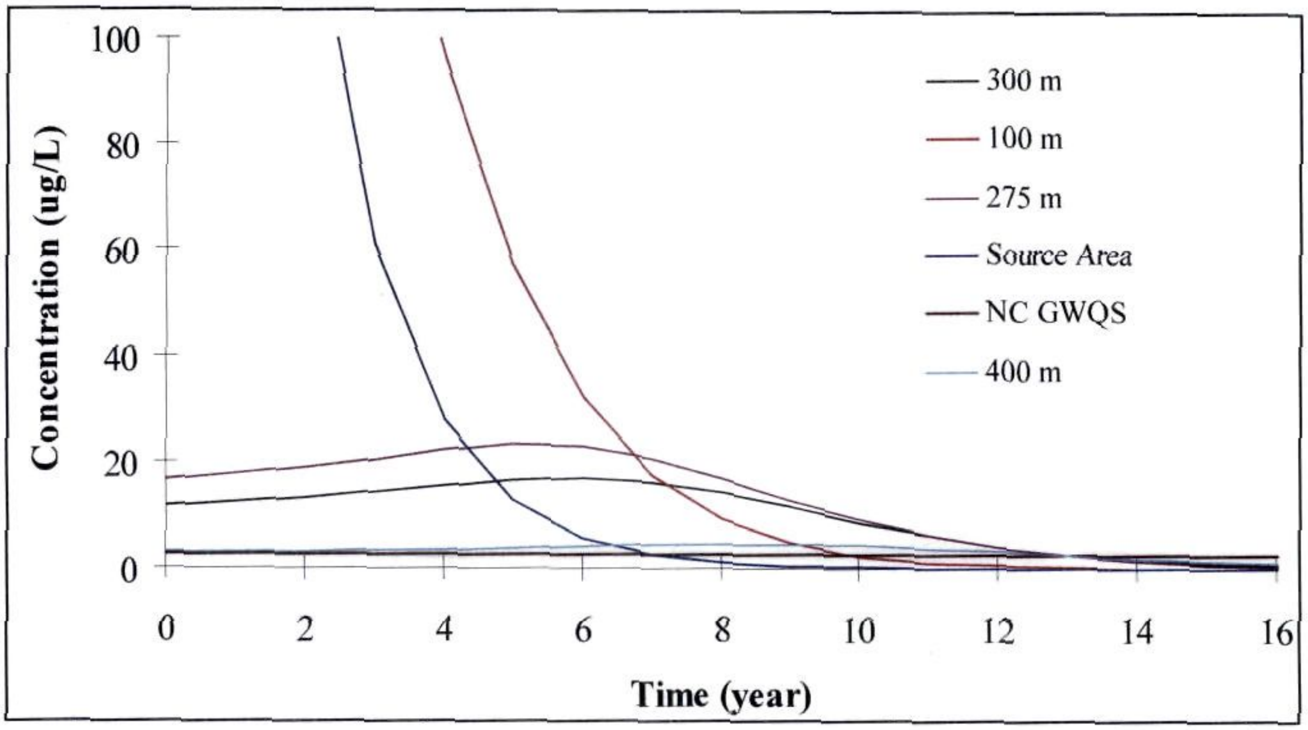

Figure A-3 (Zoomed). AT123D-Modeled Future Concentration of TCE in the Transition Zone Groundwater at the NAD Site After the Source Area Has Been Reduced to 500 mg/L Using Sodium Lactate Injection

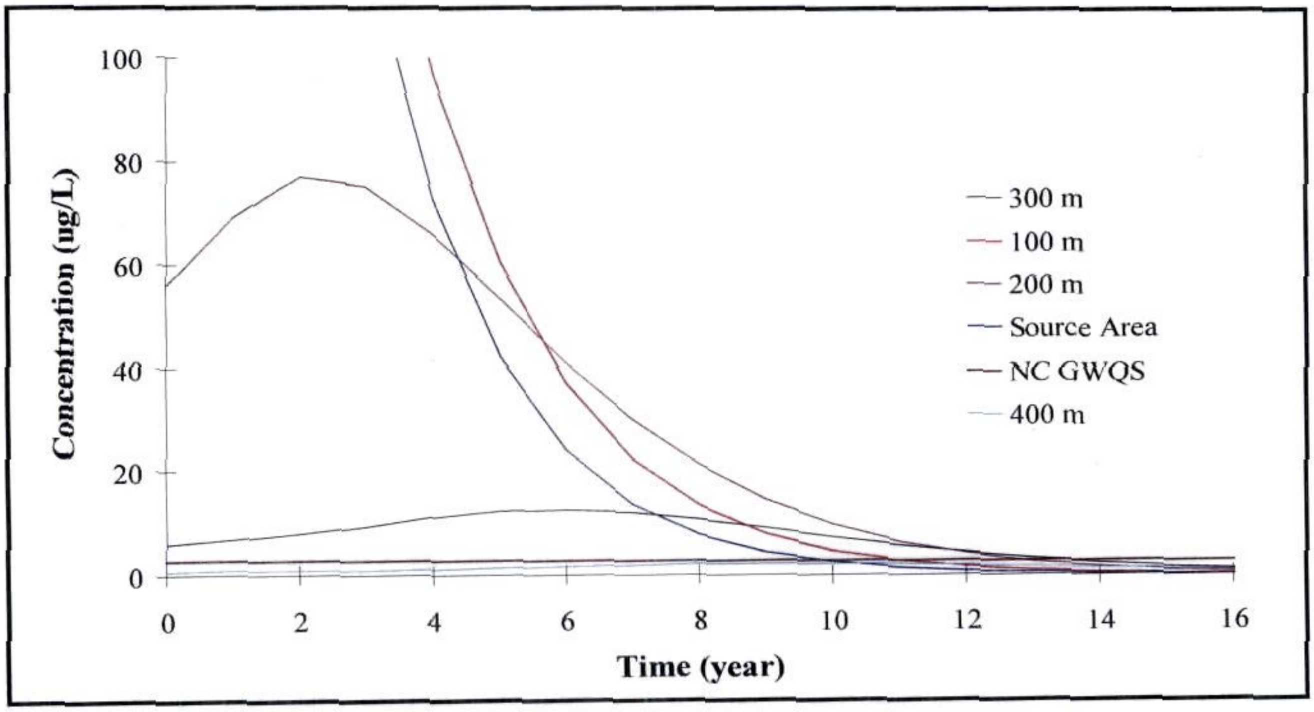

Figure A-4 (Zoomed). AT123D-Modeled Future Concentration of TCE in the Bedrock Zone Groundwater at the NAD Site After the Source Area Has Been Reduced to 500 mg/L Using Sodium Lactate Injection

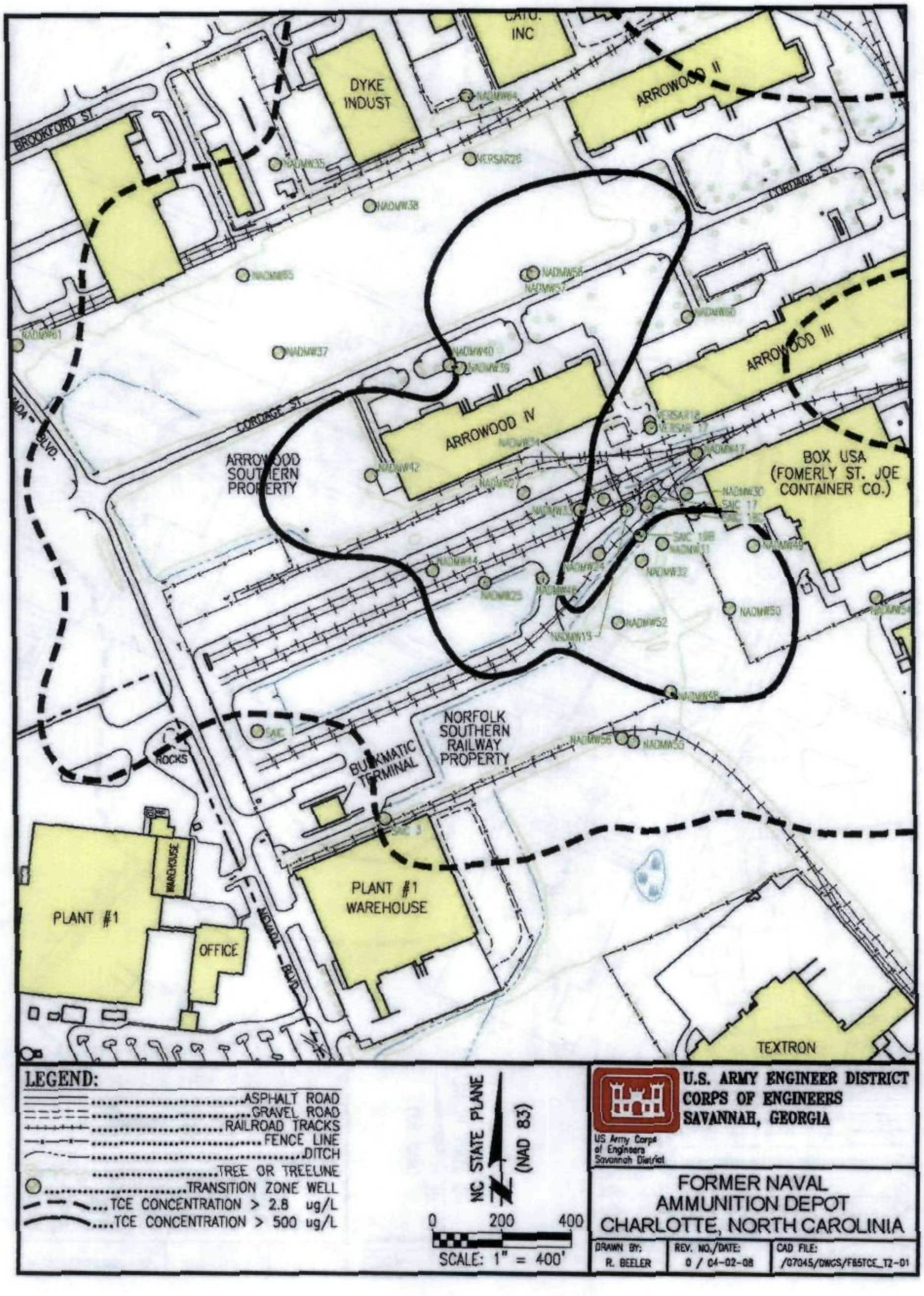

Figure A-5. TCE Concentration in the Transition Zone – 2004

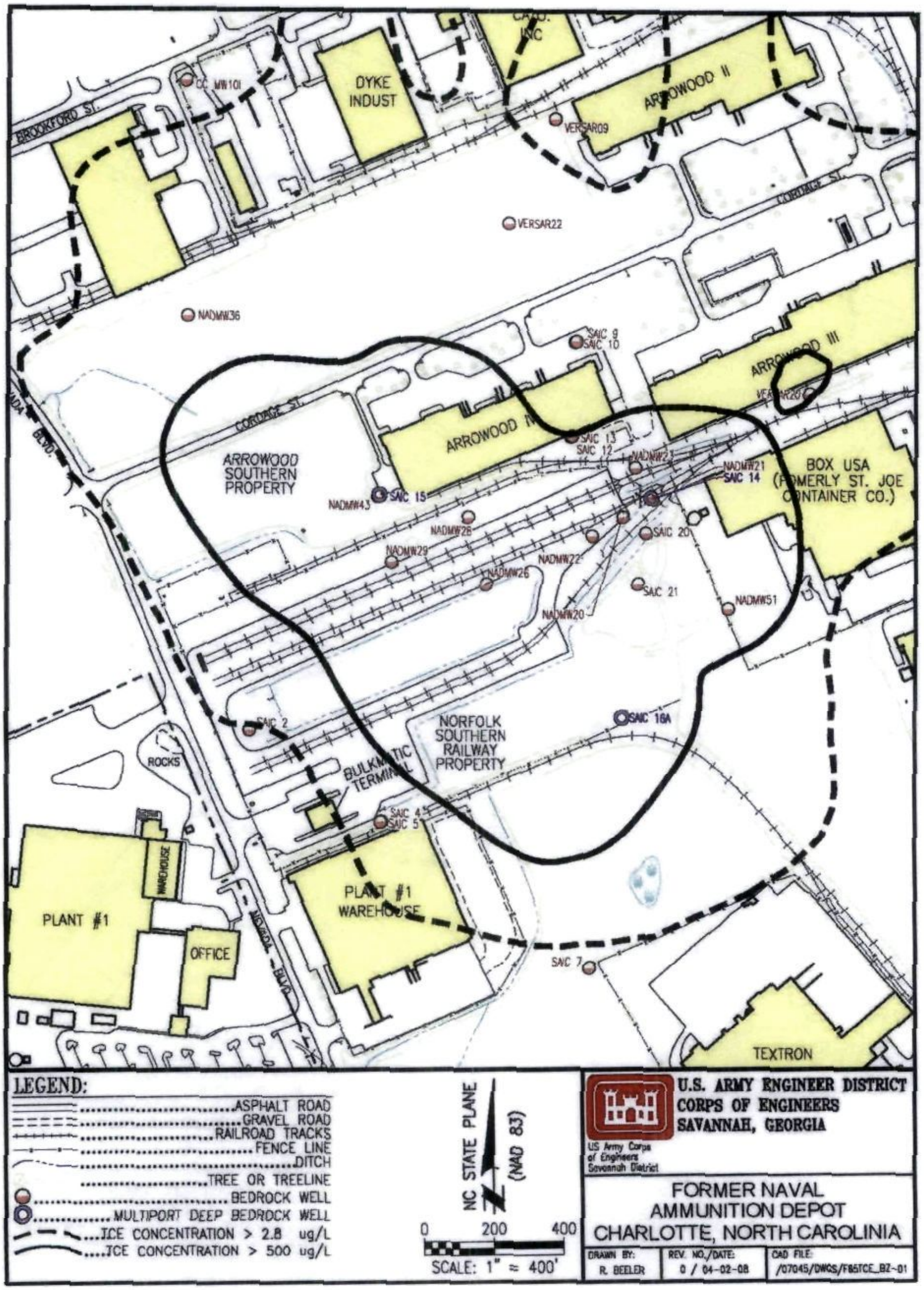

Figure A-6. TCE Concentration in the Bedrock Zone – 2004

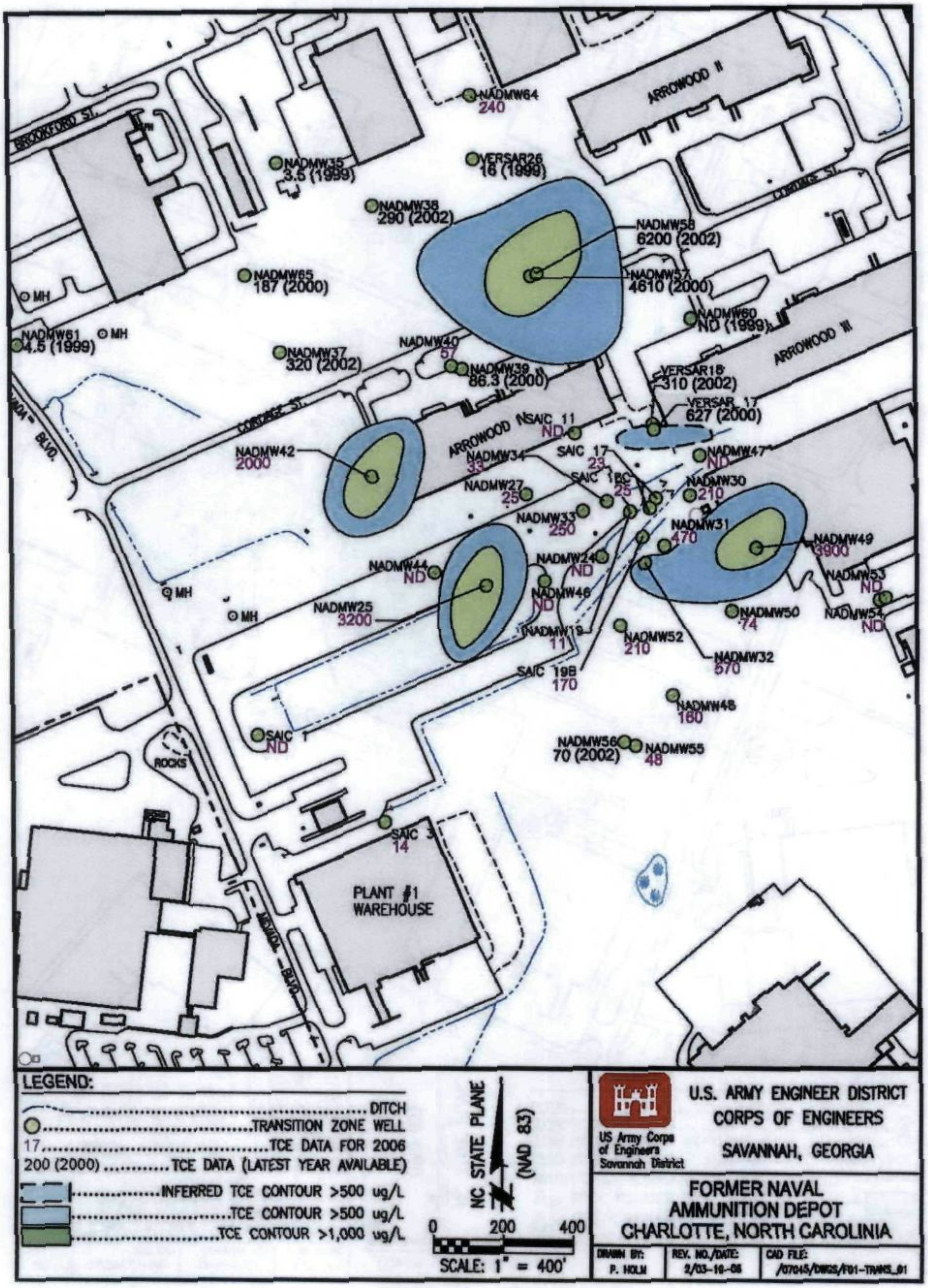

Figure A-7. TCE Concentration in the Transition Zone – 2006

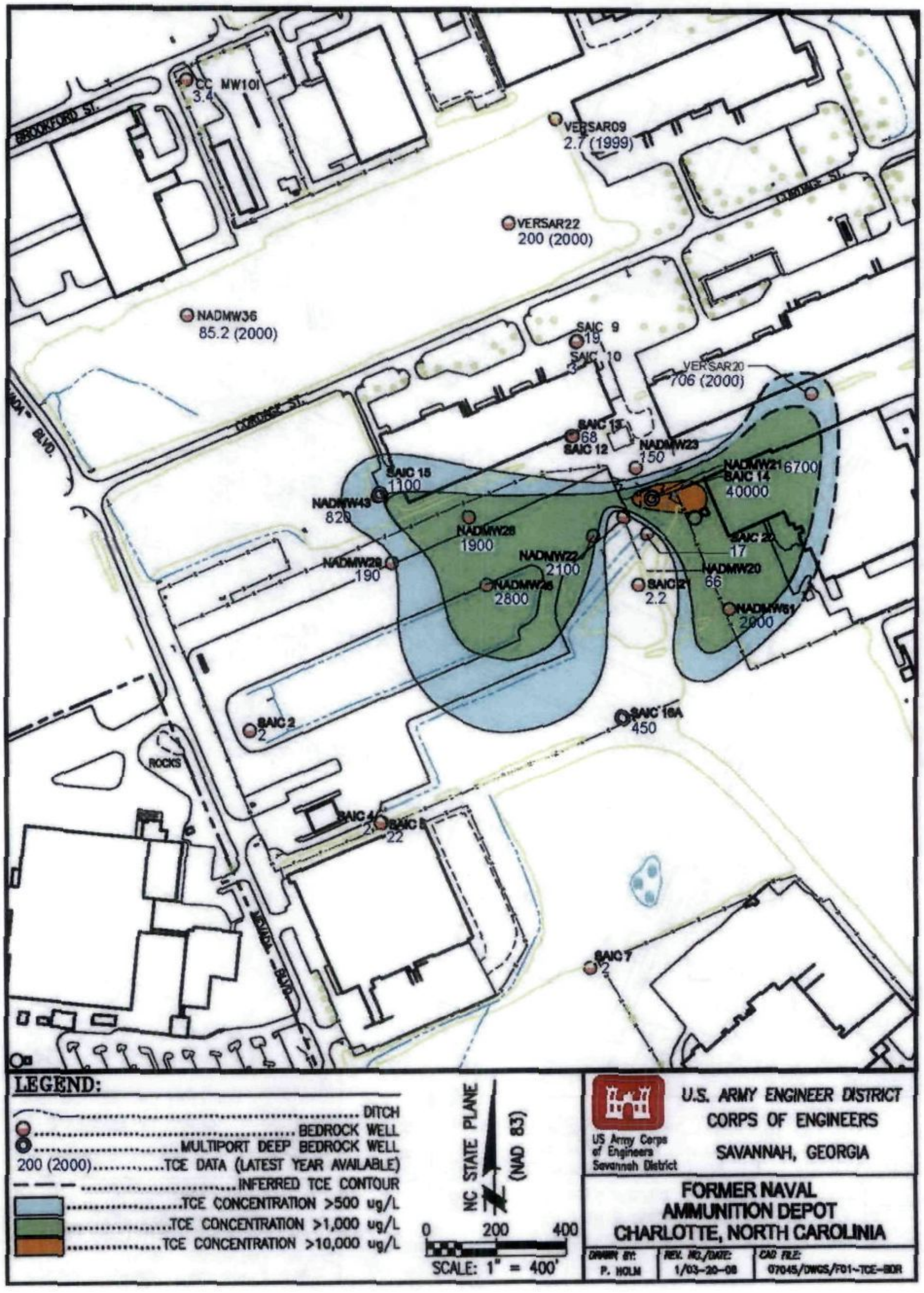

Figure A-8. TCE Concentration in the Bedrock Zone – 2006

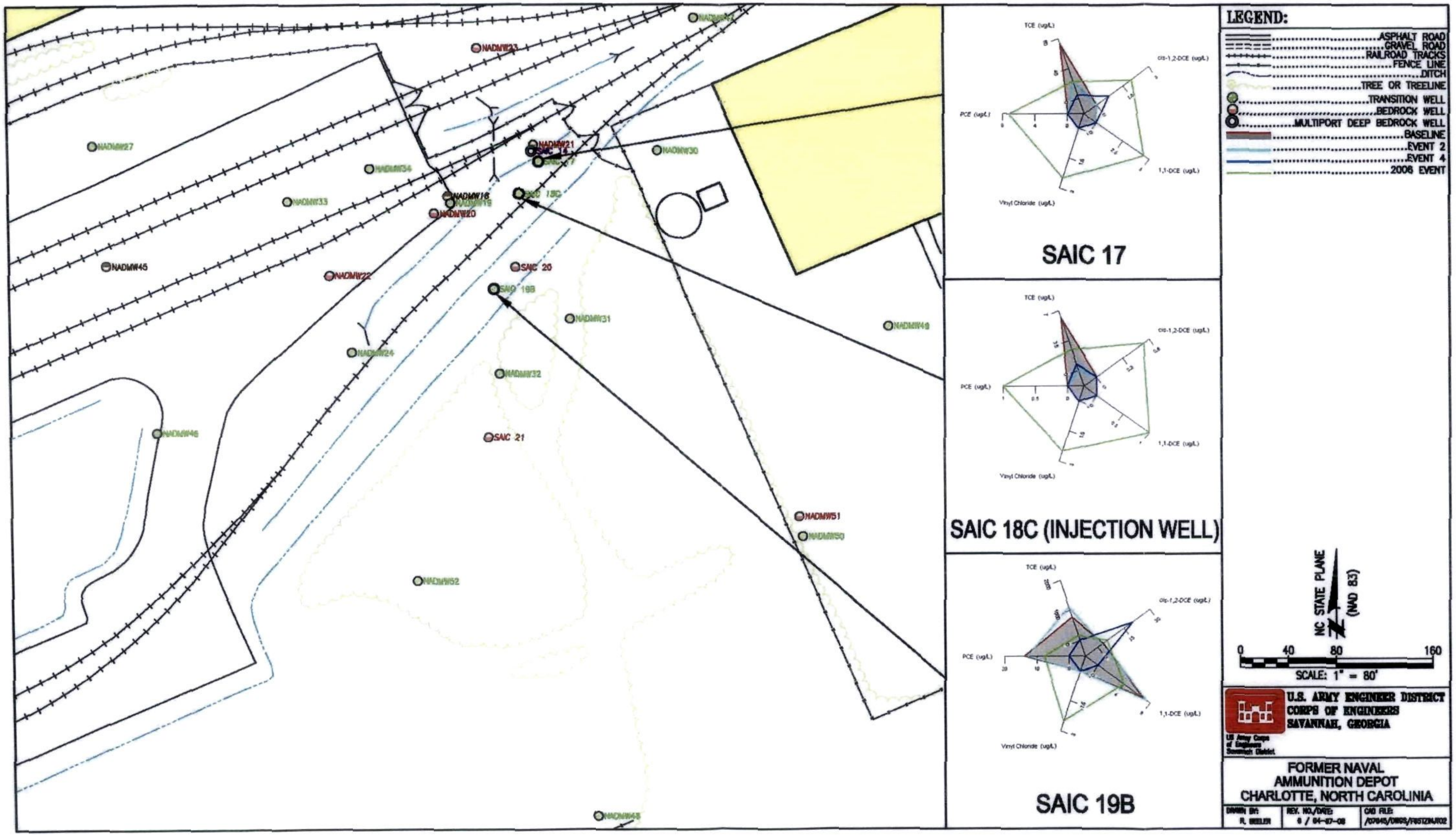

Figure A-9. Transition Zone Radial Diagram Using SEQUENCE to Assess the Effects of Sodium Lactate Injection

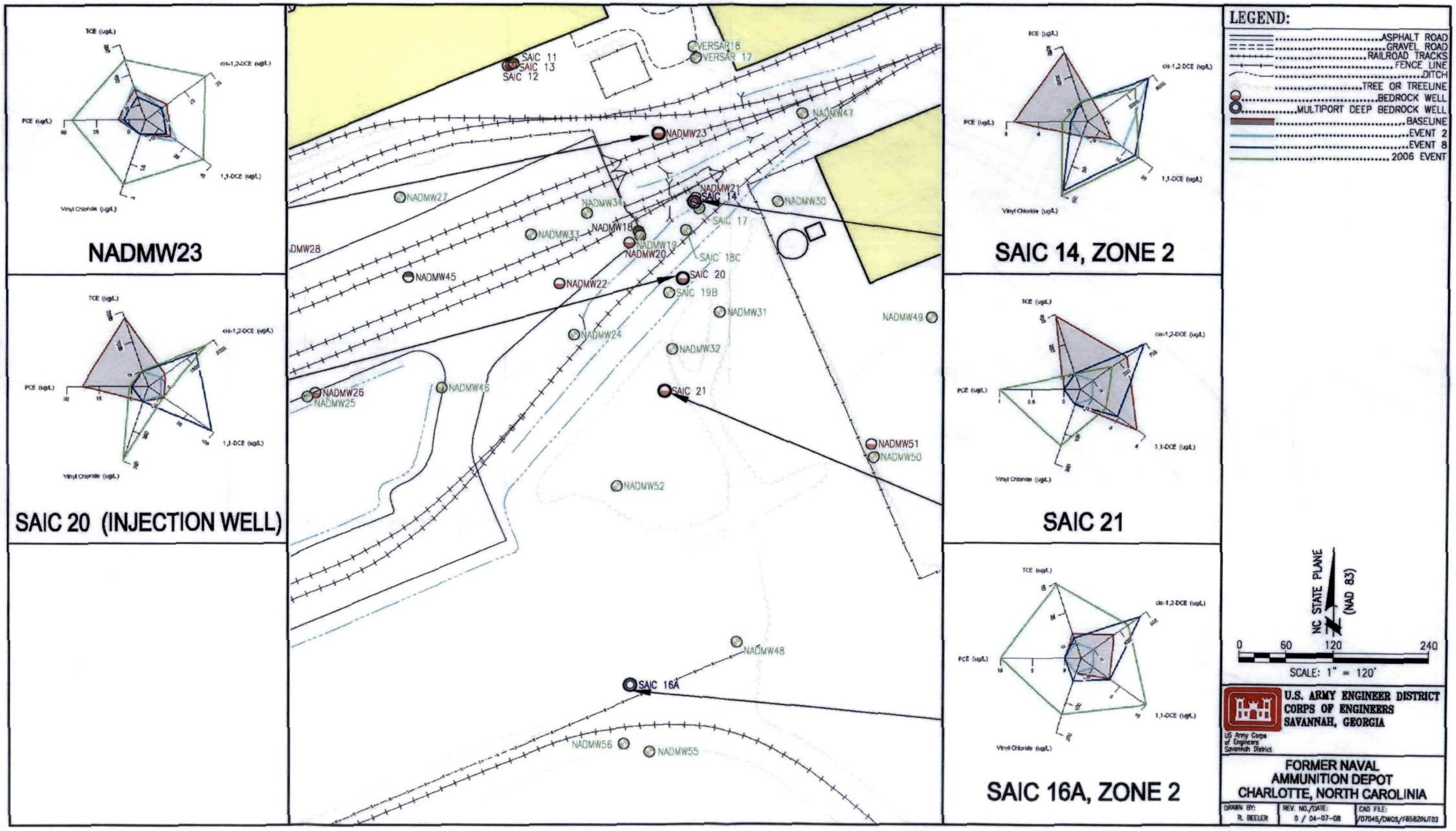

Figure A-10. Bedrock Zone Radial Diagram Using SEQUENCE to Assess the Effects of Sodium Lactate Injection

Area = 14.1 acre

Note: There are no sampling points along the direction of the arrows. Therefore, sufficient uncertainty exists beyond the blue lines. Additional sampling would be necessary at these locations to reduce the uncertainty in delineating the plume at these locations.

Figure A-11. Groundwater Concentration in Transition Zone in 2-D

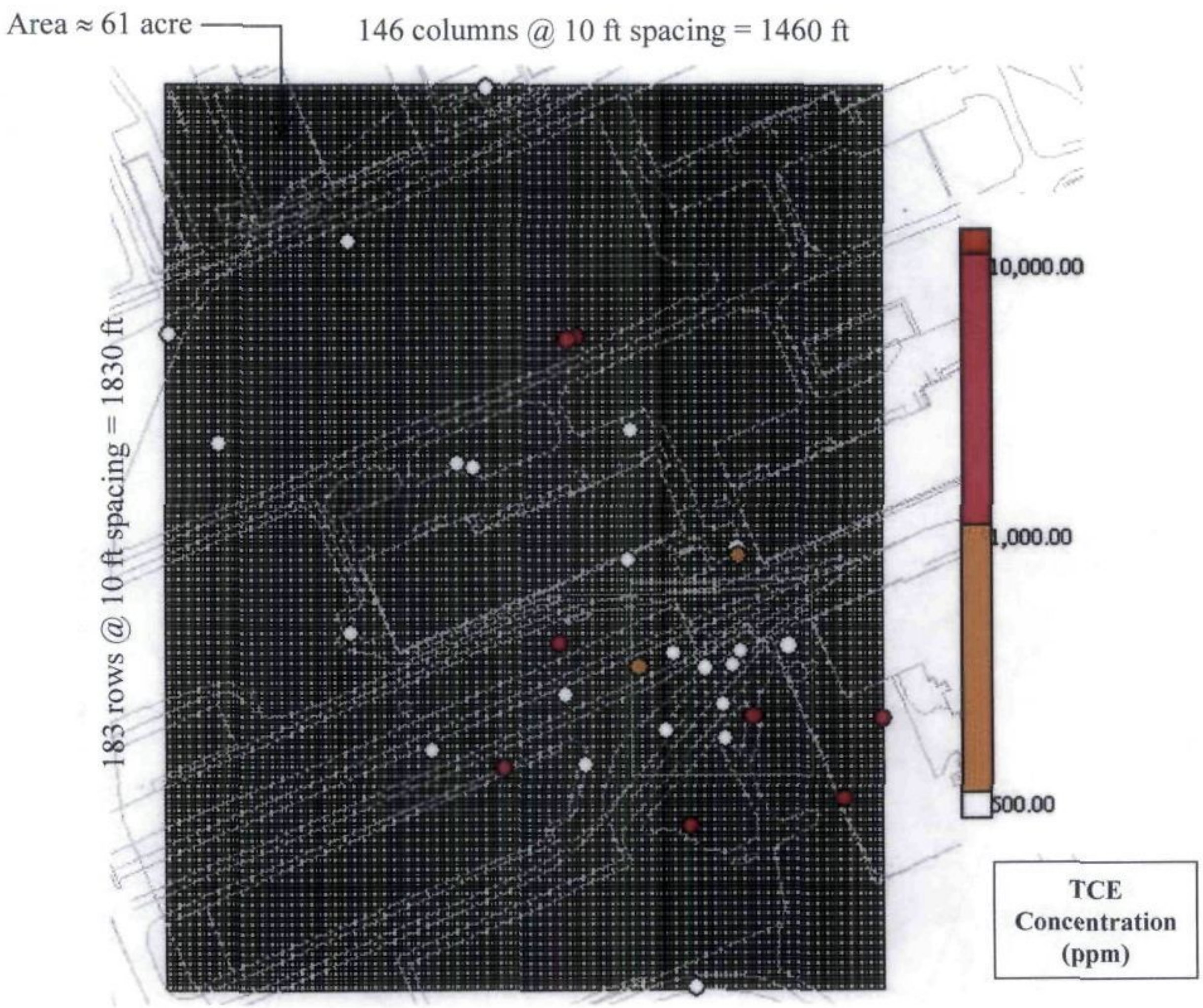

Figure A-12. Discretization of Planer Area for Geospatial Interpolation

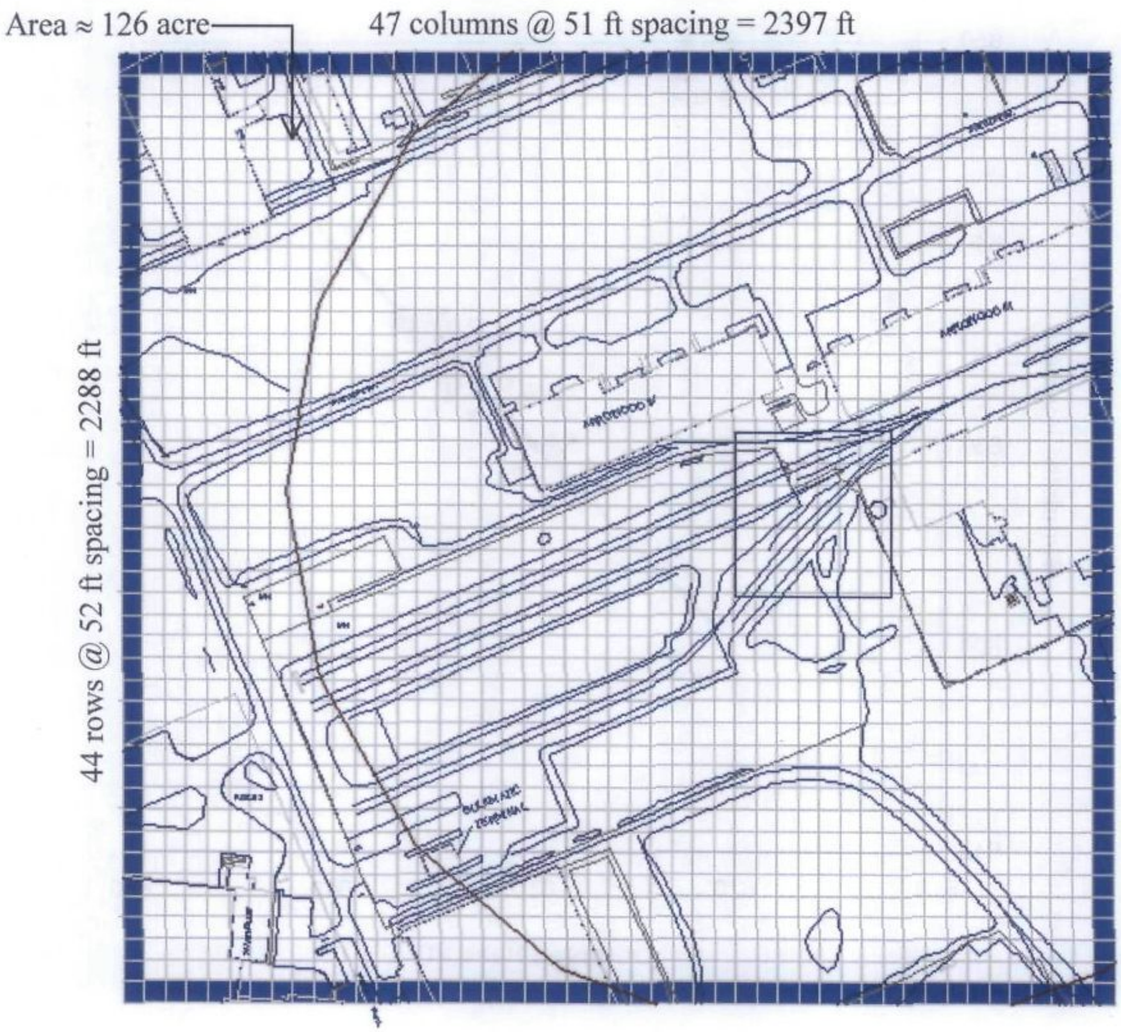

Figure A-13. Discretization of the Planar Area of the Flow Model

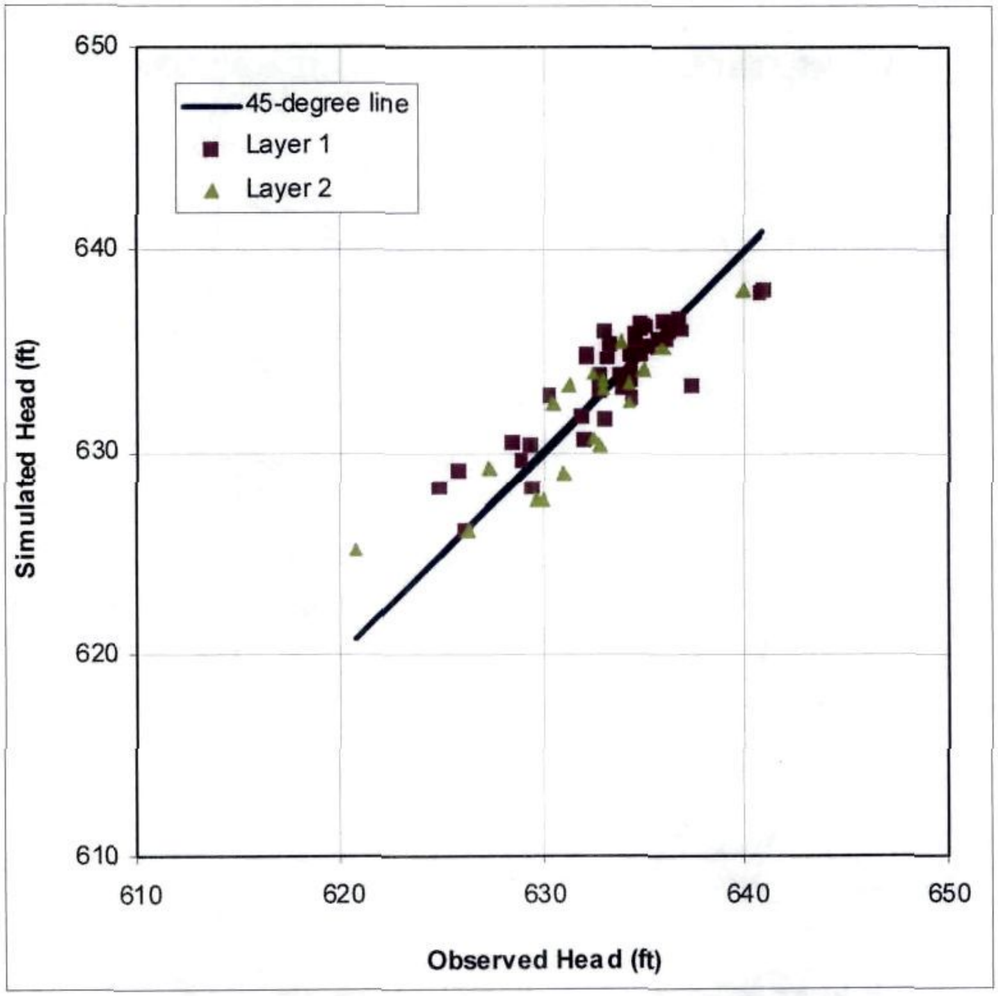

Figure A-14. Calibration Result for Steady Condition

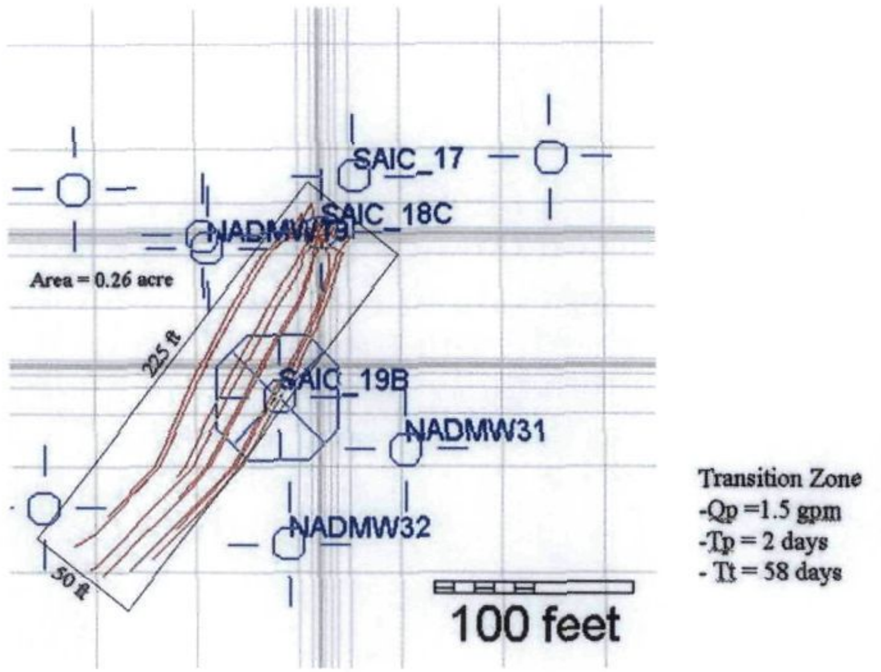

Figure A-15. Capture Zone for the Transition Zone

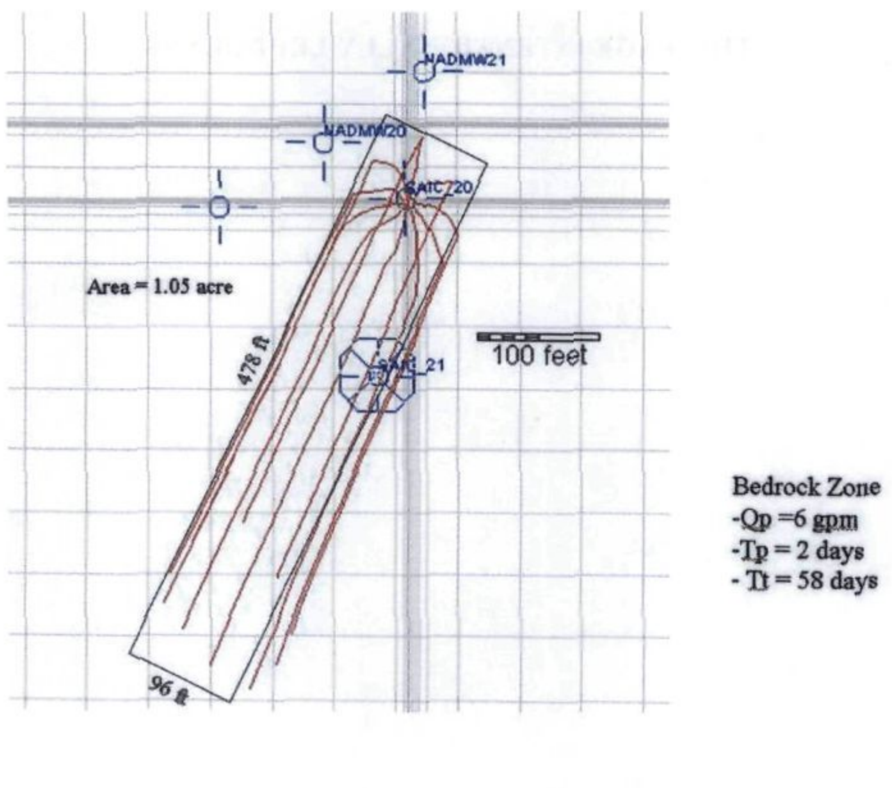

Figure A-16. Capture Zone for the Bedrock Zone

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APPENDIX B
PILOT STUDY BORING LOGS AND WELL CONSTRUCTION DIAGRAMS

APPENDIX C
PILOT STUDY ANALYTICAL SUMMARY TABLES AND GRAPHS

APPENDIX D
PILOT STUDY AND 2006 SAMPLING EVENT LABORATORY ANALYTICAL DATA SHEETS

APPENDIX E
COST ESTIMATE

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD)
Mecklenburg County, Charlotte, North Carolina
Summary of Process Options

Groundwater Media Alternatives		Option Duration (yr)	Non Discounted Cost		
			Capital Cost	O&M Cost	Total
1	No Action	0	$0	$0	$0
2	Monitored Natural Attenuation	64	$336,195	$6,227,047	$6,563,242
3	Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation	15	$4,555,321	$2,568,755	$7,124,076

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 2 - Monitored Natural Attenuation (MNA)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Institutional Controls			
Groundwater Use Restrictions	hrs	120	Assume 120 hrs to implement restrictions.
Legal/Technical Labor	$/hr	90	
Monitoring Wells			
Mob/Site Preparation	$/lot	5,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Transition Wells	ea	4	Assume TD 25' (2-inch casing) - Screened 15'-25'. Inc drill, install MW, surface completion, driller perdiem.
Transition Wells	$/ea	2,801	
SAIC Geologist	$/well	662	Based on historical cost. Inc travel, perdiem, install, develop, document.
Bedrock Wells	ea	5	Assume TD 250' (2-inch casing) - Screened 230'-250' - Inc drill, install MW, surface completion, driller perdiem.
Bedrock Wells	$/ea	25,328	
SAIC Geologist	$/well	3,238	Based on historical cost. Inc travel, perdiem, install, develop, document.
IDW - Soil/water	drums	115	Assume 4 drums in transition zone and 19 drums in bedrock zone each well. Includes nonhazardous soil ($62/ea) & hazardous water ($375/ea) .
IDW - Disposal	$/drum	219	
Transportation	ea	3	
Transportation	$/event	1,415	Based on historical IDW mob, forklift, and transportation.
IDW Sampling	ea	9	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample every well.
IDW Sampling	$/ea	600	
Development Equip, H&S Equip	weeks	5	Includes PID, Horiba, gloves, eyewash, safety glasses, hard hats, etc.
Development Equip, H&S Equip	$/week	525	Based on historical equipment rental and disposable cost.
Well Installation Report	$/hours	3,200	Assume 40 hours @ $80/hr average.
O&M			
Groundwater Sampling & Analysis (Years 0 through 47)	events	56	Includes quarterly sampling for Years 0-3, semiannual for Years 4-5, and annual sampling for Years 6-47 in transition and bedrock zone. There are 14 total events. Includes 21 existing and 9 new wells that are sampled in 12 days (2.5 wells/day) plus 2 days travel. Assumes 2 sampling technicians at 10 hours/day. Sample all wells for VOCs, natural attenuation parameters (5 wells), and water quality parameters.
Sampling Labor	days	14	
Sampling Labor	hrs/event	280	
Sampling Labor	$/hr	65	
Per Diem	$/event	3,472	(2 FTE x 14 days x $124/day)
Cargo Van Rental / Gas	$/event	1,540	(1 van x 14 days x $110/day includes gas).
Sample materials	ea/event	51	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	21.00	
Sample equipment	$/event	1,200	Water quality parameter equipment, pumps, misc tools, and sampling equipment rental/purchase. Based on RACER model.
Sample equipment	lot	1,000	Purge water tank (1,000 gal) and trailer.
Analytical Cost	$/event	9,520	Analyze GW samples from 30 wells for VOCs (41 @ $120) and Natural Attenuation Parameters (10 @ $460). Includes 10% duplicate and 5% rinsate, and trip blanks.
Sample Shipment	$/event	300	6 coolers @ $50 ea.
Data Management	hrs	26	Data validation
Data Management	$/hr	70	
IDW Water Disposal	events	56	Assume 100% hazardous water ($0.38/gal @ 800 gal) to dispose. Add $5,000 pickup, transport, & tank cleanout. Add $600 sampling & analysis.
IDW Water Disposal	$/event	5,904	Based on Safety Kleen Quote.

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 2 - Monitored Natural Attenuation (MNA)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Groundwater Sampling & Analysis (Years 48 through 64)	events	17	Includes annual sampling for years 48-64 in bedrock zone. Also sampling will be used for conformational sampling in transition zone (year 48) and bedrock zone (year 64). There are 17 total events. Includes 10 existing and 5 new wells that are sampled in 6 days (2.5 wells/day) plus 2 days travel. Assumes 2 sampling technicians at 10 hours/day. Sample all wells for VOCs, natural attenuation parameters (2 wells), and water quality parameters.
Sampling Labor	days	8	
Sampling Labor	hrs/event	160	
Sampling Labor	$/hr	65	
Per Diem	$/event	1,984	(2 FTE x 8 days x $124/day)
Cargo Van Rental / Gas	$/event	880	(1 van x 8 days x $110/day includes gas).
Sample materials	ea/event	23	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	21.00	
Sample equipment	$/event	1,200	Water quality parameter equipment, pumps, misc tools, and sampling equipment rental/purchase. Based on RACER model.
Sample equipment	lot	1,000	Purge water tank (1,000 gal) and trailer.
Analytical Cost	$/event	3,440	Analyze GW samples from 15 wells for VOCs (21 @ $120) and Natural Attenuation Parameters (2 @ $460). Includes 10% duplicate and 5% rinsate, and trip blanks.
Sample Shipment	$/event	150	3 coolers @ $50 ea.
Data Management	hrs	12	Data validation
Data Management	$/hr	70	
IDW Water Disposal	events	17	Assume 100% hazardous water ($0.38/gal @ 400 gal) to dispose. Add $5,000 pickup, transport, & tank cleanout. Add $600 sampling & analysis.
IDW Water Disposal	$/event	5,752	Based on Safety Kleen Quote.
Reporting			
Annual/Periodic Report	$/event	9,600	Assume 120 hours @ $80/hr average for analytical report and to recalibrate GW model.
5-Year Reviews	event	12	Assume 5-Year reviews for years 5-60.
5-Year Reviews	$/event	6,400	Assume 80 hours @ $80/hr.
Well Abandonment			
Abandon Monitoring Well	lot	1	Assume 15 wells @ 25 ft, 10 wells @ 100 ft, and 5 wells @ 250 ft. Assume $1,000 mob, $12/lf to grout, and $300 per well to remove surface casing and restore.
Abandon Monitoring Well	$/lot	41,500	

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 2 - Monitored Natural Attenuation (MNA)
Cost Estimate

CAPITAL COST $336,195

Activity (unit)	Quantity	Unit Cost	Total
Institutional Controls			
Groundwater Use Restrictions (hrs)	120	$90	$10,800
Monitoring Wells			
Mob/Site Preparation (ea)	1	$5,000	$5,000
Transition Wells (ea)	4	$3,463	$13,854
Bedrock Wells (ea)	5	$28,566	$142,832
IDW Disposal (drums)	115	$219	$25,128
Transportation (ls)	1	$1,415	$1,415
IDW Sampling (ea)	9	$600	$5,400
Development Equip, H&S Equip (wk)	5	$525	$2,625
Well Installation Report (ea)	1	$3,200	$3,200
Subtotal			$210,253
Design		10%	$21,025
Office Overhead		5%	$10,513
Field Overhead		15%	$31,538
Subtotal			$273,329
Profit		8%	$21,866
Contingency		15%	$40,999
Total			$336,195

OPERATION AND MAINTENANCE $6,227,047

Activity (unit)	Quantity	Unit Cost	Total Cost
O&M Sampling & Analysis (Years 0 through 47)			
Sampling Labor (event)	56	$18,200	$1,019,200
Per Diem (event)	56	$3,472	$194,432
Cargo Van Rental / Gas (event)	56	$1,540	$86,240
Sample materials (event)	56	$1,071	$59,976
Sample equipment (event)	56	$1,200	$67,200
Purge Water Tank and Trailer (lot)	1	$1,000	$1,000
Analytical Cost (event)	56	$9,520	$533,120
Sample Shipment (event)	56	$300	$16,800
Data Management (event)	56	$1,820	$101,920
IDW Disposal (event)	56	$5,904	$330,624
O&M Sampling & Analysis (Years 48 through 64)			
Sampling Labor (event)	17	$10,400	$176,800
Per Diem (event)	17	$1,984	$33,728
Cargo Van Rental / Gas (event)	17	$880	$14,960
Sample materials (event)	17	$483	$8,211
Sample equipment (event)	17	$1,200	$20,400
Purge Water Tank and Trailer (lot)	1	$1,000	$1,000
Analytical Cost (event)	17	$3,440	$58,480
Sample Shipment (event)	17	$150	$2,550
Data Management (event)	17	$840	$14,280
IDW Disposal (event)	17	$5,752	$97,784

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 2 - Monitored Natural Attenuation (MNA)
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total Cost
Reporting			
Annual/Periodic Report (ea)	73	$9,600	$700,800
5-Year Review (ea)	12	$6,400	$76,800
Monitoring Well Abandonment			
Abandon Monitoring Well (lot)	1	$41,500	$41,500
Subtotal O&M			$3,657,805
Design		8%	$292,624
Office Overhead		5%	$182,890
Field Overhead		15%	$548,671
Subtotal			$4,681,990
Profit		8%	$374,559
Contingency		25%	$1,170,498
Total			$6,227,047

TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost) **$6,563,242**

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 3 - Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Institutional Controls			
Groundwater Use Restrictions	hrs	120	Assume 120 hrs to implement restrictions.
Legal/Technical Labor	$/hr	90	
Monitoring Wells			
Mob/Site Preparation	$/lot	5,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Transition Wells	ea	4	Assume TD 25' (2-inch casing) - Screened 15'-25'. Inc drill, install MW, surface completion, driller perdiem.
Transition Wells	$/ea	2,801	
SAIC Geologist	$/well	662	Based on historical cost. Inc travel, perdiem, install, develop, document.
Bedrock Wells	ea	5	Assume TD 250' (2-inch casing) - Screened 230'-250' - Inc drill, install MW, surface completion, driller perdiem.
Bedrock Wells	$/ea	25,328	
SAIC Geologist	$/well	3,238	Based on historical cost. Inc travel, perdiem, install, develop, document.
IDW - Soil/water	drums	115	Assume 4 drums in transition zone and 19 drums in bedrock zone each well. Includes nonhazardous soil ($62/ea) & hazardous water ($375/ea) .
IDW - Disposal	$/drum	219	
Transportation	ea	3	
Transportation	$/event	1,415	Based on historical IDW mob, forklift, and transportation.
IDW Sampling	ea	9	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample every well.
IDW Sampling	$/ea	600	
Development Equip, H&S Equip	weeks	5	Includes PID, Horiba, gloves, eyewash, safety glasses, hard hats, etc.
Development Equip, H&S Equip	$/week	525	Based on historical equipment rental and disposable cost.
Well Installation Report	$/hours	3,200	Assume 40 hours @ $80/hr average.
In Situ Biodegredation			
Injection Well Installation			
Injection Permit	ea	3200	Assume 40 hours @ $80/hr average.
Mob/Site Preparation	$/lot	5,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Transition Wells	ea	54	Assume TD 25' (2-inch casing) - Screened 8'-25'. Inc drill, install MW, surface completion, driller perdiem.
Transition Wells	$/ea	2,801	
SAIC Geologist	$/well	395	Based on historical cost. Inc travel, perdiem, install, develop, document.
Bedrock Wells	ea	31	Assume TD 100' (2-inch casing) - Screened 25'-100' - Inc drill, install MW, surface completion, driller perdiem.
Bedrock Wells	$/ea	10,626	
SAIC Geologist	$/well	1,336	Based on historical cost. Inc travel, perdiem, install, develop, document.
IDW - Soil/water	drums	526	Assume 4 drums in transition zone and 10 drums in bedrock zone each well. Includes nonhazardous soil ($62/ea) & hazardous water ($375/ea) .
IDW - Disposal	$/drum	219	
Transportation	ea	1	
Transportation	$/event	19,810	Based on historical IDW mob, forklift, and transportation.
IDW Sampling	ea	9	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample every 10 wells.
IDW Sampling	$/ea	600	
Development Equip, H&S Equip	weeks	17	Includes PID, Horiba, gloves, eyewash, safety glasses, hard hats, etc.
Development Equip, H&S Equip	$/week	525	Based on historical equipment rental and disposable cost.
Well Installation Report	$/hours	32,000	Assume 400 hours @ $80/hr average.

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 3 - Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
<u>Injection System Setup</u>			
Injector Installation Labor	days	43	Duration based on installing 2 injector setups/day.
Injector Installation Labor	$/days	700	1 FTE at $70/hr and 10 hour days.
Injector Installation Matls	wells	85	
Injector Installation Matls	$/well	300	Engineer Estimate
Injection Program - Fixed Cost			Includes fixed equipment cost.
Metering Pump	$/lot	9,000	3 each @ $3,000, up to 50 gpm, Engineer Estimate
Header System	$/lot	42,000	10 each @ $3,500, Engineer Estimate
Storage Sheds	$/lot	20,000	1 each @ 20,000, Heated, Engineer Estimate
Pressure Pipe	$/lot	375,000	Includes 15,000 lf of 2" HDPE pipe with direct bury installation. $25/lf.
Injection Setup	hours	400	One time setup. Assume 2 field techs for 20 days @ 10 hour/day to setup prior to injection.
Injection Setup	$/hour	60	
Per Diem	$/event	4,960	(2 people x 20 days x $124/day)
Cargo Van Rental / Gas	$/event	4,000	(2 trucks x 20 days x $100/day).
Installation Report	$/report	15,000	Estimate Includes 200 hrs @ $75/hour.
<u>Injection System Operations - Transition Zone</u>	events	4	
Injection Labor	hrs/event	160	Includes 4 injection events. Assume all wells are injected in 8 days. Includes travel. Total effort = 2 FTE x 8 days x 10 hrs/day.
Injection Labor	$/hr	70	
Per Diem	$/lot	1,360	(2 people x 8 days x $85/day)
Cargo Van Rental / Gas	$/lot	1,760	(2 trucks x 8 days x $110/day) Includes gas.
Fork Lift Rental	$/lot	600	Includes mob and rental.
Sodium Lactate Materials - Transition Zone	event	4	Pumping duration 2 days @ 24 hrs/day = 48 hours. 54 injection wells @ 1.5 gpm = approx 81 gpm Total gallons = 48 hours x 60 minutes/hr x 81 gallons/minute = 233,280 gal Assume 1% Lactate by volume = 2,332 gals of 60% lactate (as delivered) = 2,332/0.6 = 3,900 @ $0.77/lb x (600lb/55gal)= $33,000/event
Sodium Lactate Materials	$/event	33,000	
Water	$/event	1,000	
<u>Injection System Operations - Bedrock Zone</u>	events	7	
Injection Labor	hrs	160	Includes 7 injection events. Assume all wells are injected in 8 days. Includes travel. Total effort = 2 FTE x 8 days x 10 hrs/day.
Injection Labor	$/hr	70	
Per Diem	$/lot	1,360	(2 people x 8 days x $85/day)
Cargo Van Rental / Gas	$/lot	1,760	(2 trucks x 8 days x $110/day) Includes gas.
Fork Lift Rental	$/lot	5,000	Includes mob and rental.
Sodium Lactate Materials - Bedrock Zone	event	4	Pumping duration 2 days @ 24hrs/day = 48 hours. 31 injection wells @ 6 gpm = approx 186 gpm Total gallons = 48 hours x 60 minutes/hr x 186 gallons/minute = 535,680 gal Assume 1% Lactate by volume = 5,360 gals of 60% lactate (as delivered) = 5,360/0.6 = 8,950 @ $0.77/lb x (600lb/55gal)= $76,000/event
Sodium Lactate Materials	$/event	76,000	
Water	$/event	1,500	

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 3 - Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Verification Sampling & Analysis - Events 1-4	events	4	Includes sampling to monitor effectiveness of sodium lactate injection. Includes monitoring after first four injections. The baseline sampling will be included under O&M. Includes 30 monitoring wells that are sampled in 12 days (2.5 wells/day) plus 2 days travel. Assumes 2 sampling technicians at 10 hours/day. Sample all wells for VOCs, natural attenuation parameters (10 wells), and water quality parameters.
Sampling Labor	days	14	
Sampling Labor	hrs/event	280	
Sampling Labor	$/hr	65	
Per Diem	$/event	3,472	(2 FTE x 14 days x $124/day)
Cargo Van Rental / Gas	$/event	1,540	(1 van x 14 days x $110/day includes gas).
Sample materials	ea/event	51	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	21.00	
Sample equipment	$/event	1,200	Water quality parameter equipment, pumps, misc tools, and sampling equipment rental/purchase. Based on RACER model.
Sample equipment	lot	1,000	Purge water tank (1,000 gal) and trailer.
Analytical Cost	$/event	9,520	Analyze GW samples from 30 wells for VOCs (41 @ $120) and Natural Attenuation Parameters (10 @ $460). Includes 10% duplicate and 5% rinsate, and trip blanks.
Sample Shipment	$/event	300	6 coolers @ $50 ea.
Data Management	hrs	26	Data validation
Data Management	$/hr	70	
IDW Water Disposal	events	4	Assume 100% hazardous water ($0.38/gal @ 800 gal) to dispose. Add $5,000 pickup, transport, & tank cleanout. Add $600 sampling & analysis.
IDW Water Disposal	$/event	5,904	Based on Safety Kleen Quote.
Verification Sampling & Analysis (Events 4-7)	events	3	Includes sampling to monitor effectiveness of sodium lactate injection. Includes monitoring after injections 4-7 in bedrock zone. The baseline sampling will be included under O&M. Includes 15 monitoring wells that are sampled in 6 days (2.5 wells/day) plus 2 days travel. Assumes 2 sampling technicians at 10 hours/day. Sample all wells for VOCs, natural attenuation parameters (10 wells), and water quality parameters.
Sampling Labor	days	8	
Sampling Labor	hrs/event	160	
Sampling Labor	$/hr	65	
Per Diem	$/event	1,984	(2 FTE x 8 days x $124/day)
Cargo Van Rental / Gas	$/event	880	(1 van x 8 days x $110/day includes gas).
Sample materials	ea/event	26	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	21.00	
Sample equipment	$/event	1,200	Water quality parameter equipment, pumps, misc tools, and sampling equipment rental/purchase. Based on RACER model.
Analytical Cost	$/event	4,820	Analyze GW samples from 15 wells for VOCs (21 @ $120) and Natural Attenuation Parameters (5 @ $460). Includes 10% duplicate and 5% rinsate, and trip blanks.
Sample Shipment	$/event	150	3 coolers @ $50 ea.
Data Management	hrs	13	Data validation
Data Management	$/hr	70	
IDW Water Disposal	events	3	Assume 100% hazardous water ($0.38/gal @ 400 gal) to dispose. Add $5,000 pickup, transport, & tank cleanout. Add $600 sampling & analysis.
IDW Water Disposal	$/event	5,752	Based on Safety Kleen Quote.
Reporting			
Injection and Monitoring Report	$/event	16,000	Assume 200 hrs @ $80/hr.

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 3 - Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M			
Groundwater Sampling & Analysis (Years 0 through 15)	events	26	Includes quarterly sampling for Years 0-3, semiannual for Years 4-5, and annual sampling for Years 6-15 in transition and bedrock zone. Includes conformational sampling in the transition and bedrock zone (year 15). There are 8 total events. Includes 21 existing and 9 new wells that are sampled in 12 days (2.5 wells/day) plus 2 days travel. Assumes 2 sampling technicians at 10 hours/day. Sample all wells for VOCs, natural attenuation parameters (5 wells), and water quality parameters.
Sampling Labor	days	14	
Sampling Labor	hrs/event	280	
Sampling Labor	$/hr	65	
Per Diem	$/event	3,472	(2 FTE x 14 days x $124/day)
Cargo Van Rental / Gas	$/event	1,540	(1 van x 14 days x $110/day includes gas).
Sample materials	ea/event	51	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	21.00	
Sample equipment	$/event	1,200	Water quality parameter equipment, pumps, misc tools, and sampling equipment rental/purchase. Based on RACER model.
Sample equipment	lot	1,000	Purge water tank (1,000 gal) and trailer.
Analytical Cost	$/event	9,520	Analyze GW samples from 30 wells for VOCs (41 @ $120) and Natural Attenuation Parameters (10 @ $460). Includes 10% duplicate and 5% rinsate, and trip blanks.
Sample Shipment	$/event	300	6 coolers @ $50 ea.
Data Management	hrs	26	Data validation
Data Management	$/hr	70	
IDW Water Disposal	events	26	Assume 100% hazardous water ($0.38/gal @ 800 gal) to dispose. Add $5,000 pickup, transport, & tank cleanout. Add $600 sampling & analysis.
IDW Water Disposal	$/event	5,904	Based on Safety Kleen Quote.
Reporting			
Annual/Periodic Report	$/event	9,600	Assume 120 hours @ $80/hr average for analytical report and to recalibrate GW model.
5-Year Reviews	event	3	Assume 5-Year reviews for years 5-15.
5-Year Reviews	$/event	6,400	Assume 80 hours @ $80/hr.
Well Abandonment			
Abandon Monitoring Well	lot	1	Assume 70 wells @ 25 ft,41 wells @ 100 ft, and 5 wells @ 250 ft. Assume $1,000 mob, $12/lf to grout, and $500 per well to remove surface casing and restore.
Abandon Monitoring Well	$/lot	120,400	

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 3 - Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation
Cost Estimate

CAPITAL COST $4,555,321

Activity (unit)	Quantity	Unit Cost	Total
Institutional Controls			
Groundwater Use Restrictions (hrs)	120	$90	$10,800
Monitoring Wells			
Mob/Site Preparation (ea)	1	$5,000	$5,000
Transition Wells (ea)	4	$3,463	$13,854
Bedrock Wells (ea)	5	$28,566	$142,832
IDW Disposal (drums)	115	$219	$25,128
Transportation (ls)	1	$1,415	$1,415
IDW Sampling (ea)	9	$600	$5,400
Development Equip, H&S Equip (wk)	5	$525	$2,625
Well Installation Report (ea)	1	$3,200	$3,200
In Situ Biodegredation			
Injection Well Installation			
Injection Permit (ea)	1	$3,200	$3,200
Mob/Site Preparation (lot)	1	$5,000	$5,000
Transition Wells (ea)	54	$3,196	$172,598
Bedrock Wells (ea)	31	$11,962	$370,825
IDW Disposal (drums)	526	$219	$114,931
Transportation (ls)	1	$19,810	$19,810
IDW Sampling (ea)	9	$600	$5,100
Development Equip, H&S Equip (wk)	17	$525	$8,925
Installation Report (ea)	1	$32,000	$32,000
Injection System Setup			
Injector Installation Labor (days)	43	$700	$30,100
Injector Installation Matls (wells)	85	$300	$25,500
Injection Program - Fixed Cost			
Metering Pump (lot)	1	$9,000	$9,000
Header System (lot)	1	$42,000	$42,000
Storage Sheds (lot)	1	$20,000	$20,000
Pressure Pipe (lot)	1	$375,000	$375,000
Injection Setup	400	$60	$24,000
Per Diem (lot)	1	$4,960	$4,960
Cargo Van Rental / Gas (lot)	1	$4,000	$4,000
Installation Report (ea)	1	$15,000	$15,000
Injection System Operations - Transition Zone			
Injection Labor (events)	4	$11,200	$44,800
Injection Program - Per Diem (events)	4	$1,360	$5,440
Injection Program - Rental Vehicle (events)	4	$1,760	$7,040
Fork Lift Rental	4	$600	$2,400
Sodium Permanganate Materials (events)	4	$33,000	$132,000
Water (events)	4	$1,000	$4,000

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 3 - Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total
Injection System Operations - Bedrock Zone			
Injection Labor (events)	7	$11,200	$78,400
Injection Program - Per Diem (events)	7	$1,360	$9,520
Injection Program - Rental Vehicle (events)	7	$1,760	$12,320
Fork Lift Rental	7	$5,000	$35,000
Sodium Permanganate Materials (events)	7	$76,000	$532,000
Water (events)	7	$1,500	$10,500
Verification Sampling & Analysis - Events 1-4			
Sampling Labor (event)	4	$18,200	$72,800
Per Diem (event)	4	$3,472	$13,888
Cargo Van Rental / Gas (event)	4	$1,540	$6,160
Sample materials (event)	4	$1,071	$4,284
Sample equipment (event)	4	$1,200	$4,800
Sample equipment (event)	1	$1,000	$1,000
Analytical Cost (event)	4	$9,520	$38,080
Sample Shipment (event)	4	$300	$1,200
Data Management (event)	4	$1,820	$7,280
IDW Disposal (event)	4	$5,904	$23,616
Verification Sampling & Analysis - Events 5-7			
Sampling Labor (event)	3	$10,400	$31,200
Per Diem (event)	3	$1,984	$5,952
Cargo Van Rental / Gas (event)	3	$880	$2,640
Sample materials (event)	3	$546	$1,638
Sample equipment (event)	3	$1,200	$3,600
Analytical Cost (event)	3	$4,820	$14,460
Sample Shipment (event)	3	$150	$450
Data Management (event)	3	$910	$2,730
IDW Disposal (event)	3	$5,752	$17,256
Reporting			
Injection and Monitoring Report (lot)	1	$16,000	$16,000
Subtotal			$2,634,656
Design		10%	$263,466
Office Overhead		5%	$131,733
Field Overhead		15%	$395,198
Subtotal			$3,425,053
Profit		8%	$274,004
Contingency		25%	$856,263
Total			$4,555,321

Focused Feasibility Study at the Former Naval Ammunition Depot (NAD), Charlotte, North Carolina
Alternative 3 - Enhanced Bioremediation using Sodium Lactate with Monitored Natural Attenuation
Cost Estimate

OPERATION AND MAINTENANCE — **$2,568,755**

Activity (unit)	Quantity	Unit Cost	Total Cost
O&M Sampling & Analysis (Years 0 through 15)			
Sampling Labor (event)	26	$18,200	$473,200
Per Diem (event)	26	$3,472	$90,272
Cargo Van Rental / Gas (event)	26	$1,540	$40,040
Sample materials (event)	26	$1,071	$27,846
Sample equipment (event)	26	$1,200	$31,200
Purge Water Tank and Trailer (lot)	1	$1,000	$1,000
Analytical Cost (event)	26	$9,520	$247,520
Sample Shipment (event)	26	$300	$7,800
Data Management (event)	26	$1,820	$47,320
IDW Disposal (event)	26	$5,904	$153,504
Reporting			
Annual/Periodic Report (ea)	26	$9,600	$249,600
5-Year Review (ea)	3	$6,400	$19,200
Monitoring Well Abandonment			
Abandon Monitoring Well (lot)	1	$120,400	$120,400
Subtotal O&M			$1,508,902
Design		8%	$120,712
Office Overhead		5%	$75,445
Field Overhead		15%	$226,335
Subtotal			$1,931,395
Profit		8%	$154,512
Contingency		25%	$482,849
Total			$2,568,755

TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost) — **$7,124,076**