DRAFT FINAL

FEASIBILITY STUDY

FOR THE

FORMER CHARLOTTE ARMY MISSILE PLANT, MECKLENBURG COUNTY, CHARLOTTE, NORTH CAROLINA

Prepared for

U. S. ARMY CORPS OF ENGINEERS
SAVANNAH DISTRICT

CONTRACT NO. DACA21-95-D-0022
DELIVERY ORDER 0070

June 2004

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ACRONYMS

3-D	three-dimensional
ARAR	applicable or relevant and appropriate requirement
AT123D	Analytical Transient 1-, 2-, 3-Dimensional (Model)
BTEX	benzene, toluene, ethylbenzene, and xylene
BZ	bedrock zone
CAMP	Charlotte Army Missile Plant
CBC	criterion background concentration
CeB2	Cecil sandy clay loam with 2 to 8% slopes
CeD2	Cecil sandy clay loam with 8 to 15% slopes and eroded surfaces
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	*Code of Federal Regulations*
COC	contaminant of concern
COPC	contaminant of potential concern
CSM	conceptual site model
CuB	Cecil-urban land complex
DERP	DoD Environmental Restoration Program
DNAPL	dense nonaqueous-phase liquid
DO	dissolved oxygen
DoD	U. S. Department of Defense
EPA	U. S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FS	feasibility study
FUDS	Formerly Utilized Defense Sites
GMZ	groundwater management zone
gpm	gallons per minute
GPR	ground-penetrating radar
GRA	general response action
HHRA	human health risk assessment
HQW	High Quality Waters
IDW	investigation-derived waste
ISCO	in situ chemical oxidation
JE	Johnson Ettinger (Model)
LDR	land disposal restriction
LEL	lower explosive limit
M&E	Metcalf and Eddy
MCL	maximum contaminant level
MTBE	methyl tertiary butyl ether
NC	North Carolina
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")
NEPA	National Environmental Policy Act
NRHP	National Register of Historic Places
O&M	operation and maintenance
ORC	oxygen-releasing compound
ORP	oxidation-reduction potential
ORW	Outstanding Resource Waters

PCE	tetrachloroethene
PCV	polyvinyl chloride
PID	photoionization detector
PPE	personal protective equipment
psig	pounds per square inch gauge
RAO	remedial action objective
RBC	risk-based concentration
RI	Remedial Investigation
RQ	reportable quantity
SAIC	Science Applications International Corporation
SARA	Superfund Amendment and Reauthorization Act of 1986
scfm	standard cubic feet per minute
SCM	site conceptual model
SHPO	State Historic Preservation Office
SRS	Savannah River Site
SVOC	semivolatile organic compound
SZ	shallow zone
TAL	Target Analyte List
TBC	to be considered
TCE	trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TZ	transition zone
USACE	U. S. Army Corps of Engineers
UST	underground storage tank
VOC	volatile organic compound

EXECUTIVE SUMMARY

This feasibility study (FS) has been prepared to develop, screen, and evaluate potential remedial alternatives for addressing contaminated groundwater at the former Charlotte Army Missile Plant (CAMP) located on Statesville Avenue in Charlotte, Mecklenburg County, North Carolina. Investigation and cleanup of the site are being administered under the U. S. Department of Defense (DoD) Environmental Restoration Program–Formerly Utilized Defense Sites (DERP–FUDS) Program. This FS was prepared by Science Applications International Corporation (SAIC) Engineering of North Carolina under Contract No. DACA21-95-D-0022, Delivery Order No. 0070, administered by the Savannah District U. S. Army Corps of Engineers (USACE).

The CAMP was used to support DoD operations from 1954 to 1967. The site is currently used as an industrial park and is primarily a trucking distribution center for the Eckerd Drug Company. Five former tank sites and two other areas of operation comprise the CAMP investigation area.

CERCLA Phase I and II Remedial Investigations (RIs) were conducted at the site by Metcalf and Eddy, on behalf of the USACE, in 1996 through 1997 and 1999 through 2000, respectively. Two supplemental investigations were conducted by SAIC in 2001 and 2003. Conclusions from these investigations are summarized in the following paragraphs.

RI and Supplemental Investigation Findings

The groundwater flow regime identified at the CAMP has been subdivided into three hydrogeologic zones: the shallow, transition, and bedrock. The shallow zone is characterized by the unconsolidated residuum and 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. The bedrock zone is characterized by the presence of water-bearing fractures within the competent diorite. Groundwater in each of these zones was monitored.

The RI and supplemental investigations concluded that trichloroethene (TCE) concentrations in groundwater exceeded the North Carolina (NC) drinking water standard of 2.8 µg/L. The distribution of TCE can be categorized into three hot spot areas. Hot Spot No. 1 extends from monitoring well SAIC-10 north to SAIC-18 and contains the majority of TCE mass identified. Monitoring well SAIC-10 is located along the east end of Building 1, and SAIC-18 is located along the south side of Building 2. This hot spot is characterized by concentrations of TCE > 500 µg/L with peak concentrations of up to 7,500 µg/L. The vertical distribution of TCE > 500 µg/L in this area extends from the shallow groundwater table into the transition zone.

Hot Spot No. 2 is located along the eastern end of Building 2. The identified concentration of TCE appears aerially localized and is limited to the shallow zone.

Hot Spot No. 3 is located along the northwest corner of Building 1 and is located within the footprint of Hot Spot No. 1. This location is considered independent of Hot Spot No. 1, as the TCE concentration > 500 µg/L was detected within the bedrock zone. With a detected TCE concentration of 5,000 µg/L, this is the only location at the CAMP facility where TCE was identified within a bedrock monitoring well at concentrations exceeding 500 µg/L.

No specific source for the TCE in groundwater has been identified. However, the significant concentrations of TCE along the eastern end of Building 1 indicate this area is most likely an initial entry location.

Surface water from the CAMP is collected into a storm sewer network and transported to an outfall at a manmade drainage channel located in the northwest corner of the site across Statesville Avenue. One surface water sample was collected in support of the Phase II RI at the outfall. Analytical results of this sample detected TCE levels between the federal maximum contaminant level (MCL) [5 μg/L] and the North Carolina Administrative Code (NCAC) 2B surface water criteria (92.4 μg/L). Follow-up investigations by SAIC resulted in the identification of an area potentially susceptible to groundwater infiltration into the storm drain system. The area identified occurs within the shallow contaminant plume of concern. A water sample from the storm sewer was collected from the manhole located just south of monitoring wells SAIC-5 and SAIC-12. This water sample was analyzed for volatile organic compounds, with only TCE detected (310 μg/L). The reported concentration exceeded both the federal MCL and the NCAC 2B surface water criteria.

Exposure Pathways

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

Several groundwater contaminants of potential concern (COPCs) were identified from the Phase I, Phase II, and FS sampling results based on comparison to residential drinking water standards. These chemicals are currently not contaminants of concern (COCs) because groundwater is not used as a source of potable water in this area. However, TCE and chloroform were consistently detected at elevated concentrations throughout the groundwaters at the CAMP and are considered COCs for potential future exposures.

The potential for exposure to groundwater contamination via vapor intrusion into buildings was investigated based on new U. S. Environmental Protection Agency guidance. The potential risk from TCE was estimated to be 1×10^{-6} at one building. This is equal to the *deminimis* risk level for remedial action. Given the conservative assumptions used in this assessment, all of the estimated risks are considered to be minor, and exposure to contaminants in groundwater as a result of vapor intrusion is not considered to be a complete pathway under current conditions; therefore, no groundwater COCs are identified for exposure via vapor intrusion.

The concentration of TCE detected in the storm sewer sample is below applicable surface water standards; therefore, exposure via discharge to surface water is considered incomplete. While no current exposures are identified for contaminants in the storm sewer, the sewer represents a potential migration pathway to surface water if concentrations were to increase in the future.

Remedial Action Objective

Therefore, the only medium requiring further evaluation is groundwater. The North Carolina Department of Environment and Natural Resources (NCDENR) and the USACE–Savannah District have agreed that Hot Spot No. 1 is the only area to be considered for active remediation within this FS. It was agreed that treatment would consist of reducing the TCE concentrations in Hot Spot No. 1 to 100 μg/L via active treatment, with the implementation of monitoring of natural attenuation to achieve the North Carolina Groundwater Quality Standard of 2.8 μg/L. Hot Spot Nos. 2 and 3 will not be specifically addressed within this FS, as they are considered highly localized and impracticable to treat at this time. As Hot Spot No. 3 is located within the footprint of Hot Spot No. 1, it is anticipated that the treatment of this area will consequently reduce the bedrock TCE concentrations as an auxiliary process.

Based on these agreements, the remedial action objective (RAO) for the remedial action at the CAMP is to remediate groundwater at the area of contamination identified as Hot Spot No. 1 in order to reduce TCE concentrations to 100 µg/L. Although the RAO only addresses Hot Spot No. 1, reductions in bedrock TCE concentrations are also expected.

Alternative Description

The No Action alternative (Alternative 1) and four action alternatives were identified for further evaluation for the contaminated groundwater:

- Alternative 2, Bioaugmentation;
- Alternative 3, Biostimulation;
- Alternative 4, Permeable reactive barrier; and
- Alternative 5, In situ chemical oxidation (or ISCO).

In Alternative 2, groundwater in the shallow and transition zones of Hot Spot No. 1, containing TCE concentrations greater than 500 µg/L, would be treated by injection of aerobic bacteria and nutrients. The resulting biodegradation would be monitored and supplemented at monthly intervals for 6 months until TCE concentrations are less than 100 µg/L. Once treatment operations have been completed, the groundwater would be monitored every 5 years until the RAO is achieved (anticipated to be 85 years).

Alternative 2 includes installation of 106 injection wells in the shallow and transition zones of Hot Spot No. 1. Following an initial injection of aerobic bacteria, additional injections of bacteria and/or nutrients would be performed monthly for up to six injections, with the levels of both TCE and other parameters monitored before each subsequent injection. Concentrations of TCE would be monitored to verify that natural attenuation of residual contamination is occurring following the final injection of bacteria and/or nutrients.

In Alternative 3, groundwater in the shallow and transition zones of Hot Spot No. 1, containing TCE concentrations greater than 500 µg/L, would be treated by enhancing or stimulating co-metabolic biodegradation processes until TCE concentrations are less than 100 µg/L (estimated to take approximately 2 years). Once treatment operations have been completed, the groundwater would be monitored every 5 years until the RAO is achieved (anticipated to be 85 years).

The stimulation of co-metabolic biodegradation of TCE-contaminated groundwater would be accomplished by installing two 800-ft, parallel, horizontal wells above the bedrock beneath the shallow and transition contaminant zones. The horizontal wells would be stainless steel pipe, with the portion beneath the contaminated groundwater screened to allow slow sparging (injection) with an approximately 3% methane in air mixture. [The lower explosive limit (LEL) for methane in air is 5%.] The screened portion of the wells would run approximately 400 ft. The air-methane mixture would be injected at a rate of approximately 400 standard cubic feet per minute (scfm) per well, corresponding to a delivery rate of 1.0 scfm per linear foot of screen. The anticipated radius of influence for each horizontal well is 60 ft; therefore, the wells would be spaced approximately 120 ft apart and would realize a treatment zone width of 240 ft. This methane would be pulsed (i.e., delivered for 8 hours and then stopped for 16 hours) to prevent fouling of the screens.

In Alternative 4, a subsurface permeable reactive barrier would be installed full depth through the shallow and transition zones, downgradient of Hot Spot No. 1. The permeable reactive barrier would contain a mixture of sand and iron filings, which would reduce and dechlorinate the TCE as the groundwater flows through the barrier.

Alternative 4 would consist of a series of 1-ft-diameter columns, arrayed in two rows spaced on 2-ft centers, but offset 1 ft for a total length of 330 ft. The anticipated reactive barrier length would be longer than the width of the 500 µg/L TCE plume contour and largely capture the 100 µg/L of TCE plume as well. Concentrations of TCE downgradient from or outside the dimensions of the reactive barrier would not be reduced; however, that residual mass would be expected to attenuate since areas containing more than 100 µg/L of TCE would have been remediated. Due to the anticipated length of treatment (160 years), long-term monitoring would be needed to evaluate the effectiveness of this process option—particularly to verify the effectiveness and "integrity" of the columns (i.e., no heterogeneous short circuiting or breakthrough of TCE around or between columns).

Alternative 5 includes installation of 106 injection wells in the shallow and transition zones of Hot Spot No. 1 and injecting a sodium permanganate solution until the TCE concentration reaches 100 µg/L. Once treatment operations have been completed, the groundwater would be monitored every 5 years until the RAO is achieved (anticipated to be 85 years). A permanganate solution would be metered into the injection wells over the course of one week. The injection rate would vary, depending on site conditions, but is expected to be around 3 gpm for 5 days at a pressure of 50 lbs per square inch gauge (psig) or less.

An additional permanganate solution would then be injected every 6 to 12 months for up to four injections, with the levels of both TCE and permanganate monitored before each subsequent injection. Concentrations of TCE outside (principally downgradient from) the injection zone would be monitored to verify that natural attenuation is occurring following the final injection of oxidant.

Alternative Evaluation

The No Action alternative would not meet the site RAO; however, it was evaluated as required by the National Oil and Hazardous Substances Pollution Contingency Plan, referred to as the "National Contingency Plan." All four action alternatives would achieve the RAO of reducing TCE concentrations in groundwater at Hot Spot No. 1 to 100 µg/L. Bioaugmentation, biostimulation, and in situ chemical oxidation (or ISCO) would achieve the RAO in similar time periods (85 years). The permeable reactive barrier would require the longest time to meet the RAO at 160 years. All alternatives would be implementable but would require close coordination with the property owners so as not to interrupt site operations during well installations. Biostimulation provides the most comprehensive coverage while minimizing impacts to site operations. However, there would be minimal impact to site operations once the wells have been installed.

Alternative 1, the No Action alternative, has no costs associated with implementation. Of the four action alternatives, Alternative 3, Biostimulation, is the least expensive ($3.4 million) followed by Alternative 2, Bioaugmentation ($6.7 million), Alternative 4, Permeable Reactive Barrier ($5.1 million), and Alternative 5, In Situ Oxidation ($11.6 million).

Alternative 4 (Permeable Reactive Barrier) has a high cost and long-term monitoring requirements. Alternatives 2, 3, and 5 will achieve the RAO and do so in similar time periods, and all three are implementable. Alternative 3 is less expensive than Alternatives 2 and 5; however, in situ biostimulation has not been used as frequently and, therefore, has more uncertainties associated with its effectiveness and cost.

Due to the site-specific geologic, hydrogeologic, and groundwater geochemical conditions at the CAMP, a pilot test would be required to determine the effectiveness of the selected technology. A single

remedial alternative will be selected for pilot-scale testing after discussions with the USACE and NCDENR.

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1.0 INTRODUCTION

This feasibility study (FS) has been prepared to develop, screen, and evaluate potential remedial alternatives for addressing contaminated groundwater at the Charlotte Army Missile Plant (CAMP) located in Charlotte, Mecklenburg County, North Carolina (Figure 1-1). The CAMP is currently an industrial park that was previously used to support U. S. Department of Defense (DoD) operations. Investigation and cleanup of the site are being administered under the DoD Environmental Restoration Program–Formerly Utilized Defense Sites (DERP–FUDS) Program. This FS was prepared by Science Applications International Corporation (SAIC) Engineering of North Carolina, Inc., under Contract No. DACA21-95-D-0022, Delivery Order No. 0070, administered by the Savannah District U. S. Army Corps of Engineers (USACE).

1.1 PURPOSE AND ORGANIZATION

The purpose of this FS is to develop and evaluate potential alternatives to address contaminated groundwater present at the CAMP. This document evaluates potential 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 (SARA). 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].

The FS is divided into seven chapters. Chapter 1.0 describes the purpose and organization of the FS, provides a summary of the site characteristics, provides the results of previous investigations, and presents the conceptual site model (CSM). Chapter 2.0 is a discussion of the objectives of the remedial action and the remediation approach. Contaminants of concern (COCs) are identified in Chapter 3.0. Chapter 4.0 identifies and screens applicable remedial technologies, which are used for the development and screening of alternatives in Chapter 5.0. Chapter 6.0 contains a detailed analysis of alternatives and ends with a comparative analysis of alternatives and remedial actions for further consideration. Chapter 7.0 provides full citations for documents used in the preparation of this report.

1.2 SITE BACKGROUND

1.2.1 Site Description

The CAMP is located on Statesville Avenue in Mecklenberg County, Charlotte, North Carolina (Figure 1-1). The site is currently used as an industrial park although it is primarily a trucking distribution center for the Eckerd Drug Company. Five former tank sites and two other areas of operation comprise the CAMP investigation area. Figure 1-2 shows the former investigation area boundaries. Site 1 contained an 8,000-gal transmission oil tank, an 8,000-gal motor oil tank, a 10,000-gal diesel tank, and a 10,000-gal antifreeze tank. Site 3 included a 10,000-gal sulfuric acid tank, a chrome holding tank, a cyanide and neutralization tank, and a sulfur dioxide storage area. Site 4 contained a 10,000-gal underground storage tank (UST) with one compartment holding 4,410 gal of toluene and the other compartment holding 5,420 gal of xylenes with two 1.5-in. lines running from the tank to Building 50. Site 5 included a 5,000- to 6,000-gal UST used to store gasoline. Site 6 contained a 3,000-gal tank used to store sulfuric, chromic, and hydrochloric acids. Site 7 included six 6,000-gal USTs used to store heating oil used for a boiler facility. Site 8 was a former solvent dispensing area that included a 6,000-gal aboveground

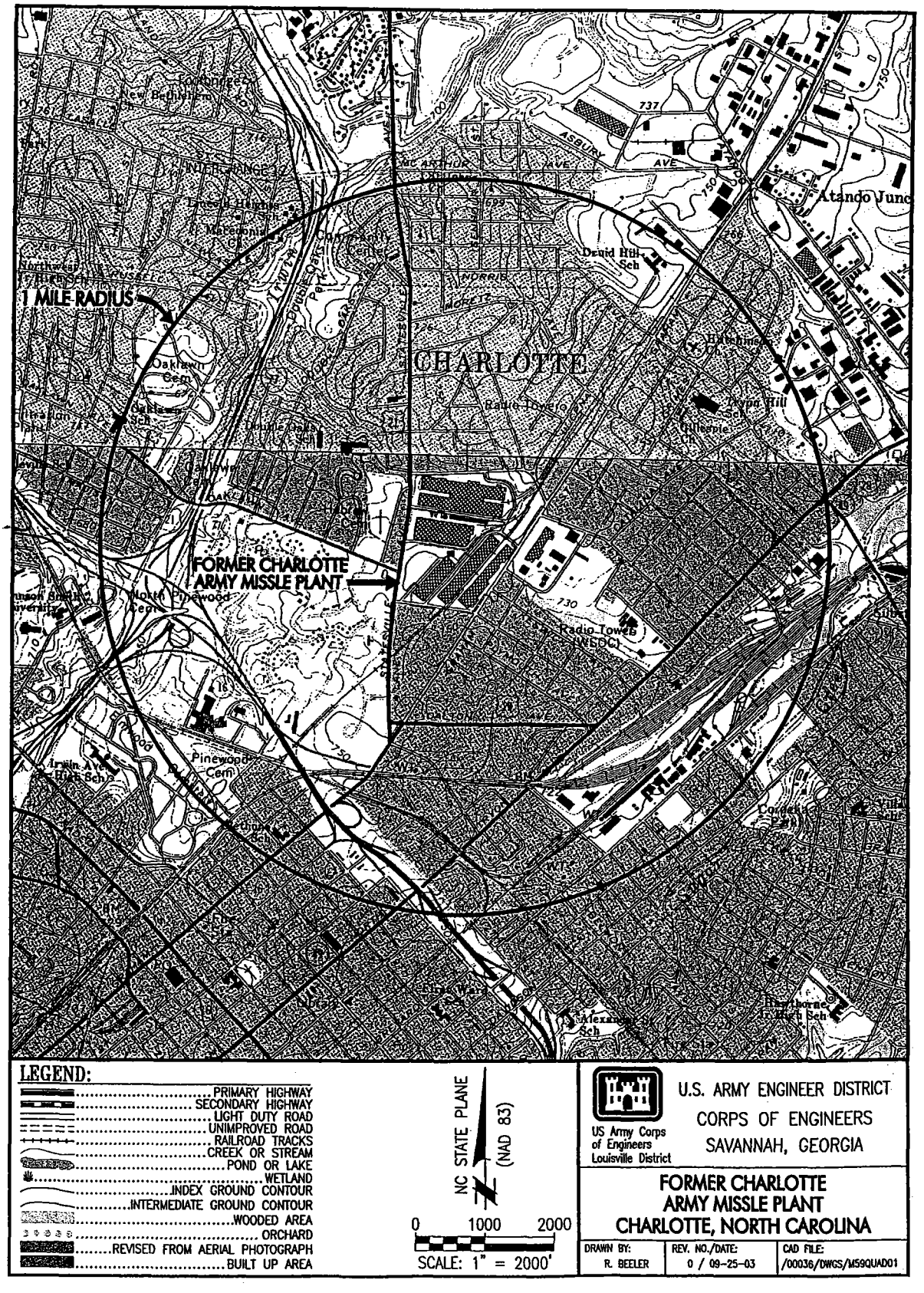

Figure 1-1. Site Location Map of Former CAMP

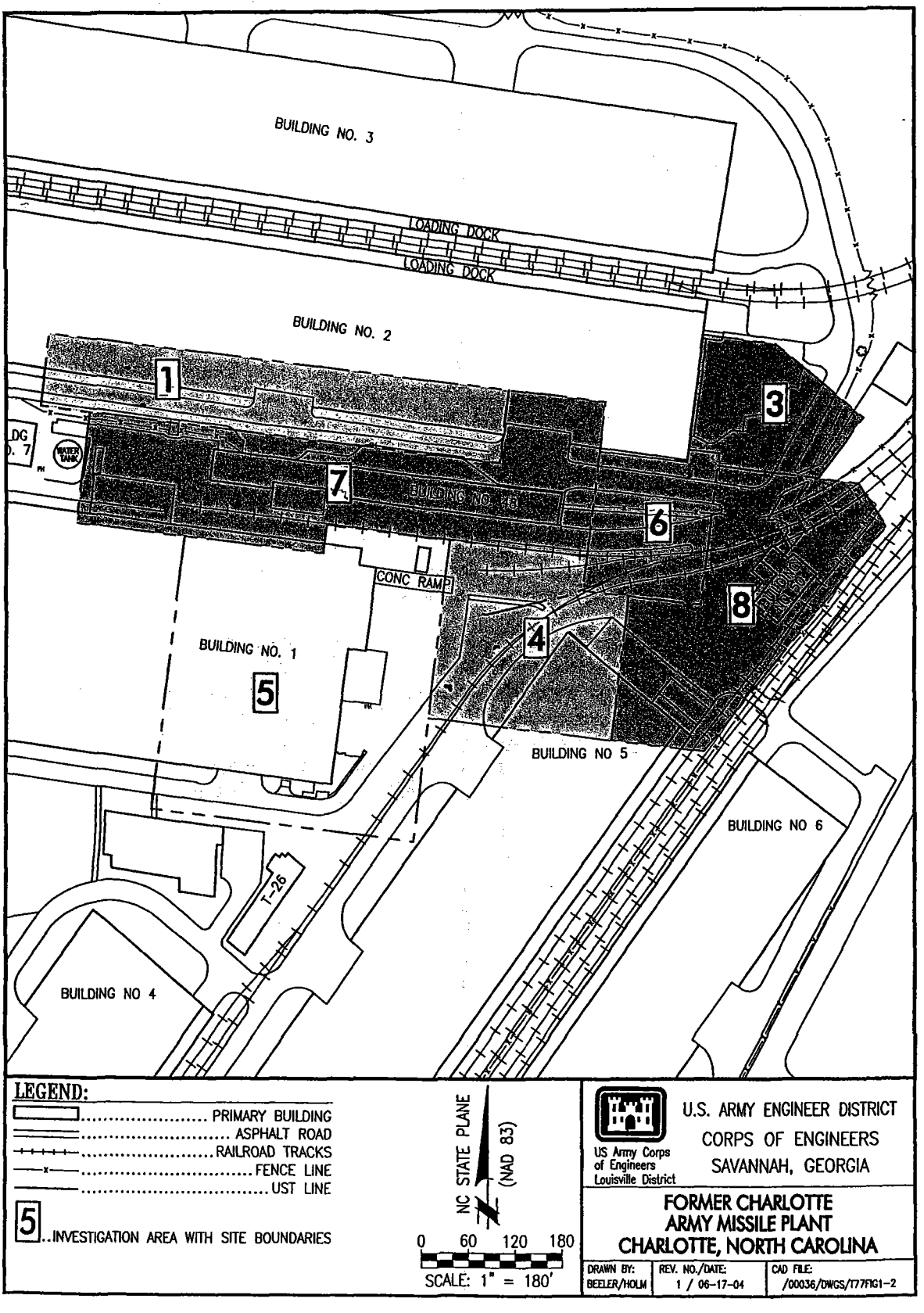

Figure 1-2. Investigation Area Site Boundaries

trichloroethene (TCE) storage tank. A 1.5-in. line ran from the tank to Building 50, which was the solvent dispensing area. Potential source areas associated with these sites are shown on Figure 1-3.

The majority of the former CAMP, and the mass of the contaminant plume, is located on property owned by Eckerd Drug Stores and is surrounded by a fence; it is accessed through one of two guard posts, which are manned 24 hours a day. The remaining portions of the site are owned by others, and access is restricted by fencing and locked gates (Figure 1-2). More than 85% of the CAMP is covered with asphalt, concrete, and buildings. Most soil has been cut, filled, and graded, and very few natural surface features remain. Infiltration is low and there is a high volume of surface runoff.

1.2.2 Site History

Circa 1924, the CAMP facility was privately owned farmland. In 1924, Henry Ford purchased the property, which would become a new factory specifically designed for the mass production of automobiles (Building No. 1). The plant manufactured a total of 231,066 cars and trucks from 1924 to 1932 when production ceased as a result of the stock market crash of 1929. Ford used the site until 1941 as a sales and service branch for the automobiles sold in the area. Between 1941 and 1948, the U. S. Army acquired 80.05 acres in fee and by lease and easement. The Charlotte Quartermaster Depot was activated at the site on May 16, 1941, with the mission to supply U. S. Army posts in the two Carolinas and Virginia (http://www.cmhpf.org/surveys&rfordplant.htm). However, during World War II, the unit was called upon to send emergency supplies overseas. From the end of World War II to January 1949, the depot was used to repatriate the war dead. The American Graves Registration Division took over the depot in August 1946 and returned the bodies of 5,170 deceased service personnel to their next-of-kin in North and South Carolina, Virginia, Tennessee, and Georgia (http://www.cmhpf.org/surveys&rfordplant.htm).

In 1945, the site was redesignated the "Charlotte Army Missile Plant" and converted to production of Nike guided missiles and repair parts. During the 1960s, the site was predominantly used to produce Nike Ajax and Nike Hercules missiles and parts, under the direction of Douglas Aircraft Corporation. The plant included six major buildings for manufacturing and administration, along with associated facilities. By quitclaim deed dated 1 September 1967, the United States conveyed 79.61 acres of land (77.65 acres fee and 1.96 acres easement) to Eighteen-Twenty, Inc. (a.k.a. Pat Hill Enterprises). Current owners of the site are Eckerd Drug Company, 1830 Statesville Avenue, L.L.C, Bancroft Realty, Jerry L. and Joyce Dellinger, and the Grief Brothers Corporation.

1.3 PREVIOUS INVESTIGATIONS

A December 1965 survey by Charlotte Engineers, Inc., reported numerous storage tanks on the property. Two tanks were removed from the site between 1965 and 1977. In 1990, Eckerd had four USTs removed (Site 5) along with collection of soil samples. The resulting report recommended additional investigation near the diesel and gasoline storage tanks.

In 1991, Petroleum Testing Services, Inc., performed a Phase I Site Assessment for Eckerd. The assessment included the installation of one monitoring well (MW01) and the advancement of one soil boring at the site of the former UST previously located in Site 5. The site assessment report stated that benzene, TCE, and total petroleum hydrocarbon (TPH) [diesel and gasoline] concentrations were detected above regulatory limits and recommended additional investigation to define the extent of contamination in the soil and groundwater.

Between 1991 and 1993, Shield Environmental Associates, Inc. (Shields) performed additional characterization activities associated with Site 5. Eight new monitoring wells were installed (MW-1

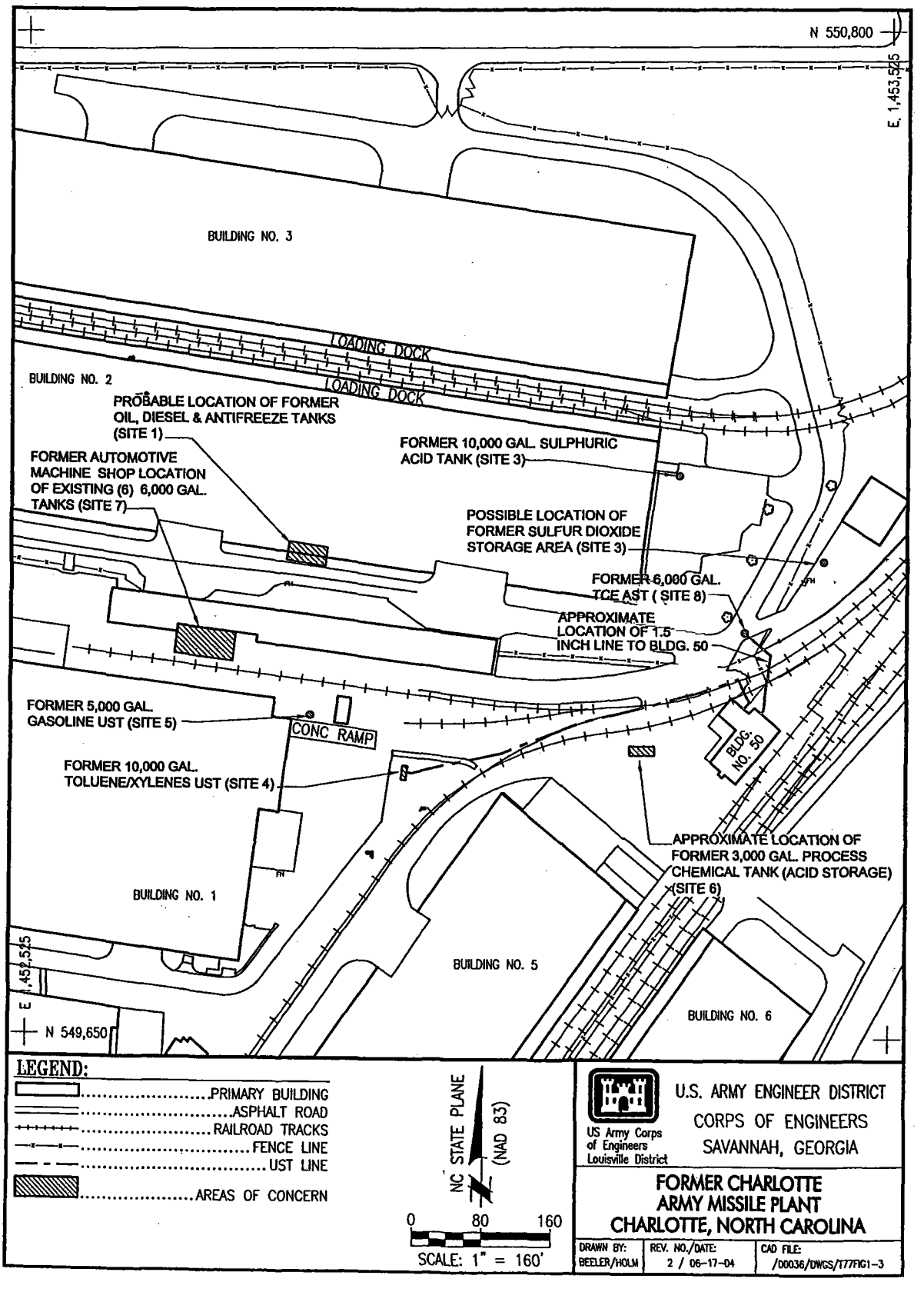

Figure 1-3. Possible Source Areas of Concern (as derived from M&E 2000)

through MW-7, and MW-1A), and four supplemental soil borings were advanced near the area where the former USTs were located. In addition, in 1992, a Hydropunch® investigation was initiated to further characterize the sitewide groundwater. During the investigations performed by Shields, tetrachloroethene (PCE); TCE; benzene, toluene, ethylbenzene, and xylenes (BTEX); and chloroform were detected in groundwater at levels that exceeded the North Carolina Administrative Code (NCAC) 2L groundwater standards in at least one sample. Additionally, methyl tertiary butyl ether (MTBE) was detected at two locations (MW-1 and MW-6). Since MTBE was not added to fuels until the late 1970s, this would indicate that a potentially responsible party other than the DoD stored fuel in the USTs in that vicinity. The September 1993 report recommended the following actions:

post-1970s contam.

- No further action for in situ soil since petroleum-impacted soils were below the March 1993 action levels of 180 mg/L for low-boiling-point fuels and 720 mg/L for high-boiling fuels.

- Passive remediation for petroleum hydrocarbons in the groundwater, since constituents were not moving significantly, will naturally degrade over time, and no groundwater receptors are within 1,500 ft of the site.

- Semi-annual sampling of all monitoring wells until benzene levels reduce to below 0.001 mg/L in MW-01.

- Non-petroleum-related volatile organic compound (VOC) constituents identified in groundwater should be addressed by the USACE.

The USACE, on behalf of the DoD, tasked Metcalf and Eddy (M&E) to conduct remedial investigation (RI) activities at the site. The Phase I and II RI activities and results are discussed in Section 1.4.

1.4 SUMMARY OF RI ACTIVITIES

The Phase I RI was conducted from December 1996 to August 1997 and the Phase II RI from June 1999 to March 2000. The results of these investigations are documented in the *Final Report for Phase I Remedial Investigation at Former Charlotte Army Missile Plant, Charlotte, North Carolina*, April 1999, and the *Final Phase II Remedial Investigation Report for the Former Charlotte Army Missile Plant, Mecklenburg County, Charlotte, North Carolina*, October 2000. The RIs were initiated to determine the nature and extent of contamination at former DoD operational areas at the CAMP.

1.4.1 Summary of Phase I RI Activities and Findings

The purpose of the Phase I RI was to determine the nature and extent of contamination at former operations areas where contamination had previously been identified, and operations areas where contamination had not been discovered. M&E was also tasked with assessing the overall soil, geologic, and hydrogeologic setting of the site and collecting information to support a baseline risk assessment. Applicable or relevant and appropriate requirements (ARARs) were identified and a visual inspection of the site was conducted to ensure that all transformers, blasting caps, primer cord, and aboveground storage tanks that were used during DoD ownership were removed.

The field investigation activities performed by M&E included a ground-penetrating radar (GPR) survey, the collection of subsurface soil samples, the installation of monitoring wells, and the collection of groundwater samples.

The GPR survey provided no evidence of USTs in Site 1. However, electromagnetic anomalies recorded in Sites 4, 6, and 8 were consistent with the presence of buried metallic piping, presumed to be the 1.5-in.-diameter distribution lines.

The results of the chemical analysis were compared to NCDENR Method 1 target concentrations for both soils and groundwater. This comparison produced the following conclusions:

- Aluminum, lead, iron, manganese, and vanadium were detected in subsurface soils at concentrations that exceeded both ARARs and two times the average background concentrations. Historical research provided no information regarding the use of these metals at the site.

- Groundwater samples from permanent groundwater wells indicated that metals concentrations detected on-site were less than two times the average background concentrations in all samples except one well where manganese exceeded two times its average background concentration.

- VOCs (TCE, chloroform, and carbon tetrachloride) were consistently detected in groundwater samples. These data suggested that two distinct plumes might exist in the groundwater, indicating that at least two sources of these contaminants may have been present at the site. Concentrations of TCE detected in deeper groundwater samples suggest that this contamination was migrating vertically through the aquifer and is present in lower portions of the water-bearing zone.

The baseline risk assessment reported that the occurrence of chemicals in groundwater could not be linked to contamination identified in the shallow soils. Additional investigation activities were recommended in order to delineate source areas associated with the groundwater contamination. The conclusion of the Phase I investigation was that VOC contamination (carbon tetrachloride, chloroform, and TCE) should be assessed on a sitewide basis since contamination could not be associated with any one site as a source. TCE was, by far, the predominant contaminant at the CAMP with respect to number of detections and concentration.

(*) No source of TCE id'd.

Further actions recommended by M&E included one year of quarterly sampling to monitor VOC concentrations over time, installation of seven deep and four shallow wells, collection of additional information regarding the tanks near COEMW4 (see Figure 1-3) and other possible sitewide contaminant sources, and collection of background soil samples to establish a better statistical determination of the metals concentrations in background soils.

1.4.2 Summary of Phase II RI Activities and Findings

The objectives of the Phase II RI were to establish the geologic and hydrogeologic framework of shallow and bedrock aquifers, delineate the vertical and horizontal extent of groundwater contamination identified in the Phase I RI, determine contaminant characteristics in soil and groundwater, conduct a quantitative risk assessment, evaluate contaminant concentrations with respect to ARARs, and recommend further action, including corrective action, if needed.

The Phase II field investigation activities performed by M&E included a potable well survey, a lineament study, the collection of surface and subsurface soil samples, the installation of monitoring wells, borehole geophysics, slug testing and the collection of groundwater samples.

The North Carolina Department of Environment and Natural Resources (NCDENR) well registration files indicated that there were seven private wells within a 1-mile radius of the CAMP; however, they were all located in up-gradient or side-gradient locations and were unlikely to be affected by contamination associated with the CAMP. M&E was unable to determine if the wells were active or not.

Eight shallow zone (SZ) wells, seven transition zone (TZ) wells, and three bedrock zone (BZ) wells were installed as part of Phase II activities. Groundwater levels and aquifer testing indicated a groundwater flow direction toward the northwest under an average hydraulic gradient of 0.02 ft/ft (USACE 2000). Bedrock topography, which slopes to the northwest in the vicinity of the plume, apparently influenced the northwesterly migration of the plume.

* GW flow to NW

Acetone and polycyclic aromatic hydrocarbons (PAHs) were detected in surface soil samples at concentrations above their respective EPA Region 3 risk-based concentrations (RBCs). Trace concentrations of acetone identified in surface soil samples may reflect incidental laboratory or field contamination. PAHs that were identified in two of five surface soil samples are likely associated with vehicular discharges common in parking areas surrounding Buildings 4 and 5. Several metals were detected in surface soil samples; however, only arsenic concentrations exceeded the RBC criterion.

+ Subsurface TCE found on property 26/30

Subsurface soil samples were analyzed for VOCs, semivolatile organic compounds (SVOCs), sulfate, polychlorinated biphenyls (PCBs), and Target Analyte List (TAL) metals. The analytical results show that acetone was detected in nine samples, but concentrations were well below the RBC. TCE was detected at two locations (COEMW26 and COEMW30) at concentrations well below the RBC. Sulfate was not detected in any sample. Aroclor-1260 was detected at one downgradient location (COEMW30) below the screening criteria. No SVOCs were detected in the subsurface soil samples. Several metals were detected in subsurface soil samples but did not exceed their respective industrial RBCs.

* TCE in surface water on prop.

One surface water sample (COESW01) was collected from the outfall of a manmade stream drainage feature. This sample was analyzed for VOCs, TAL metals, cyanide, methane alkalinity, chloride, and nitrite/nitrate. The surface water sample location was downgradient of the site, and it is the only surface water identified in the area. According to maps from the NCDENR Division of Water Quality Planning Branch, Water Supply Watershed Protection, surface water at the site is not classified as Class I, II, III, or IV. No surface water parameters exceed NCAC 2B standards; however, TCE (detected at 45 µg/L) exceeded the Federal drinking water maximum contaminant level (MCL) of 5.0 µg/L.

* Free product but not on our prop.

Groundwater samples were analyzed for VOCs, TAL metals, and water quality parameters. Four wells were also analyzed for cyanide. COEMW4 was again not sampled during the Phase II RI due to the presence of an oily free product, and M&E was unable to find any other information as to the source of this free product. Several organic compounds exceeded MCLs as well as NCAC 2L standards. Constituents exceeding the standards included chlorinated VOCs; most prevalent among these were chloroform, TCE, and 1,1-dichloroethene. Several other chlorinated VOC compounds and naphthalene were present at concentrations above the MCL and NCAC 2L standards; however, TCE was the most widespread constituent and occurred at the highest concentration. Inorganics detected in groundwater appear to be associated with naturally occurring sources. Aluminum, chromium, iron, and manganese concentrations in several groundwater samples exceeded the MCL and NCAC 2L standards.

TCE most prev. constit. in gw

M&E recommended that additional monitoring wells be installed to fully delineate the horizontal extent of TCE in groundwater before screening remedial alternatives. It was also suggested that an annual monitoring plan be instituted to gather data on TCE migration over time.

1.5 SUMMARY OF SUPPLEMENTAL INVESTIGATION ACTIVITIES AND FINDINGS

SAIC was tasked by the USACE to install the additional monitoring wells recommended by M&E and better define VOC groundwater plume boundaries identified by M&E during the Phase I and II RIs, as well as collect information to support the development of feasibility and pilot studies.

Two separate field projects were conducted by SAIC to further delineate the groundwater contamination at the CAMP. The first project took place during May 2001 and was designed to better define the dissolved-phase VOC plume boundary identified in the Phase I and II RIs, delineate the previously identified source areas, and collect groundwater natural attenuation parameter data to support the feasibility and pilot studies. The second project took place in January, February, and April of 2003. The objective of the latter investigation was to further characterize the extent of VOC contamination with a focus on specific hot spots, collect additional natural attenuation parameter data from the new monitoring wells, and determine whether contamination is entering the storm sewer system in the vicinity of monitoring wells SAIC-05 and COEMW06. The activities conducted and results are documented in the *Final Letter Report for the Feasibility Study/Remedial Design at the Former Charlotte Army Missile Plant, Mecklenburg County, Charlotte, North Carolina*, August 2002, and *2003 Letter Report for the Feasibility Study/Remedial Design at the Former Naval Ammunition Depot (NAD), Mecklenburg County, Charlotte, North Carolina*, June 2003. The results of the supplemental investigations conducted by SAIC are summarized below.

1.5.1 Groundwater Investigation

A total of 19 new groundwater-monitoring wells were installed by SAIC during the supplemental investigations to complement the 30 wells installed by M&E during the Phase I and II RI activities (Figure 1-4). Groundwater samples were collected from 30 wells during the 2001 field activities and 15 wells during the 2003 field activities. Figures 1-5, 1-6, and 1-7 provide a composite view of the reported TCE concentrations within the shallow, transition, and bedrock zones, respectively. As all wells within a particular zone were not sampled during a single event, the concentrations shown are representative of the latest available data for each monitoring well.

1.5.1.1 Groundwater in the shallow zone

Ten shallow wells were sampled in 2001, one of which (SAIC-01) was newly installed (Figure 1-5). TCE concentrations in SZ wells detected during the 2001 sampling event generally remained constant. Shallow wells COEMW02, COEMW06, and MW01 exhibited concentrations greater than 1,000 µg/L.

In 2003, eight shallow wells were sampled, two of which were newly installed (SAIC-16 and SAIC-19), and the TCE concentrations again remained relatively constant (Figure 1-5).

1.5.1.2 Groundwater in the transition zone

Fourteen TZ monitoring wells were sampled during the 2001 investigation, seven of which were newly installed wells (SAIC-02, SAIC-04, SAIC-05, SAIC-06, SAIC-07, SAIC-09, and SAIC-10) [Figure 1-4]. All but four of the wells sampled exhibited TCE concentrations above the NCAC 2L Standard criterion of 2.8 µg/L. No metals were determined to be potential COCs in groundwater within the TZ.

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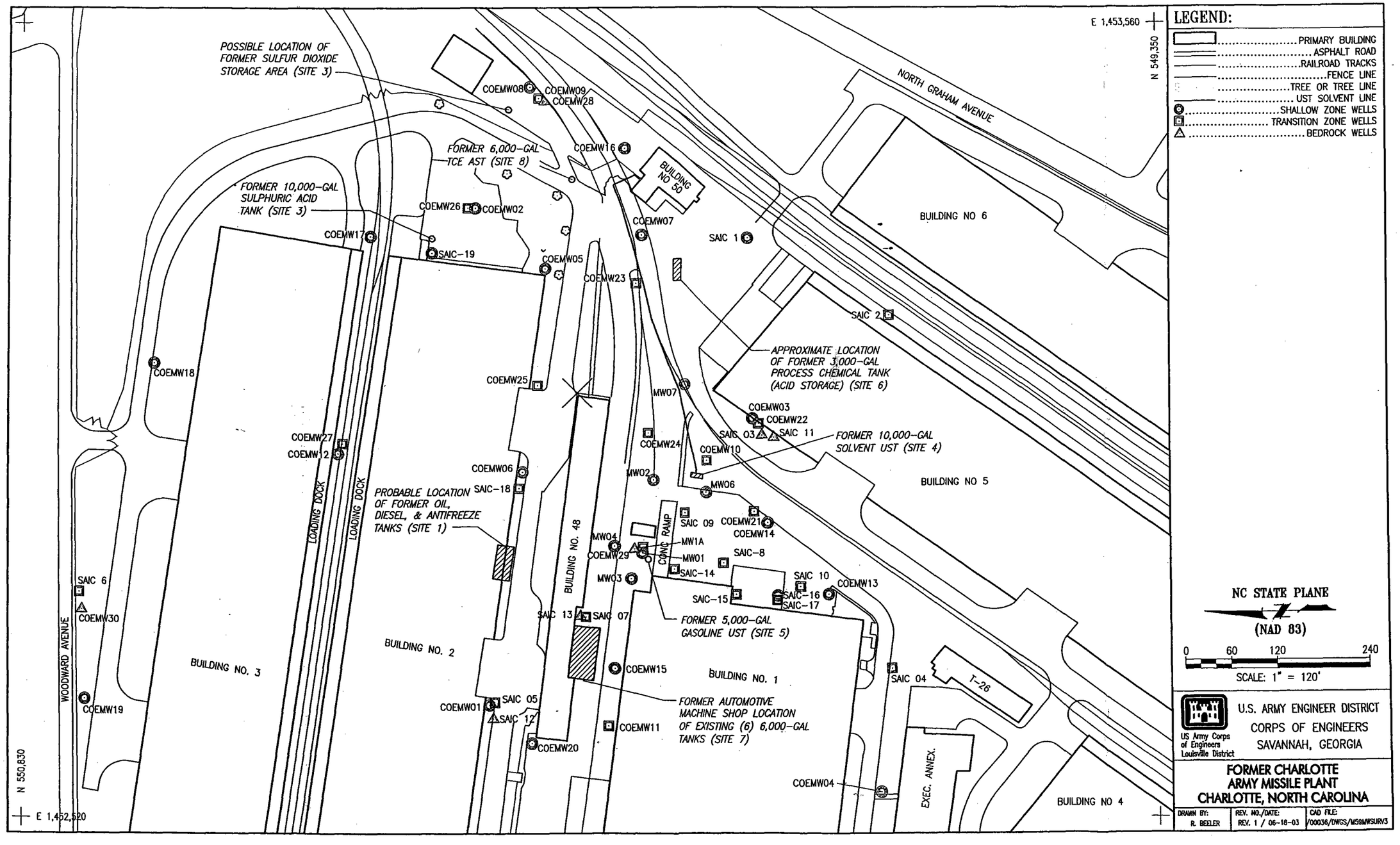

Figure 1-4. Site Map/Monitoring Well Locations

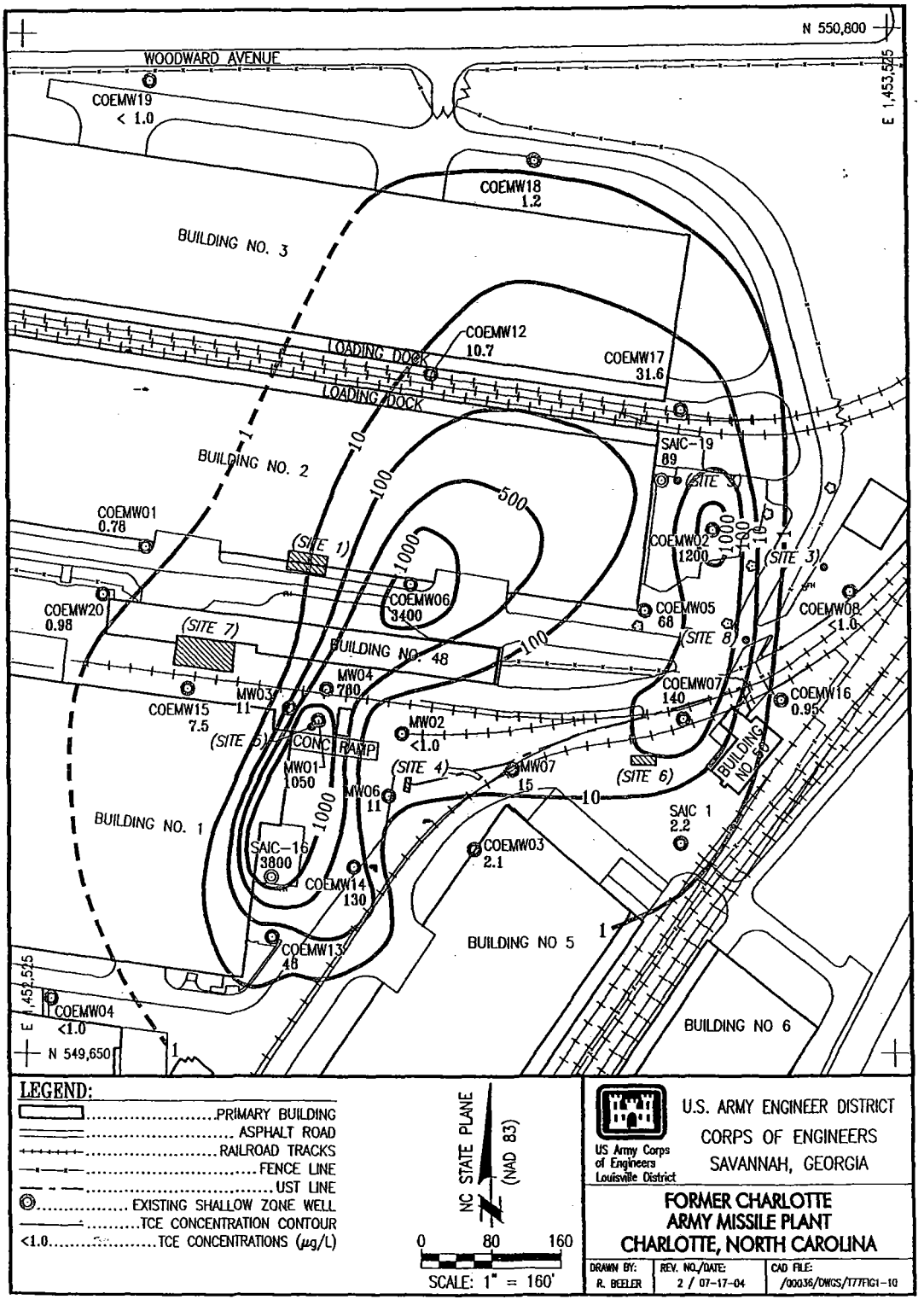

Figure 1-5. TCE Concentrations in Shallow Zone Wells

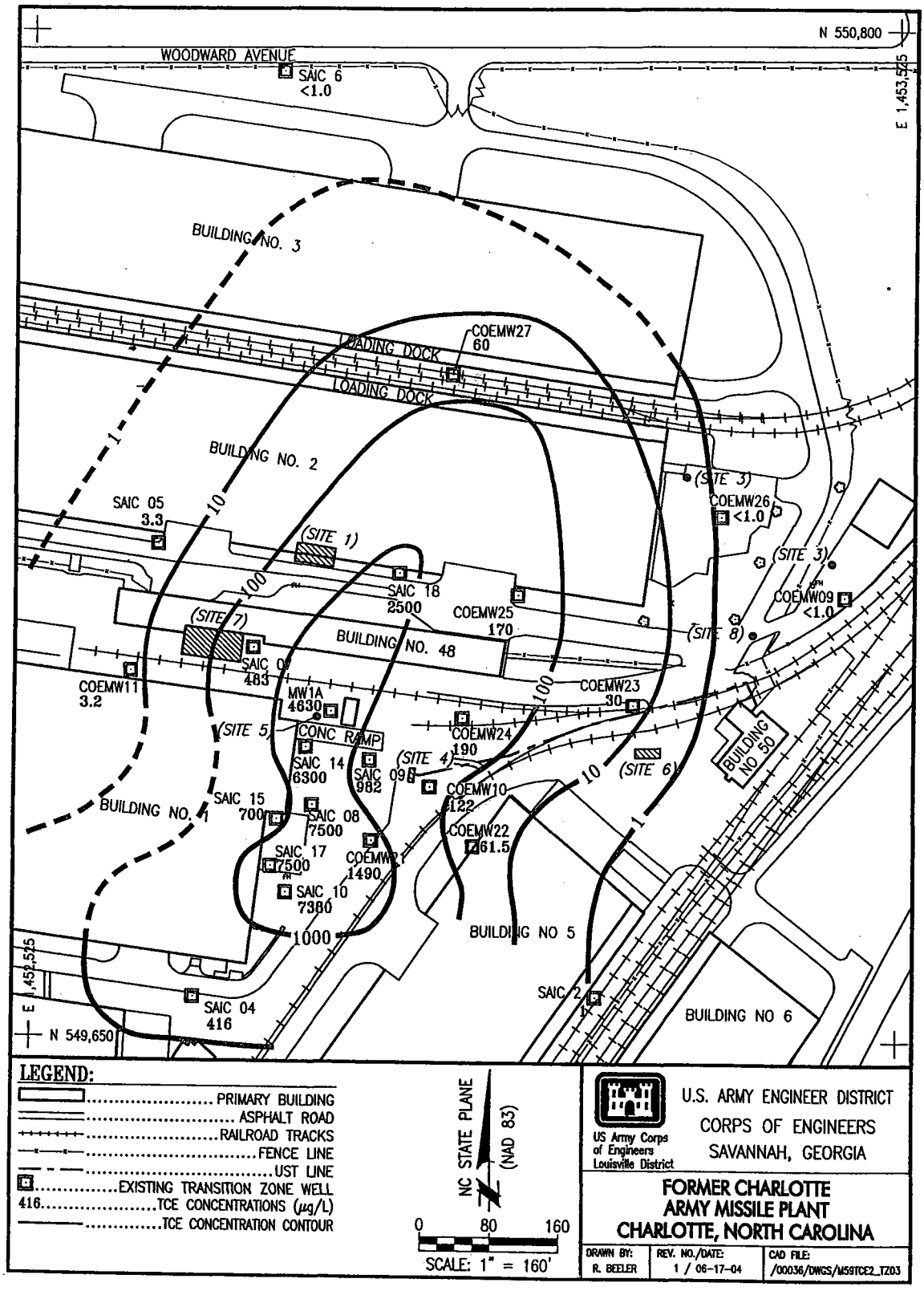

Figure 1-6. TCE Concentrations inTransition Zone Wells, February 2003

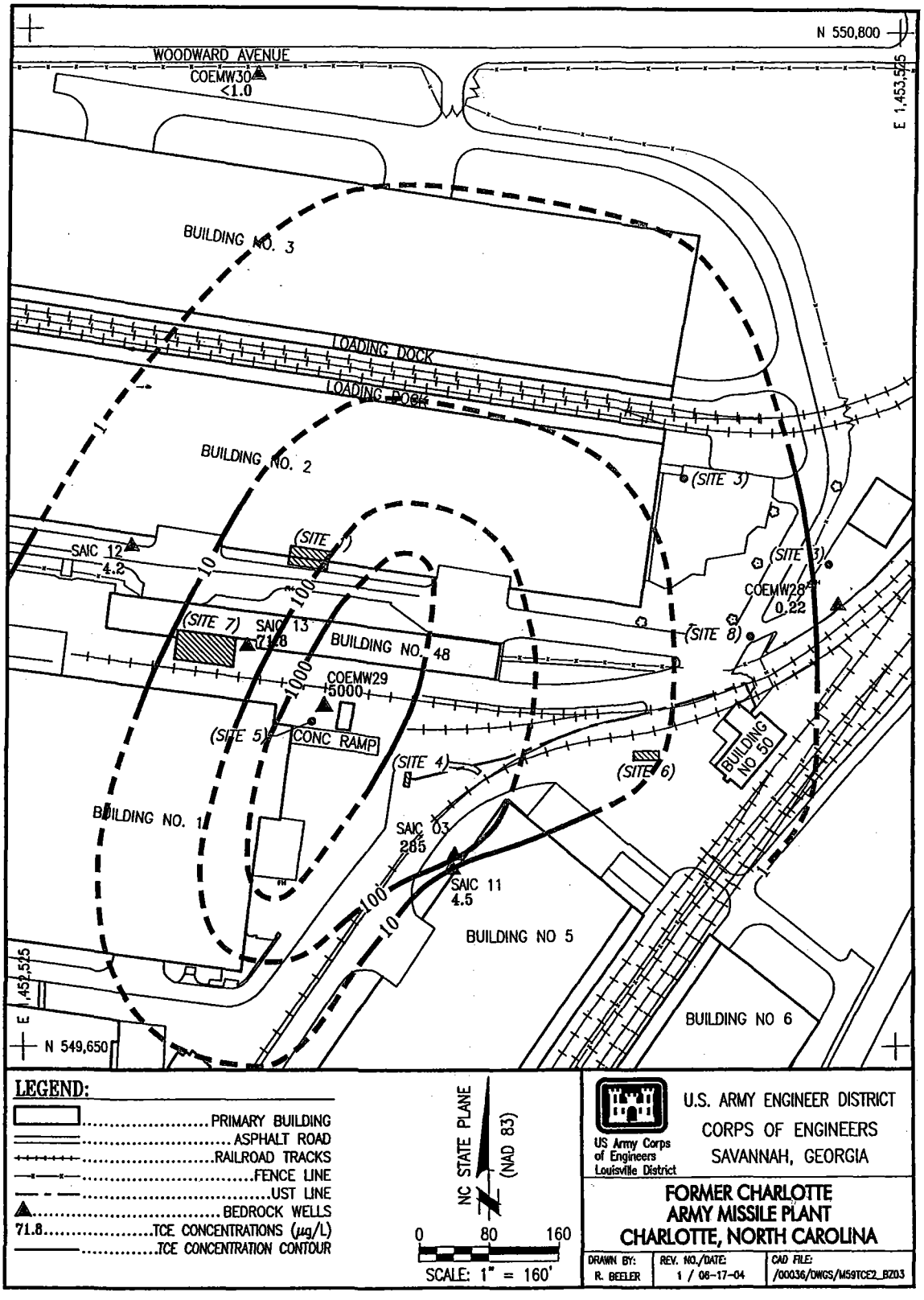

Figure 1-7. TCE Concentrations in Bedrock Wells, February 2003

In 2003, six TZ wells were sampled, five of which were newly installed (SAIC-08, SAIC-14, SAIC-15, SAIC-17, and SAIC-18). All TZ wells sampled exhibited TCE concentrations greater than the NCAC 2L criterion of 2.8 µg/L. The TZ is the primary zone of TCE impact at the CAMP, especially in the areas east of the loading bay of Building 1 and south of Building 2 (Figure 1-6). Concentrations of TCE in monitoring well SAIC-18, installed in the TZ near COEMW06 (SZ well), indicate that TCE is migrating from the SZ to the TZ. A few wells were also found to slightly exceed the NCAC 2L standards for chloroform and PCE. All filtered metals concentrations were either non-detects or below the established background criteria.

1.5.1.3 Groundwater in the bedrock zone

Six bedrock wells were sampled during 2001 and one during the 2003 investigations. Monitoring well COEMW29 exhibited the highest TCE concentrations in bedrock and is presumed to be near the source area (Figure 1-7). Monitoring well COEMW29 was originally installed with two screened intervals [92.5 to 97.5 ft below ground surface (bgs) and 112.5 to 117.5 ft bgs]. Based on previous sampling events, it was undetermined if the elevated TCE concentrations were emanating from the lower or upper screened interval. Therefore, the lower screen was abandoned in 2001. The 2003 analytical results for COEMW29 indicated a TCE concentration of 5,000 µg/L, an increase of 59% over the reported value from 2001. TCE was not reported at concentrations exceeding 500 µg/L in any of the remaining bedrock monitoring wells.

TCE ↑ in bedrock by 59%

1.5.2 Subsurface Soil

During the 2003 field investigation, the cuttings from each borehole were screened with a photoionization detector (PID). Based on the PID screening, a minimum of one confirmatory soil sample was collected from each boring. Each soil sample was analyzed for VOCs. Eight additional subsurface soil samples were collected from 6 to 38 ft bgs while installing monitoring wells in January 2003. All of the samples were collected within the saturated zone and, therefore, were more representative of groundwater conditions than soil. TCE was reported in four of the eight samples collected with concentrations ranging from 240 µg/kg at SAIC-08 to 1,000 µg/kg at SAIC-18.

Samples from SAIC-16 and SAIC-19 were also analyzed for total organic carbon (TOC) content. TOC concentrations were below the reporting limit (1 mg/kg) for both samples. Table 1-1 presents the data from the soil samples.

Table 1-1. Soil Analytical Data Summary

Station ID	Date Collected	Depth (ft bgs)	Analyte (µg/kg)		
			TCE	2-butanone	2-hexanone
NC "contained in" Soil Criteria			**18**	**690**	**560,000**
SAIC-08	1/27/2003	24	**240**	N/D	N/D
SAIC-14	1/25/2003	34	**280**	N/D	N/D
SAIC-15	1/24/2003	18	**470**	N/D	N/D
SAIC-16	1/23/2003	18	8.9	N/D	N/D
SAIC-17	1/22/2003	20	N/D	N/D	N/D
SAIC-17	1/22/2003	38	N/D	47	42
SAIC-18	1/29/2003	6	**1,000**	N/D	N/D
SAIC-19	1/29/2003	6	N/D	N/D	N/D

bgs = below ground surface.
ID = Identification.
N/D = Not detected.
SAIC = Science Applications International Corporation.
TCE = Trichloroethene.
Bold font indicates that the concentration exceeded the North Carolina "contained in" soil criteria.

1.5.3 Stormwater/Surface Water

The storm sewer system at the CAMP was visually examined on August 10, 2001, based on the observation that aquifer water levels were above the base of the storm sewer in the sewer line running between Building 2 and Building 48. No precipitation was recorded 10 days prior to August 10, 2001, yet several storm drains and manholes were observed to contain running water.

The storm drain system, located within the hot spot areas of the shallow groundwater plume, was assessed as to depth and the presence of water. This investigation identified an area potentially susceptible to groundwater infiltration into the storm drain system, as the groundwater table was observed at levels above the base of the storm drain (Figure 1-8). The area identified occurs within the footprint of the shallow contaminant plume of concern. However, the potential for flow onto and through the CAMP from storm drains emanating upgradient (to the east and south) of the site was not evaluated. Therefore, the location(s) of the initial upgradient entry point for storm water flow into the storm drainage system is uncertain.

Based on the results of the storm sewer inspection, on April 29, 2003, one storm sewer sample was collected from the manhole near monitoring wells SAIC-5 and SAIC-12 (downgradient of the shallow groundwater hot spot) and analyzed for VOCs. The water sample collected from the storm sewer system contained 310 µg/L of TCE, which exceeds the 92.4 µg/L regulatory criteria established in NCAC 2B for surface water. Alternatives for preventing groundwater seepage into the storm sewer were not evaluated in this FS.

1.5.4 Borehole Geophysics

Borehole geophysics were conducted on the four bedrock soil borings installed during 2001. An acoustic televiewer survey was conducted in addition to flow, caliper, resistivity, and spontaneous potential logs. The results indicated that fracture density and, thus, groundwater flow significantly decrease with depth within the bedrock.

1.6 SUMMARY OF SITE CHARACTERISTICS

Geologic, hydrogeologic, and groundwater geochemical information and data for the CAMP were obtained from the RIs (Section 1.4) and supplemental investigations (Section 1.5) conducted at the site. Each of these characteristics is described in the following sections to provide a brief yet comprehensive overview of the site.

1.6.1 Site-specific Geology

The CAMP 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 (USACE 2000). Regional geologic features include the Carolina Slate, 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 CAMP is located within the Charlotte belt, which 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 (USACE 2000).

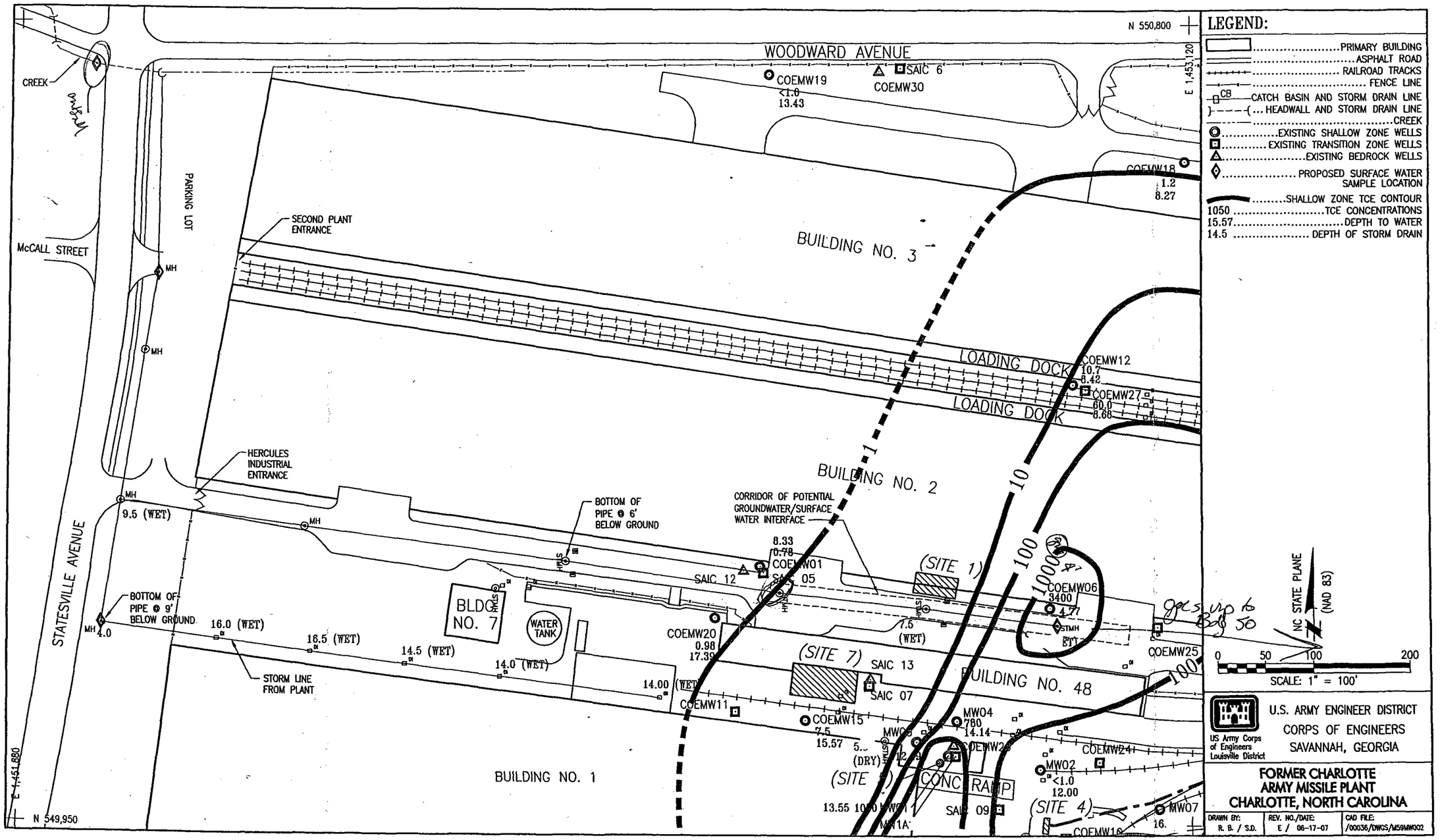

Figure 1-8. Stormwater Drainage Pathways

1.6.1.1 Soils

As presented in the Phase II RI report (USACE 2000), the surface soils at the CAMP are disturbed by anthropogenic activities and are comprised of three primary soil types: Cecil sandy clay loam (CeB2) with 2 to 8% slopes, Cecil sandy clay loam (CeD2) with 8 to 15% slopes and eroded surfaces, and Cecil-urban land complex (CuB) with 2 to 8% slopes.

Based upon field observations, the unconsolidated subsurface soils encountered during the four site investigations described earlier in this chapter include primarily residuum and saprolite material. Up to approximately 35 ft of residuum, consisting of micaceous sandy silts, silty sands, silty clay, and clayey sands, underlie the site. 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 saprolite ranges in thickness from approximately 15 to 50 ft.

M&E reported a continuous, partially weathered rock zone lying along the bedrock/overburden interface (USACE 2000). This zone was not encountered continuously across the site during supplemental site investigations (USACE 2002, USACE 2003). As presented by M&E, the partially weathered rock zone was characterized by increased drilling difficulty and decreased split-spoon recovery. The samples that were recovered consisted of fragments of metagranite, gneiss, and hydrothermally altered mafic or vein rock. Due to the destructive nature of the drilling methods (mud rotary) employed by M&E, a more accurate description of the subsurface could not be obtained. For this reason, during the 2003 site investigation performed by SAIC, rotosonic drilling methods were employed to obtain a continuous sample of the consolidated and unconsolidated material.

Site-specific unconsolidated characteristics observed during the 2003 site investigation included zones of partially weathered rock in a matrix of saprolite. However, this zone was not exclusive to nor identified consistently along the overburden/bedrock interface, but rather was sporadic across the area investigated. Within the zone of saprolite described above, sections of soil core consisted of material weathered to only sand-sized particles and/or material weathered to gravel. At several locations, unweathered diorite boulders with a thickness of up to 2 ft were encountered. These observances were not consistently identified at each boring location, but were rather encountered as random observances. The heterogeneous nature of the unconsolidated materials observed is illustrated in Figure 1-9.

1.6.1.2 Bedrock

The bedrock material encountered during the supplemental site investigations performed by SAIC consisted primarily of dioritic material. Diorite was consistently observed in all borings advanced into the bedrock during the 2003 investigation. The material was observed as having the characteristic phaneritic salt and pepper texture typically associated with diorites. There were no vein materials of alternate origin observed within the competent bedrock.

Along the bedrock/overburden interface, weathered and fractured bedrock material was encountered at several locations but not consistently across the area investigated (Figure 1-9). Where encountered, the fractures present in the upper portion of the bedrock material were generally found to decrease in density as depth increased. The limited fractures observed within the upper portions of the BZ were evidenced during the advancement of the original boring SAIC-08, which was co-located with SAIC-09. At this location, the overburden material was cased off with the intent of installing a monitoring well within the bedrock. However, subsequent to drilling into the bedrock and allowing the hole to remain open for two days,

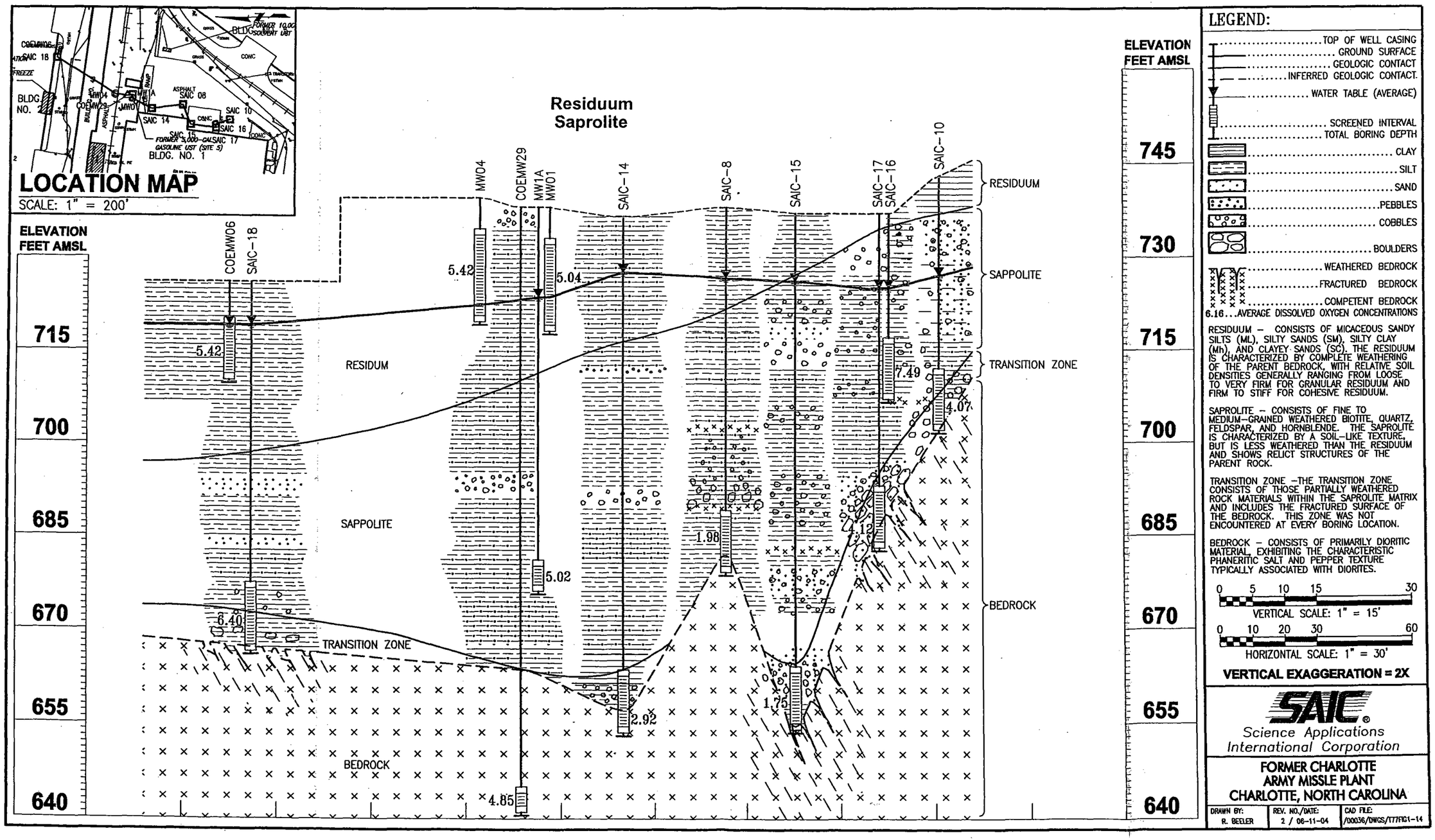

Figure 1-9. Site Cross-Section

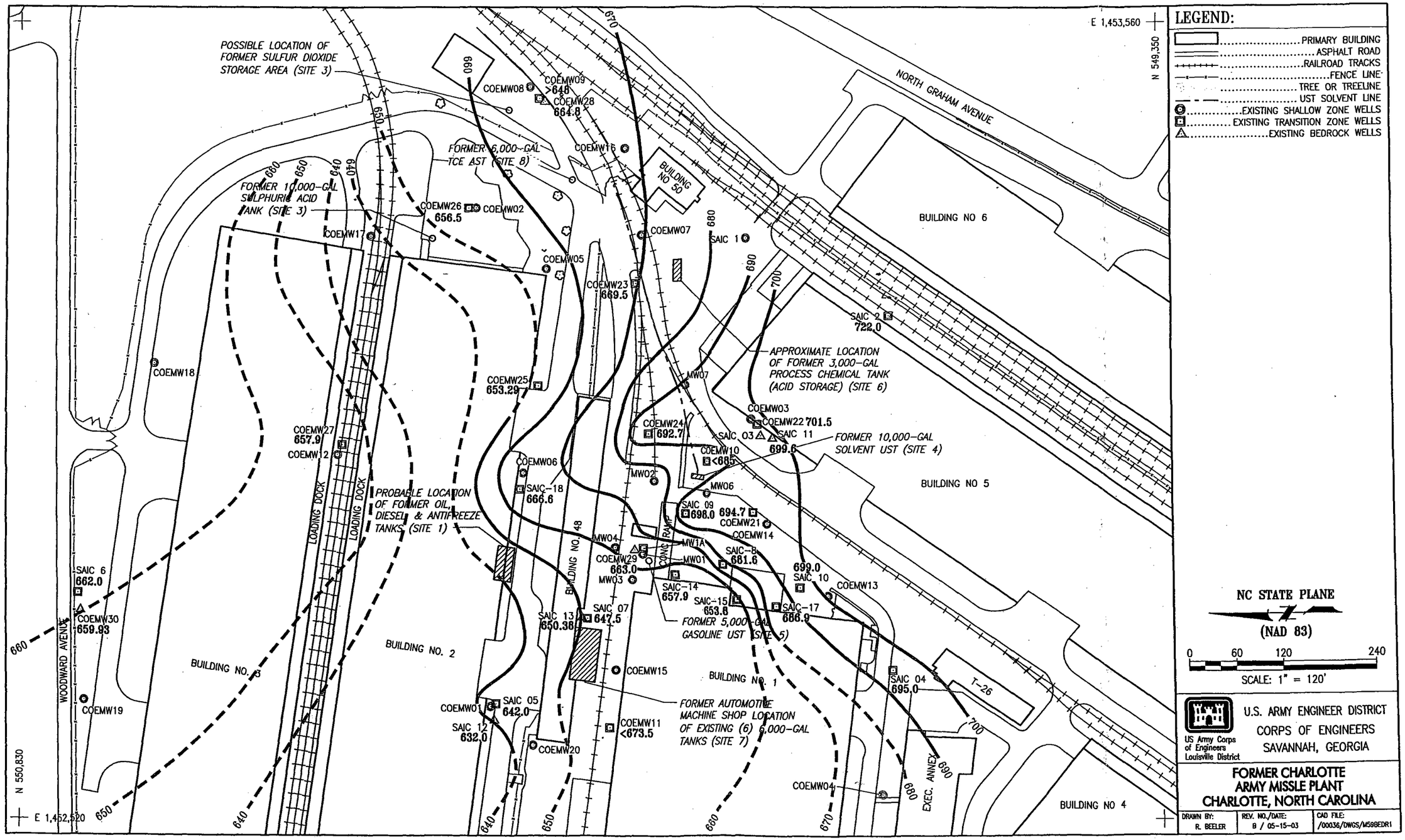

Figure 1-10. Top of Bedrock Isopleth

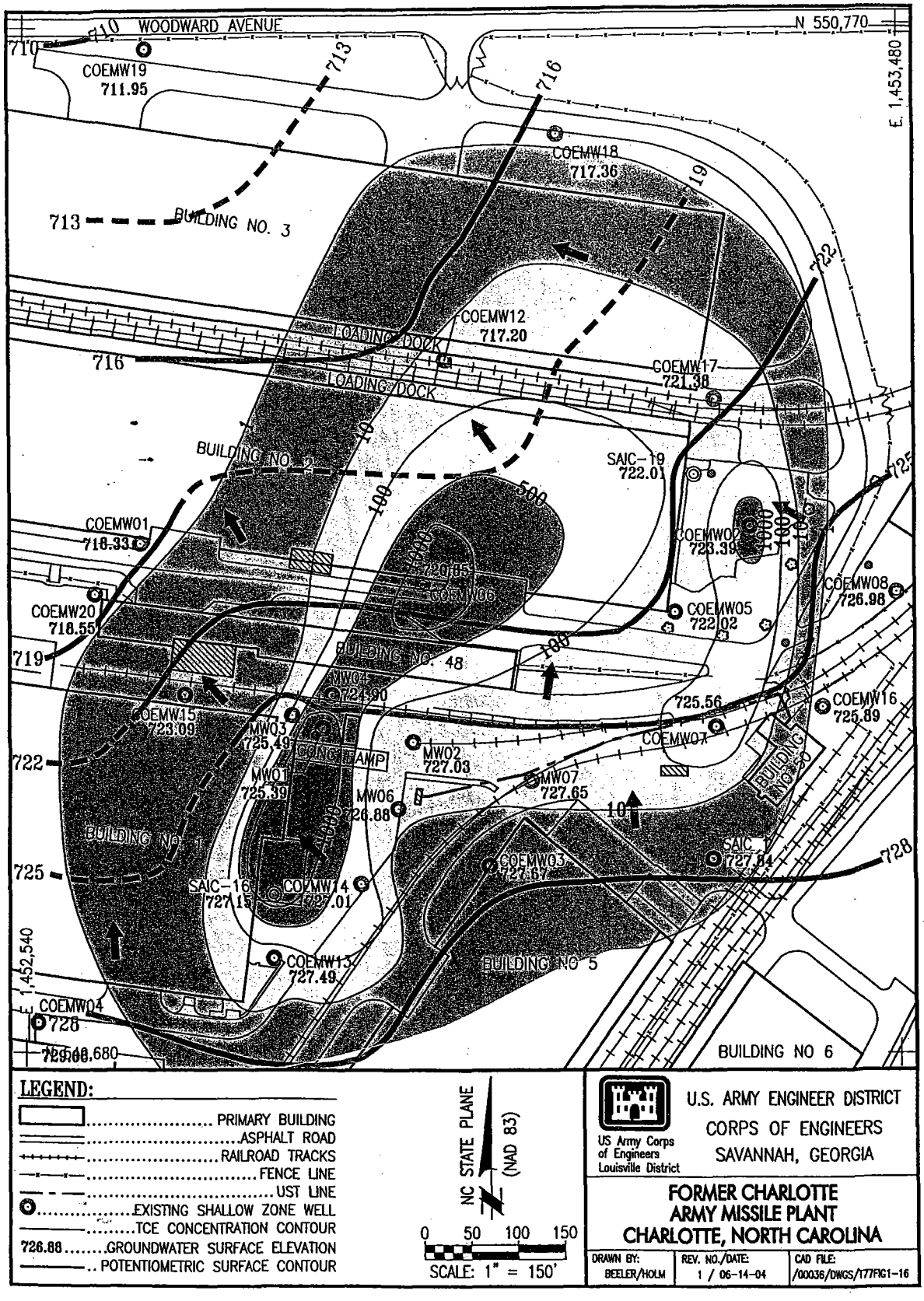

Figure 1-11. Shallow Zone Potentiometric Surface, February 2003, and TCE Concentrations

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5,000 μg/L, this is the only location at the CAMP facility where TCE was identified within a bedrock monitoring well at concentrations exceeding 500 μg/L. However, COEMW29 is the only bedrock well located within the suspected source area.

1.8 CONCEPTUAL SITE MODEL

The purpose of the CSM is to illustrate and 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 exposure pathways is presented in Chapter 2.0. Figure 1-17 illustrates the CSM that has been developed for the CAMP.

1.8.1 Potential Sources

During the investigative process employed at the CAMP by M&E (USACE 1999, USACE 2000) and SAIC (USACE 2002, USACE 2003), no remaining specific source for the TCE groundwater impact has been identified. However, the significant concentrations of TCE in groundwater along the eastern end of Building 1 (Figure 1-18) indicate this area is most likely an initial entry location.

★ Bldg 1 = initial entry

1.8.2 Potential Exposure Pathways

Information developed through the site investigations referenced above (and discussed in Chapter 2.0) has identified the potential exposure pathways for the CAMP. The exposure pathways were developed for specific media with identified contaminants of potential concern (COPCs). Potential exposure pathways evaluated included surface soil, subsurface soil, groundwater, and surface water. Each pathway assessed was considered incomplete (see Chapter 2.0).

1.9 CONTAMINANT FATE AND TRANSPORT

Based on the site characteristics described above, 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 CAMP was to determine the following:

1. How long will it take the TCE plume to degrade naturally?

2. How far will the plume migrate if monitored natural attenuation is selected as the remedial alternative?

3. Based on various hot spot treatment scenarios, how long will it take the plume to degrade to 2.8 μg/L?

1.6.5 Surface Water

The surface water flow regime at the CAMP consists primarily of sheet surface flow into the storm sewer drainage network. Approximately 85% of the CAMP is covered by buildings or paved areas of concrete and asphalt, which inhibit groundwater recharge rates to the site. Thus, large local fluctuations in the water table are unlikely. Water level data in the SZ indicate that the water level fluctuations are minimal, typically less than 1.5 ft.

Not pt, drain below shallow gw table 5'-15'

The storm drain network varies in depth across the CAMP, ranging from approximately 5 to 15 ft bgs. The depth of the storm drain system is significant in that, at certain areas of the facility, the storm drain is positioned below the shallow groundwater table. In these areas, it is possible that the shallow groundwater could infiltrate into the storm drainage network and act as a preferential pathway to potential receptors.

The storm sewer drainage network that conducts all surface flow from the CAMP is extensive. Generally, sheet flow enters the storm drain system where it is forwarded to the main drainage line along Statesville Avenue (Figure 1-8). However, a limited survey of the storm drain network indicates additional flow paths directed underneath buildings, perpendicular to the main drain lines. It was also noted that, due to the age of the storm drain system, buckling and cracking of the drains were significant at several locations.

storm drain to stream

The main drainage line along Statesville Avenue was observed to discharge at a manmade culvert at the intersection of Statesville and Woodward Avenues. The receiving stream was described by M&E as an ephemeral stream. However, based on the streambed elevation, it is possible that the shallow groundwater could discharge into the unnamed stream. This discharge point receives drainage from both north and south Statesville Avenue as well as Woodward Avenue.

1.7 CONTAMINANT PLUME CONFIGURATION

Hot spot = TCE > 500 ppb

#1

Based upon the analytical, chemical, and physical findings from the Phase I and Phase II RIs and supplemental investigations, the groundwater distribution of TCE at the CAMP has been categorized into hot spot areas relative to potential remedial actions. A potential remedial action hot spot is defined as an area that exhibits TCE concentrations greater than 500 µg/L. Hot Spot No. 1 extends within the TZ from monitoring well SAIC-10 north to SAIC-18 (Figure 1-12) and contains the majority of TCE mass identified. Monitoring well SAIC-10 is located along the east end of Building 1, and SAIC-18 is located along the south side of Building 2. This hot spot is characterized by concentrations of TCE > 500 µg/L with peak concentrations of up to 7,500 µg/L. The vertical distribution of TCE > 500 µg/L in this area extends from the shallow groundwater table through the TZ and into the underlying BZ.

#2

Hot Spot No. 2 is located along the eastern end of Building 2 (Figure 1-4). TCE concentrations identified in shallow monitoring well COEMW02 (1,200 µg/L) exceed the hot spot criteria of 500 µg/L. However, the identified concentration appears localized and is limited to the SZ. This is demonstrated by the reported TCE concentrations for the adjacent TZ monitoring well COEMW26 and the downgradient monitoring well SAIC-19. TCE was not reported above the laboratory method detection limit in monitoring well COEMW26, and the downgradient shallow well SAIC-19 contained a reported TCE concentration of only 92 µg/L.

#3

Hot Spot No. 3 is located within the BZ along the northeast corner of Building 1 and is located within the footprint of Hot Spot No. 1 (Figure 1-12). This location is considered independent of Hot Spot No. 1 as the TCE concentration > 500 µg/L was detected within the BZ. With a detected TCE concentration of

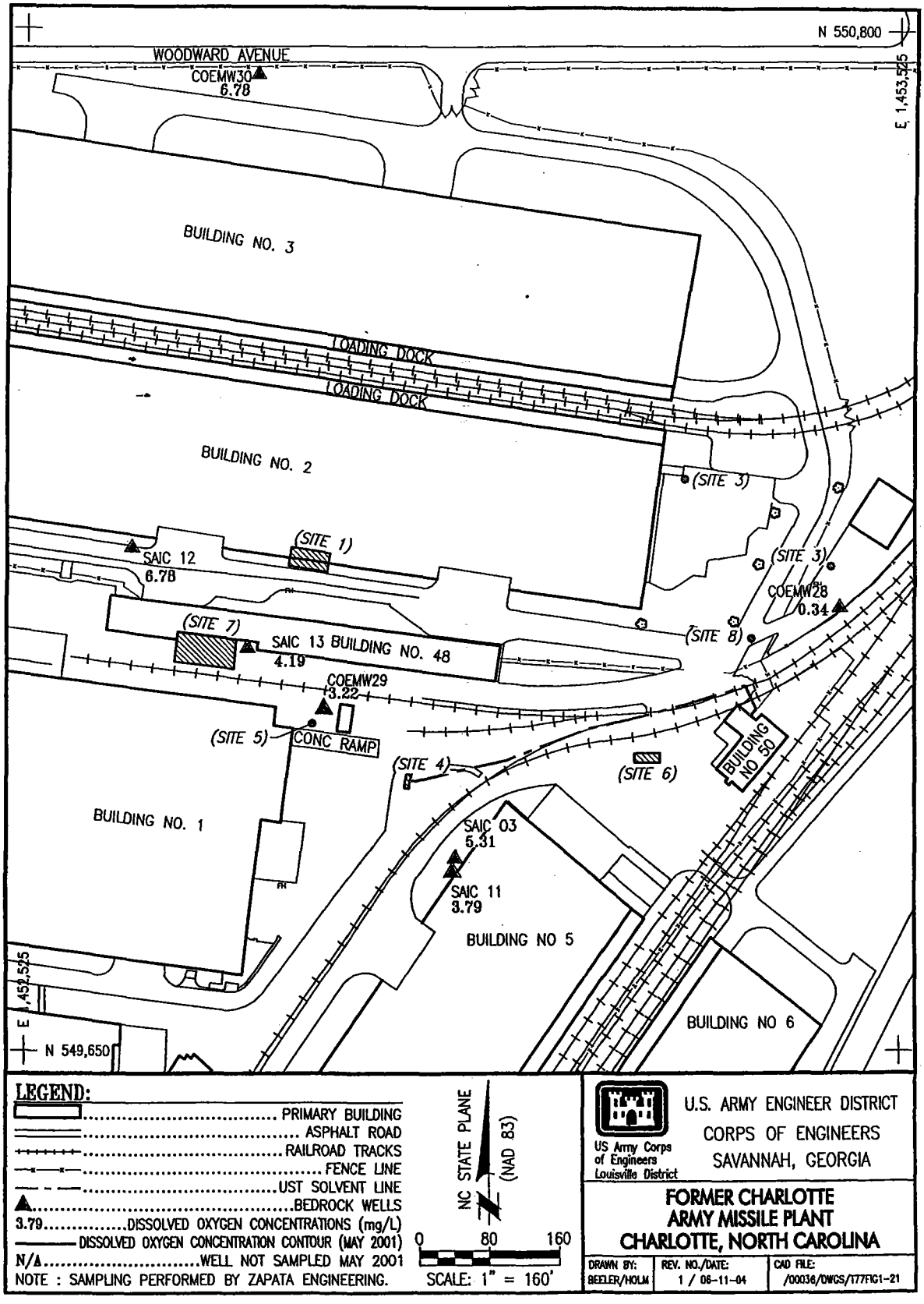

Figure 1-16. Bedrock Zone Dissolved Oxygen Concentrations

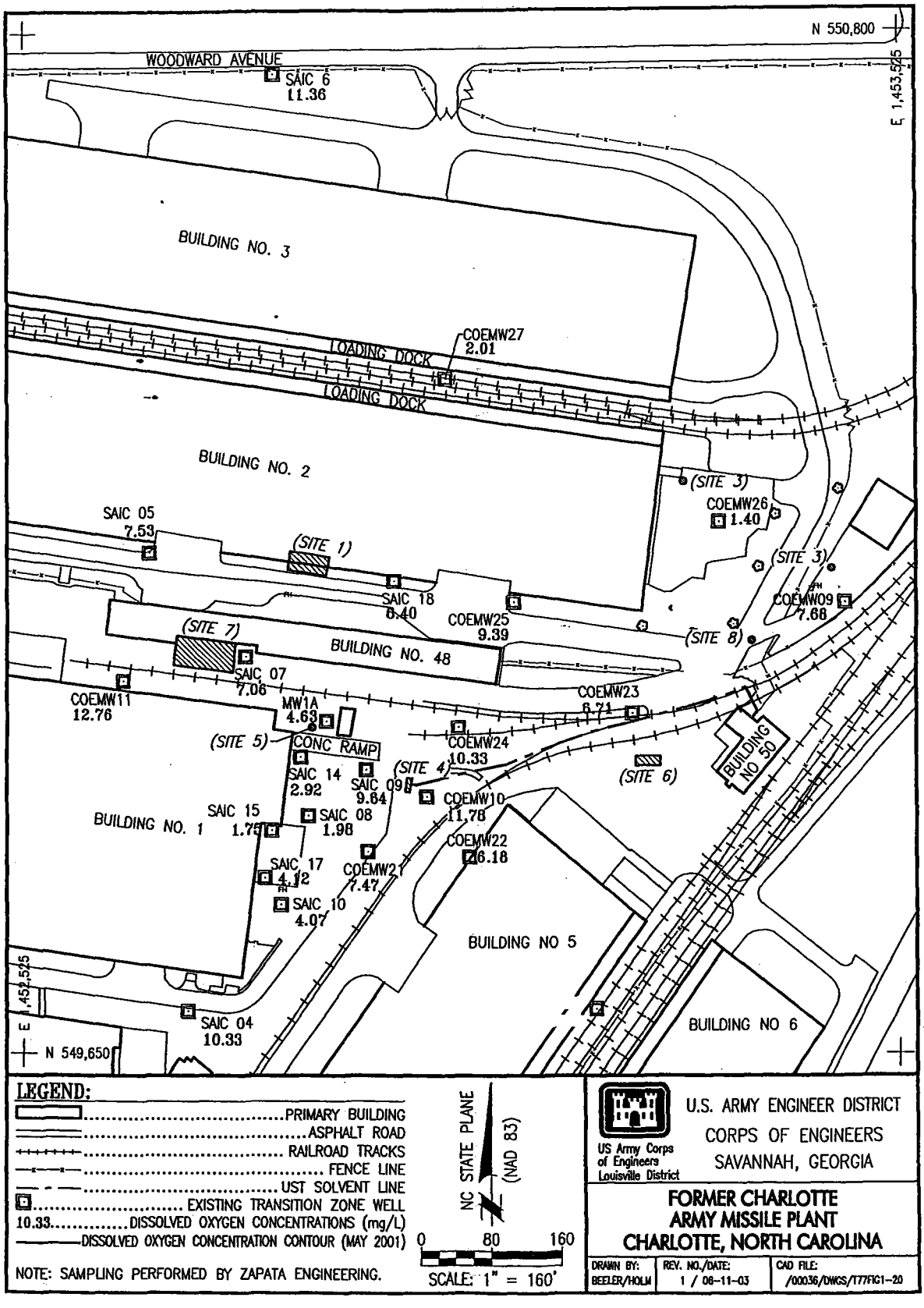

Figure 1-15. Transition Zone Dissolved Oxygen Concentrations

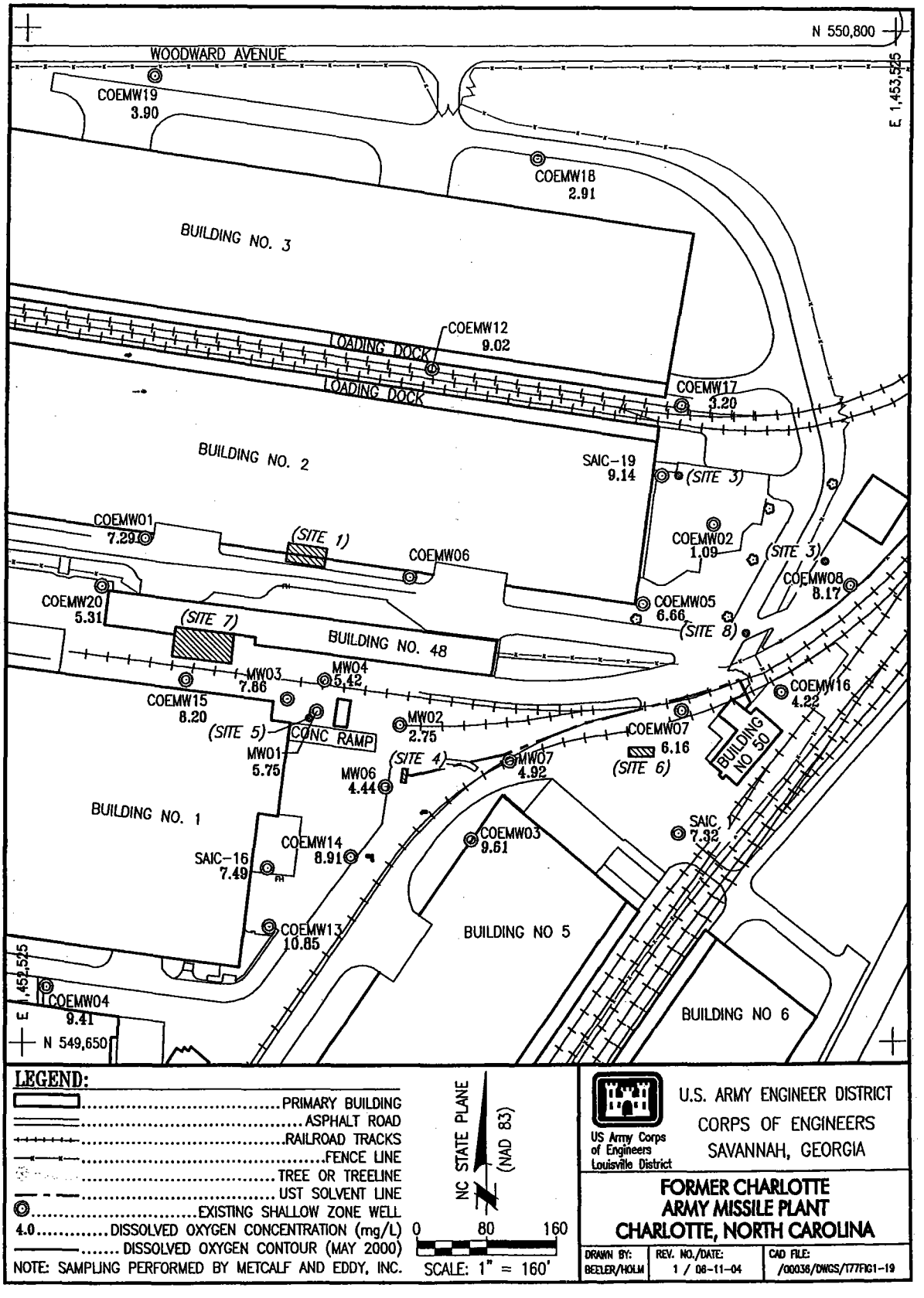

Figure 1-14. Shallow Zone Dissolved Oxygen Concentrations

Table 1-3. Groundwater Geochemical Parameters

Station ID	Date Collected	Ammonia as Nitrogen	Chloride	Methane	Nitrate	Nitrite	Sulfate	DO	ORP
Units		mg/L	mg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mV
SAIC-1	05/30/01	N/D	3.96	19	0.827	N/D	23.2	7.32	N/M
SAIC-2	05/30/01	N/D	4.31	N/D	0.793	N/D	2.58	14.26	N/M
SAIC-3	06/01/01	N/D	18	N/D	0.845	N/D	20.6	5.31	N/M
SAIC-4	05/31/01	N/D	9.4	16.5	0.908	N/D	0.82	10.33	N/M
SAIC-5	05/31/01	N/D	14.9	N/D	0.612	N/D	5.29	7.53	N/M
SAIC-6	06/01/01	N/D	2.55	12.5	1.29	N/D	1.48	11.36	N/M
SAIC-7	05/31/01	N/D	15.5	7.4	1.08	N/D	3.32	7.06	N/M
SAIC-8	02/27/03	N/D	32	N/D	1.2	0.1	24	1.98	-250
SAIC-9	06/01/01	N/D	16.9	46.4	2.27	N/D	3.69	9.64	--
SAIC-10	06/01/01	N/D	17.1	14.3	1.72	N/D	1.47	4.07	--
SAIC-11	05/31/01	N/D	23.1	N/D	0.142	N/D	22.6	3.79	--
SAIC-12	05/31/01	N/D	14.2	5.6	0.593	0.081	6.63	6.78	--
SAIC-13	05/31/01	N/D	13.2	9.2	0.85	N/D	8.06	4.19	--
SAIC-14	02/28/03	N/D	24	N/D	1.7	ND	16	2.92	29
SAIC-15	02/27/03	N/D	48	N/D	0.73	ND	12	1.75	-78
SAIC-16	02/27/03	N/D	20	N/D	1.7	ND	11	7.49	2
SAIC-17	02/28/03	N/D	22	N/D	2.1	ND	14	4.12	101
SAIC-18	02/27/03	N/D	23	N/D	1.9	ND	11	6.40	145
SAIC-19	02/24/03	N/D	8.3	N/D	1.7	ND	22	3.49	188

DO = Dissolved oxygen.
ID = Identification.
N/D = Not detected.
ORP = Oxidation-reduction potential.
SAIC = Science Applications International Corporation.

The site-specific geochemical parameters presented in Table 1-3 are an important indication of the aquifer conditions and the site's ability to naturally biodegrade the dissolved-phase TCE contaminant plume. Typically, TCE is biodegraded under natural conditions via reductive dechlorination. The CAMP, however, exhibits "Type 3" behavior with respect to chlorinated compound biodegradation. The Type 3 behavior is characterized by inadequate concentrations of native and/or anthropogenic carbon and concentrations of dissolved oxygen (DO) that are greater than 1 mg/L (Figures 1-14, 1-15, and 1-16). Based on the aerobic conditions defined by the elevated DO and oxidation-reduction potential (ORP) concentrations, and the elevated sulfate (> 10 mg/L) and nitrate (> 1 mg/L) concentrations recorded for the CAMP, significant natural reductive dechlorination of the TCE contaminant plume is not likely.

1.6.4 Soil Geochemistry

Two soil samples were collected by SAIC during the 2003 field investigation and analyzed for TOC. The significance of TOC is that it is a carbon and energy source, which drives the dechlorination process. The TOC values are also used in the calculations for sorption and solute-retardation calculations. The analytical results of the two soil samples indicated that TOC was not present at detectable concentrations within the CAMP soils.

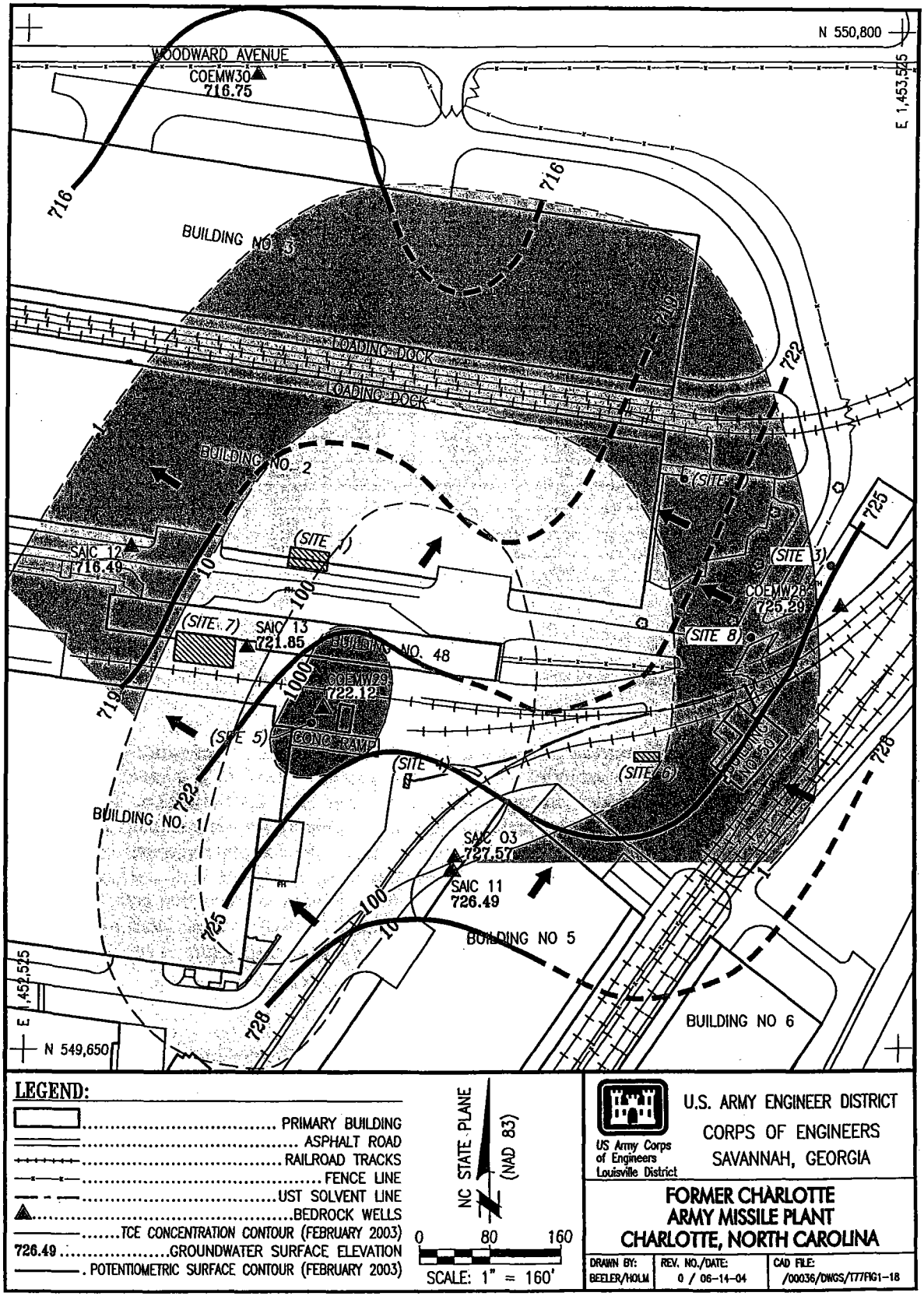

Figure 1-13. Bedrock Zone Potentiometric Surface, February 2003

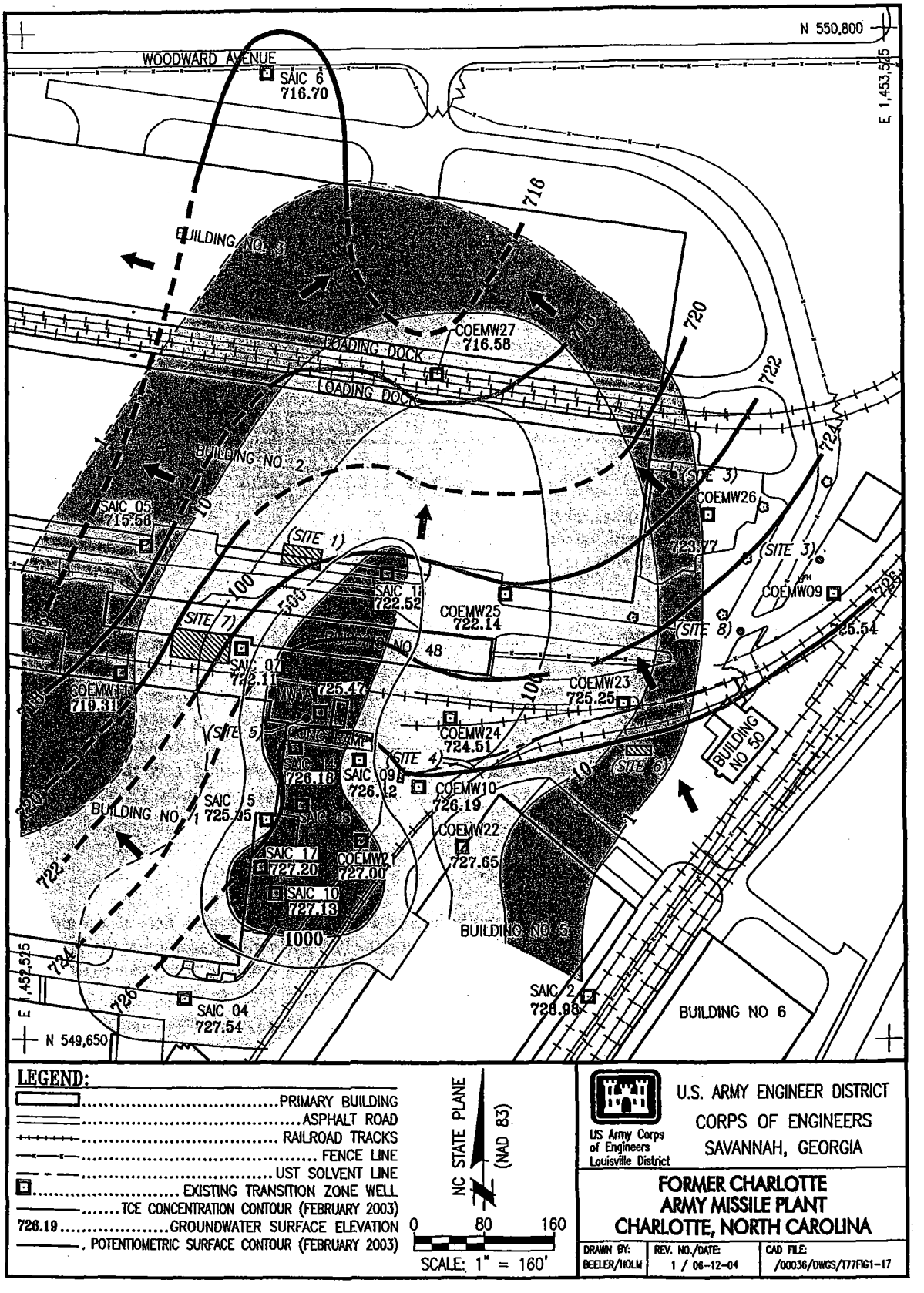

Figure 1-12. Transition Zone Potentiometric Surface, February 2003

Table 1-2. Summary of Slug Test Results[a]

Well ID	Zone	Hydraulic Conductivity		
		ft/min	ft/day	cm/sec
MW1A	Transition	8.49E-03	12.23	4.31E-03
MW04	Shallow	8.82E-03	12.7	4.48E-03
COEMW05	Shallow	1.10E-03	1.58	5.59E-04
COEMW08	Shallow	2.76E-02	39.77	1.40E-02
COEM09	Transition	9.38E-03	13.51	4.77E-03
COEMW10	Transition	3.96E-04	0.57	2.01E-04
COEMW11	Transition	2.99E-05	0.04	1.52E-05
COEMW14	Shallow	7.60E-03	10.95	3.86E-03
COEMW25	Transition	8.00E-04	1.15	4.06E-04
COEMW28	Bedrock	1.40E-04	0.2	7.11E-05
Shallow		1.13E-02	16.25	5.73E-03
Transition		3.82E-03	6.88	1.94E-03
Bedrock		1.40E-04	0.20	7.11E-05

[a]Metcalf and Eddy (2000).
COE = Corps of Engineers.
ID = Identification.
MW = Monitoring Well.

The hydraulic gradient for the TZ was calculated to be 0.02. The hydraulic conductivity values for the TZ were determined by M&E as presented in Table 1-2. Ranging from 0.57 (COEMW10) to 13.51 (COEMW09) ft/day, the widely variable hydraulic conductivities observed are likely due to the heterogeneous nature of the unconsolidated material measured. With an average hydraulic conductivity value of 6.88 ft/day, the conductivity of the TZ is less than half that calculated for the SZ (USACE 2000). Based on the hydraulic conductivity measurements obtained and the estimated effective porosity of the subsurface materials, the seepage velocity was estimated to be 125.5 ft/year in the TZ (USACE 2000).

1.6.2.3 Bedrock potentiometric surface bedrock

The 2003 BZ potentiometric surface is represented in Figure 1-13. The groundwater flow is toward the northwest, consistent with the shallow and the transition zones. The hydraulic gradient for the BZ was calculated to be 0.02. The hydraulic conductivity value for the BZ was obtained from one monitoring well, COEMW28, at 0.2 ft/day. In comparison to the transition and shallow zones, the hydraulic conductivity of the BZ is significantly less, again confirming the low density of water-bearing fractures within the shallow bedrock. Based on the hydraulic conductivity measurements obtained and the estimated effective porosity of the bedrock materials, the seepage velocity was estimated to be 7.3 ft/year in the BZ (USACE 2000). NW

1.6.3 Groundwater Geochemistry

During the two supplemental field investigations performed by SAIC, water quality or monitoring of natural attenuation parameters were measured to determine the site-specific groundwater geochemical characteristics. Table 1-3 presents a summary of those geochemical parameters measured.

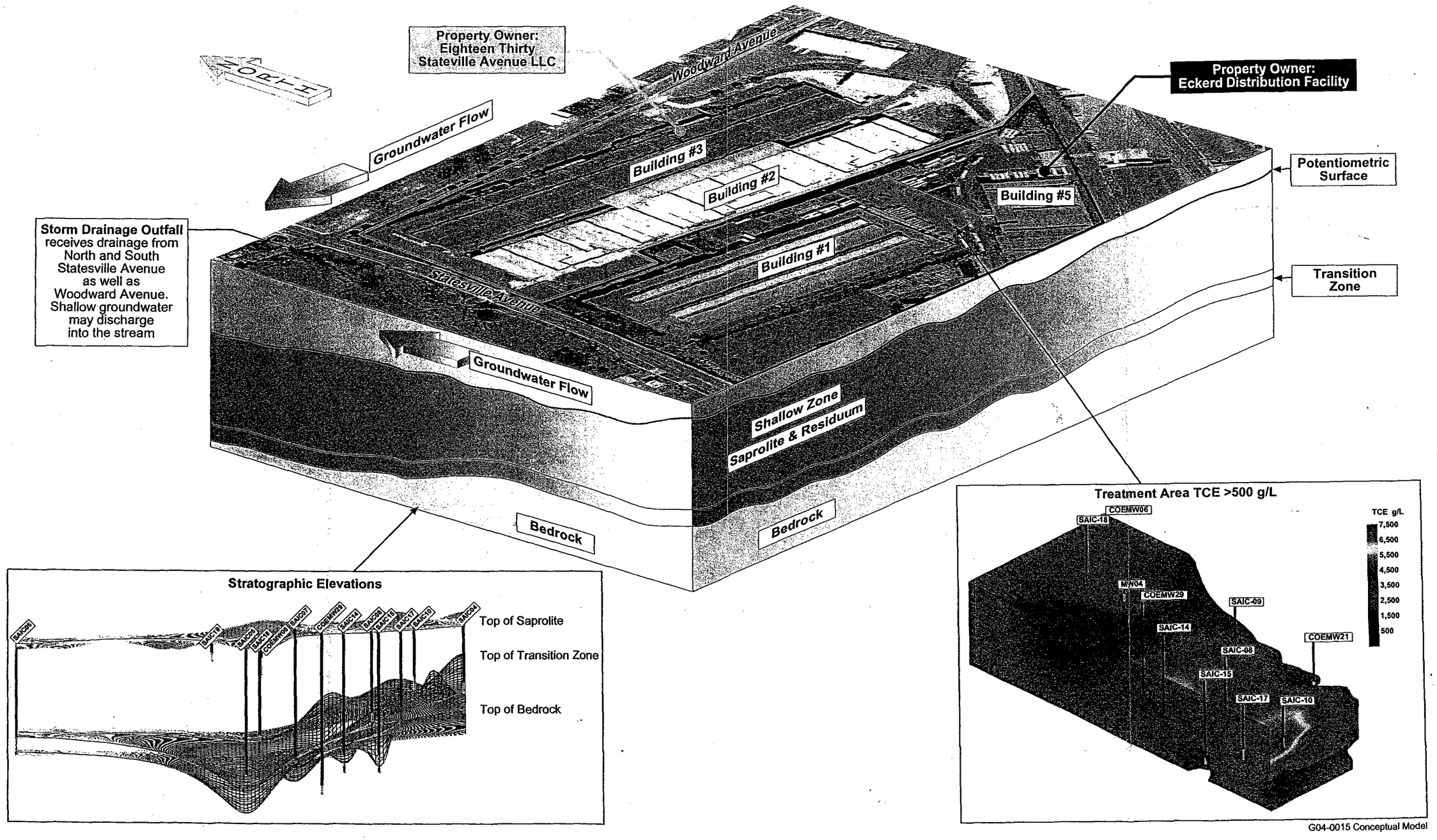

Figure 1-17. Conceptual Site Model for the Former Charlotte Army Missile Plant (CAMP)

As discussed in Section 1.6, the hydrogeologic zones of the CAMP were subdivided into three zones: shallow, transition, and bedrock. As the BZ is not a target for remedial action, only the shallow and transition zones were included in the modeling effort. The endpoint for each modeling run was based on the distance to Woodward Avenue, the effective site boundary. For each zone (shallow and transition), three scenarios were modeled as presented in Table 1-4.

Table 1-4. Modeling Scenario Summary

No.	Modeled Scenario	Hydrogeologic Zone	Distance the Plume will Migrate Before Reaching an MCL of 2.8 µg/L (ft)	Time it will take to Reach the MCL of 2.8 µg/L (years)	Maximum Concentration the Plume will Exhibit at Woodward Avenue (µg/L)	Time it will take to Reach the Maximum Concentration at Woodward Avenue (years)
1	No Action/MNA	SZ	1,312	200	35	100
	No Action/MNA	TZ	1,710	195	60	90
2	Hot Spot No. 1 >/= 1,000 µg/L reduced to 100 µg/L	SZ	1060	105	7	60
	Hot Spot No. 1 >/= 1,000 µg/L reduced to 100 µg/L	TZ	1,260	100	11	50
3	Hot Spot No.1 >/= 500 µg/L reduced to 100 µg/L	SZ	980	65	N/A	N/A
	Hot Spot No. 1 >/= 500 µg/L reduced to 100 µg/L	TZ	920	85	N/A	N/A

MCL = maximum contaminant level.
MNA = monitored natural attenuation.
N/A = Not applicable.

Based on the historical information provided in Section 1.2, the operational period of the CAMP was estimated to extend from 1954 through 1967. With a potential release period of 13 years, it was estimated that the source loading began at that time and continued consistently for a period of 10 years (1977). The source loading was assumed to continually decrease between 10 (1977) and 30 years (1997), when the source loading had completely stopped.

The distribution of TCE in the shallow and transition zones is illustrated on Figures 1-11 and 1-12. Within the hot spot source area, TZ concentrations of TCE range from 700 µg/L (SAIC-15) to 7,500 µg/L at SAIC-17 and SAIC-08. Within the SZ, TCE concentrations range from 3,400 µg/L at COEMW06 to 3,800 µg/L at SAIC-16. Based on the reported shallow and transition zone TCE concentrations, the full saturated thickness of the unconsolidated overburden contains TCE concentrations in excess of 1,000 µg/L. Figures 1-11 and 1-12 illustrate that the groundwater plume configuration is consistent with the potentiometric flow regimes.

The groundwater plume configuration is indicative of the persistence of TCE and the slow migration rates of the contaminant plume. However, the modeling showed that no matter what remedial scenario was selected, the leading edge of the plume would likely continue to migrate.

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2.0 IDENTIFICATION OF CONTAMINANTS OF CONCERN

COPCs were identified for soil, groundwater, and surface water in the Phase I and Phase II RIs (USACE 1999, USACE 2000) as contaminants having maximum detected concentrations above risk-based screening levels. Following the Phase II RI, additional sampling data were collected for the FS/RD for subsurface soil, groundwater, and stormwater. These additional data were also compared to risk-based screening levels to identify COPCs.

COCs are identified as the subset of COPCs for soil, groundwater, and surface water that have the potential to represent a risk to human health based on a pathway analysis.

2.1 CONTAMINANTS OF CONCERN FOR SOIL

Surface (0 to 1 ft bgs) and subsurface (> 1 ft bgs) data are discussed in Sections 3.1.1 and 3.1.2 below.

2.1.1 Surface Soil

2.1.1.1 Phase I remedial investigation

No surface soil samples were available for the Phase I analysis.

2.1.1.2 Phase II remedial investigation

Surface soil samples collected from 0 to 1 ft bgs were evaluated using EPA Region 3 RBCs for industrial land use. Concentrations of inorganics were also compared to Criterion Background Concentrations (CBCs).

No organic chemicals were detected above the industrial RBCs. One metal (arsenic) was identified above both the RBC and CBC values. Surface soil quality was considered marginally affected by commercial/industrial activities in the area, and no surface soil COPCs were identified for inclusion in the FS.

2.1.1.3 Supplemental FS investigation

No additional surface soil samples were collected to supplement the FS.

2.1.1.4 Pathway analysis

No COPCs were identified in surface soil using conservative, risk-based screening values; therefore, no complete exposure pathway exists.

2.1.1.5 Summary of COCs for surface soil

No COPCs and, therefore, no COCs were identified for inclusion in the FS for surface soil.

2.1.2 Subsurface Soil

2.1.2.1 Phase I remedial investigation

Subsurface soil samples collected from 4 to 52 ft bgs were included in the Phase I analysis. COPCs were identified using Method I from the *North Carolina Risk Analysis Framework–Methods for Determining Contaminant Target Concentrations in Soil &and Groundwater* (NCDENR 1996). Method I utilizes look-up tables of non-site-specific target concentrations that are pre-calculated by the NCDENR. Target concentrations are available for several common exposure situations and migration pathways. The Phase I analysis used the most conservative screening levels for soil (S-1, residential ingestion of soil).

COPCs identified in the Phase I subsurface soil samples were limited to the following metals:

Aluminum	Manganese
Iron	Vanadium
Lead	

2.1.2.2 Phase II Remedial Investigation

Eighteen subsurface soil samples were collected during the Phase II RI from 5 to 92 ft bgs. However, all concentrations of organic and inorganic constituents were below their respective RBCs. During the Phase II RI, site-specific CBCs were determined, and the soils data collected during the Phase I RI were re-evaluated using the EPA Region 3 RBCs and CBCs (inorganics only). The quantitative risk assessment concluded that there were no COPCs identified at concentrations exceeding the screening criteria.

2.1.2.3 Supplemental FS Investigation

Eight additional subsurface soil samples were collected from 6 to 38 ft bgs while installing monitoring wells in January 2003 for the FS and analyzed for VOCs. All of these samples were collected within the saturated zone and, therefore, are more representative of groundwater conditions than soil. Groundwater is evaluated in Section 3.2.

2.1.2.4 Pathway analysis

Because the area is paved, there is no potential for human contact with the subsurface soil. Therefore, no COPCs were identified in subsurface soil using conservative, risk-based screening values; therefore, no complete exposure pathway exists.

2.1.2.5 Summary of COCs for subsurface soil

Because the area is paved, there is no potential for human contact with the subsurface soil; therefore, no COPCs and, thus, no COCs were identified for inclusion in the FS for subsurface soil.

2.2 CONTAMINANTS OF CONCERN FOR GROUNDWATER

2.2.1 Phase I Remedial Investigation

Groundwater COPCs were identified using Method I from NCDENR (1996). The Phase I analysis used the most conservative screening levels for groundwater (G-1, current or potential drinking water and current or potential non-drinking water exposures such as from swimming pools or irrigation). Results from permanent monitoring wells were used to identify the following Phase I groundwater COPCs:

bis(2-Ethylhexyl)phthalate	Manganese
Carbon tetrachloride	Trichloroethane
Chloroform	

2.2.2 Phase II Remedial Investigation

Groundwater samples were compared to NCAC groundwater standards (2L standards) and federal MCLs. Both the North Carolina and federal standards are based on potable (i.e., drinking water) use.

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

Acetone	Manganese
Carbon tetrachloride	Methylene chloride
Chloroform	Naphthalene
Chromium	Total Xylenes
1,1-Dichloroethene	1,1,2-Trichloroethane
Iron	Trichloroethene
Lead	

Bromodichloromethane was also detected, but no screening value is available for comparison.

The CAMP is zoned for commercial/industrial use. Residential areas are located to the north of the CAMP across Woodward Avenue. A well survey conducted as part of the Phase II investigation indicated that the CAMP and adjacent properties are served by a municipal water supply, and no private wells are present near the CAMP. Several wells were identified within a 1-mile radius, but their status is unknown. 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 3E-04. This result exceeds the range for remediation of Superfund sites of 1E-06 to 1E-04. The primary contributors to risk were TCE and 1,1-dichloroethene. The total hazard index value was calculated to be 0.74 and is below the generally accepted value of one.

2.2.3 Supplemental FS Investigation

Groundwater samples collected in 2001 and 2003 to supplement the FS were compared to NCAC groundwater standards (2L standards) and federal MCLs. Both the North Carolina and federal standards are based on potable (i.e., drinking water) use.

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

Acetone*	Tetrachloroethene	Aluminum
Benzene	1,1,1-Trichloroethane*	Antimony
Carbon tetrachloride	1,1,2-Trichloroethane	Iron
Chloroform	Trichloroethene	Manganese
1,1-Dichloroethene*	Total Xylenes*	
Naphthalene*		

*Acetone, 1,1-dichloroethene, naphthalene, 1,1,1-trichloroethane, and total xylenes were detected above drinking water standards in samples collected in 2000, but were not detected above drinking water standards in 2001 or 2003.

Bromodichloromethane was also detected (in 2000 only), but no screening value is available for comparison. Methylene chloride, chromium, and lead, identified as COPCs in the Phase II RI, and bis(2-ethylhexyl)phthalate, identified in the Phase I RI, were not detected above their respective groundwater standards during this more recent sampling.

2.2.4 Pathway Analysis

As noted in the Phase II report, the CAMP is zoned for commercial/industrial use with residential areas located to the north, across Woodward Avenue. A well survey conducted as part of the Phase II investigation indicated that the CAMP site and adjacent properties are served by a municipal water supply, and no private wells are present nearby; however, several wells were identified within a 1-mile radius of the site. More recently (May 2003) the Mecklenburg County Well Information System (available at http://maps.co.mecklenburg.nc.us) indicates a lack of private wells. It is possible that an undocumented well could exist outside the CAMP; however, the groundwater plume does not extend off-site, and no potable wells are present on the site. Based on this information, exposure to groundwater via potable use (i.e., drinking water and other domestic or industrial use) is not currently a complete pathway.

Exposure to groundwater may occur as a result of vapor movement from the groundwater into overlying buildings. The potential for this pathway to be complete was evaluated using EPA's *OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)* [EPA 2003]. This guidance uses a tiered approach to determine whether the vapor intrusion pathway may be complete for a site.

Tier I Screen

Tier I asks the question – are chemicals present that are sufficiently volatile and toxic to be of concern for vapor intrusion? The CAMP fails the Tier I screening criteria and must advance to Tier II screening because

- eleven COPCs (acetone, benzene, carbon tetrachloride, chloroform, 1,1-dichloroethene, naphthalene, tetrachloroethene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, trichloroethene, and total xylenes) are present and meet the criteria of being sufficiently volatile and toxic; and

- buildings are present directly above the contaminated groundwater, and the water table is approximately 4 to 20 ft bgs.

Because the site fails the Tier I screen, exposure via vapor intrusion may be a potentially complete pathway; therefore, a Tier II screen was performed to further evaluate this possibility.

Tier II Screen

Tier II first compares chemical concentrations in groundwater to generic screening criteria based on cancer risk levels of 1.0E-06 to 1.0E-04 or a hazard quotient of 1.0. If these criteria are exceeded, chemical concentrations are further evaluated in the Tier III screen. Groundwater samples collected at the water table from wells closest to the buildings were used as recommended per the EPA guidance. Maximum detected concentrations of COPCs in shallow groundwater are shown along with Tier II criteria in Table 2-1. The site fails the Tier II screening because

- The maximum detected concentration of carbon tetrachloride in COEMW18 (9 µg/L in 2001) exceeds the generic criteria at the 10^{-6} and 10^{-5} risk levels (5 µg/L) but not at the 10^{-4} risk level (13 µg/L);
- The maximum detected concentration of tetrachloroethene in MW01 (14.2 µg/L in 2001) exceeds the generic criteria at the 10^{-6} and 10^{-5} risk levels (11 and 5 µg/L) but not at the 10^{-4} risk level (110 µg/L);
- The maximum detected concentration of 1,1,2-trichloroethane in MW04 (78 µg/L in 2000) exceeds the generic criteria at the 10^{-6} and 10^{-5} risk levels (41 and 5 µg/L) but not at the 10^{-4} risk level (410 µg/L); and
- Maximum detected concentrations of trichloroethene in shallow wells MW01, MW03, MW04, MW06, MW07, COEMW2, COEMW5, COEMW6, COEMW7, COEMW12, COEMW13, COEMW14, COEMW15, COEMW17, SAIC-16, and SAIC-19 range from 7.5 µg/L (March 2000) to 3,800 µg/L (February 2003). These concentrations exceed the generic criteria at the 10^{-6}, 10^{-5}, and 10^{-4} risk levels (5 to 5.3 µg/L).

Because the site fails the Tier II screen, exposure via vapor intrusion may be a potentially complete pathway; therefore, a Tier III analysis is performed to further evaluate this possibility.

Tier III Screen

Conditions at the site meet the criteria for using the Johnson Ettinger (JE) model for calculating Tier III screening levels. TCE, PCE, 1,1,2-trichloroethene, and carbon tetrachloride failed the Tier II screen and are addressed in the Tier III screen. Potential risks from vapor intrusion shown in Table 2-2 were estimated using the JE model with the input parameters shown in Tables 2-3 and 2-4. These input parameters are a combination of standard defaults from the vapor intrusion guidance, average site-specific values, and conservative site-specific values. Buildings 2 and 48 were modeled for TCE because portions of these buildings are located over the highest groundwater TCE concentrations. Building 48 was modeled for tetrachloroethene and 1,1,2-trichloroethane because the maximum concentrations of these chemicals were located near this building and other detections were scattered. Building 3 was modeled for carbon tetrachloride because the maximum carbon tetrachloride concentration was measured in a monitoring well adjacent to this building. Potential risks are estimated for a standard industrial scenario.

For evaluating contaminated sites, cancer risks below 10^{-6} are considered negligible per EPA (1990). Risks above 10^{-4} are considered unacceptable. Within the range of 10^{-6} to 10^{-4}, the level of risk that is considered to be acceptable at a specific site is a risk management decision and is decided on a case-specific basis. Non-science issues, such as technical feasibility, economics, social, political, and legal factors, are all considered in assigning an acceptable risk level. Estimated risks associated with carbon tetrachloride at Building 3, TCE at Building 2, and tetrachloroethene and 1,1,2-trichloroethane at Building 48 are below 1×10^{-6}. The estimated risk associated with TCE at Building 48 is 1×10^{-6}.

Table 2-1. Tier I and II Groundwater Screening Levels and Sampling Results at the CAMP Site

COPC	Maximum Concentration in Shallow Groundwater (µg/L)				Groundwater Screening Levels (µg/L)			
						Tier II		
	2000	2001	2003	Well	Tier I[a]	10^{-4}	10^{-5}	10^{-6}
Acetone	1,200	ND (< 10)	ND (< 10)	COEMW2	Yes	2.20E+05	2.20E+05	2.20E+05
Benzene	5	4.1	NS	MW01	Yes	1.40E+02	1.40E+01	5.00E+00[b]
Carbon tetrachloride	6.2	9	NS	COEMW18	Yes	1.30E+01	5.00E+00[b]	5.00E+00[b]
Chloroform	35	NS	5.7	MW04	Yes	8.00E+01[b]	8.00E+01[b]	8.00E+01[b]
1,1-Dichloroethylene	11	0.72	1.9	COEMW2	Yes	1.90E+02	1.90E+02	1.90E+02
Naphthalene	22	NA	NA	COEMW2	Yes	1.50E+02	1.50E+02	1.50E+02
Total Xylenes	4.8	0.83	NS	MW01	Yes	2.20E+04[c]	2.20E+04[c]	2.20E+04[c]
Tetrachloroethene	4.6	14.2	NS	MW01	Yes	1.10E+02	1.10E+01	5.00E+00[b]
1,1,2-Trichloroethane	78	NS	2.0	COEMW6	Yes	4.10E+02	4.10E+01	5.00E+00[b]
1,1,1-Trichloroethane	3	ND (< 1.0)	ND (< 1.0)	COEMW6	Yes	3.10E+03	3.10E+03	3.10E+03
Trichloroethylene	NS	NS	3,800	SAIC16	Yes	5.30E+00[d]	5.00E+00[b]	5.00E+00[b]

[a]Tier I = Yes, chemical is volatile and toxic enough to warrant further evaluation. No, chemical is not volatile or toxic.
[b]The target groundwater concentrations is the maximum contaminant level (MCL). The MCL for chloroform is the MCL for total Trihalomethanes.
[c]The criteria listed for total Xylenes is the minimum of the criteria for m-Xylene, o-Xylene, and p-Xylene.
[d]The screening level for trichloroethylene is based on the upper-bound cancer slope factor (SF) identified in the U. S. Environmental Protection Agency's draft risk assessment for trichloroethylene. The SF is based on state-of-the-art methodology; however, the TCE assessment is still undergoing review. As a result, the SF and the target concentration values for TCE may be revised further.
COPC = Chemical of potential concern.
NA = Not analyzed.
ND = Non-detect (< detection limit).
NS = Not sampled.

Table 2-2. Results of Tier III Site-Specific Analysis at the CAMP Site

COPC	Building	Groundwater Concentration (µg/L)	Estimated Cancer Risk
Carbon Tetrachloride	3	9[a]	1E-07
Trichloroethene	2	785[b]	2E-07
Trichloroethene	48	656[c]	1E-06
Tetrachloroethene	48	14.2[d]	1E-08
1,1,2-Trichloroethane	48	78[e]	1E-07

[a]Concentration detected in COEMW18. This is the only detected concentration of carbon tetrachloride near Building 3 in shallow groundwater.
[b]Average of reported concentrations in samples from wells surrounding Building 2 collected in 2003 (COEMW02, and COEMW06), 2001 (COEMW01, COEMW12, and COEMW17), and 2000 (COEMW05). If a well was not sampled in 2003, the concentration reported in 2001 or 2000 was used.
[c]Average of reported concentrations in samples from wells surrounding Building 48 collected in 2003 (MW04 and COEMW06), 2001 (MW01 and COEMW01), and 2000 (MW02, MW03, COEMW15, and COEMW20). If a well was not sampled in 2003, the concentration reported in 2001 or 2000 was used.
[d]Concentration detected in well MW01 (2001). This is the highest detected concentration and the only detect near Building 48 in shallow groundwater.
[e]Concentration detected in well MW04 (2000). This is the highest detected concentration and the only detect near Building 48 in shallow groundwater.

Table 2-3. Site-Specific Vapor Intrusion Modeling Parameters for Buildings at the CAMP Site

Parameter	Value Used			Source
	Building 2	Building 3	Building 48	
Chemical	Trichloroethene	Carbon tetrachloride	Trichloroethene, Tetrachloroethene, and 1,1,2-Trichloroethane	Detected in shallow groundwater at the building in concentrations that exceed Tier II screening levels.
Average groundwater temperature	16.67°C (62°F)	16.67°C (62°F)	16.67°C (62°F)	EPA 2003 (Figure 8).
Depth below grade to bottom of floor	15 cm	15 cm	15 cm	Default (EPA 2003).
Depth below grade to water table	213.7 cm (7.01 ft)	259.69 cm (8.52 ft)	405.7 cm (13.31 ft)	Average from wells near building (see Table 2-4).
Thickness of Soil Stratum A	213.7 cm (7.01 ft)	259.69 cm (8.52 ft)	405.7 cm (13.31 ft)	Vadose zone is fairly homogeneous,; only one stratum is defined.
Soil Stratum A SCS soil type	Silt loam (SIL)	Sandy loam (SL)	Sandy loam (SL)	Predominant soil type from wells near building.
Soil Stratum directly above water table	A	A	A	Vadose zone is fairly homogeneous, only one stratum is defined.
Soil type directly above water table	Silt loam (SIL)	Sandy loam (SL)	Sandy loam (SL)	Predominant soil type from wells near building (see Table 2-4).
Stratum A soil dry bulk density	1.5 g/cm^3	1.5 g/cm^3	1.5 g/cm^3	Default (EPA 2003).
Stratum A soil total porosity	0.439	0.387	0.387	Default for sandy loam (EPA 2000) Table 2.
Stratum A soil water-filled porosity	0.33	0.29	0.26	Average from wells near building (see Table 2-4).
Floor thickness	15 cm	15 cm	15 cm	Default (EPA 2003).
Soil-building pressure differential	40 g/cm-s^2	40 g/cm-s^2	40 g/cm-s^2	Default (EPA 2003).
Enclosed space floor length	35433 cm (1162.5 ft)	35433 cm (1162.5 ft)	13716 cm (450 ft)	From USACE (2002) Figures 5 and 6.
Enclosed space floor width	5143.5 cm (168.75 ft)	5143.5 cm (168.75 ft)	1143 cm (37.5 ft)	From USACE (2002) Figures 5 and 6.
Enclosed space height	365.76 cm (12 ft)	365.76 cm (12 ft)	304.8 cm (10 ft)	Notes from Paula Bond.
Floor-wall seam crack width	0.1 cm	0.1 cm	0.1 cm	Default (EPA 2003).
Indoor air exchange rate	0.45 hr^{-1}	0.45 hr^{-1}	0.45 hr^{-1}	Average (EPA 2003).
Averaging time for carcinogens	70 years	70 years	70 years	Default (EPA 1989).
Exposure duration	25 years	25 years	25 years	Occupational default (EPA 1989).
Exposure frequency	250 days/year	250 days/year	250 days/year	Occupational default (EPA 1989).

CAMP = Charlotte Army Missile Plant.
EPA = U. S. Environmental Protection Agency.
SCS = Soil Conservation Service.
USACE = U. S. Army Corps of Engineers.

Table 2-4. Soil and Groundwater Parameters used in Vapor Intrusion Modeling for the CAMP Site

Well[a]	Depth to Water Table (ft bgs)	% Moisture	% Sand	% Silt	% Clay	USC	SCS	Groundwater Concentration (µg/L)		
								2003	2001	2000
Building 2								**Trichloroethene**		
COEMW12	8.42	44	11.3	73.4	15.3	MH	SiL	NS	10.7	18
COEMW17	4.00	27.9	69	ND	ND	SM	SL	NS	31.6	58
COEMW01	8.33	20.6	52.8	42.7	4.5	SM	SL	NS	0.78	(< 1)
COEMW06	4.77	42	37.5	56.9	5.6	ML	SiL	3,400	3,510	660
COEMW05	7.48	29.2	35.9	59.2	4.9	ML	SiL	NS	NS	68
COEMW02	5.62	32.4	41.5	53.2	5.3	ML	SiL	1,200	1,050	1,600
SAIC05	10.44	NA	NA	NA	NA	NA	NA	NS	NA	NA
Average	7.01	33						785[b]	778[c]	401
Building 3								**Carbon Tetrachloride**		
COEMW18	8.27	25.7	69	ND	ND	SM	SL	NS	9	6.2
COEMW12	8.42	44	11.3	73.4	15.3	MH	SiL	NS	(< 1)	(< 1)
COEMW17	4.06	27.9	69	ND	ND	SM	SL	NS	(< 1)	(< 1)
COEMW19	13.43	20.4	44	ND	ND	CH	ND	NS	NS	(< 1)
Average	8.52	29						--	--	--
Building 48								**Trichloroethene**		
MW04	14.14	ND	ND	ND	ND	ND	ND	780	NS	3,500
COEMW20	17.39	17.8	56	ND	ND	SM	ND	NS	NS	0.98
COEMW06	4.77	42	37.5	56.9	5.6	ML	SiL	3,400	3,510	660
COEMW01	8.33	20.6	52.8	42.7	4.5	SM	SL	NS	0.78	(< 1)
COEMW15	15.57	24.1	60	ND	ND	SM	ND	NS	NS	7.5
MW03	12.19	ND	ND	ND	ND	ND	ND	NS	NS	11
MW01	13.55	ND	ND	ND	ND	ND	ND	NS	1,050	720
MW02	12.00	ND	ND	ND	ND	ND	ND	NS	NS	(< 1)
SAIC13	17.11	NA	NA	NA	NA	NA	NA	NS	NA	NA
SAIC07	16.66	NA	NA	NA	NA	NA	NA	NS	NA	NA
Average	13.31	26						656[b]	1,010[c]	613

[a]Soil parameters (% moisture, sand, silt, clay, and USC) taken from U. S. Army Corps of Engineers (USACE) 1999 for COEMW01 through COEMW12 and from USACE 2000 for COEMW13 through COEMW26.
[b]Reported results in 2001 or 2000 (most recent available) were used for wells not sampled in 2003 to calculate the average concentration.
[c]Reported result in 2000 was used for wells not sampled in 2001 to calculate the average concentration.
CH = Clay of high plasticity, fat clay.
MH = Silt of high plasticity, elastic silt.
ML = Micaceous sandy silt.
NA = Not applicable - this well is completed in the transition or bedrock zones and is used for depth to water table only.
ND = No data.
NS = Not sampled.
SCS = Soil Conservation Service.
SiL = Silt loam.
SL = Sandy loam.
SM = Silty sand.
USC = Unified Soil Classification.
(< 1) = This sample was non-detect with a detection limit of 1 µg/L.

These estimated risks are based on the following assumptions:

- The buildings are constructed on a slab-type foundation. This is a conservative assumption because basement/utility tunnels present under portions of these buildings would result in dilution of vapor concentrations.

- Workers are present in the building 8 hrs/day, 250 days/year, for 25 years. This is a conservative assumption because these buildings are currently used for storage.

- Groundwater concentrations of TCE were estimated as the average of the concentration measured in 2003 in the shallow monitoring wells nearest each building. For wells not sampled in 2003, results from 2001 or 2000 were used. This is considered a conservative assumption because the location of the wells is biased toward the area of maximum concentration; therefore, the actual average concentration under the entire building is expected to be lower. The average concentration of TCE near Building 48 was higher in 2001 than 2003 (see Table 2-4). The risk associated with the average concentration in 2001 is 2×10^{-6}.

- Groundwater concentrations of carbon tetrachloride, tetrachloroethene, and 1,1,2-trichloroethane were estimated as the maximum concentration in shallow monitoring wells because there were very few detections, and they were scattered over a relatively large area. This is considered a conservative assumption because many of the wells near the building modeled were non-detects for these chemicals; therefore, the actual average concentration under the entire building is expected to be lower.

- Average building ventilation parameters reported for residential buildings were used. These assumptions may over- or under-estimate exposures depending on the actual building construction.

Given the conservative assumptions used in this assessment, all of the estimated risks are considered to be minor, and exposure to contaminants in groundwater as a result of vapor intrusion is not considered to be a complete pathway under current conditions. These risk estimates may be refined with more site-specific information regarding building construction and use. These estimated risks are applicable only to (1) the exposures modeled (i.e., a worker present every day), and (2) the groundwater concentrations measured in 2003. If activities or groundwater concentrations change (especially if groundwater concentrations increase in the future), these estimated risks would change.

2.2.5 Summary of COCs for Groundwater

Several COPCs were identified from the Phase I, Phase II, and Supplemental FS sampling results based on comparison to residential drinking water and NCAC 2L standards. These chemicals are currently not COCs because groundwater is not used as a source of potable water in this area. With the exception of chloroform and TCE, elevated concentrations of COPCs are limited to a few scattered wells and are not likely to migrate off-site in the future. Chloroform has been detected above the NCAC 2L standard of 0.19 µg/L in 44 of 57 monitoring wells but has not been detected above the federal MCL for trihalomethanes of 200 µg/L in any wells. TCE has been detected in 42 of 57 monitoring wells at up to three orders of magnitude above both the NCAC 2L standard of 2.8 µg/L and the federal MCL of 5 µg/L. Based on their prevalence in the groundwater at high concentrations, chloroform and TCE may be considered COCs in groundwater for potential future exposures.

The potential for exposure to groundwater contamination via vapor intrusion into buildings was investigated based on new guidance (EPA 2003). The potential risk from TCE was estimated to be 1×10^{-6} at one

building. This is equal to the *deminimis* risk level for remedial action. Given the conservative assumptions used in this assessment, estimated risks are considered to be minor, and exposure to contaminants in groundwater as a result of vapor intrusion is not considered to be a complete pathway; therefore, no groundwater COCs are identified for exposure via vapor intrusion.

2.3 CONTAMINANTS OF CONCERN FOR SURFACE WATER

2.3.1 Phase I Remedial Investigation

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

2.3.2 Phase II Remedial Investigation

One surface water sample was collected from the outfall of a manmade drainage culvert for the Phase II RI. 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.

No contaminants were detected above the NCAC 2B standards for surface water.

2.3.3 Supplemental FS Investigation

No additional surface water samples were collected to support the FS.

2.3.4 Pathway Analysis

As noted in the Phase II report, no human health risk is anticipated for exceeding the tap water standard since this ditch will not be used for drinking water.

2.3.5 Summary of COCs for Surface Water

No COPCs and, therefore, no COCs were identified for inclusion in the FS for surface water.

2.4 STORM SEWERS

2.4.1 Phase I Remedial Investigation Report

No storm water samples were collected for the Phase I RI activities.

2.4.2 Phase II Remedial Investigation Report

No storm water samples were collected during the Phase II RI activities.

2.4.3 Supplemental FS Investigation

One water sample was collected from the storm sewer manhole between Buildings 2 and 48, near monitoring wells SAIC-5 and SAIC-12. This storm drain is located below the water table and likely

receives groundwater in this area. TCE (310 μg/L) was identified in this sample above the NCAC surface water standard (92 μg/L) and is, therefore, considered a COPC.

2.4.4 Pathway Analysis

Exposure to contaminants in the storm sewer may occur in two ways, as described below.

Storm water discharges to surface water near the intersection of Woodward Avenue and Statesville Avenue. Children playing in this ditch may be exposed to surface water. The surface water sample collected during the Phase II investigation was taken at this location. Contaminant concentrations in this sample were below applicable surface water standards; therefore, no COPCs were identified.

Workers in the manhole may be exposed by inhalation of vapors. This pathway is considered insignificant because (1) this type of exposure would occur very infrequently (i.e., less than once per year), and (2) worker exposures are addressed by health and safety regulations that require proper ventilation and monitoring while in an enclosed space.

2.4.5 Summary of COCs for Storm Sewers

While no current exposures are identified for contaminants in the storm sewer, the sewer represents a potential migration pathway for contaminated groundwater to infiltrate into the storm drain and subsequently discharge to surface water if concentrations increase in the future.

2.5 SUMMARY AND CONCLUSIONS

The Phase I and II RIs, and the data collected to supplement this FS, did not identify any COCs or complete exposure pathways for surface soil, subsurface soil, or surface water.

Several groundwater COPCs were identified from the Phase I, Phase II, and supplemental FS sampling results based on comparison to residential drinking water and NCAC 2L standards. These chemicals are currently not COCs because groundwater is not used as a source of potable water in this area. With the exception of chloroform and TCE, elevated concentrations of COPCs are limited to a few scattered wells and are not likely to migrate off-site in the future. Chloroform has been detected above the NCAC 2L standard of 0.19 μg/L in 44 of 57 monitoring wells but has not been detected above the federal MCL for trihalomethanes of 200 μg/L in any wells. TCE has been detected in 42 of 57 monitoring wells at up to three orders of magnitude above both the NCAC 2L standard of 2.8 μg/L and the federal MCL of 5 μg/L. Based on their prevalence in the groundwater at high concentrations, chloroform and TCE may be considered COCs in groundwater for potential future exposures.

The potential for exposure to groundwater contamination via vapor intrusion into buildings was investigated based on new EPA (2003) guidance. The potential risk from TCE was estimated to be 1×10^{-6} at one building. This is equal to the *deminimis* risk level for remedial action. Given the conservative assumptions used in this assessment, all of the estimated risks are considered to be minor, and exposure to contaminants in groundwater as a result of vapor intrusion is not considered to be a complete pathway under current conditions; therefore, no groundwater COCs are identified for exposure via vapor intrusion.

One water sample was collected from the storm sewer manhole between Buildings 2 and 48, near monitoring wells SAIC-5 and SAIC-12. The concentration of TCE detected in this sample is above the applicable surface water standards; however, exposure via discharge to surface water is not of concern because concentrations measured in surface water did not exceed the NCAC 2B criteria. Worker

exposures are addressed by health and safety regulations that require proper ventilation and monitoring while in an enclosed space and, therefore, are not considered complete. While no current exposures are identified for contaminants in the storm sewer, the sewer represents a potential migration pathway for contaminated groundwater to infiltrate into the storm drain and subsequently discharge to surface water.

3.0 REMEDIAL ACTION OBJECTIVES

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 CAMP 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 TCE and chloroform were both identified as potential COCs, TCE was detected at much higher concentrations and will be the model compound for remedial action. It is anticipated that with any remedial action, concentrations of all chlorinated compounds will be reduced. As agreed between the NCDENR and the USACE–Savannah District on July 28, 2003, Hot Spot No. 1 is the only hot spot to be considered for treatment within this FS. It was agreed that treatment would consist of reducing the hot spot TCE concentrations to 100 µg/L via active treatment, with the implementation of monitoring of natural attenuation to achieve the NCAC 2L criterion of 2.8 µg/L. Hot Spot Nos. 2 and 3 will not be specifically addressed within this FS, as they are considered localized and impracticable to treat at this time. As Hot Spot No. 3 is located within the footprint of Hot Spot No. 1, it is anticipated that the treatment of this area will consequently reduce the bedrock TCE concentrations as an ancillary process. Similarly, because the storm drain passes within the footprint of Hot Spot No. 1, it is anticipated that the treatment of this area will consequently reduce potential TCE concentrations from entering the storm drain system.

Based on these agreements, the RAO for the remedial action at the CAMP is to remediate groundwater at the area of contamination identified as Hot Spot No. 1 in order to reduce TCE concentrations to 100 µg/L. Ultimately, the aquifer would be restored to beneficial use through the natural attenuation of TCE to 2.8 µg/L.

3.2 ARARS

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 1998a]. Regulations that are codified in the NCP govern the identification of, and subsequent compliance with, 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 CAMP and chemical-specific, action-specific, and location-specific criteria.

3.2.1 Chemical-specific ARARs

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

Table 3-1. Federal and North Carolina Groundwater Standards and Reportable Quantities

COPCs Identified for the CAMP FS	NCAC 2L[a] Standard (µg/L)	Federal MCL (µg/L)	NCAC 2B[b] Standard (µg/L)	Federal Ambient Water Quality Standards[a,c] (µg/L)
Acetone	700	NA[d]	NA	NS[e]
Carbon tetrachloride	0.3	5	4.42	0.25
Chloroform	0.19	NA	NA	5.7
1,1-Dichloroethene	7	7	NA	0.057
Benzene	1	5	71.4	1.2
Naphthalene	21	NA	NA	NS
Total xylenes	530	10,000	NA	NS
Chromium	50	100	NA	Cr III: 74 Cr IV: 11
Iron	300	300*	NA	1,000 (CCC)[c]
Manganese	50	50*	NA	NS
1,1,1-Trichlorothane	200	200	NA	NS
1,1,2-Trichloroethane	NA	5	NA	0.60
Trichloroethene	2.8	5	92.4	2.7

[a]NCAC 2L – North Carolina Administrative Code Chapter 15, groundwater quality standards.
[b]NCAC 2B – North Carolina Administrative Code Chapter 15, surface water quality standards
[c]Criterion continuous concentration (CCC) in accordance with the Federal Water Quality Standards. Criteria maximum concentration (CMC) is not applicable for all inorganic constituents, except Cr III: 570 and Cr IV: 16.
[d]NS = Not specified, and [e]NA = Not applicable to this study or not specified in regulations.
*Indicates Federal Secondary Drinking Water Standards.

3.2.1.1 Groundwater

Federal MCLs [40 *Code of Federal Regulations* (*CFR*) 141] and NCAC 2L groundwater standards (Title 15A, Subchapter 2L, Sections .0100, .0200, and .0300) are being used to develop ARARs for the CAMP. The NCAC 2L groundwater standards contain more stringent standards than those found in the federal MCLs. As the NCAC 2L standards are more stringent, they will be used to screen COPCs. Table 3-1 details the federal and state standards for each COPC.

3.2.1.2 Soil

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

3.2.1.3 Surface water

North Carolina has promulgated surface water standards (Title 15A Subchapter 2B, Sections .0100 and .0200). These state standards have been established to maintain the water quality of surface waters of the state. Additionally, and in accordance with CERCLA Section 121(d)(2)(a), federal ambient water quality criteria (AWQC) established under the Clean Water Act of 1972 must be attained when they are relevant

and appropriate. The NCAC 2B and Federal AWQCs for site COPCs are listed in Table 3-1 [EPA National Recommended Water Quality Criteria, 63 *FR* 68354, December 10, 1998 (EPA 1998)].

3.2.2 Potential Action-Specific ARARs

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 (15A NCAC 13A Section .0106-5) also will be considered a hazardous waste.

TCE has been detected in groundwater samples across the CAMP and is the main constituent of concern. 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 AWQCs (see chemical-specific criteria, Section 3.2) are relevant and appropriate, and NC 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 Emergency Planning and Community Right-to-Know Act

The Emergency Planning and Community Right-to-Know Act (EPCRA), Section 304 notification requirements would apply to any release within 24 hours of a hazardous substance greater than or equal to its reportable quantity (RQ). It is unlikely that RQs of COPCs would be released during soil excavation activities or active treatment alternatives; however, should such a release occur, notification of the State Emergency Response Commission and Local Emergency Planning Committee would be required.

3.2.2.4 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 (DENR 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 DENR Environmental Management 2D Section .0400 regulations.

3.2.2.5 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 an ARAR to be considered. 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 twenty coastal counties, and/or
- development draining to Outstanding Resource Waters (ORW) or High Quality Waters (HQW).

Additionally, the substantive standard of Sedimentation Control (15A NCAC 04) is an ARAR to be considered, depending upon the actual remedial action selected, as the standards may be relevant to site and/or stormwater conveyance disturbance.

3.2.3 Location-specific ARARs

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).

Natural habitat is negligible at the CAMP due to ~ 85% building and pavement coverage. The remaining 15% of the site is primarily 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 CAMP. However, the Endangered Species Act of 1973 (50 *CFR* 17) is a potential ARAR for the 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 State Historic Preservation Office has a listing of historical areas in Mecklenburg County, North Carolina. The NRHP is a potential ARAR to be considered, as the list is updated periodically.

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 to be considered, as previously mentioned.

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4.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

This chapter provides the basis for development of a range of remedial alternatives for contaminated groundwater at the CAMP. Potentially applicable technology types and process options are identified and screened based on information gathered during the Phase I and II RIs and supplemental FS investigations. This screening process consists of the following analytical steps:

- identify contaminants and media volumes of concern (Chapter 1.0),
- identify GRAs (Section 4.1),
- identify and screen remedial technologies and process options (Section 4.2), and
- evaluate and select representative process options (Section 4.3).

These steps are outlined in the EPA RI/FS guidance manual (EPA 1988) and the NCP.

4.1 GENERAL RESPONSE ACTIONS

GRAs are broad categories of remedial action that meet the RAOs developed in Chapter 3.0 for the CAMP. 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 GRAs that were considered too impractical to implement (for example, ex situ treatment may be considered impractical to implement due to site spatial constraints). For each GRA, potentially applicable technology types and process options are identified. In developing alternatives, combinations of GRAs may be identified.

Following are the descriptions of the GRAs considered for the CAMP. These GRAs include no action, institutional controls, containment, in situ treatment, ex situ treatment, and removal (see Table 4-1).

4.1.1 No Action

The No Action alternative is considered in accordance with CERCLA and the NCP requirements for comparison with other alternatives. Under this alternative, no remedial action would be implemented at CAMP 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 downgradient. Institutional controls in place to protect human health and the environment (such as restrictions on excavation or access controls) would cease. 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 provided a baseline for comparison with other alternatives.

4.1.2 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. The volume, mobility, and toxicity of contaminants are not reduced through the application of institutional controls.

Table 4-1. General Response Actions, Technology Types and Process Options for the CAMP 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
Containment	Vertical Barriers	Slurry Walls
		Sheet Piling
		Grout Curtain
	Hydraulic Containment	Pumping
In situ Treatment	Physical Treatment	Air Sparging
		Electrical Resistance Heating
		Stream Injection
	Biological Treatment	Monitored Natural Attenuation
		Bioaugmentation
		Biostimulation
		Enhancement with Air Sparging
		Oxygen Enhancement with Hydrogen Peroxide
	Chemical Treatment	Permeable Reactive Barrier
		Chemical Oxidation – HRC and Permanganate
Ex situ Treatment	Physical Treatment	Air Stripping
		Carbon Adsorption
		UV Irradiation
	Biological Treatment	Bioreactors
	Groundwater Extraction	Well Points
		Deep Wells
		French Drains

CAMP = Charlotte Army Missile Plant.
HRC = Hydrogen-releasing compound.
UV = Ultraviolet.

4.1.3 Containment

Containment technologies involve the construction of an engineered barrier or controlling the groundwater hydraulic gradients and flow directions to isolate contamination within the aquifer. When properly constructed and maintained, containment technologies can provide reliable and effective methods for controlling contaminant transport. Containment does not reduce the volume, mobility, or toxicity of contaminants.

4.1.4 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.

4.1.5 Ex situ Treatment

Ex situ treatment involves removing contaminated groundwater and treating it in aboveground units. Relative to in situ treatment technologies, ex situ treatment has the advantage of greater certainty in verification of the effectiveness of treatment. The disadvantage of ex situ treatment is increased handling of contaminated materials resulting in greater potential of exposure to workers and typically higher costs. Removing the groundwater from the subsurface is accomplished by extraction technologies such as vertical or horizontal wells, deep wells, or French drains. Once removed the contaminated groundwater can be treated or disposed of on-site or off-site.

4.2 SCREENING OF PROCESS OPTIONS

As specified in EPA RI/FS guidance (EPA 1988), two steps are taken to reduce the number of technology types and process options that undergo detailed analysis. First, each process option was screened to determine whether it is technically applicable at the site. The second step was the evaluation of the remaining technology types and process options to determine which could be developed into remedial alternatives. To determine technical applicability, the capabilities of the process options were evaluated against the site conditions and the contaminant types and concentrations. Process options that were not technically applicable at the site or for the TCE contamination were eliminated from further consideration. Figure 4-1 identifies and briefly describes each process option for the GRAs under consideration. The screening comment in the figure identifies those process options screened out on the basis of lack of technical applicability to site conditions or contaminant type. In addition to the No Action alternative, the process options that were retained for further evaluation are as follows:

Technology Type	Process Option
Access and Use Restrictions	Administrative controls, deed restrictions, and physical barriers
Monitoring and Maintenance	Long-term monitoring and physical surveillance and maintenance
Biological Treatment	Monitored natural attenuation, bioaugmentation, and biostimulation (co-metabolic processes)
Chemical Treatment	Permeable reactive barrier wall and chemical oxidation

Section 4.3 contains a more detailed description of each retained process option.

4.3 EVALUATION AND SELECTION OF REPRESENTATIVE PROCESS OPTIONS

In this section, the remaining 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. The representative process options that were eliminated from further consideration are shaded in Figure 4-1. Because the selected process options represent a technology type, options not carried forward may be reevaluated in the Proposed Plan, the ROD, or the remedial design 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 CAMP are achieved. This section presents the effectiveness,

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General Response Action	Technology Type	Process Option	Description	Screening Comment
No action	None	No action	No action	The NCP requires the no action alternative to be carried through the detailed analysis as a baseline for comparison to other remedial alternatives.
Institutional Controls	Access/use restrictions	Administrative Controls	Control site entry, security patrols, and use of PPE	Administrative controls, deed restrictions, and physical barriers are carried forward as representative process options to use in combination with other technologies to reduce risk.
		Deed restrictions	Restrictions issued for property to manage use	
		Physical barriers	Maintain existing or install new security fences at site; post signs around site to limit access	
	Monitoring & Maintenance	Long-term Monitoring	Long-term monitoring of contamination in appropriate media	Monitoring and maintenance options are carried forward to use in combination with other technologies to reduce risk.
		Physical Maintenance	Long-term physical inspection and maintenance	
Containment	Vertical barrier	Slurry wall	Vertically excavated trench filled with slurry	The containment general response actions were not retained because they do not reduce volume, toxicity, or mobility of the contaminated groundwater.
		Sheet piling	Vertical barrier created by sheet pile	
		Grout curtain	Low permeability barrier constructed using pressure injection	
	Hydraulic containment	Pumping	Controlling hydraulic gradient and flow direction by withdrawal of groundwater	
Insitu Treatment	Physical treatment	Air sparging	Injection of air to cause volatilization	Less effective in tight geologic formations and contamination at depth.
		Electrical resistance heating	Heating groundwater to cause volitalization	Requires open surface area to perform work. Not considered due to space limitations and daily site operations.
		Steam injection	Injection of steam to cause volitalization	Requires open surface area to perform work. Not considered due to space limitations and daily site operations.
	Biological treatment	Monitored natural attenuation	Natural subsurface processes allowed to reduce contaminant concentrations	Representative process option for biological treatment.
		Bioaugmentation	Enhancement of biological degradation through injection of microbes	Representative process option for biological treatment
		Biostimulation	Enhancement of biological degradation through injection of methane and oxygen	Representative process option for biological treatment
		Oxygen enhancement with air sparging	Enhancement of biological degradation through air injection	Less effective for heterogenous formations containing high clay content.
		Oxygen enhancement with hydrogen peroxide	Enhancement of biological degradation through injection of hydrogen peroxide	Less effective for heterogenous formations containing high clay content.
	Chemical treatment	Permeable reactive barrier	Permeable reactive wall installed across flow of contamination	Representative process option for chemical treatment.
		Chemical oxidation	Injection of oxidants (HRC, permanganate) that react with contaminants to produce innocuous substances	Representative process option for chemical treatment. Permanganate selected as potential oxident.
Exsitu Treatment	Physical treatment	Air stripping	VOCs partitioned from groundwater by increasing surface area of contaminated water exposed to air	The ex-situ treatment general response action was not considered further due to space limitations and daily site operations.
		Carbon adsorption	Groundwater pumped through activated carbon which adsorb contaminants	
		Ultraviolet oxidation	Addition of strong oxidizers and irradiation with UV light to oxidize organics	
	Biological treatment	Bioreactor	Degradation of contaminants with micro organisms through attached or suspended biological systems	
	Groundwater extraction	Well points	Vertical small diameter pipe casing with slotted, screened intervals	The ex-situ treatment general response action was not considered further due to space limitations and daily site operations.
		Deep well	Large diameter pipe casing with slotted, screened intervals	
		French drain	Large diameter pipe laid with slotted, screened intervals laid in horizontal trench	

Figure 4-1. Summary of Representative Technology Types and Process Options

G04-0015 Sum of Technologies 2

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 the 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, assumes that present security measures limiting access and use are not maintained, and excludes short- and long-term monitoring. No implementation is required.

If no action is taken at the CAMP, unacceptable risks to human health and the environment may result as off-site migration of contaminants in groundwater would not be mitigated and groundwater would not be restricted.

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 100 µg/L.

Implementability

No implementation is required.

Cost

There are no costs involved.

The No Action process option will be retained as required by the NCP.

4.3.2 Institutional Controls

The institutional control technology types evaluated include access and use restrictions and long-term monitoring and maintenance. The process options from these technology types can be used alone or 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, control disturbance, development of the site, and 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.

- Deed restrictions—Land use could be restricted by issuing codes, deeds, or zoning which designate land use privileges. Restrictive covenants would prohibit certain activities on the site such as drilling drinking water wells and using land for residential, recreational, or agricultural purposes.

- Physical barriers—Fences, signs, or additional access barriers could be erected around the site boundaries to restrict site access to authorized personnel.

Effectiveness

Access and use restrictions, by themselves, would not be effective in meeting the CAMP 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. Security requirements would prevent unauthorized personnel from entering the site. Deed restrictions to restrict future land and groundwater use would be legally enforceable subsequent to property transfer from the current site owner's control. However, these institutional controls alone would not reduce the volume, toxicity, or mobility of the contaminated groundwater.

Implementability

Access and use restrictions are currently in place at the CAMP and could be easily implemented 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 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 environmental media to evaluate the effectiveness of the remedial action, determine whether adjustments or additional process options are needed, and 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 system 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 CAMP. 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 (e.g., reactive barrier) is required.

4.3.3 In situ Treatment

The in situ treatment process options retained are monitored natural attenuation, bioaugmentation, biostimulation processes, permeable reactive barrier wall, and in situ chemical oxidation (ISCO). These process options are described and evaluated below.

4.3.3.1 Monitored natural attenuation

Monitored natural attenuation would involve long-term monitoring of groundwater quality to observe the decrease in concentrations of COCs and to verify that RGOs have been met. During the monitored natural attenuation 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 and low permeability of the site soils.

During the natural attenuation period, organic constituents in groundwater would be degraded through either aerobic or 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:

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{cis-1,2-DCE} \rightarrow \text{vinyl chloride} \rightarrow \text{ethane.}$$

Effectiveness

Monitored natural attenuation can be effective in achieving the RAOs, particularly if naturally occurring biodegradation is already taking place. At CAMP, conditions in the aquifer are aerobic and highly oxidizing. Therefore, conditions are not favorable for intrinsic reductive dechlorination of TCE. Conditions are favorable for the intrinsic remediation of TCE daughter decomposition products. However, to date, no daughter decomposition products have been detected in the groundwater.

Modeling of the TCE in groundwater at the site (see Appendix A) has predicted that reduction in toxicity to NCAC 2L standards will be achieved in approximately 200 years. However, the plume is predicted to migrate off-site with a commensurate increase in volume before the drinking water standards are achieved. There are no current groundwater receptors within the attenuated contaminant plume

dimensions. However, continued periodic monitoring would be needed to determine whether the plume is intercepted at Woodward Avenue or diminishing over reasonable timeframes.

No increased risks are anticipated for potential receptors with implementation of monitored natural attenuation, 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 monitored natural attenuation process option cannot achieve the RAOs alone; therefore, it will be combined with the action process options. When combined with the action alternatives, RAOs may be able to be met based on the effectiveness of the treatment.

Implementability

Monitored natural attenuation 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.

The equipment and procedures required to install additional groundwater monitoring 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.

Cost

The capital costs associated with monitored natural attenuation would be low, but total costs would become significant over the long-term.

4.3.3.2 Bioaugmentation

Bioaugmentation involves the injection of microorganisms into the contaminant plume to establish or enhance biological activity and contaminant degradation. Typically, the microorganisms are delivered as a liquid containing many millions of microbes in a nutrient solution. Such injectant products as CL-Out™ and Petrox™ have been used for the bioremediation of chlorinated organic compounds under aerobic aquifer conditions.

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:

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{cis-1,2-DCE} \rightarrow \text{vinyl chloride} \rightarrow \text{ethane.}$$

At the CAMP, conditions in the aquifer are aerobic and highly oxidizing. Therefore, conditions are not favorable for reductive dechlorination of TCE. Conditions are favorable for the biodegradation of TCE daughter decomposition products. However, to date, no daughter decomposition products have been detected in the groundwater. The absence of TCE biodegradation is indicative of either no or minimal populations of native microorganisms and/or no or minimal food sources.

The objective of bioaugmentation would be to directly introduce significant populations of microorganisms throughout the contaminant plume. The microorganisms would be introduced through

injection wells. Initial biodegradation of TCE would be through co-metabolic processes; that is, the TCE would be incidentally degraded through the metabolic processes of the introduced microorganisms. Subsequent TCE daughter decomposition would occur through the natural respiration of the introduced microorganisms under the aerobic aquifer conditions.

Effectiveness

Bioaugmentation can be effective in achieving the RAOs, particularly in biodegrading TCE daughter products such as vinyl chloride. Indeed, although there are no current or anticipated groundwater receptors, short-term risks may increase locally in the near term from TCE daughter products since those products—such as vinyl chloride—are more toxic and mobile than TCE. However, biodegradation of TCE daughter products is favored and relatively rapid under the aerobic conditions found in the groundwater at CAMP. Therefore, no significant increase in risks is anticipated for potential receptors with implementation of bioaugmentation. In addition, residual risk following implementation of this process option would be reduced when compared with the baseline (although there are no groundwater receptors based on current or future land use).

The bioaugmentation process option may achieve the RAO of reducing TCE concentrations greater than 500 µg/L to below 100 µg/L.; however, bench- and/or pilot-scale testing of the process option would be necessary to demonstrate that the RAO would be achieved at CAMP. The contaminant zones at the site are well characterized, and the proposed performance monitoring network and schedule are sufficient to detect biodegradation rates and any changes in hydrologic or geochemical conditions.

Implementability

Bioaugmentation could be readily implemented over most of the site. A small portion of the TCE plume is located under existing buildings. Accessing these areas would require slant or horizontal drilling. Due to the complexity and number of horizontal wells required, it will be assumed that inaccessible areas under buildings will not be treated to meet RAOs. Bioaugmentation is a relatively proven process option 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.

The equipment and procedures required to install additional groundwater monitoring 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.

Cost

The cost for this process option is moderate to high.

4.3.3.3 Biostimulation (methane biotreatment)

Biostimulation is the incidental breakdown of contaminants caused by an enzyme or co-factor produced by aerobic microorganisms during normal metabolism of other food hydrocarbons. That is, the contaminant is oxidized and destroyed but is not consumed for food, and the microbe derives no energy from the oxidation of the contaminant. A number of chlorinated hydrocarbon contaminants—including TCE—have been observed to be oxidized co-metabolically under aerobic conditions.

Generally, a hydrocarbon food source (and electron donor) is added to increase the population of microbes and the rate of contaminant oxidation. Hydrocarbon food sources have included methane, ethene, ethane, propane, butane, toluene, and phenol. Other food sources have also included hydrogen—usually supplied by a hydrogen-releasing compound (HRC)—and long-chain aliphatic hydrocarbons such as vegetable oil.

Although studies have suggested that toluene and phenol can be more effective electron donors than methane in stimulation of co-metabolic biodegradation of TCE and its daughter decomposition by-products, these hydrocarbons are drinking water contaminants themselves. Therefore, methane is preferred for application of this process option.

Implementation of this process option would involve the installation of two horizontal wells above the bedrock. An air-methane mixture would be injected in the screened section of each horizontal well to reduce contaminant concentrations in the groundwater. The final design would be based on a pilot-scale study and may deviate from this conceptual design.

Groundwater samples would be collected from existing monitoring wells and analyzed for VOCs to serve as a baseline before treatment and to monitor the treatment effectiveness. The results from this performance monitoring would determine how long the methane-air mixture would be injected.

Effectiveness

Biostimulation to produce co-metabolic biodegradation is very effective in dechlorinating highly substituted chlorocarbons such as TCE. Moreover, not only will co-metabolic biodegradation also destroy the daughter decomposition products of TCE, but because aerobic conditions are maintained, those daughter decomposition products can also be used by aerobic bacteria as sources of food. The dissolved methane and oxygen will travel with the groundwater flow and not be retarded by the formation. It is estimated that the TCE plume travels at only 12% of the velocity of the groundwater flow. So concentrations of methane and oxygen not consumed by native bacteria will migrate downgradient, promoting increased microbial activity outside the treatment zone. In addition, gas-phase injectants have a higher conductivity in tight formations than water and will be dispersed easier and more completely than aqueous-based injectants. Biostimulation has been used to degrade TCE under similar aquifer depths and conditions at the DOE Savannah River Site (SRS) and a pilot-scale test site in Virginia performed by the Gas Research Institute (GRI).

Because of the greater conductivity of gas than water in the formation, as well as the positioning of the injection wells at the bottom of the formation, the methane and air would flow up and should be well distributed throughout the treatment zone. This process option has the best possibility of treating contaminated zones under existing buildings. Most of the injection will be air, which will maintain aerobic conditions in the aquifer, even if native populations of microorganisms increase greatly as a result of the added food source (i.e., methane).

Long-term monitoring would be needed to evaluate the long-term effectiveness.

Implementability

Materials and equipment are available for the implementation of this process option, although the number of vendors with specific horizontal well installation experience is fewer than vendors with surface well installation experience. The drilling technologies to be used are reasonably well established and have been used previously at similar sites for the same application. The injectant (i.e., methane) is commercially available in bottles in the quantities required for implementation of this process option.

Sufficient space is available at the site for installation of the horizontal wells, as well as for compressors for injection of methane and air. The horizontal wells would be installed below grade and would not interrupt daily operations once installed.

Cost

The cost for this process option is moderate.

4.3.3.4 Permeable reactive barrier

A permeable reactive barrier is a subsurface wall or structure that provides a medium for reacting with contaminants in the groundwater. A common application of this process option is the use of elemental iron to dechlorinate chlorinated hydrocarbons. Other applications, such as walls containing oxygen-releasing compounds (ORCs) or sorbents, have been demonstrated and deployed, but generally there are more cost-effective options as compared with the installation of a subsurface wall. For example, air injection is less intrusive and, therefore, less expensive than installing a wall containing ORCs.

The typical application is to dig a trench to the bedrock or a confining layer, and backfill the trench with a mixture of sand and iron filings. Chlorinated hydrocarbons are reduced and dechlorinated by the iron filings as the groundwater flows through the barrier. Depending upon local hydraulic conditions, a slurry or steel wall may be installed on either end of the permeable reactive barrier to force the flow of the groundwater to and through the reactive barrier.

The width of the permeable reactive barrier used is largely a matter of installation convenience. That is, although a barrier thickness of only a few inches is usually more than enough to dechlorinate the entire contaminant plume, trenching equipment generally is designed to dig a 2- to 3-ft-wide trench, and the cost of excavation far exceeds the cost of sand and iron backfill. Therefore, most reactive barriers are oversized and over-designed with respect to iron capacity, because it is easier and cheaper to install a reactive wall in a standard size trench than to install a specific wall thickness.

Application of this process option would consist of a variation on the wall concept, with the goal of reducing the capital cost of installation. The proposed permeable reactive barrier would consist of a series of 1-ft-diameter columns, arrayed in two rows. The first row would consist of one hundred and sixty-five (165) 1-ft-diameter columns, spaced on 2-ft centers; that is, the center of each column would be located 2 ft from the center of the adjacent column in the row, resulting in a series of 1-ft-diameter columns separated by 1-ft spaces of surface soil. A second row of one hundred and sixty-five (165) 1-ft-diameter columns, also spaced on 2-ft centers, but offset 1 ft to be immediately downgradient of the series of 1-ft spaces in the first row of columns, would be installed 2 ft downgradient from the first row of columns. (Smaller diameter columns could be installed in a similar offset pattern but would take longer to install across the 330-ft reactive barrier length and would be more expensive.) The anticipated reactive barrier length would be longer than the width of the 100-μg/L contour to capture the TCE plume. Because of the higher hydraulic conductivity within the columns, groundwater would flow preferentially to and through the columns, where the TCE would be dechlorinated by the elemental iron.

Effectiveness

The dechlorination reaction associated with elemental iron in the permeable reactive barrier is spontaneous and complete. This process option has been used successfully at a number of sites where chlorinated hydrocarbons were the contaminants, although it is a fairly new technology. The effectiveness of the barrier is dependent upon the flow-through of the plume to remediate contamination, and the flow of the plume is exceedingly slow. Based on this groundwater flow rate, it would take approximately

160 years until the entire 100-μg/L contour reaches the reactive barrier (see Appendix A). Although there would be more than enough iron to dechlorinate the entire TCE plume plus accommodate 160 years of rusting or iron dissolution, no reactive barrier has been installed for longer than 20 years. So although it should be effective for the intended service life, there are no data regarding service lives of the assumed duration.

Permeable reactive barriers have been demonstrated to be reliable and effective in dechlorinating TCE and other chlorinated compounds in a variety of homogeneous and heterogeneous porous media. Because of the greater conductivity of reactive barriers in tight formations, no funnel or barrier walls would be necessary on either end of a reactive barrier. Because of the very low TOC content in the aquifer at CAMP, no significant populations of iron bacteria, which might grow in and potentially foul the pores of the columns, are expected. Therefore, no treatment of iron bacteria is anticipated.

The two rows of columns do not constitute a continuous "wall." However, the conductivity of the sand and iron backfill in each column is so much greater than the formation that each column will represent a preferential flow pathway, and groundwater will flow toward and through the columns naturally. Based on the very low groundwater velocity, the residence or contact time in each column will be considerable, far exceeding the time required for dechlorination to occur.

A greater than 95% reduction in contaminant mass across the permeable reactive barrier is assumed for this process option. Concentrations of TCE downgradient from or outside the dimensions of the reactive barrier would not be reduced; however, that residual mass would be expected to attenuate since areas containing more than 100 μg/L of TCE would have been remediated. The long-term effect is expected to be a significant reduction in the size of the portion of the plume having a concentration in excess of the RAOs.

Due to the anticipated length of treatment (160 years), long-term monitoring would be needed to evaluate the effectiveness of this process option—particularly to verify the effectiveness and "integrity" of the columns (i.e., no heterogeneous short circuiting or breakthrough of TCE around or between columns). The long-term monitoring period would be similar in design, schedule, and cost as that used for the monitored natural attenuation process option. (For cost-estimating purposes, 37 long-term monitoring events were assumed, constituting 160 years of post-treatment monitoring.)

Implementability

Materials and equipment are available for the implementation of this process option, although the number of vendors with specific permeable wall or 1-ft-diameter column installation experience is fewer than vendors with typical environmental surface well installation experience. Several methods have been developed for construction of permeable reactive barriers, but most techniques are constrained to shallow emplacements of < 30-ft depth. At the CAMP, depth to bedrock along the permeable reactive barrier wall is approximately 70 ft. The backfill materials (i.e., sand and iron) are commercially available, although a licensing fee would be required for this option.

Sufficient space is available at the site for installation of the permeable reactive barrier. The site is an active warehouse facility currently providing access to tractor-trailers. As such, access for reactive barrier installation equipment is adequate. In addition, the footprint of the reactive barrier installation would be manageable, and following installation, would not interfere with the day-to-day operations of the facility.

Cost

The cost for this process option is moderate to high. This cost would be higher if maintenance or replacement of the reactive media is needed during the service life.

4.3.3.5 In situ chemical oxidation

ISCO involves injection of a permanganate or hydrogen peroxide solution into injection wells drilled into the TCE-contaminated groundwater to reduce contaminant concentrations. A permanganate solution was selected for evaluation and costing purposes. The following conceptual design demonstrates the feasibility of the process option and provides the basis for the cost estimate. The final design would be based on a pilot-scale study and may deviate from this conceptual design.

Injection points would be installed within the shallow, transition, and bedrock aquifer zones. A permanganate solution would be metered into the injection wells over the course of one week. Depending upon the measured concentration of permanganate in the aquifer, additional injections may follow based upon the persistence of permanganate and/or TCE in the groundwater. Four injections were assumed as the basis of the cost estimate.

Groundwater samples would be collected from existing monitoring wells and/or injection wells to serve as a baseline before treatment and to monitor the chemical dosage. The groundwater samples would be analyzed for VOCs and permanganate. A second round of groundwater samples would be collected from the monitoring and/or injection wells approximately 6 months after the completion of the initial injection and again analyzed for VOCs and permanganate. The results from this performance monitoring would determine if additional chemical injection(s) would be required in the treatment zone or at a specific location [i.e., injection well(s)] within the treatment zone.

Effectiveness

ISCO has been shown to be effective for treating TCE in groundwater. This process option has been demonstrated to be reliable in homogeneous porous media; however, the effectiveness in heterogeneous media is less certain due to preferential pathways and potential for contaminants to be isolated from the oxidants. Due to the presence of clays in the subsurface, TCE at the site is moving at only 12% of the velocity of the groundwater. Based on the TCE migration rate, the permanganate would be expected to "overrun" downgradient concentrations of TCE and would be injected at such stoichiometric excess concentrations at multiple points and depths to be well distributed throughout the formation.

Implementability

This process option could be readily implementable over most of the site. A small portion of the TCE plume is located under existing buildings. Accessing these areas would require slant or horizontal drilling. Due to the complexity and number of horizontal wells required, it will be assumed that inaccessible areas under buildings will not be treated to meet RAOs. Equipment and subcontractors providing these services are readily available. The drilling technologies to be used are well established, have been used at the site previously, and numerous contractors providing these services are available. Injection wells would be installed below grade and would not interrupt daily operations once installed. Numerous vendors provide ISCO. The chemicals (e.g., sodium permanganate) are commercially available in the quantities required for the implementation of this process option.

Cost

The cost for this process option is high.

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 FS. 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 four process options considered to achieve the RAO for the TCE plume at the CAMP are bioaugmentation, biostimulation, permeable reactive barrier, and ISCO (see Table 4-2). The process options associated with the monitored natural attenuation and institutional controls GRA were not retained as primary process options but would be used in combination with other process options to reduce risk.

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 the NCP.
Long-term Monitoring	This option would eventually attain the RAOs for TCE but does not constitute an action alternative.	Easily implementable as part of another alternative. A monitoring well network is already in place. Additional monitoring wells could be easily installed.	Low	Not retained as a stand-alone process option; will complement other options.
Monitored Natural Attenuation	This option would eventually attain the NC drinking water standard 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 RAO.
Bioaugmentation	This option has been utilized at a number of sites contaminated with chlorinated hydrocarbons.	Implementable over most of the site. Injection of microorganisms and nutrients is reasonably well established. Would require installation of a number of injection wells but relies upon standard, proven techniques.	Moderate to high	Retained. Can achieve the RAO.

Table 4-2. Summary of Preliminary Screening of Process Options (continued)

Alternative	Effectiveness	Implementable	Approximate Costs	Comments
Biostimulation	This option has been proven effective in degrading TCE at comparable aquifer depths and concentrations. This option has considerably shorter treatment times than ISCO or permeable reactive barriers.	Implementable. Horizontal well installation is reasonably well established. Methane is locally available. This option has the smallest footprint of any of the treatment operations once wells are installed. Relatively new technology.	Moderate	Retained. Can achieve the RAO.
Permeable Reactive Barrier	This option has been proven effective at other sites; permeability in the formation is considerably lower than in the reactive barrier, resulting in preferential water flow to and through the reactive barrier.	Implementable. This option uses standard well drilling and installation techniques. Construction is straightforward and sand and iron are available at low costs.	High	Retained. Can achieve the RAO.
In situ Chemical Oxidation	This option has been proven effective for oxidizing chlorinated hydrocarbons at a number of sites with much greater levels of contamination (i.e., DNAPL). Some uncertainty exists concerning the effective distribution of the oxidant throughout the formation.	Implementable over most of the site. This option relies upon standard well installation and injection technologies. The chemical oxidant is commercially available.	High	Retained. Can achieve the RAO.

CAMP = Charlotte Army Missile Plant.
DNAPL = Dense nonaqueous-phase liquid.
NCP = National Oil and Hazardous Substances Pollution Contingency Plan (e.g., National Contingency Plan).
RAO = Remedial action objective.
TCE = Trichloroethene.

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5.0 DEVELOPMENT AND DESCRIPTION OF ALTERNATIVES

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 approach to development and screening, a description of each alternative, and the screening results are provided below.

5.1 DEVELOPMENT OF ALTERNATIVES

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 FS, as defined in the 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 the NCP.

The 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 and process options were combined to form preliminary remedial alternatives. The remedial action alternatives developed in this FS are based on the data available from the Phase I and II RIs and supplemental investigations. 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 CAMP to meet the RAOs are shown below:

- Alternative 1, No Action Alternative;
- Alternative 2, Bioaugmentation;
- Alternative 3, Biostimulation;
- Alternative 4, Permeable reactive barrier
- Alternative 5, In situ chemical oxidation (or ISCO).

5.1.1 Activities Common to All Alternatives

Common activities associated with all of these remedial alternatives are: access and use restrictions, monitored natural attenuation, and waste characterization and disposal. Individual alternative discussions cover the application of these activities within the context of the specific alternative. Some of the common activities vary in the extent of their application among alternatives.

5.1.1.1 Access and use restrictions

Access and use restrictions would include administrative restrictions, deed restrictions, and physical controls to control access to the site or use of groundwater.

Each remedial alternative uses access and use restrictions to varying degrees. These measures include, but are not limited to: (1) physical or administrative access controls regulating public access to the industrial site, and (2) lease or deed restrictions on use of the groundwater. Physical controls would include maintaining the fencing that currently encloses the site and 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 the remedial alternative.

5.1.1.2 Monitored natural attenuation

Monitoring includes sampling and analysis of the groundwater at the site. Groundwater would be collected from the existing wells and newly installed monitoring wells (Figure 5-1).

Six additional downgradient groundwater-monitoring wells would be installed (two each for the shallow, transition, and bedrock zones) to augment the groundwater-monitoring network. Each monitoring well would consist of a 2-in.-diameter polyvinyl chloride (PVC) casing and a 10-ft PVC screen. New wells will be installed to depths of 25, 95, and 120 ft to monitor each zone.

Groundwater samples would be collected from the 6 new wells and 24 existing wells and analyzed for VOCs and other parameters, such as dissolved oxygen and reduction-oxidation (Redox) potential, to monitor biological activity or natural attenuation of residual levels of contamination. The analytical results would be evaluated after each monitoring event to verify that concentrations of TCE are decreasing from those detected in the RIs and supplemental samplings, and that the RAO is ultimately achieved. Long-term monitoring would be performed annually for the first 5 years and then at 5-year intervals to verify that the TCE concentrations are attenuating. The length of the long-term monitoring calculated based on remediating to 100 µg/L is 85 years, but the actual length will be based on the TCE levels achieved after implementing the remedial alternative.

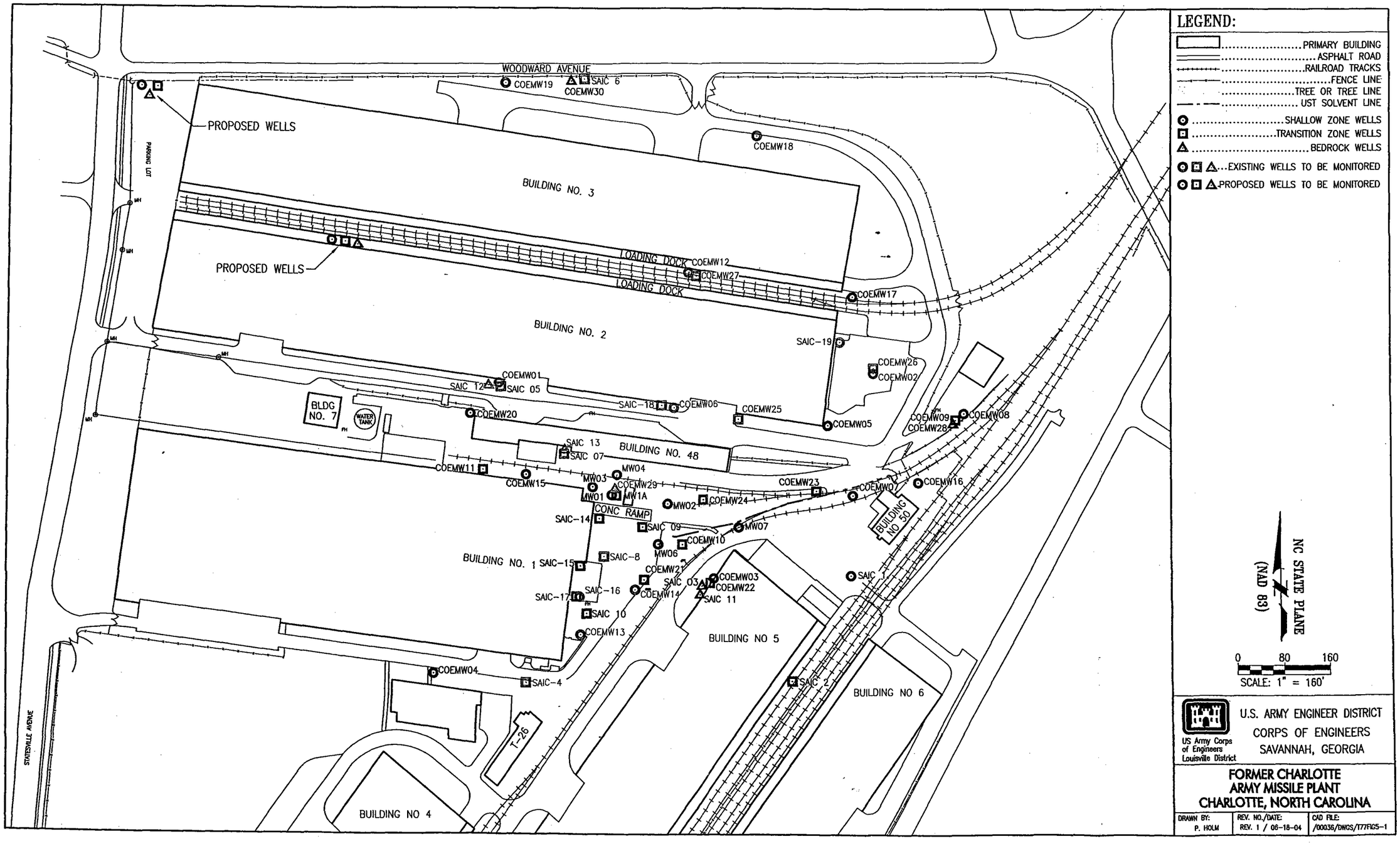

Figure 5-1. Existing and Proposed Monitoring Well Locations for Monitoring Natural Attenuation

Restrictions on site groundwater use would be imposed until groundwater at the site meets 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 reviews might determine that no further monitoring is required or that additional remedial measures should be undertaken.

5.1.1.3 Waste characterization and disposal

All of the action alternatives would generate investigation-derived wastes (IDWs) requiring characterization and disposal. Types of waste anticipated consist mostly of PPE and soil cuttings from boreholes. This waste would be characterized and disposed of accordingly at a permitted off-site facility.

5.2 DESCRIPTION OF REMEDIAL ALTERNATIVES

The following sections briefly describe each alternative.

5.2.1 Alternative 1 – No Action Alternative

The No Action alternative is considered in accordance with CERCLA and the NCP requirements for comparison with other alternatives. Under this alternative, no remedial action would be implemented at the CAMP to reduce contaminant concentrations in the contaminant plume in order to return the impaired groundwater to beneficial use. Institutional controls in place to protect human health and the environment (such as restrictions on excavation or access controls) would cease. 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. 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, this alternative is retained to comply with the NCP.

5.2.2 Alternative 2 – Bioaugmentation

In Alternative 2, groundwater in the shallow and transition zones of Hot Spot No. 1 containing TCE concentrations greater than 500 μg/L would be treated by injection of aerobic bacteria and nutrients. The resulting biodegradation would be monitored and supplemented at monthly intervals for 6 months until TCE concentrations were less than 100 μg/L. Once treatment operations have been completed, the groundwater would be monitored every 5 years until the RAO is achieved (anticipated to be 85 years).

Alternative 2 includes installation of 106 injection wells in the shallow and transition zones of Hot Spot No. 1 (Figures 5-2 and 5-3). The injection wells would include 39 shallow wells with an approximate depth of 25 ft, 39 intermediate wells with an approximate depth of 45 ft, and 28 deep wells with an approximate depth of 65 ft. The bottom 10 ft of each well would be screened. In general, each injection location would consist of a cluster of a shallow, intermediate, and deep wells.

Following an initial injection of aerobic bacteria, additional injections of bacteria and/or nutrients would be performed every month for up to six injections, with the levels of both TCE and other parameters monitored before each subsequent injection. Specifically, concentrations of dissolved oxygen, nutrients, and Redox potential would be measured to determine the extent and progress of biodegradation within the contaminant plume. The timing and nature of subsequent injections will be dependent upon

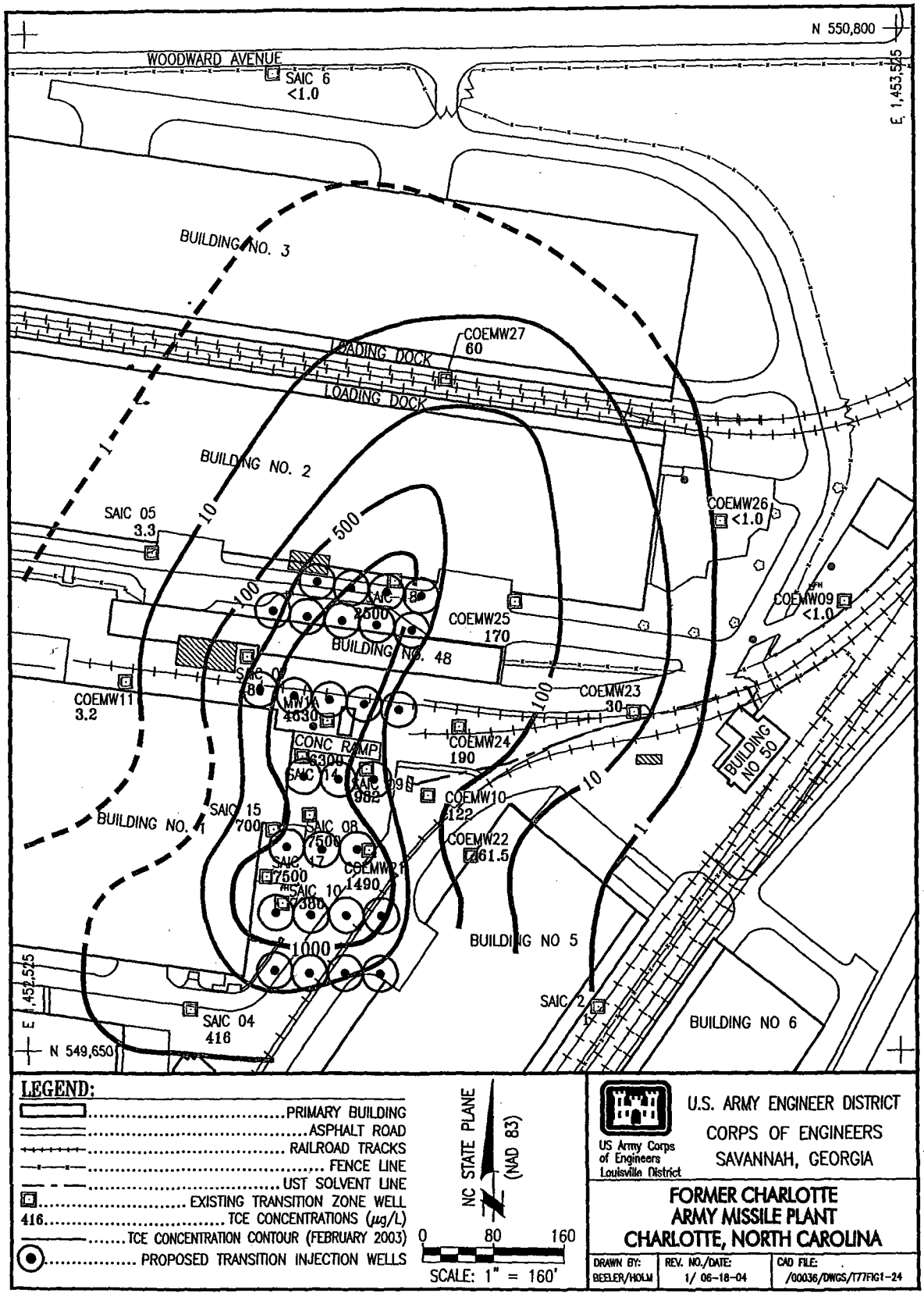

Figure 5-2. TCE Concentrations in Transition Zone Wells

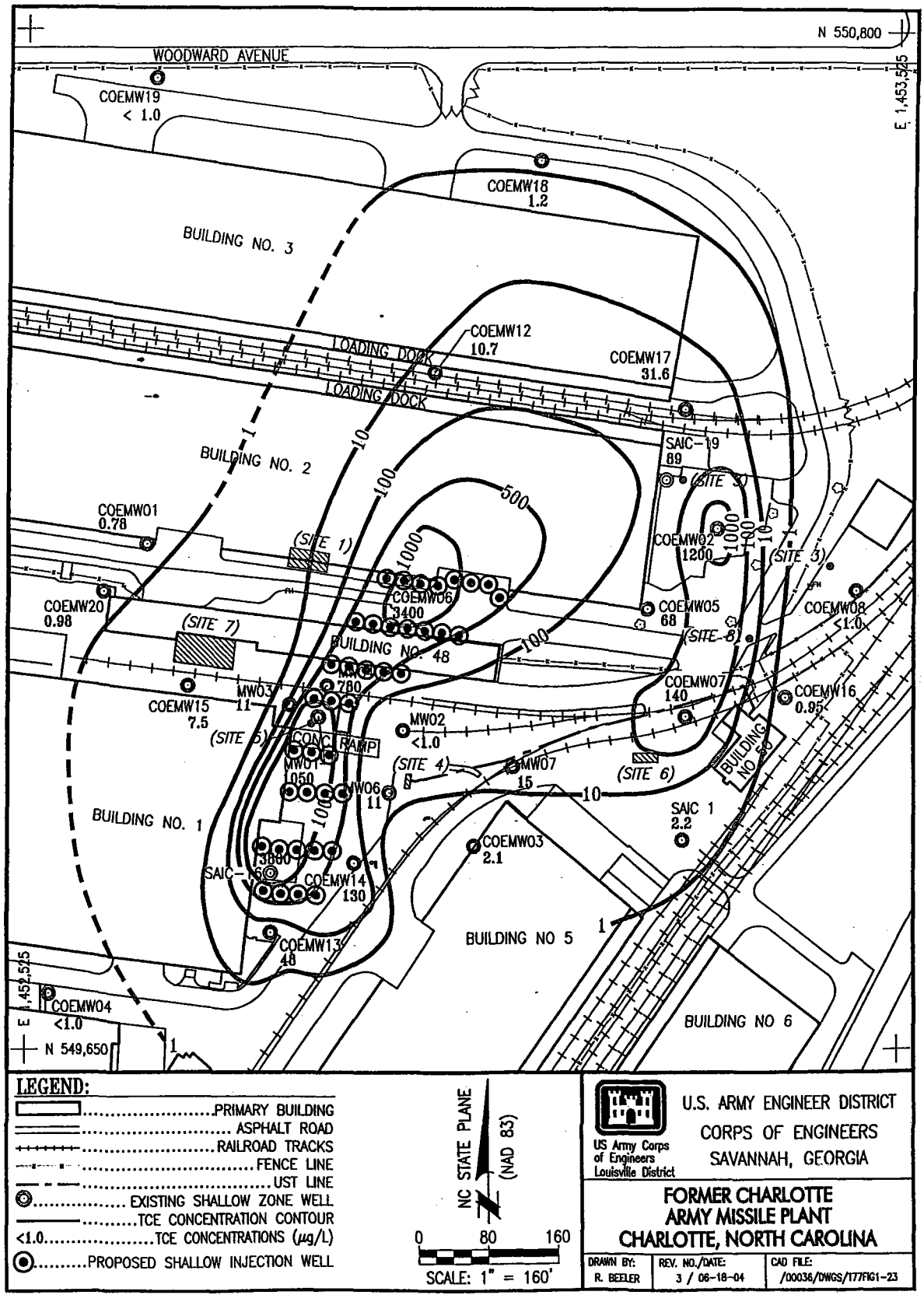

Figure 5-3. TCE Concentrations in Shallow Zone Wells

prevailing aquifer conditions. That is, whether additional aerobic bacteria, nutrients, or other additives (such as air or oxygen releasing compounds) are injected and at which locations, depths, and concentrations will be based on the results of groundwater sampling and analysis and pilot testing. Concentrations of TCE within and downgradient from the injection zone would be monitored to verify that natural attenuation of residual contamination is occurring following the final injection of bacteria and/or nutrients.

Up to seven rounds of groundwater samples would be collected as part of the injection operations. Initial baseline chemical analysis would be performed to determine the current characteristics and the optimal bacteria and nutrient loading rates. Performance monitoring for VOCs and biodegradation would be performed following each injection to evaluate the effectiveness of the treatment, as well as conditions suitable for supporting aerobic metabolism. Specifically, changes in levels of dissolved oxygen, nutrients, and Redox potential would be monitored to prevent locally overloading the aquifer and to optimize the biodegradation.

Baseline groundwater samples would be collected no earlier than 14 days after the installation of the injection wells. The injection wells would be abandoned at the completion of the treatment period after it is determined that no additional injections are required.

5.2.3 Alternative 3 – Biostimulation

In Alternative 3, groundwater in the shallow and transition zones of Hot Spot No. 1 containing TCE concentrations greater than 500 µg/L would be treated by enhancing or stimulating co-metabolic biodegradation processes until TCE concentrations are less than 100 µg/L (estimated to take approximately 2 years). Once treatment operations have been completed, the groundwater would be monitored every 5 years until the RAO is achieved (anticipated to be 85 years).

The stimulation of co-metabolic biodegradation of TCE-contaminated groundwater would be accomplished by installing two 800-ft, parallel, horizontal wells above the bedrock (Figure 5-4). The horizontal wells would be stainless steel pipe, with the portion beneath the contaminated groundwater screened to allow slow sparging (injection) with an approximately 3% methane in air mixture. [The lower explosive limit (LEL) for methane in air is 5%.] The screened portion of the wells would run approximately 400 ft. The air-methane mixture would be injected at a rate of approximately 400 standard cubic feet per minute (scfm) per well, corresponding to a delivery rate of 1.0 scfm per linear foot of screen. The anticipated radius of influence for each horizontal well is 60 ft; therefore, the wells would be spaced approximately 120 ft apart and would realize a treatment zone width of 240 ft. This methane would be pulsed (i.e., delivered for 8 hours and then stopped for 16 hours) to prevent fouling of the screens.

The injection wells would be abandoned at the completion of the treatment period after it is determined that no additional injections will be required.

The treatment operations are anticipated to take 2 years. Residual groundwater contaminant concentrations within the treatment zones and outside the radius of influence of the horizontal injection wells will attenuate naturally following the treatment period.

Long-term monitoring would be performed following the treatment period. (For cost-estimating purposes, it was assumed that 85 years of post-treatment monitoring would occur.) Six additional downgradient groundwater-monitoring wells would be installed to complete the groundwater-monitoring network. Groundwater samples would be collected from the 6 new wells and 24 existing wells. The groundwater samples would be analyzed for VOCs and natural attenuation parameters. The analytical results would

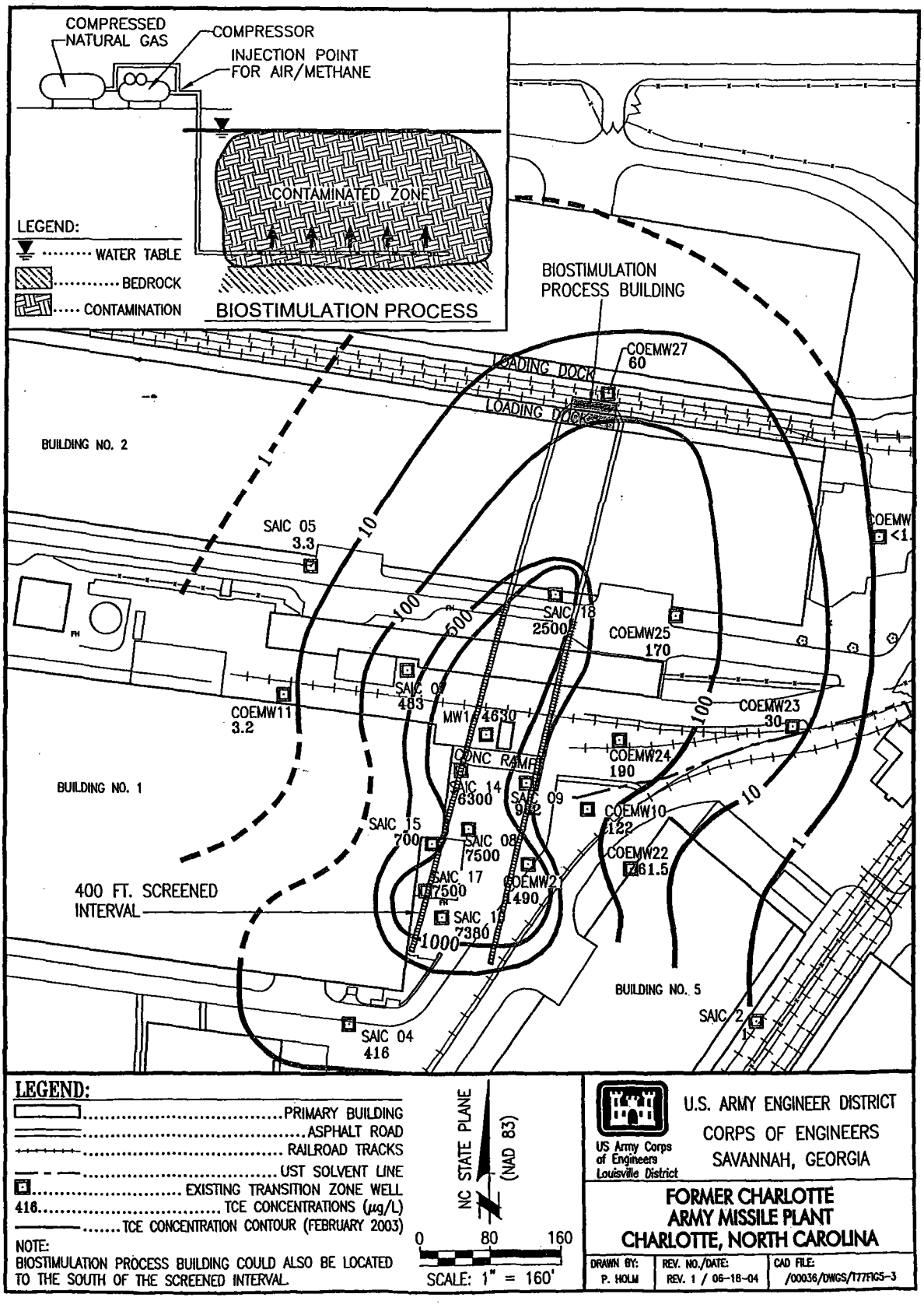

Figure 5-4. Biostimulation Well Locations

be evaluated to verify that the concentrations of site COCs are decreasing from those detected in the RI and supplemental samplings, and that the RAO is ultimately achieved. Five-year reviews of the data would be conducted to determine how rapidly the aquifer was attenuating residual contaminants.

5.2.4 Alternative 4 – Permeable Reactive Barrier Wall

In Alternative 4, a subsurface permeable reactive barrier would be installed full depth through the shallow and transition zones, downgradient of Hot Spot No. 1. The permeable reactive barrier would contain a mixture of sand and iron filings, which would reduce and dechlorinate the TCE as the groundwater flows through the barrier.

Alternative 4 would consist of a series of 1-ft-diameter columns, arrayed in two rows. The first row would consist of one hundred and sixty-five (165) 1-ft-diameter columns, spaced on 2-ft centers; that is, the center of each column would be located 2 ft from the center of the adjacent column in the row, resulting in a series of 1-ft-diameter columns separated by 1-ft spaces of surface soil. A second row of one hundred and sixty-five (165) 1-ft-diameter columns, also spaced on 2-ft centers but offset 1 ft to be immediately downgradient of the series of 1-ft spaces in the first row of columns, would be installed 2 ft downgradient from the first row of columns (Figure 5-5).

The anticipated reactive barrier length would be longer than the width of the 500 µg/L TCE plume contour and largely capture the 100 µg/L contour of TCE plume as well. Since the conductivity of the sand and iron backfill in each column is so much greater than the formation, each column will represent a preferential flow pathway, and groundwater will flow toward and through the columns naturally.

The flow of the plume at CAMP is exceedingly slow (less than 6 ft per year). Based on this groundwater flow rate, it would take approximately 160 years until the entire 100-µg/L contour reaches the reactive barrier (see Appendix B). Based on the very low groundwater velocity, the residence or contact time in each column will be considerable, far exceeding the time required for dechlorination to occur. Therefore, no "funnel" or barrier walls would be necessary on either end of a reactive barrier "gate." Because of the very low TOC content in the aquifer at CAMP, no significant populations of iron bacteria, which might grow in and potentially foul the pores of the columns, are expected. Therefore, no treatment of iron bacteria is anticipated.

Concentrations of TCE downgradient from or outside the dimensions of the reactive barrier would not be reduced; however, that residual mass would be expected to attenuate since areas containing more than 100 µg/L of TCE would have been remediated.

Due to the anticipated length of treatment (160 years), long-term monitoring would be needed to evaluate the effectiveness of this process option—particularly to verify the effectiveness and "integrity" of the columns (i.e., no heterogeneous short circuiting or breakthrough of TCE around or between columns). For cost-estimating purposes, 37 long-term monitoring events were assumed, constituting 160 years of post-treatment monitoring.

5.2.5 Alternative 5 – In situ Chemical Oxidation

Alternative 5 includes installation of 106 injection wells in the shallow and transition zones of Hot Spot No. 1 and injecting a sodium permanganate solution until the TCE concentration reaches 100 µg/L. Once treatment operations have been completed, the groundwater would be monitored every 5 years until the RAO is achieved (anticipated to be 85 years).

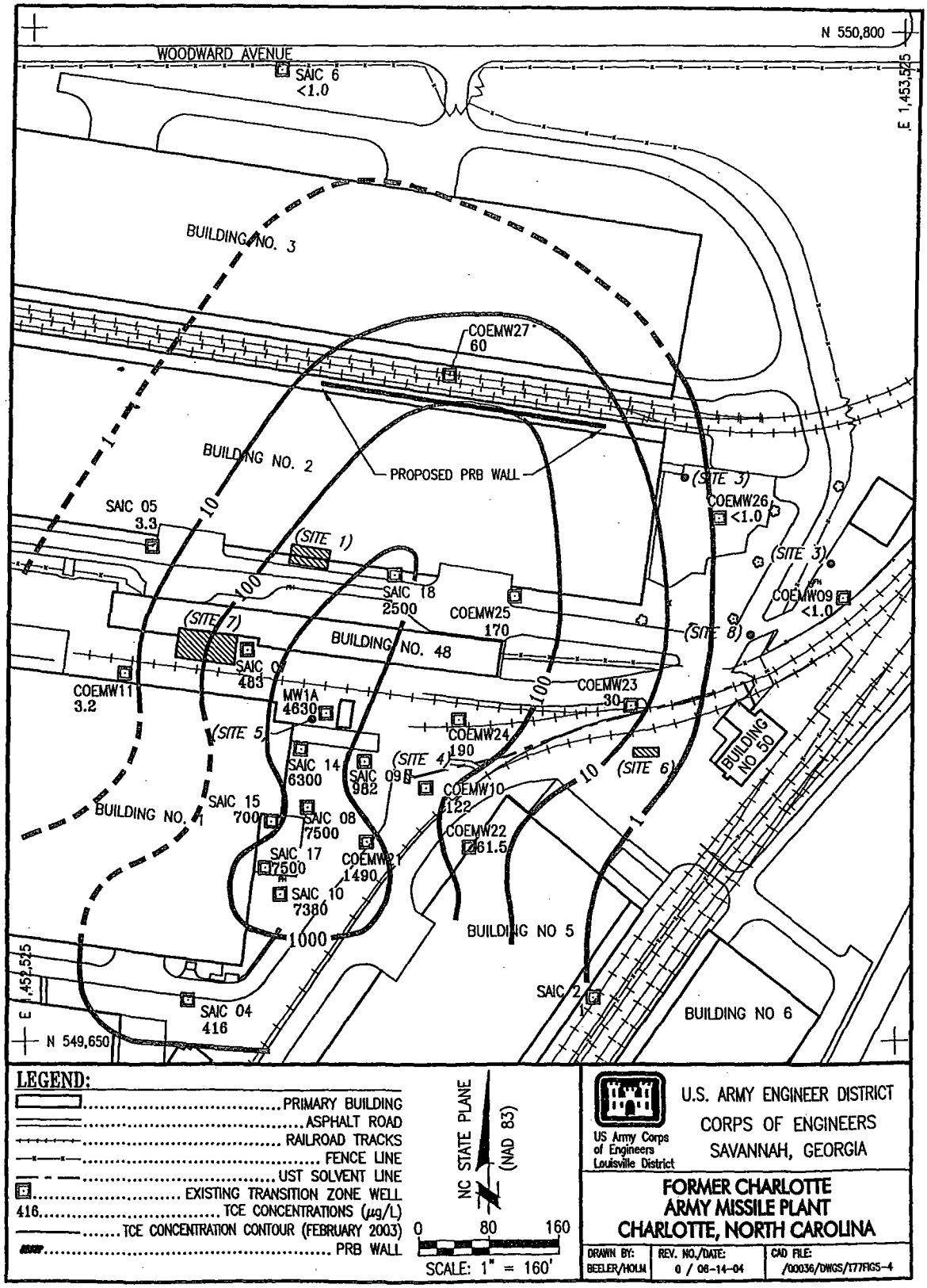

Figure 5-5. Proposed Permeable Reactive Barrier Alternative Location

The injection wells would include 39 shallow wells with an approximate depth of 25 ft, 39 intermediate wells with an approximate depth of 45 ft, and 28 deep wells with an approximate depth of 65 ft. The bottom 10 ft of each well would be screened (Figures 5-2 and 5-3). In general, each injection location would consist of a cluster of a shallow, an intermediate, and a deep well. A 40% permanganate solution would be metered into the injection wells over the course of one week. The injection rate would vary, depending on site conditions, but is expected to be around 3 gpm for 5 days at a pressure of 50 lbs per square inch gauge (psig) or less.

A 0.5% permanganate solution would then be injected every 6 to 12 months for up to four injections, with the levels of both TCE and permanganate monitored before each subsequent injection. Concentrations of TCE within and downgradient from the injection zone will be monitored to verify that natural attenuation is occurring following the final injection of oxidant.

Up to five rounds of groundwater samples would be collected as part of the injection operations. Initial baseline chemical analysis would be performed to determine the current characteristics and chemical injection rates. Performance monitoring for VOCs and permanganate would be performed 6 months following each injection to evaluate the effectiveness of the treatment. Baseline groundwater samples would be collected no earlier than 14 days after the installation of the injection wells. The injection wells would be abandoned at the completion of the treatment period after it is determined that no additional injections will be required.

Long-term monitoring would be performed following the treatment period and would consist of collecting groundwater samples from approximately 30 wells. Samples would be collected every 5 years after the completion of the treatment operations until the NCAC 2L standard for TCE is achieved or the NCDENR determines that no further monitoring is needed. (For cost-estimating purposes, it was assumed that 85 years of post-treatment monitoring would occur.) The groundwater samples would be analyzed for VOCs and natural attenuation parameters. The analytical results would be evaluated to verify that the concentrations of site COCs are decreasing from those detected in the RI and supplemental samplings, and that the RAO is ultimately achieved. Five-year reviews of the data would be conducted to determine how rapidly the aquifer was attenuating residual contaminants.

A summary of all the remedial action alternatives is shown in Table 5-1.

Table 5-1. Summary of Remedial Action Alternatives

Remedial Alternative	Active Treatment Activities	Groundwater Monitoring Required During Treatment	Long-Term Groundwater Monitoring Required
No Action		NA	NA
Bioaugmentation	Installation of 106 injection wells and injection of aerobic bacteria and nutrients	Performance monitoring during treatment operations, including baseline and monthly sampling of 10 wells for VOCs and natural attenuation parameters.	Monitoring 30 wells annually for the first 5 years, then every 5 years thereafter, for the next 85 years
Biostimulation	Installation of two 800-ft-long, horizontal treatment wells and injection of a methane-air mixture	Performance monitoring during treatment operations, including baseline and semiannual sampling of 10 wells for VOCs and natural attenuation parameters.	Monitoring 30 wells annually for the first 5 years, then every 5 years thereafter, for the next 85 years
Permeable Reactive Barrier	Installation of 330 one-foot-diameter, full-depth columns of sand and iron filings	NA; treatment is long-term.	Monitoring 30 wells annually for the first 5 years, then every 5 years thereafter, for the next 160 years
In situ Chemical Oxidation	Installation of 106 injection wells and injection of a sodium permanganate solution	Performance monitoring during treatment operations, including baseline and semiannual sampling of 10 wells for VOCs and natural attenuation parameters.	Monitoring 30 wells annually for the first 5 years, then every 5 years thereafter, for the next 85 years

NA = Not applicable.
NC = North Carolina.
TCE = Trichloroethylene.

6.0 DETAILED ANALYSIS OF ALTERNATIVES

Five remedial alternatives were retained in Section 5.2 to address contaminated groundwater at the CAMP. The 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.

6.1 EVALUATION CRITERIA FOR ANALYSIS

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

6.1.1 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.

6.1.2 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.

6.1.3 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 FS 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.

6.2 OVERVIEW OF THE EVALUATION CRITERIA

6.2.1 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 2.0. 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.

6.2.2 Criterion 2: Compliance with ARARs

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, nonpromulgated advisories, criteria, or guidance developed by EPA, other federal agencies, or states can be identified as potential to-be-considered (TBC) guidance.

6.2.3 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 FS, 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.

6.2.4 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.

6.2.5 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.

6.2.6 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.

6.2.7 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 FS are based on the expected scopes of work and assumptions provided in the detailed description of alternatives and Appendix B. Only unescalated costs are presented in this FS because of scheduling uncertainties. No direct costs are associated with the No Action alternative. Costs are presented as capital costs (direct and indirect) and operation and maintenance (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.

6.2.8 Criterion 8: State Acceptance

This FS 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.

6.2.9 Criterion 9: Community Acceptance

This FS 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.

6.3 NEPA VALUES

NEPA values are incorporated into this FS, consistent with USACE policy, and are the particular focus of specific sections of the detailed analysis. Issues related to the affected environment, including ecological resources, cultural resources, archaeological resources, land use, and socioeconomics, existing

transportation systems, visual esthetics, and ambient noise, are covered under the "long-term effectiveness and permanence" and "short-term effectiveness" sections of the analyses. Environmental consequence issues and cumulative impacts are addressed within those discussions. Unavoidable adverse impacts are also covered in the detailed analysis.

6.4 INDIVIDUAL ANALYSIS OF ALTERNATIVES

6.4.1 Alternative 1 – No Action

The No Action alternative is required by the NCP to provide a baseline for comparison with the other alternatives. Under this alternative, no action would be implemented, and contaminated groundwater would remain. The institutional controls that are in place would not be maintained, allowing unrestricted use of groundwater. No short- or long-term monitoring would be implemented.

6.4.1.1 Overall protection of human health and the environment (No Action alternative)

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 and would eventually migrate outside the site boundary.

6.4.2 Compliance with ARARs

Since the No Action alternative does not trigger action- or location-specific ARARs, only the chemical-specific ARARs are considered for the No Action alternative. ARARs are discussed in Chapter 2.0. The No Action alternative would not comply with requirements of NCAC 2L (if applicable) to reduce contaminant concentrations in the resource groundwater to meet the drinking water standards.

6.4.2.1 Long-term effectiveness and permanence

The No Action alternative would discontinue existing controls and would not implement any new controls for contaminated groundwater. Therefore, access to contaminated groundwater would be unrestricted. The No Action alternative would not remove, isolate, or treat contaminated groundwater. TCE in groundwater migrating downgradient would not be addressed by this alternative, and no short- or long-term monitoring would be performed.

6.4.2.2 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 exceedances of NCAC 2L standards will continue, as no action will be taken to reduce or isolate contamination in the groundwater. This alternative will also not provide any action to address potential exposure pathways or migration due to transport. The No Action alternative does not meet EPA's statutory preference for treatment.

6.4.2.3 Short-term effectiveness

Risks, or potential risks, to both human and ecological receptors remain unchanged under the No Action alternative. The No Action alternative would not remove, isolate, or treat contaminated groundwater at the site. Contaminants in groundwater potentially discharging to surface waters would not be addressed by this alternative. Accordingly, the residual risks presented by the contaminated groundwater would be equivalent to the current levels of risks presented by the site for an extended period of time (approximately 200 years).

6.4.2.4 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.

6.4.2.5 Cost

There would be no cost associated with the No Action alternative.

6.4.3 Alternative 2 – Bioaugmentation

6.4.3.1 Overall protection of human health and the environment

Alternative 2 would be protective of human health and the environment because the contaminant mass would be reduced. Due to site constraint, bioaugmentation may not deliver sufficient bacteria to portions of the contaminated plume beneath Buildings 1 and 2; however, the alternative is estimated to be approximately 80 to 95% effective. The RAO of 100 µg/L TCE at Hot Spot No. 1 would be met in approximately 2 years following the start of treatment. The RAO of 2.8 µg/L TCE throughout the aquifer would be met in approximately 85 years through the use of monitored natural attenuation. Remedial workers would not be exposed to contaminated groundwater as the treatment would be conducted in situ nor would workers be exposed to strong oxidants (such as with in situ chemical oxidation). Installation of injection wells to deliver aerobic bacteria into the aquifer would involve drilling into contaminated groundwater. Therefore, procedures and precautions would be implemented to minimize worker exposure to contaminants. Workers would be trained in hazardous waste operations as mandated by 29 *CFR* 1910.120.

6.4.3.2 Compliance with ARARs

Evaluation against the threshold criteria for the chemical-, action-, and location-specific ARARs is provided in this section.

Chemical-specific ARARs

The applicable chemical-specific ARARs for this alternative are discussed in Chapter 2.0. Under CERCLA Section 120(a)(4), federal facilities that are not on the NPL are subject to state laws concerning removal or remedial action. If applicable groundwater quality standards are exceeded, a groundwater management zone (GMZ) may be established to implement corrective action. As previously discussed in this FS, TCE exceeds NCAC 2L standards.

This alternative also includes monitored natural attenuation of the residual plume following shutdown of treatment operations. Increased metabolic activity would migrate TCE contamination some distance

downgradient from the treatment zone. Therefore, this alternative would ultimately comply with the chemical-specific ARARs to reduce contaminant concentrations in the impaired groundwater to meet RAOs.

Action-specific ARARs

Implementation of this alternative would include the installation of approximately six new monitoring wells and 106 injection well boreholes. Dust control measures, as appropriate, would be undertaken during the construction activities to ensure compliance with applicable environmental and safety standards. Appropriate measures would also be taken to control sedimentation from surface water run-off from construction sites. In order to reduce sediment transport from the affected areas, sediment control techniques would be employed and detailed within the remedial design.

The installation of new monitoring or injection wells would generate IDW in the form of soil cuttings and groundwater. These wastes would be characterized through testing or use of existing data to determine whether the waste is hazardous. IDW that contains or exhibits a hazardous waste characteristic would be characterized to determine the applicable LDRs associated with the waste prior to disposal. Any hazardous waste generated would be disposed of at an off-site RCRA-permitted facility.

For the purposes of the cost estimate, the soil and water generated from the installation of 106 injection wells in the treatment zone was assumed to be RCRA hazardous; however, waste generated from the installation of the new downgradient monitoring wells was assumed to be non-hazardous.

Location-specific ARARs

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

6.4.3.3 Long-term effectiveness and permanence

The alternative would be effective in both the short-term and long-term. The increased metabolic activity associated with this alternative would result in the dechlorination of TCE. Decomposition products (such as 1,2-DCE and vinyl chloride) would also be consumed, either directly as food sources for the injected aerobic microorganisms, or through incidental co-metabolic activity.

Bioaugmentation is a relatively new technology that has demonstrated destruction of 95 to 100% of chlorinated hydrocarbon mass. The technology has been proven effective for chlorinated hydrocarbon removal in aerobic aquifers. Since the injected bacteria would be free to migrate within the formation, the alternative would also enhance degradation of contaminant concentrations for short distances down- and cross-gradient from the treatment zone. In addition, the injection of nutrients would help establish and maintain significant populations of aerobic bacteria in the aquifer and increased metabolic activity. Due to site constraint, bioaugmentation may not deliver sufficient bacteria to portions of the contaminated plume beneath Buildings 1 and 2; however, the alternative is estimated to be approximately 80 to 95% effective.

Following treatment operations, natural attenuation of the groundwater plume is predicted to reduce residual concentrations of TCE throughout the aquifer to NCAC 2L standards in approximately 85 years.

There is uncertainty whether residual TCE is present in soil or bedrock zone groundwater would serve as a continuing source of TCE to the shallow or transition zone groundwaters. This uncertainty would be further evaluated during subsequent pilot studies, remedial design, and remedial action implementation.

6.4.3.4 Reduction in toxicity, mobility, or volume

This alternative would reduce the toxicity and volume of contaminated groundwater through degradation of the TCE and decomposition products in the groundwater. In addition, unlike TCE—which is retarded in the formation as compared with the velocity of groundwater flow (see Appendix A)—microorganisms will be able to migrate; discounting cross- or up-gradient locomotion, microorganisms "floating" in the groundwater flow will migrate approximately eight times faster than the contaminant plume, resulting in increased metabolic activity downgradient from the treatment zone.

6.4.3.5 Short-term effectiveness

The alternative would be effective in the short-term. Injected microbial populations would result in significant metabolic and corresponding co-metabolic activity, degrading TCE. Decomposition products of TCE are optimally degraded under the prevailing aerobic aquifer conditions; decomposition products would be sources of food for the injected aerobes.

A greater than 95% reduction in contaminant mass in the injection zone is assumed for this option. Concentrations of TCE upgradient from or outside the treatment zone would not be reduced; however, that residual mass can be expected to attenuate since nearly 80 to 95% of the areas containing more than 500 $\mu g/L$ of TCE would be remediated. The long-term effect is expected to be a significant reduction in the size of the portion of the plume having a concentration in excess of the NCAC 2L standard and a reduction in the groundwater concentration overall. However, the treatment would not be able to achieve that standard by itself, monitored natural attenuation would result in additional and continuing remediation.

It is anticipated that the treatment zone would be remediated to a concentration of 500 $\mu g/L$ in a period of approximately one year.

6.4.3.6 Implementability

Bioaugmentation is readily implementable. Anaerobic bacteria and associated nutrients amenable to TCE degradation are available from established vendors. The techniques for the installation of monitoring or injection wells and sampling and analysis of groundwater samples are well established. Alternative 2 would be compatible with current and future uses at the site. Controls on the use of groundwater at the site would be readily implementable. Industrial zoning is already in effect and the property is established as an industrial park. Deed restrictions would be consistent with the planned future development of the property. Five-year reviews would be readily implemented to confirm that groundwater use controls are maintained.

6.4.3.7 Costs

Construction and injection costs for bioaugmentation were estimated to be $5,160,000. Subsequent O&M monitoring costs for 85 years were estimated at $1,490,000.

The total cost for this alternative is estimated at $6,660,000.

6.4.4 Alternative 3 – Biostimulation

6.4.4.1 Overall protection of human health and the environment

Alternative 3 would be protective of human health and the environment because the contaminant mass would be reduced. Because this alternative involves construction of horizontal wells, biostimulation

would be able to effectively treat all portions of the plume beneath Building Nos. 1 and 2. The RAO of 100 µg/L TCE at Hot Spot No. 1 would be met in approximately 2 years. The RAO of 2.8 µg/L TCE throughout the aquifer would be met within approximately 85 years thereafter through use of monitored natural attenuation. Remedial workers would not be exposed to contaminated groundwater as the treatment would be conducted in situ nor would workers be exposed to strong oxidants. Although some applications of biostimulation have involved the injection of other drinking water contaminants (such as toluene and phenol), the proposed alternative for the CAMP (methane injection) would not degrade the quality of the groundwater. Installation of the two injection wells would involve drilling into contaminated groundwater. Procedures and precautions would be implemented to minimize worker exposure to contaminants. Workers would be trained in hazardous waste operations as mandated by 29 *CFR* 1910.120.

6.4.4.2 Compliance with ARARs

Evaluation against the threshold criteria for the chemical-, action-, and location-specific ARARs is provided in this section.

Chemical-specific ARARs

The applicable chemical-specific ARARs for this alternative are discussed in Chapter 2.0. Under CERCLA Section 120(a)(4), federal facilities that are not on the NPL are subject to state laws concerning removal or remedial action. If applicable groundwater quality standards are exceeded, a GMZ may be established to implement corrective action. As previously discussed in this FS, TCE exceeds NCAC 2L standards.

This alternative also includes monitored natural attenuation of the residual plume following shutdown of the treatment operations. Increased metabolic activity would migrate TCE contamination some distance downgradient from the treatment zone. Indeed, as outlined in Appendix A, the injected methane and nutrients would travel with the groundwater, flowing approximately eight times faster than the contaminant plume. Therefore, this alternative would comply with the chemical-specific ARARs to reduce contaminant concentrations in the impaired groundwater to meet NCAC 2L standards.

Action-specific ARARs

The implementation of this alternative would include the installation of six monitoring wells and two parallel horizontal wells. These activities would require the drilling of boreholes. Dust control measures, as appropriate, would be undertaken during the construction activities to ensure compliance with applicable environmental and safety standards. Appropriate measures would also be taken to control sedimentation from surface water run-off from construction sites. In order to reduce sediment transport from the affected areas, sediment control techniques would be employed and detailed within the remedial design.

The installation of new monitoring or injection wells would generate IDW in the form of soil cuttings and groundwater. These wastes would be characterized through testing or use of existing data to determine whether the waste is hazardous. IDW that contains or exhibits a hazardous waste characteristic would be characterized to determine the applicable LDRs associated with the waste prior to disposal. Any hazardous waste generated will be disposed of at an off-site, RCRA-permitted facility.

Location-specific ARARs

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

6.4.4.3 Long-term effectiveness and permanence

The alternative would be effective in both the short-term and long-term. The increased metabolic activity associated with this alternative would result in the dechlorination of TCE. Decomposition products (such as 1.2-DCE and vinyl chloride) would also be consumed, either directly as food sources for aerobic microorganisms or through incidental co-metabolic activity.

Biostimulation is a relatively new technology that has demonstrated destruction of 95 to 100% of chlorinated hydrocarbon mass. The technology has been proven effective for chlorinated hydrocarbon removal in aerobic aquifers. Since the dissolved concentrations of oxygen, nutrients, and methane would not be retarded by the formation, the alternative would also enhance degradation of contaminant concentrations for short distances downgradient from the treatment zone. In addition, the injection of air would help maintain aerobic conditions in the treatment zone, even under increased metabolic activity. Gas-phase injection also would aid in distributing the air and methane because of the higher conductivity of gases through tight formations as compared with liquid injectants.

Following treatment operations natural attenuation of the groundwater plume is predicted to reduce the concentrations of TCE to NCAC 2L standards in approximately 85 years.

There is uncertainty whether residual TCE is present in soil or bedrock zone groundwater would serve as a continuing source of TCE to the shallow or transition zone groundwaters. This uncertainty would be further evaluated during subsequent pilot studies, remedial design, and remedial action implementation.

6.4.4.4 Reduction of toxicity, mobility, or volume

This alternative would reduce the toxicity and volume of contaminated groundwater through degradation of the TCE in the groundwater. Since the dissolved methane and air concentrations will not be retarded in the formation as TCE is, those concentrations will migrate approximately eight times faster than the contaminant plume, overrunning and stimulating increased metabolic activity downgradient from the treatment zone. Moreover, the projected overlapping radii of influence of the two horizontal wells will encompass a larger area beyond the 500 µg/L or greater contour resulting in greater mass reduction. The second well ensures adequate coverage of the 500 µg/L or greater contour.

6.4.4.5 Short-term effectiveness

The alternative would be effective in the short-term. Microbial populations increase quickly in response to introduction of increased food sources.

A greater than 95% reduction in contaminant mass in the injection zone is assumed for this option. It is anticipated that the treatment zone would be remediated to a concentration of 100 µg/L in a period of approximately 2 years. The anticipated radii of influence will be larger than the 500 µg/L of TCE plume, largely encompassing the 100 µg/L of TCE plume as well. Concentrations of TCE upgradient from or outside the treatment zone would not be reduced; however, that residual mass can be expected to attenuate since areas containing more than 100 µg/L of TCE would be remediated. The long-term effect is expected to be a significant reduction in the size of the portion of the plume having a concentration in excess of the NCAC 2L standard and a reduction in the groundwater concentration overall. Although, monitored natural attenuation would result in continued remediation throughout the aquifer.

6.4.4.6 Implementability

The installation of horizontal wells is a relatively complex, but established technique that has been used at a number of contaminated sites and conventional pipeline construction projects. For example, horizontal wells of considerably greater length than proposed at CAMP were installed at comparable aquifer depths to remediate greater concentrations of TCE at SRS. Installation operations would be coordinated with property owners so as not to interrupt operations.

Methane treatment has also been shown effective in similar soil conditions. A pilot-scale test at a site in Virginia, performed by the Gas Research Institute (GRI), injected methane into an aquifer composed of saprolite overburden above bedrock. Pilot-scale test results showed TCE levels were reduced from 2,000 µg/L to 150 µg/L during the first three weeks of operation.

Equipment and facilities are readily available. The injection compressors and control equipment are conventional and commercially available.The site is an active warehouse facility currently providing access to tractor-trailers. As such, electricity for running compressors is available, and access for well installation equipment adequate.

The injectant (methane) is widely available through local utilities or through delivered bottles. The injectant would be safe because it would be delivered at concentrations well below the respective LEL and would be injected at a sufficiently modest rate that it would becomereadily dissolved and dispersed in the water table. Even if local pockets of methane and air were to be formed or trapped within the formation or under facility buildings or parking lots, methane can not concentrate independent of the air stream nor exceed its injection concentration and would, therefore, be inherently safe.

The alternative also has the smallest "footprint" of any of the treatment alternatives. Specifically, since the alternative uses horizontal wells, the installation and operation of the compressors can be located a considerable distance from the active warehouse facility on-site. The anticipated location of the installation and injection of methane and air for the horizontal wells is near Buildings 4 and T-26.

6.4.4.7 Costs

Construction costs for installation of the injection wells were estimated to be $1,950,000. The O&M costs for the treatment operations (2 years) as well as the natural attenuation period (85 years) were estimated at $1,420,000.

The total cost for this alternative is estimated at $3,370,000.

6.4.5 Alternative 4 – Permeable Reactive Barrier

6.4.5.1 Overall protection of human health and the environment

Alternative 4 would be protective of human health because the reactive barrier would intercept the migrating plume and destroy TCE, reducing contaminant concentrations in the groundwater, thereby mitigating potential exposure pathways to human receptors. Additionally, since the reactive barrier would be sited to intercept a greater portion of the contaminant plume, there would be less migrating contaminant mass, so that TCE concentrations at the facility fenceline would be lower as compared with other alternatives.

Because this alternative relies on natural attenuation processes and migration of the contaminant plume to the reactive barrier, the RAO of 100 μg/L TCE at Hot Spot No. 1 would not be met until approximately 160 years following installation of the permeable reactive barrier.

6.4.5.2 Compliance with ARARs

Evaluation against the threshold criteria for the chemical-, action-, and location-specific ARARs is provided in this section.

Chemical-specific ARARs

The applicable chemical-specific ARARs for this alternative are discussed in Chapter 2.0. Under CERCLA Section 120(a)(4), federal facilities that are not on the NPL are subject to state laws concerning removal or remedial action. If applicable groundwater quality standards are exceeded, a GMZ may be established to implement corrective action. As previously discussed in this FS, TCE exceeds NCAC 2L standards.

This alternative would comply with the chemical-specific ARARs to reduce contaminant concentrations in the impaired groundwater to meet RAOs. The alternative relies on natural attenuation processes and migration of the contaminant plume to the reactive barrier in order to achieve this reduction.

Action-specific ARARs

Implementation of this alternative would include the installation of six new monitoring wells and approximately 330 treatment zones. These activities would require the drilling of boreholes. Dust control measures, as appropriate, would be undertaken during the construction activities to ensure compliance with applicable environmental and safety standards. Appropriate measures would also be taken to control sedimentation from surface water run-off from construction sites. In order to reduce sediment transport from the affected areas, sediment control techniques would be employed and detailed within the remedial design.

The installation of monitoring or treatment wells also would generate IDW in the form of soil cuttings and groundwater. These wastes would be characterized through testing or use of existing data to determine whether the waste is hazardous. IDW that contains or exhibits a hazardous waste characteristic shall be characterized to determine the applicable LDRs associated with the waste prior to disposal. Any hazardous waste generated will be disposed of at an off-site, RCRA-permitted facility.

Location-specific ARARs

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

6.4.5.3 Long-term effectiveness and permanence

This alternative would result in the degradation of the entire portion of the plume flowing through the permeable reactive barrier. This alternative is predicted to reduce the concentrations of TCE to NCAC 2L standards in approximately 160 years.

Permeable reactive barriers are a relatively new but proven technology that has demonstrated removals of 95 to 100% of contaminant mass flowing through them. Although the typical application has been to use a continuous trench/wall, the difference in hydraulic conductivities between the formation and the treatment wells is such that the permeable reactive barrier represents a preferred flow path; more than

99% of the aquifer will flow through the barrier as compared with through the adjacent formation. This alternative would be effective in destroying essentially the entire quantity of TCE that flows through the reactive zone.

Although the assumed length of the barrier should be sufficient to intercept the entire plume, breakthrough or flow around either end of the barrier is possible. However, it is anticipated that due to the slow groundwater velocities, there would be sufficient time for routine, long-term monitoring to detect such breakthrough and permit barrier repair, maintenance, or other engineering control.

6.4.5.4 Reduction of toxicity, mobility, or volume

The alternative would reduce the toxicity and volume of contaminated groundwater through reductive dechlorination of TCE. A greater than 95% reduction in contaminant mass in the injection zone is estimated for this option; however, there is some uncertainty associated with this reduction rate, as a result of breakthrough or flow-around. Overall rate of reduction is slow because the alternative would require contamination to flow naturally to the barrier.

6.4.5.5 Short-term Effectiveness

This alternative would intercept the contaminant plume within the confines of CAMP; concentrations of TCE immediately downgradient from the reactive barrier and at the facility fenceline would be at undetectable levels. However, it would take many years before the bulk of the contaminant plume reached the barrier as a result of the low, prevailing aquifer velocity. The alternative would ultimately achieve the NCAC 2L standard throughout the aquifer. There would, therefore, be no increase in potential risks.

6.4.5.6 Implementability

The aboveground construction area required for installing the permeable reactive barrier would be located north of the active warehouse facility; it would pose no long-term disruption of facility activities. The equipment needed to install treatment wells is well established. Once installed, the alternative requires no power sources or other consumables—although long-term monitoring to detect potential breakthrough would be required. The equipment and procedures for collecting and monitoring groundwater samples are routine.

6.4.5.7 Costs

Construction costs for installation of the permeable reactive barrier were estimated to be $3,090,000. The O&M costs were estimated at $2,040,000.

The total cost for this alternative is estimated at $5,120,000.

6.4.6 Alternative 5 – In situ Chemical Oxidation

6.4.6.1 Overall protection of human health and the environment

Alternative 5 would be protective of human health because the chemical oxidant would destroy TCE, reducing contaminant concentrations in the groundwater, thereby mitigating potential exposure pathways to human receptors. Due to site constraints ISCO may not deliver sufficient oxidant to portions of the contaminated plume beneath Building Nos. 1 or 2. However, since the chemical oxidant will flow through the formation an estimated eight times faster than the TCE, it would mitigate downgradient TCE

concentrations for short distances. The alternative is, therefore, estimated to approximate 80 to 95% effective. The RAO of 100 µg/L TCE at Hot Spot No. 1 would be met within approximately 2 years following treatment. The RAO of 2.8 µg/L TCE throughout the aquifer would be met within approximately 85 years thereafter. This would result in further reduction of contaminant mass and move the centroid of the residual plume upgradient of the injection zone. Therefore, the residual contamination will attenuate in shorter timeframes, and TCE concentrations at the facility fenceline will be lower as compared with natural attenuation or the no action alternative.

Installation of the injection wells would involve drilling into contaminated groundwater. Procedures and precautions would be implemented to minimize worker exposure to contaminants. Workers would be trained in hazardous waste operations as mandated by 29 *CFR* 1910.120.

6.4.6.2 Compliance with ARARs

Evaluation against the threshold criteria for the chemical-, action-, and location-specific ARARs is provided in this section.

Chemical-specific ARARs

The applicable chemical-specific ARARs for this alternative are discussed in Chapter 2.0. Under CERCLA Section 120(a)(4), federal facilities that are not on the NPL are subject to state laws concerning removal or remedial action. If applicable groundwater quality standards are exceeded, a GMZ may be established to implement corrective action. As previously discussed in this FS, TCE exceeds NCAC 2L standards.

This alternative also includes monitored natural attenuation of the residual plume following shutdown of the treatment operations. Therefore, this alternative would ultimately comply with the chemical-specific ARARs to reduce contaminant concentrations in the impaired groundwater to meet NCAC 2L standards.

Action-specific ARARs

Implementation of this alternative would include the installation of six new monitoring wells and approximately 106 injection well boreholes. Dust control measures, as appropriate, would be undertaken during the construction activities to ensure compliance with applicable environmental and safety standards. Appropriate measures would also be taken to control sedimentation from surface water run-off from construction sites. In order to reduce sediment transport from the affected areas, sediment control techniques would be employed and detailed within the remedial design.

The installation of new monitoring or injection wells would generate IDW in the form of soil cuttings and groundwater. These wastes would be characterized through testing or use of existing data to determine whether the waste is hazardous. IDW that contains or exhibits a hazardous waste characteristic shall be characterized to determine the applicable LDRs associated with the waste prior to disposal. Any hazardous waste generated would be disposed of at an off-site, RCRA-permitted facility.

For the purposes of the cost estimate, the soil and water generated from the installation of 106 injection wells in the treatment zone was assumed to be RCRA hazardous; however, waste generated from the installation of the new downgradient monitoring wells was assumed to be non-hazardous.

Location-specific ARARs

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

6.4.6.3 Long-term effectiveness and permanence

This alternative would be effective in both the short-term and long-term. Destruction of TCE within the injection zone would permanently reduce TCE concentrations to below 100 µg/L. Following treatment operations to achieve a TCE concentration of 100 µg/L, natural attenuation of the groundwater plume is predicted to reduce the concentrations of TCE to NCAC 2L standards in approximately 85 years.

ISCO is a relatively new but proven technology that has demonstrated removals of 70 to 90% of contaminant mass. However, the typical application has been to use much higher concentrations of oxidant to destroy much higher concentrations of contaminant (e.g., DNAPL). A pilot study will be necessary to establish the removal efficiency of chemical oxidation, and the quantities of permanganate to be used for each injection far exceed the quantity necessary for oxidation of the TCE in the injection zone. Depending upon site-specific distribution and in situ mixing, it may be possible to achieve significant removal of TCE in fewer than the four injections assumed in the cost estimate. This alternative would be effective in destroying significant quantities of TCE in the injection zone, as well as downgradient concentrations, since the oxidant would not be retarded by the formation and would move through the formation approximately eight times faster than the contaminant plume.

A greater than 90% reduction in contaminant mass in the injection zone is estimated for this alternative; however, there is uncertainty associated with this reduction rate. Although half of the groundwater depth for any given cluster of injection wells would be screened to distribute permanganate vertically, case studies have indicated that much of the injectant enters the formation at the top of the well screen, where the hydraulic pressure is at a minimum. However, it is anticipated that due to the slow groundwater velocities, there would be sufficient time for diffusion of permanganate to occur throughout the entire formation. As mentioned above, since the plume is migrating at only 12% of the velocity of the permanganate, downgradient TCE concentrations would be mitigated for a short distance.

There is uncertainty whether residual TCE is present in soil or bedrock zone groundwater would serve as a continuing source of TCE to the shallow or transition zone groundwaters. This uncertainty would be further evaluated during subsequent pilot studies, remedial design, and remedial action implementation.

6.4.6.4 Reduction of toxicity, mobility, or volume

This alternative would reduce the toxicity and volume of contaminated groundwater through destruction of TCE. An 80 to 95% reduction is estimated. The oxidant would migrate approximately eight times faster than the contaminated plume resulting in further ISCO treatment for a short distance downgradient from the treatment zone.

6.4.6.5 Short-term Effectiveness

The ISCO process would deliver a 0.5% solution of sodium permanganate (5,000 mg/L) to the aquifer via injection. The in situ concentration of sodium permanganate is expected to fall to 500 mg/L as the injected solution mixes with the groundwater in the formation and fall further to 50 mg/L as it flows with the groundwater and disperses vertically and laterally. This would result in more than sufficient concentrations of sodium permanganate to be available; an average concentration of 5 mg/L permanganate within the contaminant plume would be enough stoichiometrically to oxidize the entire mass of TCE at CAMP. (The stoichiometric quantity necessary to oxidize 1,000 µg/L of TCE is 1,200 µg/L of sodium permanganate.) Additional injections would follow depending upon the persistence of permanganate and/or TCE in the groundwater. For purposes of cost estimating, four injection events were assumed over a two-year period, during which TCE concentrations would be remediated to less than 100 µg/L.

Concentrations of residual TCE can be expected to attenuate since areas containing more than 500 µg/L of TCE would have been remediated. The long-term effect is expected to be a significant reduction in the size of the portion of the plume having a concentration in excess of the NCAC 2L standard and a reduction in the groundwater concentration overall. However, the treatment would not be able to achieve the NCAC 2L standards by itself, monitored natural attenuation would result in additional and continuing remediation throughout the aquifer.

6.4.6.6 Implementability

ISCO would be readily implementable. Items of equipment needed to inject oxidant solution into groundwater are well established, consisting of injection wells, distribution headers and piping, flow meters, and pumps. Oxidant solutions are commercially available and have been used to oxidize significantly greater levels of contamination (including DNAPL) at other sites. A source of power is available at the site to run the injection pumps. Injections would occur over a period of 1 to 2 weeks, with subsequent injections occurring 6 to 12 months later, as needed. The equipment and procedures for collecting and monitoring groundwater samples are routine.

Several thousand gallons per injection day of water would be required. Water for blending and delivery of the reagents is available on-site. Delivery of the permanganate solution to the injection wells would be provided from the former fuel shed through control valves and buried pipes.

Sufficient space is available at the site for one week of injection once or twice a year. The footprint would consist of the former fuel shed, from which liquid, drummed reagent would be metered to the various injection wells. The site is an active warehouse facility currently providing access to tractor-trailers. Although care would have to be exercised to avoid unduly disrupting tenant operations during well installation, delivery of oxidant (i.e., permanganate solution) and injection activities would have a minimal footprint or effect on day-to-day operations.

The presence of iron and organic matter, other than the contaminants, can compete for oxidants such as permanganate, greatly increasing the volume of reagent required. However, the average TOC concentration in the overburden soil is very low, and, therefore, is not expected to negatively affect the treatment operations.

An underground injection permit, including an inventory of all injection wells utilized for injection of materials into the aquifer, would have to be obtained prior to injection operations, but those permits have been issued previously.

6.4.6.7 Costs

Construction costs for installation of the injection wells were estimated to be $10,090,00. The O&M costs for the treatment operations (2 years) as well as the natural attenuation period (85 years) were estimated at $1,490,000.

The total cost for this alternative is estimated at $11,580,000.

6.5 COMPARATIVE EVALUATION OF ALTERNATIVES

6.5.1 Introduction

Following is a comparative analysis of the No Action and four action alternatives being considered for remediating contaminated groundwater at the CAMP. The alternatives are evaluated against the NCP threshold and primary balancing criteria, similar to the individual analysis of each alternative. This analysis highlights key advantages, disadvantages, and trade-offs among the alternatives. The comparative analysis of alternatives is summarized in Table 6-1.

6.5.2 Overall Protection of Human Health and the Environment

All of the sitewide alternatives, except the No Action alternative, would achieve the RAO to reduce TCE contamination in Hot Spot No. 1 to 100 µg/L. The primary distinction between the action alternatives with respect to attainment of this RAO is the time required; Alternatives 2, 3, and 5 would achieve this RAO in two years whereas Alternative 4 would not achieve this RAO in nearly 160 years. All action alternatives would reduce both the mass and volume of contamination, while also largely preventing the migration of the contamination exceeding NCAC 2L standards outside the property boundary. The action alternatives would, therefore, be protective of human health and the environment, whereas the No Action alternative would not be protective.

6.5.3 Compliance with ARARs

The No Action alternative would not address TCE in groundwater that exceeds drinking water standards. Therefore, the No Action alternative does not comply with the primary chemical-specific ARAR for the site.

With the exception of Alternative 4, the action alternatives would result in the permanent degradation of both TCE and degradation products in a relatively short timeframe (2 years) followed by monitored natural attenuation. Although the drinking water standard would not be met until the residual contamination throughout the aquifer decreases through attenuation processes, it is projected that active remediation within the treatment zone to achieve a TCE concentration less than 100 µg/L would prevent residual contamination from leaving the CAMP before attaining the RAO.

6.5.4 Long-term Effectiveness and Permanence

The action alternatives involve reducing the contaminant mass and volume over the projected treatment time. Alternative 1 does not result in reduction of contaminant mass or volume, or other measures to protect human health or the environment, and is, therefore, not effective in the long-term. The action alternatives are effective because they would permanently destroy TCE contamination through treatment. Each alternative has been demonstrated to be effective in full-scale treatment of TCE in groundwater. In Alternative 4, although the RAO is achieved, the process is predicted to last 160 years, and no reactive barrier has been in use for more than approximately 20 years, therefore, there is uncertainty associated with Alternative 4.

Due to site constraints, alternatives that use vertical injection wells (Alternatives 2 and 5) may not be able to effectively treat portions of the contaminated plume beneath buildings and are expected to be approximately 80 to 95% effective.

Table 6-1. 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
1. No Action	Not protective	Does not comply with ARARs	Not effective	No reduction	Not effective	Easily implementable – no activities conducted	$0
2. Bioaugmentation	Protective of human health and the environment	Complies with ARARs	Effective in the long-term. Permanently biodegrades TCE. TCE concentrations reduced to the NCAC 2L standards in 85 years 80 to 95% effectiveness estimated due to site constraints	Toxicity and mass of TCE reduced through biodegradation processes 90% reduction estimated	Effective in the short-term Would reduce 500 µg/L TCE to 100 µg/L in two years	Implementable Treatment vendors and equipment readily available Installation of injection wells would require coordination with property owners with greater disruption to ongoing operations Additional wells easily installed	$6,660,000

Table 6-1. Comparative Analysis of Remedial Alternatives (continued)

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
3. Biostimulation	Protective of human health and the environment	Complies with ARARs	Effective in the long-term Following treatment operations, natural attenuation would reduce TCE from 100 µg/L to the NCAC 2L standards in 85 additional years Permanently biodegrades TCE TCE concentrations reduced to the NCAC 2L standards Most effective at treating TCE contamination under buildings	Toxicity and mass of TCE reduced 95% reduction estimated Long mass of TCE reduced through natural attenuation	Effective in the short-term Would reduce 500 µg/L of TCE to 100 µg/L in 2 years	Implementable Treatment vendors and equipment readily available Installation of injection wells would require coordination with property owners. Additional wells easily implementable	$3,370,000

Table 6-1. Comparative Analysis of Remedial Alternatives (continued)

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
4. Permeable Reactive Barrier	Protective of human health and the environment	Complies with ARARs	Effective in the long-term Permanently destroys TCE but requires plume to migrate to barrier TCE concentrations reduced to NCAC 2L Standards Effective because barrier would intercept entire plume	Toxicity and mass of TCE reduced through reductive chlorination Long-term mass of TCE reduced through natural attenuation Greater than 95% reduction estimated	Not effective in the short-term would reduce 500 µg/L TCE to 100 µg/L in nearly 160 years	Implementable Treatment vendors and equipment readily available Installation of injection wells would require coordination with property owners Additional wells easily installed	$5,120,000
5. In situ Chemical Oxidation	Protective of human health and the environment	Complies with ARARs	Effective in the long-term TCE concentrations reduced to the NCAC 2L standards in 85 additional years 80 to 95% effectiveness estimated due to site constraints	Toxicity and mass of TCE reduced through ISCO Greater than 90% reduction estimated Long-term mass of TCE reduced through natural attenuation	Effective in the short-term Would reduce 500 µg/L TCE to 100 µg/L in 2 years	Implementable Treatment vendors and equipment readily available Installation of injection wells would require coordination with property owners Additional wells easily installed	$11,580,000

ARAR = Applicable or relevant and appropriate requirement.
NCAC = North Carolina Administrative Code.
TCE = Trichloroethene.

There is uncertainty whether residual TCE is present in soil or bedrock zone groundwater would serve as a continuing source of TCE to the shallow or transition zone groundwaters. This uncertainty would be further evaluated during subsequent pilot studies, remedial design, and remedial action implementation.

6.5.5 Reduction in Toxicity, Mobility, and Volume

The No Action alternative would not provide any reduction in the toxicity, mobility, or mass of contaminants.

The action alternatives would provide the greatest overall reduction in the mass of organic contaminants in the groundwater, although bioaugmentation and ISCO have been demonstrated to achieve, on average, less destruction of chlorinated hydrocarbons, than use of methane biostimulation or zero valence iron reactive media.

6.5.6 Short-term Effectiveness

The No Action alternative and Alternative 4 are not effective in the short-term. Permeable reactive barrier timeframes are estimated to take 160 years before contamination exceeding 100 µg/L has migrated to the location of the barrier and TCE has been reduced to NCAC 2L standards. Alternatives 2, 3, and 5 would result in significant reductions in contaminant mass and toxicity over the short-term in 2 years.

6.5.7 Implementability

The No Action alternative is readily implementable; that is, no activities would be conducted for the No Action alternative. The remaining alternatives would be readily implemented in that materials, equipment, and technologies are readily available; however, each would involve varying complexities. Implementing Alternatives 2 and 5 would be more complicated because they involve drilling and multiple injections of media within an area of ongoing industrial activities for two years. Alternative 3 would involve more complex drilling for installation of horizontal wells but would be less disruptive to ongoing industrial operations. Alternative 4 would require a large footprint for installation of a large number of vertical wells; however, a barrier wall would be further removed and less disruptive to facility operations.

6.5.8 Costs

The estimated total costs for each of the five alternatives were as follows:

- Alternative 1, $0 – (1);
- Alternative 3, $3,370,000 – (3);
- Alternative 4, $5,120,000 – (2);
- Alternative 4, 2, – $5,120,000; and
- Alternative 5, $11,580,000.

6.6 PILOT STUDY

Prior to implementing any of the action alternatives, a pilot study is recommended to generate site-specific data for the design of the most suitable remedial alternative. For Alternatives 2, 3 and 5, the pilot study will include the installation of four new injection points located in two well clusters. Each cluster would include one shallow and one transition zone well. Treatment media (whether bacteria/nutrients, methane/air, or oxidant) would be injected at a single prescribed rate into each well. Subsequent to media

injection, five site visits over a six-month period (one baseline sampling event and four visits, once every four to six weeks thereafter up to six months) would be performed to measure field parameters and collect analytical samples. All pilot study data would be thoroughly evaluated to optimize the full-scale remedial action design.

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APPENDIX A

FATE AND TRANSPORT MODELING FOR THE FORMER CHARLOTTE ARMY MISSILE PLANT

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A.1 FATE AND TRANSPORT MODELING

A.1.1 INTRODUCTION

Monitored natural attenuation is an appropriate remedial approach only where it can be demonstrated capable of achieving a site's remedial objectives within a reasonable time frame. In order to determine whether monitored natural attenuation is an appropriate remedy for soils and groundwater at a given site, fate and transport modeling is performed to show that contaminants present in soils and 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 Charlotte Army Missile Plant (CAMP) site in Charlotte, North Carolina. Fate and transport modeling was also performed to support the evaluation of other feasible remedial alternatives presented in the Feasibility Study (FS) report.

The groundwater sampling data used in the analysis were analytical data obtained up to February 2003. 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 (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.

A.1.2 MODELING APPROACH

The modeling approach can be outlined as follows:

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

2. Identify the chemicals of concerns (COCs) and select a prevalent chemical to represent the chemical group with conservatism. At the CAMP site, trichloroethene (TCE) is the most prevalent chemical and was selected for modeling.

3. Perform leachate modeling using the Seasonal Soil (SESOIL) Model (assuming there is a source of COCs in soils), and calculate the soil's leachate dilution attenuation factor (DAF) [i.e., $DAF_{S\text{-}L} = C_S/C_L$, where C_S is the maximum soil concentration at the source and C_L is the predicted maximum leachate concentration]. This action was not required at the CAMP site, as there were no COCs in soils that exceeded soil remedial levels.

4. Perform steady-state saturated flow and contaminant transport modeling using the Analytical Transient 1-, 2-, 3-Dimensional (AT123D) Model to predict the maximum concentration of the prevalent chemical (i.e., TCE for this site) at the receptor location using the existing groundwater plume. This step required calibration of the model such that existing groundwater concentrations in both the shallow and the transition zones could be reasonably reproduced.

5. Perform saturated flow and contaminant transport modeling using AT123D to predict the maximum concentration over time in conjunction with source remediations in order to determine a reasonable time frame for the monitored natural attenuation alternative.

A.1.3 MODEL SELECTED

AT123D. The AT123D, is a well-known and commonly used analytical groundwater pollutant fate and transport model. This model was developed by Yeh (1981) and has been updated by GSC (1996). 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 fate and transport 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 in groundwater resulting from a mass release (either continuous or instant or depleting source) over a source area (i.e., point, line, area, or volume source).

A.1.4 PARAMETERS

The hydrologic 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. A review of Section 4.6 of the Phase II RI Report (USACE 2000) indicates that slug tests were performed on 10 wells: 4 shallow, 5 intermediate, and 1 bedrock well. Results obtained from these tests are presented in Table 4-1 of the Phase II RI Report. Although the table presents the data as arithmetic averages for hydraulic conductivity, Science Applications International Corporation calculated the geometric mean from each zone for use in the fate and transport modeling described in this document. The resulting hydraulic conductivity values were 9.67 ft/day in the shallow zone (SZ) and 1.34 ft/day in the transition zone (TZ). The bedrock zone (BZ) consisted of one data point and was not targeted for modeling.

The AT123D model was used to compare the current dissolved-phase TCE plume configuration with modeled values. The hydraulic conductivity values discussed above were combined with other aquifer and contaminant transport properties to develop the TCE modeling runs. The results of these runs are presented in Figures A.1 and A.2. As can be seen from these figures, a close match is obtained in the TZ, whereas it fails in the SZ. However, a reduction of the hydraulic conductivity in the SZ to 1.22 ft/day was able to match the SZ TCE plume (see Figure A.3). This value is well within the error potential for a slug test conducted in a shallow unconfined aquifer. These hydraulic properties developed through calibration of the AT123D model form the basis for all analytical and numerical modeling runs described in the FS.

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 the following modeling scenarios.

A.1.5 MODEL APPLICATION AND RESULTS

AT123D Modeling

As discussed in Chapter 1.0 of this report, the conceptual site model (CSM) indicated contaminant migration through two distinct flow paths (i.e., the SZ and the TZ). Therefore, AT123D modeling was performed separately for these two flow paths. The AT123D models were developed by calibrating to the TCE plumes in the shallow and transition zones. In the following paragraphs, discussions of AT123D simulations for different scenarios are presented.

Scenario 1: Supporting No Action Alternative – Shallow Zone

Assumptions and Input Parameters: A near steady-state source is assumed for conservatism. The source size and loading, together with hydraulic conductivity and longitudinal dispersivity, is characterized through calibration. It is assumed that the source loading started some 35 years ago and reached a steady-state loading that continued for 10 years. After the first 10 years, the source loading is assumed to decrease and completely stop after 30 years from the start of loading. These assumptions are made to calibrate the existing TCE plumes. The calibrated parameters, including all other AT123D model parameters, are shown below:

Source dimension = 100 m × 9 m located between COEMW06 and SAIC-16
Saturated thickness = 12.2 m
Hydraulic gradient = 0.02 m/m toward north (see figure)
Hydraulic conductivity = 0.0155 m/hr (calibrated)
Longitudinal dispersivity = 15 m (calibrated)
Transverse dispersivity = 5 m (calibrated)
Vertical dispersivity = 1.5 m (calibrated)
Source loadings (calibrated):

Period (yr)	Loading (kg/hr)
0–10	0.02184
10–20	0.00094
10–30	0.00045
30–end	0.0

Bulk density = 1.5 g/cc (EPA default)
Effective porosity = 0.20 (Mills et al. 1985)
Fraction Organic Carbon (foc) = 0.01 (Plume calibration)
Koc for TCE = 94 mL/g (EPA 1996)
Kd for TCE = 0.94 mL/g (Koc (foc))
Molecular diffusion coefficient for TCE = 3.27E-6 m2/hr
Decay constant for TCE = 3.5×10^{-6} 1/hr (plume calibration)
Applicable water quality standard (CSTD) = North Carolina Administrative Code (NCAC) 2L standard for TCE = 2.8 µg/L

Lateral migrations to the receptors were performed using the AT123D Model. The model was calibrated by matching the maximum concentrations observed in wells SAIC-16, COEMW06, COEMW12, and COEMW18. The results of the modeling are presented in Figure A.4. As can be seen from this figure, the concentrations of TCE in the SZ will be reduced to 2.8 µg/L within 200 years due to natural attenuation. Also, TCE is predicted to migrate to a downgradient distance of approximately 400 m from COEMW06 before being reduced to 2.8 µg/L through natural attenuation.

Scenario 2: Source Reduction to 100 µg/L – Shallow Zone

Assumptions and Input Parameters: 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 Alternative model), except source loading and source size, were used in this simulation. Regarding the source loading, like the No Action Alternative Model, it was assumed that contaminant loading was started 35 years ago and reached a steady-state loading that continued for 10 years. After the first 10 years, the source loading is assumed to decrease and completely stop after 30 years from the start of loading. However, instead of calibrating to the observed condition at the source, the model is calibrated to 100 µg/L at the source area and the observed concentrations at wells COEMW12 and COEMW18. The revised parameters are shown below:

Source dimension = 140 m × 9 m located between wells COEMW06 and SAIC-16

Source loadings (calibrated):

Period (yr)	Loading (kg/hr)
0–10	0.0006400
10–20	0.0000280
10–30	0.0000135
30–end	0.0

The model was calibrated by matching the maximum concentrations observed in wells COEMW12 and COEMW18 and 100 µg/L near COEMW06 (i.e., the clean-up concentrations). The results of the modeling are presented in Figure A.5. As can be seen from this figure, the concentrations of TCE in the SZ will be reduced to 2.8 µg/L within 90 years due to natural attenuation after source reduction to 100 µg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 200 m from COEMW06 before being reduced to 2.8 µg/L through natural attenuation.

Scenario 3: Source Reduction to 100 µg/L only within 1,000 µg/L TCE contour – Shallow Zone

Assumptions and Input Parameters: Simulation of this scenario using AT123D is not possible unless some simplifying assumptions are made. These simplifying assumptions include:

- the source area within 1,000 µg/L has been remediated to 100 µg/L,
- a new source area is defined which is downgradient of the existing 1,000 µg/L contour line, and
- the maximum concentration in the new source area is 1,000 µg/L.

Based on the above assumptions, the AT123D Model for this scenario was developed. All of the calibrated parameters from the No Action Alternative Model, except source loading, source size, and source location, were used in this simulation. Instantaneous contaminant mass was loaded to the new source area by trial and error to match the concentrations of 1,000 µg/L at the downgradient 1,000 µg/L plume boundary, and the concentrations at well COEMW12. The revised calibrated parameters are shown below:

Source dimension = 162 m × 9 m located between wells COEMW06 and SAIC-16

Source loadings (calibrated): 40 kg (instantaneous)

The results of the modeling are presented in Figure A.6. As can be seen from this figure, the concentration of TCE in the SZ will be reduced to its maximum contaminant level (MCL) [2.8 µg/L] within 110 years due to natural attenuation after source reduction of > 1,000 µg/L to 100 µg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 290 m from COEMW06 before being reduced to 2.8 µg/L through natural attenuation.

Scenario 4: Source Reduction to 100 µg/L only within 500 µg/L TCE contour – Shallow Zone

Assumptions and Input Parameters: Simulation of this scenario using AT123D is not possible unless some simplifying assumptions are made. These simplifying assumptions include:

- the source area within 500 µg/L has been remediated to 100 µg/L,
- a new source area is defined which is downgradient of the existing 500 µg/L contour line, and
- the maximum concentration in the new source area is 500 µg/L.

Based on the above assumptions, the AT123D Model for this scenario was developed. All of the calibrated parameters from the No Action Alternative Model, except source loading, source size, and

source location, were used in this simulation. Instantaneous contaminant mass was loaded to the new source area by trial and error to match the concentrations of 500 μg/L at the downgradient 500 μg/L plume boundary and the concentrations at well COEMW12. The revised calibrated parameters are shown below:

Source dimension = 162 m × 9 m located between wells COEMW06 and SAIC-16
Source loadings (calibrated): 15.75 kg (instantaneous)

The results of the modeling are presented in Figure A.7. As can be seen from this figure, the concentrations of TCE in the SZ will be reduced to 2.8 μg/L within 80 years due to natural attenuation after source reduction of > 500 μg/L to 100 μg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 230 m from COEMW06 before being reduced to 2.8 μg/L through natural attenuation.

Scenario 5: Source Reduction to 1,000 μg/L – Shallow Zone

Assumptions and Input Parameters: To simulate this scenario the AT123D No Action Model Alternative, with revised source size and loading, was utilized. All of the calibrated parameters from the previous model (i.e., No Action Alternative Model), except source loading and source size, were used in this simulation. Regarding the source loading, like the No Action Alternative Model, it was assumed that contaminant loading was started 35 years ago and reached a steady-state loading that continued for 10 years. After the first 10 years, the source loading is assumed to decrease and completely stop after 30 years from the start of loading. However, instead of calibrating to the observed condition at the source, the model was calibrated to 1,000 μg/L at the source area and the observed maximum concentrations at wells COEMW12 and COEMW18. The revised parameters are shown below:

Source dimension = 140 m × 9 m located between wells COEMW06 and SAIC 16
Source loadings (calibrated):

Period (yr)	Loading (kg/hr)
0–10	0.006400
10–20	0.000280
10–30	0.000135
30–end	0.0

Lateral migrations to the receptors were performed using the AT123D model. The model was calibrated by matching the maximum concentrations observed in wells COEMW12, COEMW18, and 1,000 μg/L near COEMW06 (i.e., the clean-up concentrations). The results of the modeling are presented in Figure A.8. As can be seen from this figure, the concentrations of TCE in the SZ will be reduced to 2.8 μg/L within 160 years due to natural attenuation after source reduction to 1,000 μg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 340 m from COEMW06 before being reduced to 2.8 μg/L through natural attenuation.

Scenario 6: Supporting No Action Alternative – Transition Zone

Assumptions and Input Parameters: A near steady-state source is assumed for conservatism. The source size and loading, together with hydraulic conductivity and dispersivities, are characterized through calibration. It is assumed that the source loading started some 35 years ago and reached a steady-state loading that continued for 10 years. After the first 10 years, the source loading is assumed to decrease and completely stop after 30 years from the start of loading. These assumptions were made to calibrate the existing TCE plumes in both shallow and transition zones. The calibrated parameters for the TZ, including all other AT123D model parameters, are shown below:

Source dimension = 30 m × 15 m located near wells SAIC-10, SAIC-08, and SAIC-17
Saturated thickness = 4.2 m
Hydraulic gradient = 0.02 m/m toward north (see figure)
Hydraulic conductivity = 0.018 m/hr (calibrated)
Longitudinal dispersivity = 18 m (calibrated)
Transverse dispersivity = 6 m (calibrated)
Vertical dispersivity = 1.8 m (calibrated)

Source loadings (calibrated):

Period (yr)	Loading (kg/hr)
0–10	0.010416
10–20	0.000465
10–30	0.000223
30–end	0.0

Bulk density = 1.5 g/cc (EPA default)
Effective porosity = 0.20 (EPA 1985)
Fraction Organic Carbon (foc) = 0.01 (Plume calibration)
Koc for TCE = 94 mL/g (EPA 1996)
Kd for TCE = 0.94 mL/g (Koc (foc))
Molecular diffusion coefficient for TCE = 3.27E-6 m^2/hr
Decay constant for TCE = 3.5×10^{-6} 1/hr
Applicable water quality standard (CSTD) = NCAC 2L standard for TCE = 2.8 μg/L

Lateral migrations to the receptors were performed using the AT123D Model. The model was calibrated by matching the maximum concentrations observed in wells SAIC-08, MW1A, SAIC-18, and COEMW27. The results of the modeling are presented in Figure A.9. In addition, the calibration result is shown in Figure A.2. As can be seen from these figures, the concentrations of TCE in the TZ will be reduced to 2.8 μg/L within 195 years due to natural attenuation. Also, TCE is predicted to migrate to a downgradient distance of approximately 520 m from SAIC-08 before being reduced to 2.8 μg/L through natural attenuation.

Scenario 7: Source Reduction to 500 μg/L for the area upgradient of MW1A – Transition Zone

Assumptions and Input Parameters: To simulate this scenario, the AT123D No Action Alternative Model, with revised source size and loading, was utilized. All of the calibrated parameters from the previous model (i.e., No Action Alternative Model), except source loading, source size, and source location, were used in this simulation. Regarding the source loading, like the No Action Alternative Model, it was assumed that contaminant loading in the past was at a steady-state condition for 0 years, after which source loading was reduced, and became zero at the end of 16 years. However, instead of calibrating to the observed condition at the source, the model was calibrated to 4000 μg/L near MW1A, and the observed concentrations at SAIC -8 and COEMW27. The revised parameters are shown below:

Source dimension = 6 m × 14 m located between wells MW1A and SAIC 18

Source loadings (calibrated):

Period (yr)	Loading (kg/hr)
0–10	0.0013
10–16	0.000056
16–end	0.0

Lateral migrations to the receptors were performed using AT123D. The model was calibrated by matching the maximum concentrations observed in wells SAIC-18 and COEMW27, and 4000 μg/L near MW1C. The results of the modeling are presented in Figure A.10. As can be seen from this figure, the concentrations of TCE in the SZ will be reduced 2.8 μg/L within 160 years due to natural attenuation after

source reduction to 500 μg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 460 m from well SAIC 08 before being reduced to 2.8 μg/L through natural attenuation.

Scenario 8: Source Reduction to 100 μg/L for the area within 1,000 μg/L TCE contour – Transition Zone

Assumptions and Input Parameters: Simulation of this scenario using AT123D is not possible unless some simplifying assumptions are made. These simplifying assumptions include:

- the source area within 1,000 μg/L has been cleaned,
- a new source area is defined which is downgradient of the existing 1,000 μg/L contour line, and
- the maximum concentration in the new source area is 1,000 μg/L.

Based on the above assumptions, the AT123D model for this scenario was developed. All of the calibrated parameters from the No Action Alternative Model, except source loading, source size, and source location, were used in this simulation. Instantaneous contaminant mass was loaded to the new source area by trial and error to match the concentrations of 1,000 μg/L at the downgradient 1,000 μg/L plume boundary, and also the concentrations at COEMW27. The revised calibrated parameters are shown below:

Source dimension = 39 m × 14 m located between wells SAIC-18 and COEMW27
Source loadings (calibrated): 12.74 kg (instantaneous)

The results of the modeling are presented in Figure A.11. As can be seen from the figure, the concentrations of TCE in the SZ will be reduced to 2.8 μg/L within 100 years due to natural attenuation after source reduction of > 1000 μg/L to 100 μg/L. Also, TCE is predicted to migrate to a downgradient distance of approximately 380 m from well SAIC-08 before being reduced to 2.8 μg/L through natural attenuation.

Scenario 9: Source Reduction to 100 μg/L for the area within 500 μg/L TCE contour – Transition Zone

Assumptions and Input Parameters: Simulation of this scenario using AT123D is not possible unless some simplifying assumptions are made. These simplifying assumptions include:

- the source area within 500 μg/L has been cleaned,
- a new source area is defined which is downgradient of the existing 500 μg/L contour line, and
- the maximum concentration in the new source area is 500 μg/L.

Based on the above assumptions, the AT123D model for this scenario was developed. All of the calibrated parameters from the No Action Alternative Model, except source loading, source size, and source location, were used in this simulation. Instantaneous contaminant mass was loaded to the new source area by trial and error to match the concentrations of 500 μg/L at the downgradient 500 μg/L plume boundary, and also the concentrations at COEMW27. The revised calibrated parameters are shown below:

Source dimension = 227 m × 14 m located between wells SAIC 18 and COEMW27
Source loadings (calibrated): 3.14 kg (instantaneous)

The results of the modeling are presented in Figure A.12. As can be seen from this figure, the concentration of TCE in the SZ will be reduced to its MCL (2.8 μg/L) within 65 years due to natural attenuation after source reduction of > 500 μg/L to 100 μg/L. Also, TCE is predicted to migrate to a

downgradient distance of approximately 300 m from SAIC 08 before being reduced to 2.8 μg/L through natural attenuation.

Scenario 10: Create Increased Hydraulic Gradient near the source

Assumptions and Input Parameters: Simulation of this scenario using AT123D is identical to Scenario 1, except for adjustment of hydraulic parameters, so that the increased velocity field can be created. Because of increased groundwater velocity, the TCE plume, as a whole, could not be matched. However, the contaminant loading was adjusted to match the core of the plume. The revised calibrated parameters include:

Hydraulic gradient = 0.155 m/m

Source loadings (calibrated):	Period (yr)	Loading (kg/hr)
	0–10	0.496
	10–20	0.0213
	10–30	0.0102
	30–end	0.0

Lateral migrations to the receptors were performed using the AT123D. The model was calibrated by matching the maximum concentrations observed in wells SAIC-16 and COEMW06. The results of the modeling are presented in Figure A.13. As can be seen from the figure, the concentrations of TCE will be reduced to 2.8 μg/L within 28 years.

A.1.6 LIMITATIONS/ASSUMPTIONS

Based upon the data available, a conservative approach was used, which may overestimate the contaminant concentration in the groundwater. 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.
- A highly conservative biodegradation rate for TCE was used.
- 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 such assumptions must be recognized. It is also important to note that the major geochemistry of the plume will change over time and will likely be affected by multiple solutes that are present at the site.

A.2 CAPTURE ZONE MODELING

A.2.1 INTRODUCTION

Contaminants were detected in the groundwater of the aquifer below the site. In particular, a plume of TCE contaminating the groundwater was delineated, and attempts were made to assess remedial (clean-up) alternatives for the groundwater. As such, the assessment was supported through groundwater modeling. Earlier, field tests were conducted to assess hydraulic conditions and to estimate hydraulic parameters of the aquifer. In addition, fate and transport modeling was conducted to estimate the parameters (Appendix A.1). The results from the field and the modeling were considered to develop a mathematical model to simulate groundwater flow through the aquifer. Noted, the model was developed as a screening tool using an analytical approach. It was not calibrated rigorously to site-wide conditions. The resulting model was used for the capture zone modeling required for the assessment.

A.2.2 CONCEPTUAL MODEL

The history, nature, and extent of the plume and a conceptual model for the site are discussed in the main section of this report. Conceptually, the history of the plume suggests release of the contaminant some time ago. The nature and extent of the plume suggests it is trapped and the subsurface medium acts as a source of contamination for the aquifer. In the domain of interest, the site composition is conceptualized to vary from a shallow zone to an intermediate zone to a transition zone to the bedrock with depth below ground surface. Groundwater in the aquifer flows with an average hydraulic gradient of 0.02 ft/ft to the northwest considering field observation. The effective porosity was estimated as 0.2, considering field composition. Hydraulic conductivity was estimated as 1.22, 1.42, and 0.2 ft/day, respectively, for the SZ, TZ, and the bedrock through the fate and transport modeling.

A.2.3 MODELING APPROACH

The modeling approach attempted to analyze groundwater flow under stress. A 3-D model was developed using parameter estimates from the field test and the transport modeling. Priority was given to estimates from the transport modeling, whenever possible. Attempts were made to match the simulated heads to observed heads in the northwest direction through calibration using a trial-and-error technique. In addition, a 3-D particle-tracking model was developed using parameter estimates from the field test and the transport modeling. Again, priority was given to estimates from the transport modeling, whenever possible. The heads generated by the flow model were used to generate the particle tracks by the particle-tracking model. These tracks helped to delineate the capture zone of a stress.

A.2.4 MATHEMATICAL MODEL

A mathematical model was selected considering the conceptual model and the modeling approach. The 3-D model to simulate groundwater flow under stress was developed using the MODFLOW (McDonald and Harbaugh 1988) simulator under the Groundwater Vistas (ESI 1999) environment. MODFLOW is a 3-D, finite-difference, ground-water simulator. This simulator 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 (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.

The 3-D model to simulate particle tracks under stress was set up using the MODPATH (Pollock 1989) simulator under the Groundwater Vistas environment. It can use the heads generated by the MODFLOW model to generate the particle tracks.

A.2.5 MODEL SET-UP/CALIBRATION

The groundwater flow model was developed in multiple steps. First, a 3-D model to simulate groundwater flow was set up using the MODFLOW simulator under the Groundwater Vistas (ESI 1999) environment. The domain of the model was assumed to contain multiple hydrogeologic units, while the flow in the domain was assumed to occur under steady-state condition. Horizontally, the area of the model was extended sufficiently away from the plume to reduce the impact of the boundary conditions on the flow (Figure A.14). An area covering 2500 ft by 2500 ft was considered. The area was discretized using 50 rows and 50 columns. The spacing of the rows and columns was 50 ft. Vertically, the domain was extended from the ground surface through the SZ, TZ, and bedrock units. The domain was discretized using three layers. The SZ of the top and bottom surfaces of the layers were estimated considering field data and the upper 40 ft of the bedrock. The flow in Layer 1 was assumed under unconfined condition, and the saturated thickness of the flow was observed to depend on the elevations of groundwater table and the bottom surface of the layer. The flow in Layer 2 was assumed under a potentially unconfined, or unconfined/confined, condition. The flow in Layer 3 was assumed under a confined condition. In addition, constant-head boundary conditions were considered along the perimeter of the model. Hydraulic conductivity was assumed as 1.22, 1.42, and 0.20 ft/day for Layers 1, 2, and 3 respectively, considering the transport modeling. Effective porosity was assumed as 0.20, 0.20, and 0.01 for Layers 1, 2, and 3, respectively, considering field composition. Most of the area in the domain was assumed to be impervious. No recharge was considered. Second, the boundary conditions were revised through calibration using a trial-and-error technique. Attempts were made to match the simulated groundwater levels to the observed groundwater levels in the northwest direction within an acceptable limit. The simulated head for natural (ambient or prevalent) condition is shown in Figure A.14.

A.2.6 MODEL APPLICATION

The groundwater flow model was assumed acceptable near the plume and, hence, suitable for performing the assessment.

Scenario 1: Chemical Injection in the Shallow Zone

The impact of chemical injection for remediation was studied using the model. First, the grid was refined near the plume to improve accuracy using telescopic mesh refinement (TMR). A sub-domain near the plume was extracted using the technique. It was discretized using 190 rows and 155 columns (Figure A.15). The spacing of these rows and columns was 5 ft. Head for natural conditions was again simulated using the TMR model. The generated heads matched well with the parent model (Figure A.15). Second, an injection well near the center of the plume was considered. The grid was further refined near the center. It was discretized using 197 rows and 162 columns. The spacing of the rows and columns was varied from 0.3 ft to 50 ft with the small spacing near the well (Figure A.16). Third, the model was set up for a transient condition. Fourth, groundwater flow and particle-tracking simulations were performed to estimate the distance a groundwater particle will travel under an injection of 2 gpm for 5 days followed by no injection for 30 days. The distance of travel was observed to vary radially. It was estimated as 8 ft

upgradient, 11 ft downgradient, and between these limits in other directions (Figure A.17). Thus, the average velocity was estimated as between 0.26 and 0.31 ft/day over the 35-day period.

Scenario 2: Chemical Injection in the Transition Zone

The impact of chemical injection in the TZ was studied using the TMR model used from Scenario 1. An injection well near the center of the plume was considered. Thereafter, groundwater flow and particle-tracking simulations were performed to estimate the distance a groundwater particle will travel under an injection of 3 gpm for 5 days followed by no injection for 30 days. The distance of travel was estimated as 19 ft upgradient, 22 ft downgradient, and between these limits in other directions (Figure A.18). Thus, the average velocity was estimated as between 0.54 and 0.63 ft/day over the 35-day period.

A.2.7 CONCLUSIONS

Mathematical models to simulate groundwater flow and particle tracks were developed to support the assessment of remedial alternatives. Two scenarios were considered. First, the impact of an injection in the SZ was estimated. Second, the impact of an injection in the TZ was estimated. The average velocity was estimated as between 0.54 and 0.63 ft/day over the 35-day period.

Assessment of a remedial alternative using a numerical model is difficult. The accuracy of the model is limited to the assumptions and calibration used in developing the model. As such, the assessment needs to be accepted with caution.

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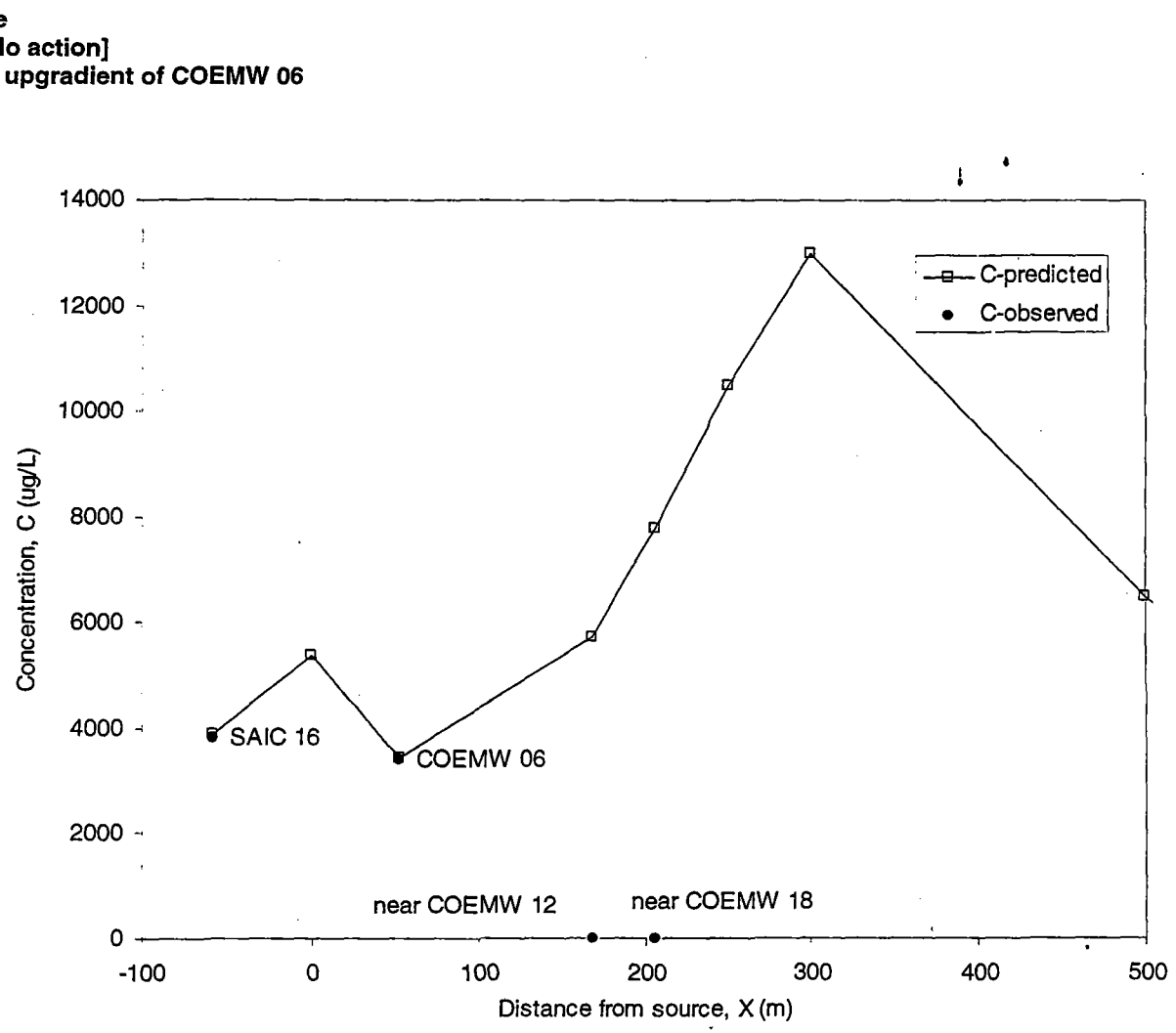


Figure A.1. AT123D Simulation Results for Shallow Zone Using Field Hydraulic Conductivity

Transition Zone
Scenario 6 (No Action)
X = 0 at SAIC 08

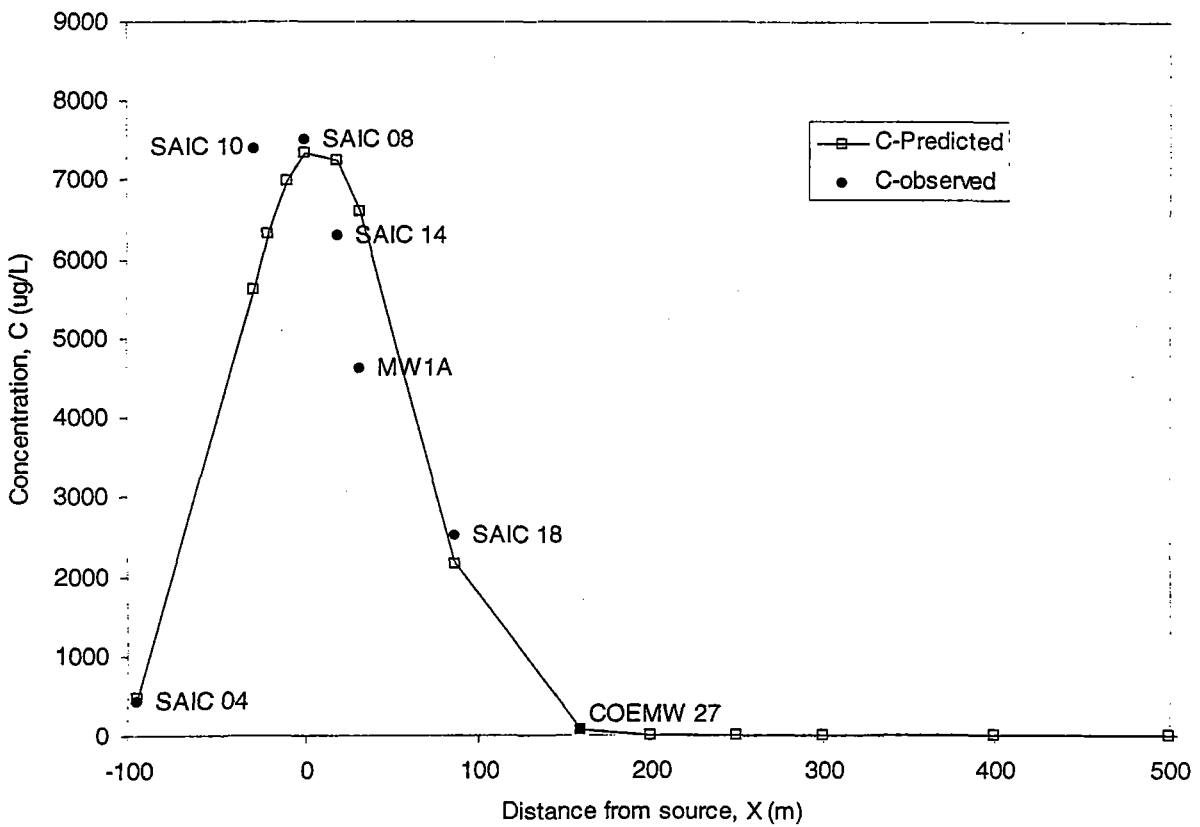


Figure A.2. AT123D Simulation Results for the Transition Zone Using the Geometric Mean Field Hydraulic Conductivity

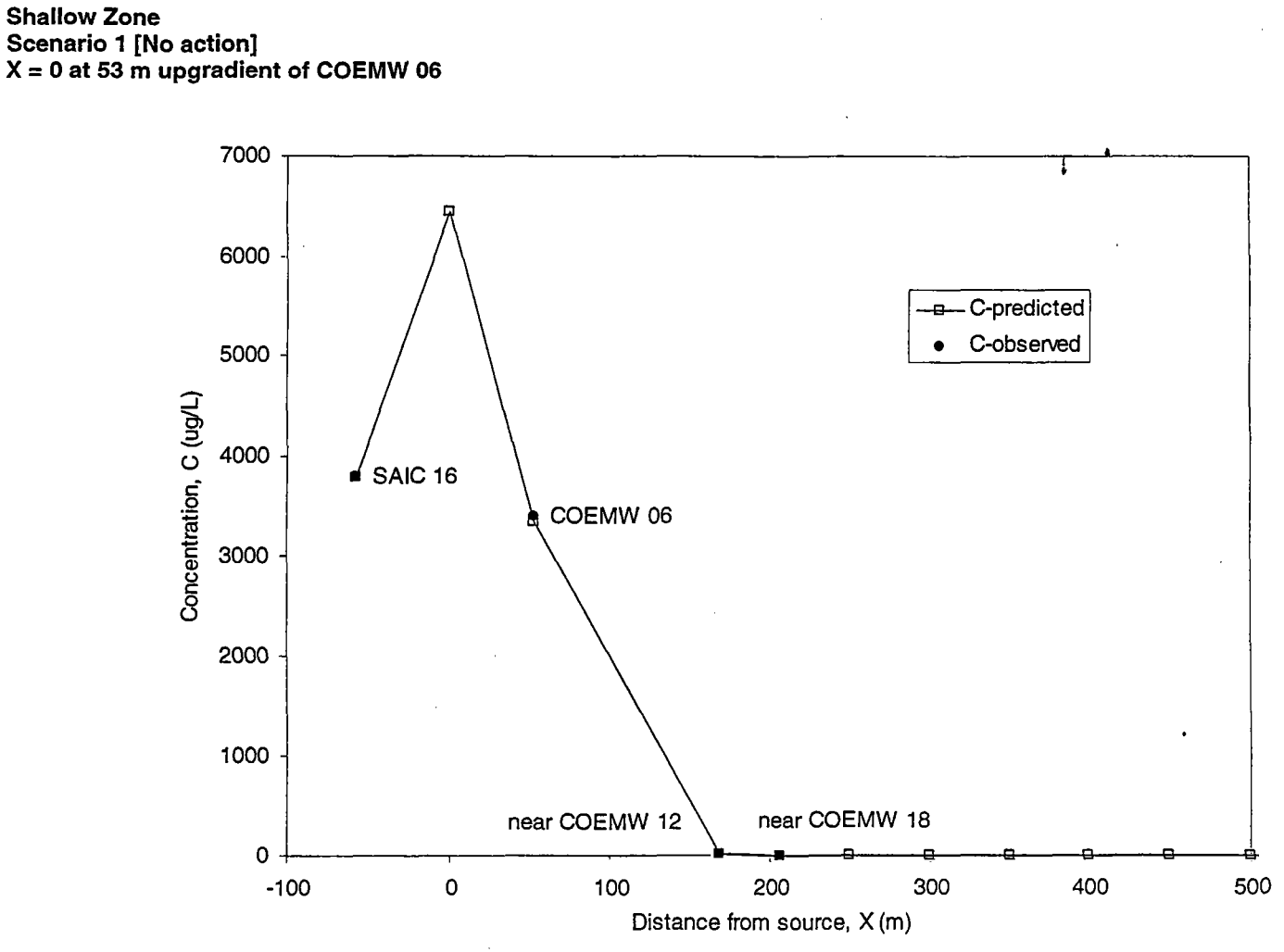


Figure A.3. AT123D Simulation Results for the Shallow Zone Based on Calibration (by revising the field hydraulic conductivity)

Shallow Zone
Scenario 1 [No action]
X=0 at 53m upgradient of COEMW 06

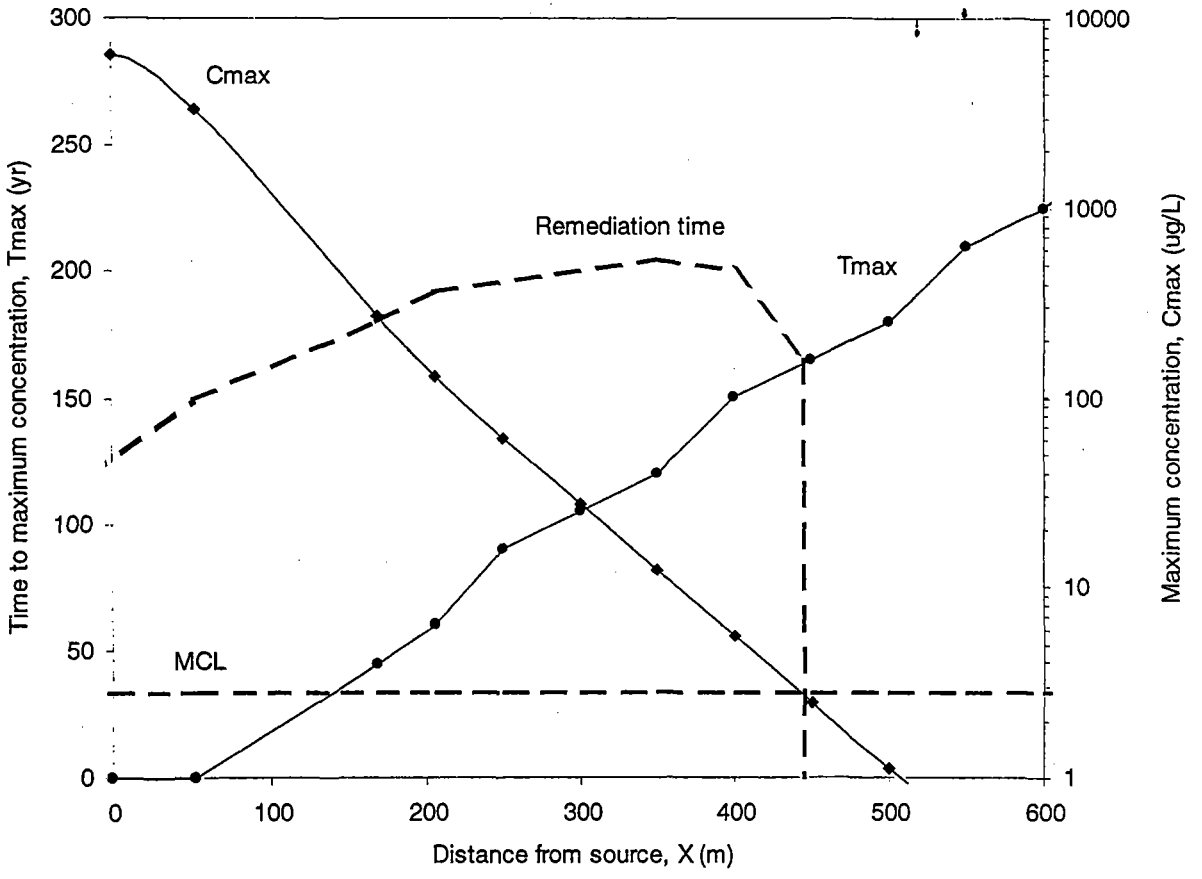


Figure A.4. AT123D Predicted Maximum Concentration, Time to Maximum Concentration, and Remediation Time Versus Down-gradient Distance

Shallow Zone
Scenario 2 [Source reduction to 100 µg/L over the site]
X=0 at 53m upgradient of COEMW 06

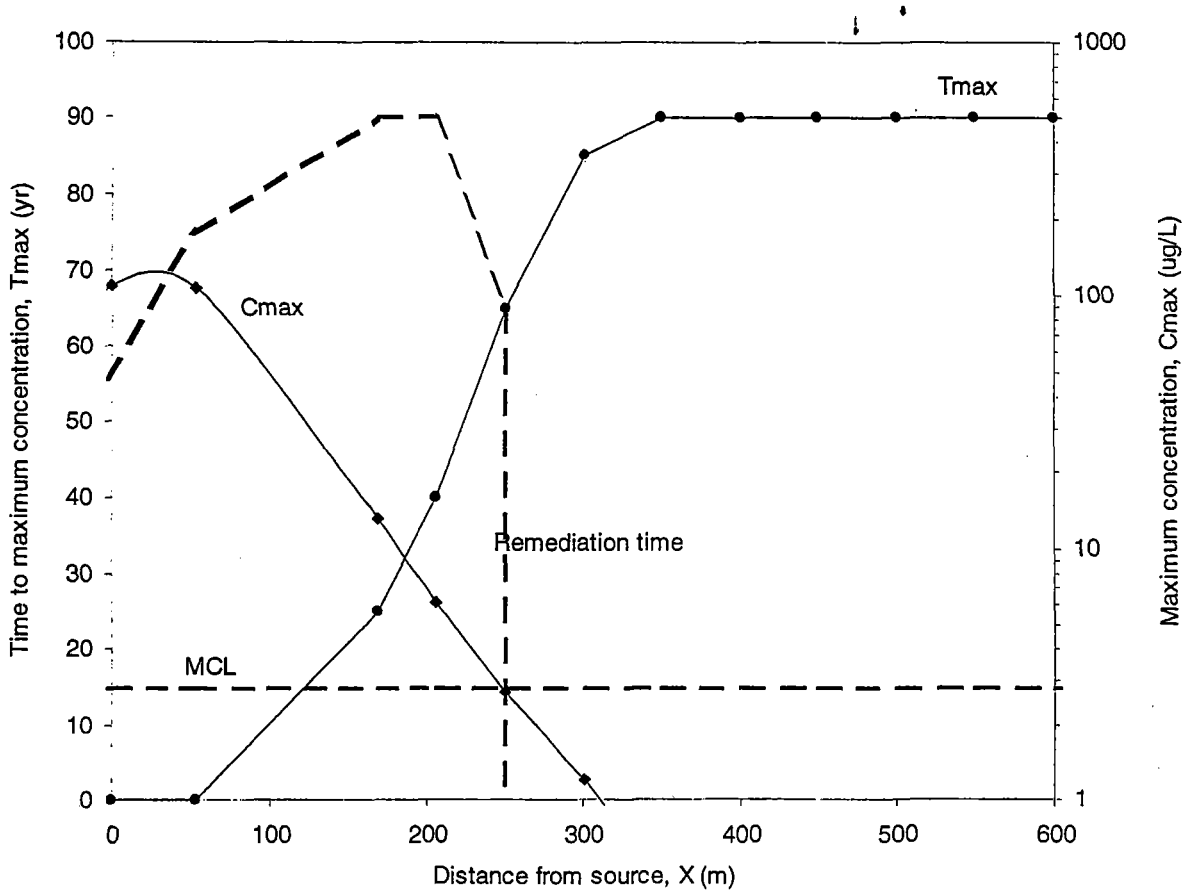


Figure A.5. AT123D predicted maximum concentration, time to maximum concentration, and remediation time versus down-gradient distance

Shallow Zone
Scenario 3 [Source reduction to 100 µg/L within 1000 µg/L plume]
X=0 at 53m upgradient of COEMW 06

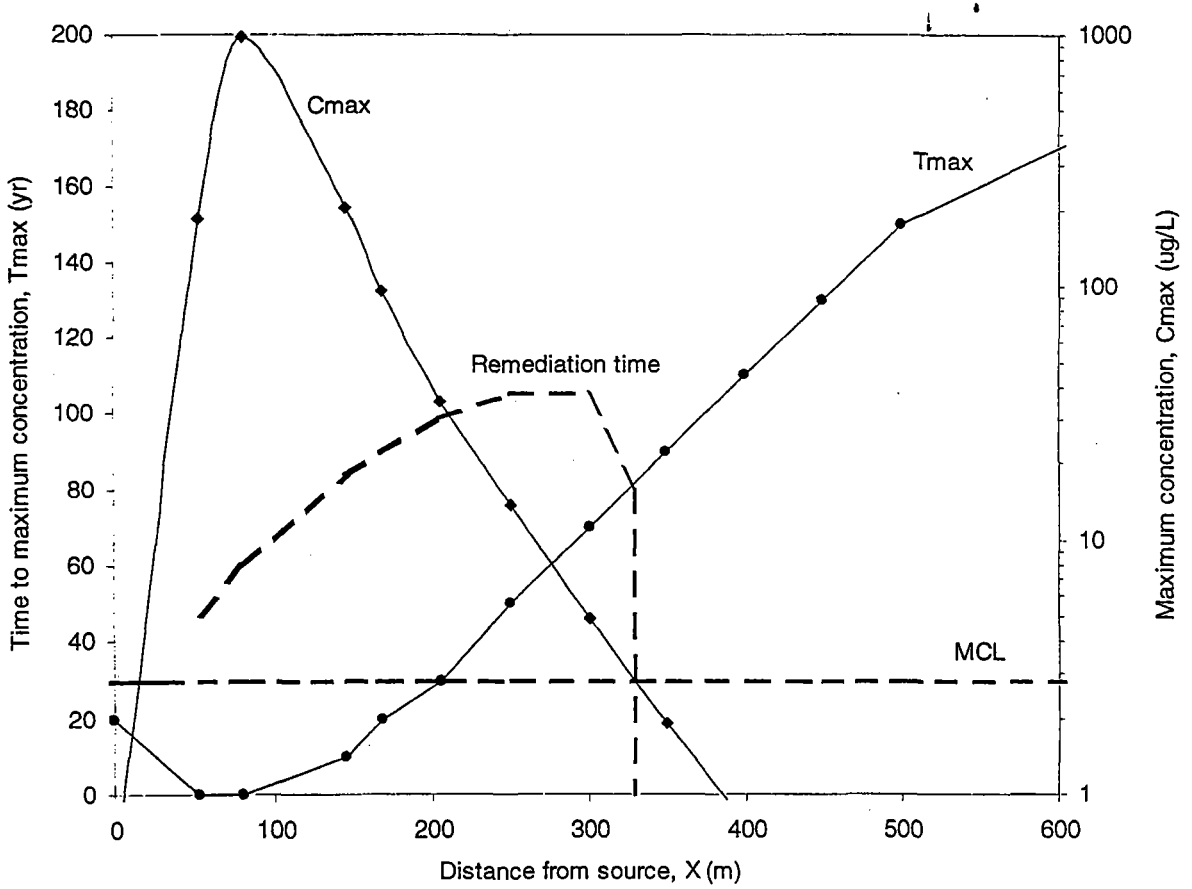


Figure A.6. AT123D predicted maximum concentration, time to maximum concentration, and remediation time versus down-gradient distance

Shallow Zone
Scenario 4 [Source reduction to 100 µg/L within 500 µg/L plume]
X=0 at 53m upgradient of COEMW 06

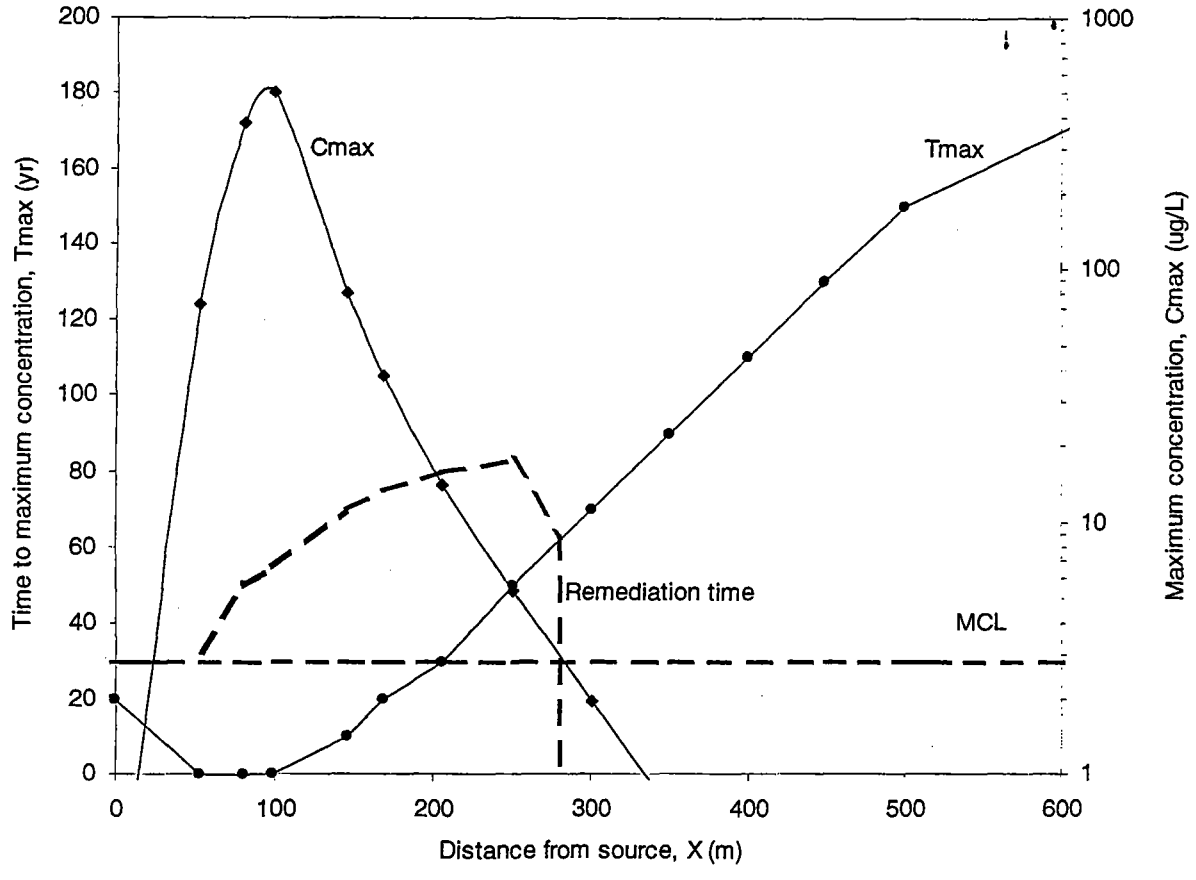
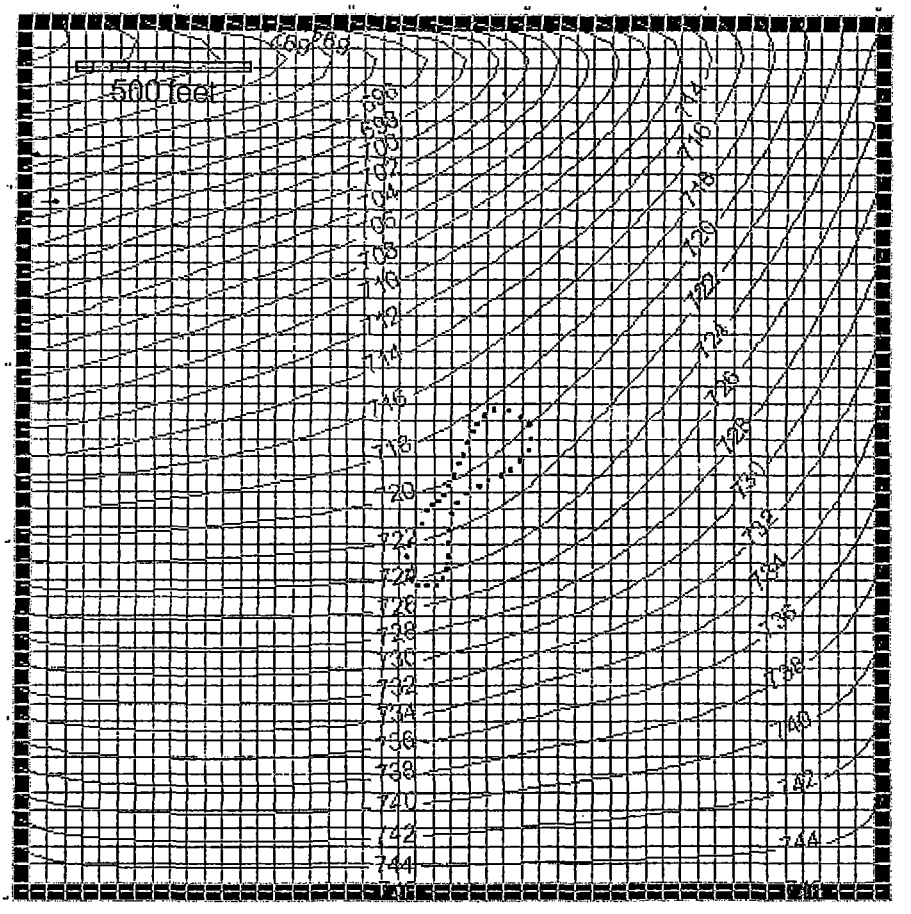
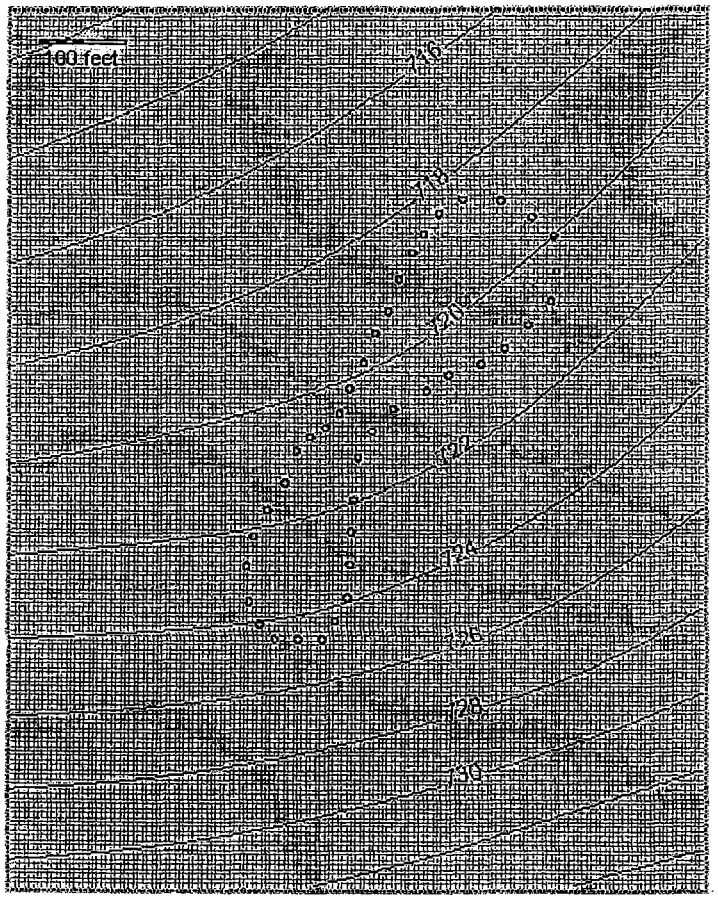


Figure A.7. AT123D predicted maximum concentration, time to maximum concentration, and remediation time versus down-gradient distance



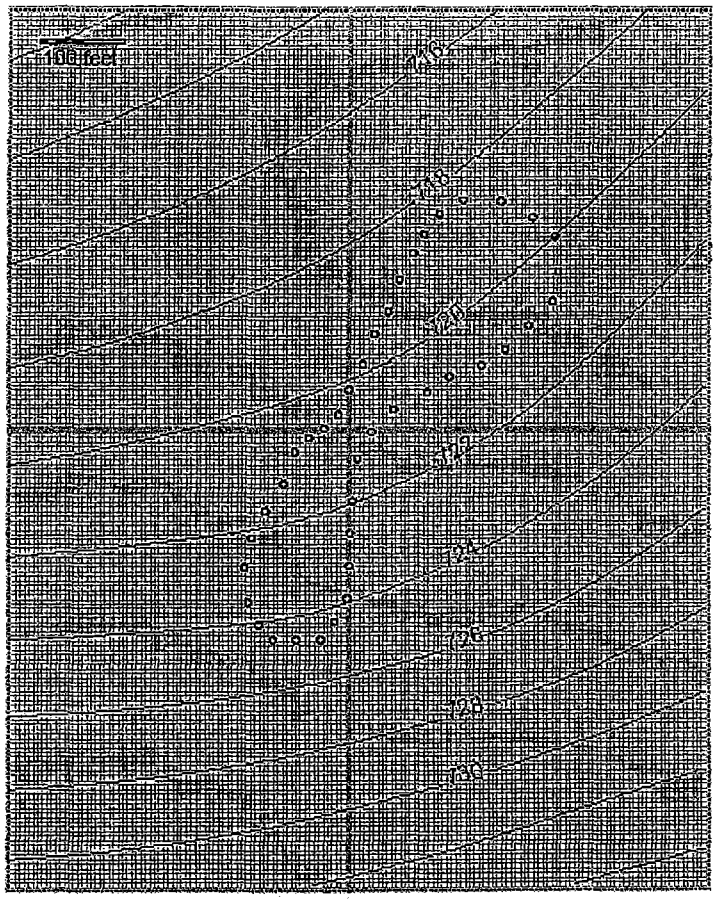
50 rows × 50 columns
dR = 50 ft, dC = 50 ft

Figure A.14. Initial grid for MODFLOW set-up



190 rows × 155 columns
dR = 5 ft, dC = 5 ft

Figure A.15. Refined grid for MODFLOW set-up developed using telescopic mesh refinement (TMR) technique



197 rows × 162 columns
dR = 0.3 to 5.0 ft
dC = 0.3 to 5.0 ft

Figure A.16. Refined grid for MODFLOW set-up developed refining TMR grid

Q = 2 gpm
T1 = 5 days (with injection)
T2 = 30 days (no injection)
Total = 35 days

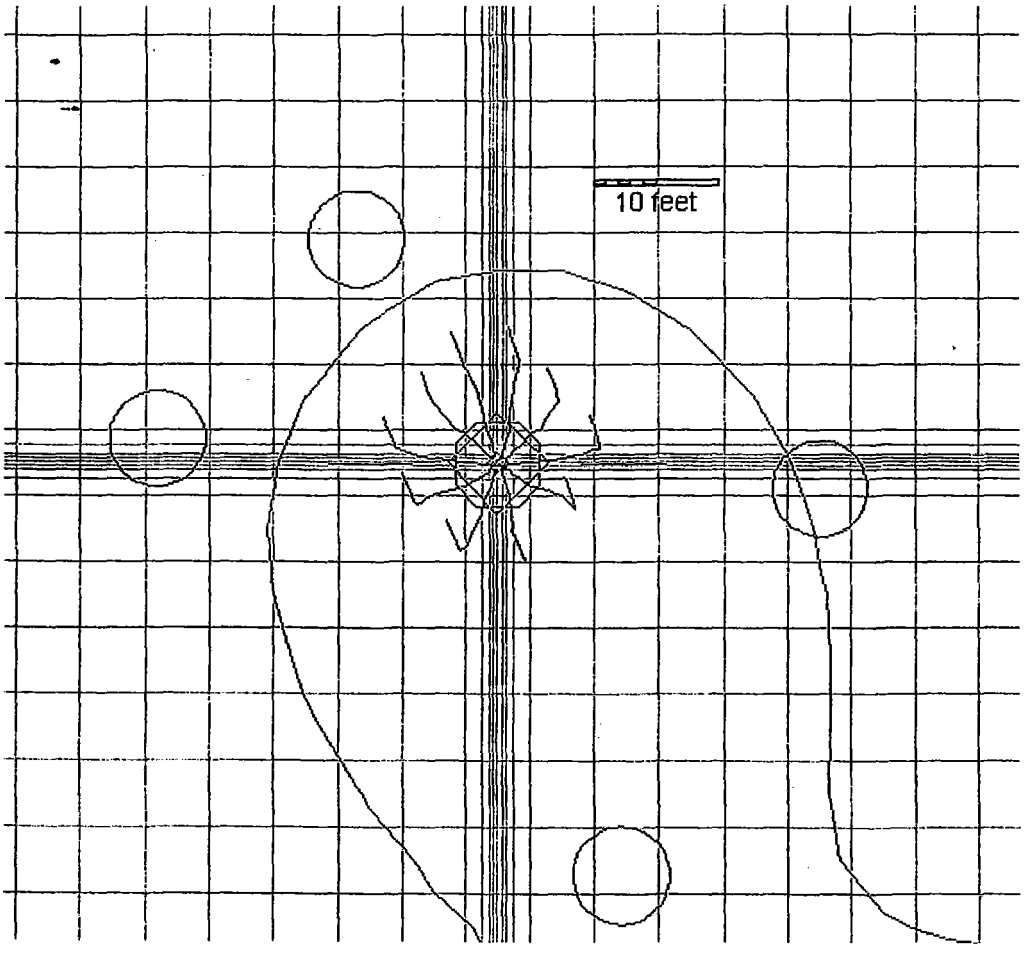


Figure A.17. Particle tracks in shallow zone under injection

C03

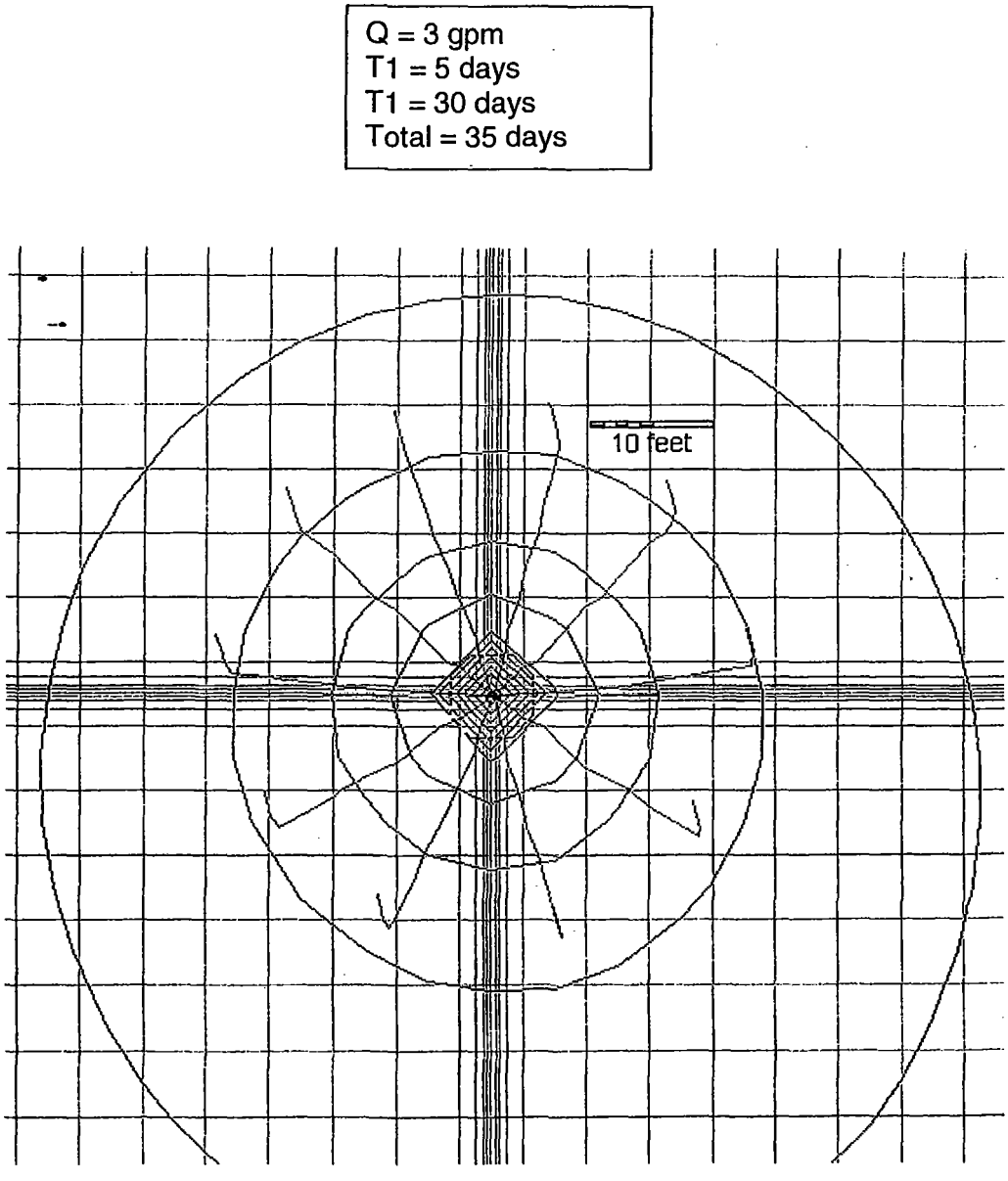


Figure A.18. Particle tracks in transition zone under injection

APPENDIX B

COST ESTIMATES FOR THE FORMER CHARLOTTE ARMY MISSILE PLANT

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Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Summary of Process Options

Dissolved Phase Plume Options		Option Duration (yr)			
			Capital Cost	O&M Cost	Total
1	No Action	0	$0	$0	$0
2	Bioaugmentation (CL-Out)	85	$5,163,885	$1,492,256	$6,656,142
3	Biostimulation (In Situ Co-metabolic Biodegradation)	85	$1,954,163	$1,418,805	$3,372,967
4	Permeable Reactive Barrier	160	$3,086,603	$2,037,482	$5,124,085
5	In Situ Chemical Oxidation	85	$10,090,200	$1,492,256	$11,582,456

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 2 - Bioaugmentation (CL-Out)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Site Work			
Civil Survey (Injection or Monit. Well)	$/well	90.0	Based on historical survey cost.
Civil Survey (monument)	$/mon	120	Based on historical survey cost to establish control. Assume 2 ea.
Surveyor Deliverables	$/ls	1,500	Based on historical survey cost. Data submittal, Drawings, etc.
Utility Locate	$/ea	3,000	Based on historical locating services
Water	$/lot	5,000	Assumed cost to extend water supply to injection control building.
Electric	$/lot	5,000	Extend electric and install temp transformer at injection control building.
Rehabilitate Existing Sewer	$/ls	100,000	Based on relining the existing sewer system. Engineering Estimate
In Situ Biodegredation			
Pilot Study	$/lot	270,000	Install 4 wells, inject 4 times, monitor, report. Based on 10% of full scale.
Injection Permit	$/ea	3200	Assume 40 hrs @ $80/hr.
Injection Well Installation			
Mob/Site Preparation	$/lot	6,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Shallow Wells	ea	39	Assume TD 25' (8" Boring) - Screened 15'-25' - Inc drill, install well, well vault,
Shallow Wells	$/ea	2,791	driller perdiem.
SAIC Geologist	$/ea	858	Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document
Intermediate Wells	ea	39	Assume TD 45' (8" Boring) - Screened 35'-45' - Inc drill, install well, well vault,
Intermediate Wells	$/ea	4,181	driller perdiem.
SAIC Geologist	$/ea	827	Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document
Deep Wells	ea	28	Assume TD 65' (8" Boring) - Screened 55'-65' - Inc drill, install well, well vault,
Deep Wells	$/ea	8,236	driller perdiem.
SAIC Geologist	$/ea	827	Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document
IDW - Hazardous Soil/water	drums	860	Assume 5 drums shallow, 7 drums intermediate, and 14 drums deep for each
IDW - Hazardous Disposal	$/drum	375	well installed. Includes hazardous soil & water combined.
Transportation	ea	12	
Transportation	$/event	1,415	Based on historical IDW disposal cost. Includes mob, forklift, and transportation.
IDW Sampling	ea	123	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample
IDW Sampling	$/ea	425	every 7 drums.
Development Equip, H&S Equip	weeks	11	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.
Injection System Setup			
Injector Installation Labor	days	53	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	106	
Injector Installation Matls	$/well	300	Engineer Estimate
Injection Program - Fixed Cost			Includes fixed equipment cost.
Metering Pump	$/lot	12,000	2 each @ $6,000, up to 10 gpm @ 100 psi, Engineer Estimate
Header System	$/lot	42,000	12 each @ $3,500, Engineer Estimate
Storage Sheds	$/lot	20,000	1 each @ 20,000, Heated, Engineer Estimate
Pressure Pipe	$/lot	500,000	Includes 20,000 lf of 2" HDPE pipe with direct bury installation. $25/lf.
Injection Setup	hours	800	One time setup. Assume 2 field techs for 40 days @ 10 hour/day to setup prior to
Injection Setup	$/hour	60	injection.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 2 - Bioaugmentation (CL-Out)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Per Diem	$/event	9,920	(2 people x 40 days x $124/day)
Cargo Van Rental / Gas	$/event	8,000	(2 trucks x 40 days x $100/day).
Injection Labor	hrs	1,800	Includes 6 injection events. Assume wells are injected in 10 days. Includes travel. Total effort = 2 FTE x 6 events x 15 days x 10 hrs/day
Injection Labor	$/hr	70	
Per Diem	$/lot	15,300	(2 people x 6 events x 15 days x $85/day)
Bioremediation Microbes	events	6	Assume 6 monthly injections @ 5 days each.
Bioremediation Microbes	ea	456	Includes 240 drums injected in shallow zone, 70 drums in the transition zone, and 70 drums in the deep zone. Increased vendor estimate by 20%.
Bioremediation Microbes	$/ea	1,500	Based on vendor quote.
Installation Report	$/report	30,000	Estimate Includes 400 hrs @ $75/hour.
Verification Sampling & Analysis	events	7	
Sampling Labor	wells	10	Includes sampling to monitor effectiveness of sodium permanganate injection. Includes baseline (prior to injection) and after each injection (7 total). Assume 10 injection/monitoring wells sampled during each event. Includes 1 day travel and app
Sampling Labor	hrs/event	60	
Sampling Labor	$/hr	60	
Per Diem	$/event	744	(2 people x 3 days x $124/day)
Cargo Van Rental / Gas	$/event	400	(1 van x 3 days x $100/day). Add $100 for gas
Sample materials	ea/event	23	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	19.96	
Sample equipment	$/event	1,000	Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase.
Analytical Cost	$/event	2,725	Analyze GW samples from 10 wells VOCs (13 @ $125) and natural attenuation parameters (10 @ $110). Includes 10% duplicate, 5% rinsate, and trip blanks.
Sample Shipment	$/event	100	2 coolers @ $50 ea.
Data Management	hrs	23	Data validation
Data Management	$/hr	80	
IDW - Hazardous Water	drum	1	Assume 1 drum for 10 wells.
IDW - Hazardous Disposal	$/drum	375	Based on historical IDW disposal cost.
IDW Transportation	$/event	1,415	Based on historical IDW disposal cost.
Reporting			
Injection and Monitoring Report	$/event	18,000	Based on historical cost. Assume 240 hrs @ $75/hr.
Monitoring Wells			
Mob/Site Preparation	$/lot	6,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Shallow Wells	ea	2	Assume TD 25' (2-inch casing) - Screened 15'-25'. Inc drill, install MW, surface completion, driller perdiem.
Shallow Wells	$/ea	2,426	
SAIC Geologist	$/well	951	Based on historical cost. Inc travel, perdiem, install, develop, document.
Intermediate Wells	ea	2	Assume TD 95' (6" Boring) - Screened 85'-95' - Inc drill, install MW, surface completion, driller perdiem.
Intermediate Wells	$/ea	6,972	
SAIC Geologist	$/well	1,272	Based on historical cost. Inc travel, perdiem, install, develop, document.
Bedrock Wells	ea	2	Assume TD 120' (6" Boring) - Screened 110'-120' - Inc drill, install MW, surface completion, driller perdiem.
Bedrock Wells	$/ea	8,626	
SAIC Geologist	$/well	1,702	Based on historical cost. Inc travel, perdiem, install, develop, document.
IDW - Nonhazardous Soil/water	drums	46	Assume 4 drums shallow, 9 drums intermediate, and 10 drums deep for each well installed. Includes nonhazardous soil & water combined.
IDW - Nonhazardous Disposal	$/drum	62	

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 2 - Bioaugmentation (CL-Out)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Transportation	ea	1	
Transportation	$/event	1,415	Based on historical IDW disposal cost. Includes mob, forklift, and transportation.
IDW Sampling	ea	7	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample
IDW Sampling	$/ea	425	every 7 drums.
Development Equip, H&S Equip	weeks	2	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.
Reporting			
Work Plan	$/event	15,000	Includes 200 hrs @ $75/hr.
O&M			
Site Wide Sampling & Analysis			
Sampling Labor	events	22	Assume an 85-year monitoring period (based on a cMAX of 100 ug/L in the
Sampling Labor	wells	35	transition zone). Includes baseline and annual sampling in Years 1-5, then once
Sampling Labor	hrs/event	160	every five years for years 10 - 85. Assume an average of 35 wells per sampling event. Includes 1 day travel and approximately 5 wells/day. Includes 2 FTE for 8
Sampling Labor	$/hr	60	days @ 10 hrs/day.
Per Diem	$/event	1,984	(2 people x 8 days x $124/day)
Cargo Van Rental / Gas	$/event	900	(1 van x 8 days x $100/day). Add $100 for gas.
Sample materials	ea/event	42	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon
Sample materials	$/ea	19.96	materials.
Sample equipment	$/event	2,500	Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase.
Analytical Cost	$/event	5,250	Analyze GW samples from 30 wells for VOCs (42 @ $125). Includes 10% duplicate, 5% rinsate, and trip blanks.
Sample Shipment	$/event	350	7 coolers @ $50 ea.
Data Management	hrs	42	Assume 1 hour/sample.
Data Management	$/hr	80	
IDW - Nonhazardous Soil/water	drum	2	Assume 2 drums for 35 wells.
IDW - Nonhazardous Disposal	$/drum	62	Based on historical IDW disposal cost.
IDW Transportation	$/event	1,415	Based on historical IDW disposal cost.
Reporting			
Initial Baseline Report	$/event	18,000	Estimate based on historical costs and includes monitoring well installation details. Includes 240 hrs @ $75/hour.
Annual Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
5-Year Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
Well Abandonment			
Abandon Monitoring Wells	lot	1	Assume 43 injection and 35 monitoring wells. Assume $1,000 mob and
Abandon Monitoring Wells	$/lot	118,000	$1500/well to grout.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 2 - Bioaugmentation (CL-Out)
Cost Estimate

CAPITAL COST			$5,163,885
Activity (unit)	Quantity	Unit Cost	Total
Site Work			
Civil Survey (well)	112	$90	$10,080
Civil Survey (monument)	2	$120	$240
Surveyor Deliverables (ls)	1	$1,500	$1,500
Utility Locate	1	$3,000	$3,000
Water (lot)	1	$5,000	$5,000
Electric (lot)	1	$5,000	$5,000
Rehabilitate Existing Sewer (ls)	1	$100,000	$100,000
CL-Out			
Pilot Study (lot)	1	$270,000	$270,000
Injection Permit (ea)	1	$3,200	$3,200
Mob/Site Preparation (lot)	1	$6,000	$6,000
Shallow Wells (ea)	39	$3,649	$142,311
Intermediate Wells (ea)	39	$5,008	$195,312
Deep Wells (ea)	28	$9,063	$253,764
IDW Disposal (drums)	860	$375	$322,500
Transportation (ls)	1	$1,415	$1,415
IDW Sampling (ea)	123	$425	$52,214
Development Equip, H&S Equip (wk)	11	$525	$5,775
Injection System Setup			
Injector Installation Labor (days)	53	$700	$37,100
Injector Installation Materials (well)	106	$300	$31,800
In-Line Injector Pumps (lot)	1	$12,000	$12,000
Header System (lot)	1	$42,000	$42,000
Storage Sheds (lot)	1	$20,000	$20,000
Direct Bury Pressure Pipe (lot)	1	$500,000	$500,000
Injection Setup (hours)	800	$60	$48,000
Injection Setup - Per Diem (lot)	1	$9,920	$9,920
Injection Setup - Cargo Van Rental / Gas (lot)	1	$8,000	$8,000
Injection Program (hours)	1,800	$70	$126,000
Injection Program - Per Diem (lot)	1	$15,300	$15,300
Injection Program - Rental Vehicle (lot)	1	$8,000	$8,000
CL-Out (drums)	456	$1,500	$684,000
Installation Report (ea)	1	$30,000	$30,000
Verification Sampling & Analysis			
Sampling Labor (event)	7	$3,600	$25,200
Per Diem (event)	7	$744	$5,208
Cargo Van Rental / Gas (event)	7	$400	$2,800
Sample materials (event)	7	$459	$3,214
Sample equipment (event)	7	$1,000	$7,000

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 2 - Bioaugmentation (CL-Out)
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total
Verification Sampling & Analysis			
Analytical Cost (event)	7	$2,725	$19,075
Sample Shipment (event)	7	$100	$700
Data Management (event)	7	$1,840	$12,880
IDW Disposal (event)	7	$1,790	$12,530
Reporting			
Final Review and Confirmation Report (ea)	1	$18,000	$18,000
Monitoring Wells			
Mob/Site Preparation (ea)	1	$6,000	$6,000
Shallow Wells (ea)	2	$3,377	$6,754
Intermediate Wells (ea)	2	$8,244	$16,487
Deep Wells (ea)	2	$10,328	$20,655
IDW Disposal (drums)	46	$46	$2,116
Transportation (ls)	1	$1,415	$1,415
IDW Sampling (ea)	7	$425	$2,975
Development Equip, H&S Equip (wk)	2	$525	$1,050
Reporting			
Work Plan (ea)	1	$15,000	$15,000
Subtotal			$3,128,490
Design		6%	$187,709
Office Overhead		5%	$156,424
Field Overhead		15%	$469,273
Subtotal			$3,941,897
Profit		6%	$236,514
Contingency		25%	$985,474
Total			$5,163,885

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 2 - Bioaugmentation (CL-Out)
Cost Estimate

OPERATION AND MAINTENANCE			$1,492,256
Activity (unit)	Quantity	Unit Cost	Total Cost
O&M Sampling & Analysis			
Sampling Labor (event)	22	$9,600	$211,200
Per Diem (event)	22	$1,984	$43,648
Cargo Van Rental / Gas (event)	22	$900	$19,800
Sample materials (event)	22	$838	$18,443
Sample equipment (event)	22	$2,500	$55,000
Analytical Cost (event)	22	$5,250	$115,500
Sample Shipment (event)	22	$350	$7,700
Data Management (event)	22	$3,360	$73,920
IDW Disposal (event)	22	$1,539	$33,858
Reporting			
Initial Baseline Report (ea)	1	$18,000	$18,000
Annual Reports (ea)	5	$9,000	$45,000
5-Year Reports (ea)	16	$9,000	$144,000
Monitoring Well Abandonment			
Abandon Monitoring Well (lot)	1	$118,000	$118,000
Subtotal O&M			$904,069
Design		6%	$54,244
Office Overhead		5%	$45,203
Field Overhead		15%	$135,610
Subtotal			$1,139,127
Profit		6%	$68,348
Contingency		25%	$284,782
Total			$1,492,256

TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost)	$6,656,142

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 3 - Biostimulation (In Situ Co-metabolic Biodegradation)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Site Work			
Civil Survey (Injection or Monit. Well)	$/well	90.0	Based on historical survey cost.
Civil Survey (monument)	$/mon	120	Based on historical survey cost to establish control. Assume 2 ea.
Surveyor Deliverables	$/ls	1,500	Based on historical survey cost. Data submittal, Drawings, etc.
Utility Locate	$/ea	3,000	Based on historical locating services
Gas	$/lot	0	Included below under Horizontal Well Components.
Electric	$/lot	0	Included below under Horizontal Well Components.
Rehabilitate Existing Sewer	$/ls	100,000	Based on relining the existing sewer system. Engineering Estimate
In Situ Co-metabolic Biodegradation			
Pilot Study	$/lot	100,000	Install 1 well, inject, monitor, report. Based on 10% of full scale.
Horizontal Wells	lf	1,600	Includes 2 horizontal wells at 800 lf each. Based on historical cost for similar application at Savannah River Site.
Horizontal Wells	$/lf	200	
Horizontal Well Ancillary Components	lf	1,600	Includes all ancillary labor, equipment, and materials including utility hookups, metering and controls, compressors, distribution piping, IDW collection and disposal, and permitting. Based on historical cost for similar application at Savannah River Site.
Horizontal Well Ancillary Components	$/lf	200	
Injection System O&M			
Injection Monitoring	hours	400	Assume 4 hrs labor per week to monitor injection. Total duration = 100 weeks.
Injection Program	$/hour	60	Assume local labor.
Methane Gas	1000 cf	24,192	Pumping duration = 100 weeks @ 24 hrs/day. 2 injection wells @ 400 cf/minute/well. Methane = 3% or 12 cf/min/well or 34,560 cf/day for both wells. Total volume = 100 weeks x 7 days/week x 34,560 cf/day = 24,192,000 cf.
Methane Gas	$/cf	6.00	Cost based on $6/1000cf. ECHOS 33132916
Installation Report	$/report	24,000	Estimate Includes 320 hrs @ $75/hour.
Verification Sampling & Analysis	events	5	Includes sampling to monitor effectiveness of co-metabolic injection. Includes baseline (prior to injection) and semi-annual sampling for 2 years (5 total).
Sampling Labor	wells	10	Assume 10 injection/monitoring wells sampled during each event. Includes 1 day travel and approximately 5 wells/day. Includes 2 FTE for 3 days @ 10 hrs/day.
Sampling Labor	hrs/event	30	
Sampling Labor	$/hr	60	
Per Diem	$/event	744	(2 people x 3 days x $124/day)
Cargo Van Rental / Gas	$/event	400	(1 van x 3 days x $100/day). Add $100 for gas
Sample materials	ea/event	23	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	19.96	
Sample equipment	$/event	1,000	Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase.
Analytical Cost	$/event	2,725	Analyze GW samples from 10 wells VOCs (13 @ $125) and natural attenuation parameters (10 @ $110). Includes 10% duplicate, 5% rinsate, and trip blanks.
Sample Shipment	$/event	100	2 coolers @ $50 ea.
Data Management	hrs	23	Data validation
Data Management	$/hr	80	
IDW - Hazardous Water	drum	1	Assume 1 drum for 10 wells.
IDW - Hazardous Disposal	$/drum	375	Based on historical IDW disposal cost.
IDW Transportation	$/event	1,415	Based on historical IDW disposal cost.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 3 - Biostimulation (In Situ Co-metabolic Biodegradation)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Reporting			
Injection and Monitoring Report	$/event	18,000	Based on historical cost. Assume 240 hrs @ $75/hr.
Monitoring Wells			
Mob/Site Preparation	$/lot	6,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Shallow Wells	ea	2	Assume TD 25' (2-inch casing) - Screened 15'-25'. Inc drill, install MW, surface completion, driller per diem. Based on historical cost.
Shallow Wells	$/ea	2,426	
SAIC Geologist	$/well	951	Based on historical cost. Inc travel, per diem, install, develop, document.
Intermediate Wells	ea	2	Assume TD 95' (6" Boring) - Screened 85'-95' - Inc drill, install MW, surface completion, driller per diem. Based on historical cost.
Intermediate Wells	$/ea	6,972	
SAIC Geologist	$/well	1,272	Based on historical cost. Inc travel, per diem, install, develop, document.
Bedrock Wells	ea	2	Assume TD 120' (6" Boring) - Screened 110'-120' - Inc drill, install MW, surface completion, driller per diem. Based on historical cost.
Bedrock Wells	$/ea	8,626	
SAIC Geologist	$/well	1,702	Based on historical cost. Inc travel, per diem, install, develop, document.
IDW - Nonhazardous Soil/water	drums	46	Assume 4 drums shallow, 9 drums intermediate, and 10 drums deep for each well installed. Includes nonhazardous soil & water combined.
IDW - Nonhazardous Disposal	$/drum	62	
Transportation	ea	1	
Transportation	$/event	1,415	Based on historical IDW disposal cost. Includes mob, forklift, and transportation.
IDW Sampling	ea	7	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample every 7 drums.
IDW Sampling	$/ea	425	
Development Equip, H&S Equip	weeks	2	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.
Reporting			
Work Plan	$/event	15,000	Includes 200 hrs @ $75/hr.
O&M			
Site Wide Sampling & Analysis			
Sampling Labor	events	22	Assume an 85-year monitoring period (based on a cMAX of 100 ug/L in the transition zone). Includes baseline and annual sampling in Years 1-5, then once every five years for years 10 - 85. Assume an average of 35 wells per sampling event. Includes 1 day travel and approximately 5 wells/day. Includes 2 FTE for 8 days @ 10 hrs/day.
Sampling Labor	wells	35	
Sampling Labor	hrs/event	160	
Sampling Labor	$/hr	60	
Per Diem	$/event	1,984	(2 people x 8 days x $124/day)
Cargo Van Rental / Gas	$/event	900	(1 van x 8 days x $100/day). Add $100 for gas
Sample materials	ea/event	42	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	19.96	
Sample equipment	$/event	2,500	Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase.
Analytical Cost	$/event	5,250	Analyze GW samples from 30 wells for VOCs (42 @ $125). Includes 10% duplicate, 5% rinsate, and trip blanks.
Sample Shipment	$/event	350	7 coolers @ $50 ea.
Data Management	hrs	42	Assume 1 hour/sample.
Data Management	$/hr	80	
IDW - Nonhazardous Soil/water	drum	2	Assume 2 drums for 35 wells.
IDW - Nonhazardous Disposal	$/drum	62	Based on historical IDW disposal cost.
IDW Transportation	$/event	1,415	Based on historical IDW disposal cost.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 3 - Biostimulation (In Situ Co-metabolic Biodegradation)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Reporting			
Initial Baseline Report	$/event	18,000	Estimate based on historical costs and includes monitoring well installation details. Includes 240 hrs @ $75/hour.
Annual Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
5-Year Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
Well Abandonment			
Abandon Monitoring Wells	lot	1	Assume 2 horizontal wells and 35 monitoring wells. Assume $1,000 mob,
Abandon Monitoring Wells	$/lot	73,500	$10,000 to grout each horizontal well, and $1500/well to grout monitoring well.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 3 - Biostimulation (In Situ Co-metabolic Biodegradation)
Cost Estimate

CAPITAL COST			$1,954,163
Activity (unit)	Quantity	Unit Cost	Total
Site Work			
Civil Survey (well)	6	$90	$540
Civil Survey (monument)	2	$120	$240
Surveyor Deliverables (ls)	1	$1,500	$1,500
Utility Locate	1	$3,000	$3,000
Rehabilitate Existing Sewer (ls)	1	$100,000	$100,000
In Situ Co-metabolic Biodegradation			
Pilot Study (lot)	1	$100,000	$100,000
Horizontal Wells (ea)	1,600	$200	$320,000
Horizontal Wells Ancillary Components (ea)	1,600	$200	$320,000
Injector System O&M			
Injector Monitoring (hrs)	400	$60	$24,000
Methane Gas (1000 cf)	24,192	$6	$145,152
Installation Report (ea)	1	$24,000	$24,000
Verification Sampling & Analysis			
Sampling Labor (event)	5	$1,800	$9,000
Per Diem (event)	5	$744	$3,720
Cargo Van Rental / Gas (event)	5	$400	$2,000
Sample materials (event)	5	$459	$2,295
Sample equipment (event)	5	$1,000	$5,000
Analytical Cost (event)	5	$2,725	$13,625
Sample Shipment (event)	5	$100	$500
Data Management (event)	5	$1,840	$9,200
IDW Disposal (event)	5	$1,790	$8,950
Reporting			
Injection and Monitoring Report (ea)	1	$18,000	$18,000
Monitoring Wells			
Mob/Site Preparation (ea)	1	$6,000	$6,000
Shallow Wells (ea)	2	$3,377	$6,754
Intermediate Wells (ea)	2	$8,244	$16,487
Deep Wells (ea)	2	$10,328	$20,655
IDW Disposal (drums)	46	$62	$2,852
Transportation (ls)	1	$1,415	$1,415
IDW Sampling (ea)	7	$425	$2,975
Development Equip, H&S Equip (wk)	2	$525	$1,050

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 3 - Biostimulation (In Situ Co-metabolic Biodegradation)
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total
Reporting			
Work Plan (ea)	1	$15,000	$15,000
Subtotal			$1,183,910
Design		6%	$71,035
Office Overhead		5%	$59,196
Field Overhead		15%	$177,587
Subtotal			$1,491,727
Profit		6%	$89,504
Contingency		25%	$372,932
Total			$1,954,163

OPERATION AND MAINTENANCE $1,418,805

Activity (unit)	Quantity	Unit Cost	Total Cost
O&M Sampling & Analysis			
Sampling Labor (event)	22	$9,600	$211,200
Per Diem (event)	22	$1,984	$43,648
Cargo Van Rental / Gas (event)	22	$900	$19,800
Sample materials (event)	22	$838	$18,443
Sample equipment (event)	22	$2,500	$55,000
Analytical Cost (event)	22	$5,250	$115,500
Sample Shipment (event)	22	$350	$7,700
Data Management (event)	22	$3,360	$73,920
IDW Disposal (event)	22	$1,539	$33,858
Reporting			
Initial Baseline Report	1	$18,000	$18,000
Annual Reports	5	$9,000	$45,000
5-Year Reports	16	$9,000	$144,000
Monitoring Well Abandonment			
Abandon Monitoring Well (lot)	1	$73,500	$73,500
Subtotal O&M			$859,569
Design		6%	$51,574
Office Overhead		5%	$42,978
Field Overhead		15%	$128,935
Subtotal			$1,083,057
Profit		6%	$64,983
Contingency		25%	$270,764
Total			$1,418,805

TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost) $3,372,967

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 4 - Permeable Reactive Barrier
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Site Work			
Civil Survey (Injection or Monit. Well)	$/well	90.0	Based on historical survey cost.
Civil Survey (monument)	$/mon	120	Based on historical survey cost to establish control. Assume 2 ea.
Surveyor Deliverables	$/ls	1,500	Based on historical survey cost. Data submittal, Drawings, etc.
Utility Locate	$/ea	3,000	Based on historical locating services
Water	$/lot	0	Assumed cost to extend water supply to injection control building.
Electric	$/lot	0	Extend electric and install temp transformer at injection control building.
Rehabilitate Existing Sewer	$/ls	100,000	Based on relining the existing sewer system. Engineering Estimate
Permeable Reactive Barrier (PRB) Installation			
Geotechnical Investigation	holes	7	Assume 7 holes at 40 ft centers.
Geotechnical Investigation	$/hole	2000	Includes mob/demob, drill rig and crew, 14 samples. Ref RACER.
Geotechnical Analysis	$/hole	1200	Assume 2 samples/hole. Analyze for grain size, permeability, moisture content, and SG.
Mob/Site Preparation	$/lot	15,000	Based on vendor quote.
Length of PRB	ft	330	PRB installation includes drilling 380 ea. - 1 ft dia. holes. The PRB columns will be installed along 2 parallel lines at 2 ft centers.
PRB Columns	ea	330.0	
PRB Columns Diameter	ft	1.0	
Height of PRB	ft	70.0	
Volume of Excavation	cy	672	In-situ volume.
PRB Wall Installation	$/lf	85.00	Based on vendor quote.
Iron Materials	cf	4,536	Vendor quote. Includes 20% Fe, delivery to site, and 5% waste.
Iron Materials	$/cf	68	Vendor quote. Includes delivery to site.
Treatment Media Sand	cy	571	Includes sand delivered to site and 5% waste.
Treatment Media Sand	$/cy	21	
Iron and Sand Installation	$/lf	17	Based on vendor quote.
IDW - Hazardous Soil/water	drums	2,592	Assume 7 drums intermediate for each well installed. Includes nonhazardous soil & water combined.
IDW - Hazardous Disposal	$/drum	375	
Transportation	ea	1	Based on historical IDW disposal cost. Includes mob, forklift, and transportation.
Transportation	$/event	1,415	
IDW Sampling	ea	370	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample every 7 drums.
IDW Sampling	$/ea	425	
Development Equip, H&S Equip	weeks	48	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.
Decon Pad	$/lot	2,000	Engineering estimate.
Demobilization	$/lot	0	Included in mobilization cost.
Installation Report	$/report	15,000	Assumes 200 hrs @ $75/hr to prepare report.
PRB License Fee	%	15.0%	License fee was applied to the mob/demob & construction of the PRB.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 4 - Permeable Reactive Barrier
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Monitoring Wells			
Mob/Site Preparation	$/lot	6,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Shallow Wells	ea	2	Assume TD 25' (2-inch casing) - Screened 15'-25'. Inc drill, install MW,
Shallow Wells	$/ea	2,426	surface completion, driller per diem. Based on historical cost.
SAIC Geologist	$/well	951	Based on historical cost. Inc travel, per diem, install, develop, document.
Intermediate Wells	ea	2	Assume TD 95' (6" Boring) - Screened 85'-95' - Inc drill, install MW,
Intermediate Wells	$/ea	6,972	surface completion, driller per diem. Based on historical cost.
SAIC Geologist	$/well	1,272	Based on historical cost. Inc travel, per diem, install, develop, document.
Bedrock Wells	ea	2	Assume TD 120' (6" Boring) - Screened 110'-120' - Inc drill, install MW,
Bedrock Wells	$/ea	8,626	surface completion, driller per diem. Based on historical cost.
SAIC Geologist	$/well	1,702	Based on historical cost. Inc travel, per diem, install, develop, document.
IDW - Nonhazardous Soil/water	drums	46	Assume 4 drums shallow, 9 drums intermediate, and 10 drums deep for
IDW - Nonhazardous Disposal	$/drum	62	each well installed. Includes nonhazardous soil & water combined.
Transportation	ea	1	Based on historical IDW disposal cost. Includes mob, forklift, and
Transportation	$/event	1,415	transportation.
IDW Sampling	ea	7	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite
IDW Sampling	$/ea	425	sample every 7 drums.
Development Equip, H&S Equip	weeks	2	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.
Reporting			
Work Plan	$/event	15,000	Includes 200 hrs @ $75/hr.
O&M			
Site Wide Sampling & Analysis			
Sampling Labor	events	37	Assume an 160-year monitoring period (based on a cMAX of 100 ug/L in
Sampling Labor	wells	35	the transition zone). Includes baseline and annual sampling in Years 1-5,
Sampling Labor	hrs/event	160	then once every five years for years 10 - 160. Assume an average of 35
Sampling Labor	$/hr	60	wells per sampling event. Includes 1 day travel and approximately 5 wells/day. Includes 2 FTE for 8 days @ 10 hrs/day.
Per Diem	$/event	1,984	(2 people x 8 days x $124/day)
Cargo Van Rental / Gas	$/event	900	(1 van x 8 days x $100/day). Add $100 for gas
Sample materials	ea/event	42	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon
Sample materials	$/ea	19.96	materials.
Sample equipment	$/event	2,500	Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase.
Analytical Cost	$/event	5,250	Analyze GW samples from 30 wells for VOCs (42 @ $125). Includes 10% duplicate, 5% rinsate, and trip blanks.
Sample Shipment	$/event	350	7 coolers @ $50 ea.
Data Management	hrs	42	Assume 1 hour/sample.
Data Management	$/hr	80	
IDW - Nonhazardous Soil/water	drum	2	Assume 2 drums for 35 wells.
IDW - Nonhazardous Disposal	$/drum	62	Based on historical IDW disposal cost.
IDW Transportation	$/event	1,415	Based on historical IDW disposal cost.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 4 - Permeable Reactive Barrier
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Treatment System O&M			
PRB Replacement	$/ls	0	Assume PRB will not require replacement or removal.
PRB Removal	$/ls	0	Will PRB need to be replaced
Reporting			
Initial Baseline Report	$/event	18,000	Estimate based on historical costs and includes monitoring well installation details. Includes 240 hrs @ $75/hour.
Annual Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
5-Year Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
Well Abandonment			
Abandon Monitoring Wells	lot	1	Assume 35 monitoring wells. Assume $1,000 mob and $1500/well to grout.
Abandon Monitoring Wells	$/lot	53,500	

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 4 - Permeable Reactive Barrier
Cost Estimate

CAPITAL COST			$3,086,603
Activity (unit)	**Quantity**	**Unit Cost**	**Total**
Site Work			
Civil Survey (Injection or Monit. Well)	6	$90	$540
Civil Survey (monument)	1	$120	$120
Surveyor Deliverables	1	$1,500	$1,500
Utility Locate	1	$3,000	$3,000
Rehabilitate Existing Sewer (ls)	1	$100,000	$100,000
Permeable Reactive Barrier (PRB) Installation			
Geotechnical Investigation (hole)	7	$2,000	$14,000
Geotechnical Analysis (hole)	7	$1,200	$8,400
Mob/Site Preparation (lot)	1	$15,000	$15,000
PRB Wall Installation (lf)	330	$85	$28,050
Iron Materials (cf)	4,536	$68	$308,436
Treatment Media Sand (cy)	571	$21	$11,995
Iron and Sand Installation (lf)	330	$17	$5,610
IDW - Hazardous Soil/water (drum)	2,592	$375	$971,963
Transportation (lot)	1	$1,415	$1,415
IDW Sampling (ea)	370	$425	$157,366
Development Equip, H&S Equip (wk)	48	$525	$25,200
Installation Report (ea)	1	$15,000	$15,000
PRB License Fee (ls)	1	$234,365	$234,365
Monitoring Wells			
Mob/Site Preparation (lot)	1	$6,000	$6,000
Shallow Wells (ea)	2	$3,377	$6,754
Intermediate Wells (ea)	2	$8,244	$16,487
Bedrock Wells (ea)	2	$10,328	$20,655
IDW - Nonhazardous Soil/water (drum)	46	$62	$2,852
Transportation (lot)	1	$1,415	$1,415
IDW Sampling (ea)	7	$425	$2,975
Development Equip, H&S Equip (wk)	2	$525	$1,050
Reporting			
Work Plan (ea)	1	$15,000	$15,000
Subtotal			$1,869,988
Design		6%	$112,199
Office Overhead		5%	$93,499
Field Overhead		15%	$280,498
Subtotal			$2,356,185
Profit		6%	$141,371
Contingency		25%	$589,046
Total			$3,086,603

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 4 - Permeable Reactive Barrier
Cost Estimate

OPERATION AND MAINTENANCE **$2,037,482**

Activity (unit)	Quantity	Unit Cost	Total Cost
Site Wide Sampling & Analysis			
Sampling Labor (event)	37	$9,600	$355,200
Per Diem (event)	37	$1,984	$73,408
Cargo Van Rental / Gas (event)	37	$900	$33,300
Sample materials (event)	37	$838	$31,018
Sample equipment (event)	37	$2,500	$92,500
Analytical Cost (event)	37	$5,250	$194,250
Sample Shipment (event)	37	$350	$12,950
Data Management (event)	37	$3,360	$124,320
IDW - Nonhazardous Disposal (event)	37	$124	$4,588
IDW Transportation (event)	37	$1,415	$52,355
Reporting			
Initial Baseline Report	1	$18,000	$18,000
Annual Reports	5	$9,000	$45,000
5-Year Reports	16	$9,000	$144,000
Well Abandonment			
Abandon Monitoring Wells (lot)	1	$53,500	$53,500
Subtotal O&M			$1,234,389
Design		6%	$74,063
Office Overhead		5%	$61,719
Field Overhead		15%	$185,158
Subtotal			$1,555,330
Profit		6%	$93,320
Contingency		25%	$388,832
Total			$2,037,482

TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost) **$5,124,085**

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 5 - In Situ Chemical Oxidation
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Site Work			
Civil Survey (Injection or Monit. Well)	$/well	90	Based on historical survey cost.
Civil Survey (monument)	$/mon	120	Based on historical survey cost to establish control. Assume 2 ea.
Surveyor Deliverables	$/ls	1,500	Based on historical survey cost. Data submittal, Drawings, etc.
Utility Locate	$/ea	3,000	Based on historical locating services
Water	$/lot	5,000	Assumed cost to extend water supply to injection control building.
Electric	$/lot	5,000	Extend electric & install temp transformer at injection control building.
Rehabilitate Existing Sewer	$/ls	100,000	Based on relining the existing sewer system. Engineering Estimate
In Situ Chemical Oxidation			
Pilot Study	$/lot	540,000	Install 4 wells, inject 4 times, monitor, report. Based on 10% of full scale.
Sodium Permang. Inject. Permit	$/ea	3200	Assume 40 hrs @ $80/hr.
Injection Well Installation			
Mob/Site Preparation	$/lot	6,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Shallow Wells	ea	39	Assume TD 25' (8" Boring) - Screened 15'-25' - Inc drill, install well, well vault,
Shallow Wells	$/ea	2,791	driller per diem. Based on historical cost.
SAIC Geologist	$/ea	858	Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document
Intermediate Wells	ea	39	Assume TD 45' (8" Boring) - Screened 35'-45' - Inc drill, install well, well vault,
Intermediate Wells	$/ea	4,181	driller per diem. Based on historical cost.
SAIC Geologist	$/ea	827	Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document
Deep Wells	ea	28	Assume TD 65' (8" Boring) - Screened 55'-65' - Inc drill, install well, well vault,
Deep Wells	$/ea	8,236	driller per diem. Based on historical cost.
SAIC Geologist	$/ea	827	Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document
IDW - Hazardous Soil/water	drums	860	Assume 5 drums shallow, 7 drums intermediate, and 14 drums deep for each
IDW - Hazardous Disposal	$/drum	375	well installed. Includes nonhazardous soil & water combined.
Transportation	ea	12	Based on historical IDW disposal cost. Includes mob, forklift, and
Transportation	$/event	1,415	transportation.
IDW Sampling	ea	123	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample
IDW Sampling	$/ea	425	every 7 drums.
Development Equip, H&S Equip	weeks	11	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.
Injection System Setup			
Injector Installation Labor	days	53	Duration based on installing 2 injector setups/day.
Injector Installation Labor	$/day	700	1 FTE at $70/hr and 10 hour days.
Injector Installation Matls	wells	106	
Injector Installation Matls	$/well	300	Engineer Estimate
Injection Program - Fixed Cost			Includes fixed equipment cost.
Metering Pump	$/lot	12,000	2 each @ $6,000, up to 10 gpm @ 100 psi, Engineer Estimate
Header System	$/lot	42,000	12 each @ $3,500, Engineer Estimate
Storage Sheds	$/lot	20,000	1 each @ 20,000, Heated, Engineer Estimate
Direct Bury Pressure Pipe	$/lot	500,000	Includes 20,000 lf of 2" HDPE pipe with direct bury installation. $25/lf.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 5 - In Situ Chemical Oxidation
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Injection Setup	hours	800	One time setup. Assume 2 field techs for 40 days @ 10 hour/day to setup prior to injection.
Injection Setup	$/hour	60	
Per Diem	$/event	9,920	(2 people x 40 days x $124/day)
Cargo Van Rental / Gas	$/event	8,000	(2 trucks x 40 days x $100/day).
Injection Program	days	80	Assume 2 injections each in Years 1 and 2. Total = 4 injections. Assume 2 field techs for 20 days @ 10 hour/day per injection (covers travel, setup, and injection). Total = 80 days or 1,600 hrs for technicians.
Injection Program	hours	1,600	
Injection Program	$/hour	60	
Per Diem	$/event	19,840	(2 people x 80 days x $124/day)
Cargo Van Rental / Gas	$/event	16,600	(2 trucks x 80 days x $100/day) Add $600 for gas..
Sodium Permanganate Materials	event	4	Pumping duration 5 days = 120 hours. 106 injection wells @ 3 gpm = approx 318 gpm Total system flow = 318 gpm Total gallons = 120 hours x 60 minutes/hr x 318 gallons/minute = 2,289,600 gallons Assume 0.5% permanganate by volume = 11,448 gallons of 40% permanganate (as delivered to site) required 11,448 / 0.4 = 28,620 gallons
Sodium Permanganate Materials	$/event	860,000	($3/lb) - Approx. $30.00/gallon = $860,000 / per 5 day injection
Installation Report	$/report	30,000	Estimate Includes 400 hrs @ $75/hour.
Verification Sampling & Analysis	events	5	Includes sampling to monitor effectiveness of sodium permanganate injection. Includes baseline (prior to injection) and 6 months after each injection (5 total). Assume 10 injection/monitoring wells sampled during each event. Includes 1 day travel and approximately 5 wells/day. Includes 2 FTE for 3 days @ 10 hrs/day.
Sampling Labor	wells	10	
Sampling Labor	hrs/event	60	
Sampling Labor	$/hr	60	
Per Diem	$/event	744	(2 people x 3 days x $124/day)
Cargo Van Rental / Gas	$/event	400	(1 van x 3 days x $100/day). Add $100 for gas.
Sample materials	ea/event	23	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	19.96	
Sample equipment	$/event	1,000	Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase.
Analytical Cost	$/event	2,725	Analyze GW samples from 10 wells VOCs (13 @ $125) and natural attenuation parameters (10 @ $110). Includes 10% duplicate, 5% rinsate, and trip blanks.
Sample Shipment	$/event	100	2 coolers @ $50 ea.
Data Management	hrs	23	Assume 1 hour/sample.
Data Management	$/hr	80	
IDW - Hazardous Water	drum	1	Assume 1 drum for 10 wells.
IDW - Hazardous Disposal	$/drum	375	Based on historical IDW disposal cost.
IDW Transportation	$/event	1,415	Based on historical IDW disposal cost.
Reporting			
Injection and Monitoring Report	$/event	18,000	Based on historical cost. Assume 240 hrs @ $75/hr.
Monitoring Wells			
Mob/Site Preparation	$/lot	6,000	Based on historical drilling cost. Inc mob/demob, and decon pad.
Shallow Wells	ea	2	Assume TD 25' (2-inch casing) - Screened 15'-25'. Inc drill, install MW, surface completion, driller per diem. Based on historical cost.
Shallow Wells	$/ea	2,426	
SAIC Geologist	$/well	951	Based on historical cost. Inc travel, per diem, install, develop, document.

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 5 - In Situ Chemical Oxidation
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Intermediate Wells	ea	2	Assume TD 95' (6" Boring) - Screened 85'-95' - Inc drill, install MW, surface completion, driller per diem. Based on historical cost.
Intermediate Wells	$/ea	6,972	
SAIC Geologist	$/well	1,272	Based on historical cost. Inc travel, per diem, install, develop, document.
Bedrock Wells	ea	2	Assume TD 120' (6" Boring) - Screened 110'-120' - Inc drill, install MW, surface completion, driller per diem. Based on historical cost.
Bedrock Wells	$/ea	8,626	
SAIC Geologist	$/well	1,702	Based on historical cost. Inc travel, per diem, install, develop, document.
IDW - Nonhazardous Soil/water	drums	46	Assume 4 drums shallow, 9 drums intermediate, and 10 drums deep for each well installed. Includes nonhazardous soil & water combined.
IDW - Nonhazardous Disposal	$/drum	62	
Transportation	ea	1	Based on historical IDW disposal cost. Includes mob, forklift, and transportation.
Transportation	$/event	1,415	
IDW Sampling	ea	7	Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample every 7 drums.
IDW Sampling	$/ea	425	
Development Equip, H&S Equip	weeks	2	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.
Reporting			
Work Plan	$/event	15,000	Includes 200 hrs @ $75/hr.
O&M			
Site Wide Sampling & Analysis			
Sampling Labor	events	22	Assume an 85-year monitoring period (based on a cMAX of 100 ug/L in the transition zone). Includes baseline and annual sampling in Years 1-5, then once every five years for years 10 -85. Assume an average of 35 wells per sampling event. Includes 1 day travel and approximately 5 wells/day. Includes 2 FTE for 8 days @ 10 hrs/day.
Sampling Labor	wells	35	
Sampling Labor	hrs/event	160	
Sampling Labor	$/hr	60	
Per Diem	$/event	1,984	(2 people x 8 days x $124/day)
Cargo Van Rental / Gas	$/event	900	(1 van x 8 days x $100/day). Add $100 for gas.
Sample materials	ea/event	42	Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials.
Sample materials	$/ea	19.96	
Sample equipment	$/event	2,500	Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase.
Analytical Cost	$/event	5,250	Analyze GW samples from 30 wells for VOCs (42 @ $125). Includes 10% duplicate, 5% rinsate, and trip blanks.
Sample Shipment	$/event	350	7 coolers @ $50 ea.
Data Management	hrs	42	Assume 1 hour/sample.
Data Management	$/hr	80	
IDW - Nonhazardous Soil/water	drum	2	Assume 2 drums for 35 wells.
IDW - Nonhazardous Disposal	$/drum	62	Based on historical IDW disposal cost.
IDW Transportation	$/event	1,415	Based on historical IDW disposal cost.
Reporting			
Initial Baseline Report	$/event	18,000	Estimate based on historical costs and includes monitoring well installation details. Includes 240 hrs @ $75/hour.
Annual Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
5-Year Reports	$/event	9,000	Estimate based on historical costs. Includes 120 hrs @ $75/hr.
Well Abandonment			
Abandon Monitoring Wells	lot	1	Assume 43 injection and 35 monitoring wells. Assume $1,000 mob and $1500/well to grout.
Abandon Monitoring Wells	$/lot	118,000	

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 5 - In Situ Reductive Declorination
Cost Estimate

CAPITAL COST			$10,090,200
Activity (unit)	Quantity	Unit Cost	Total
Site Work			
Civil Survey (well)	112	$90	$10,080
Civil Survey (monument)	2	$120	$240
Surveyor Deliverables (ls)	1	$1,500	$1,500
Utility Locate	1	$3,000	$3,000
Water (lot)	1	$5,000	$5,000
Electric (lot)	1	$5,000	$5,000
Rehabilitate Existing Sewer (ls)	1	$100,000	$100,000
In Situ Biodegredation			
Pilot Study (lot)	1	$540,000	$540,000
Injection Permit (ea)	1	$3,200	$3,200
Mob/Site Preparation (lot)	1	$6,000	$6,000
Shallow Wells (ea)	39	$3,649	$142,311
Intermediate Wells (ea)	39	$5,008	$195,312
Deep Wells (ea)	28	$9,063	$253,764
IDW Disposal (drums)	860	$375	$322,500
Transportation (ls)	1	$1,415	$1,415
IDW Sampling (ea)	123	$425	$52,214
Development Equip, H&S Equip (wk)	11	$525	$5,775
Injection System Setup			
Injector Installation Labor (days)	53	$700	$37,100
Injector Installation Materials (well)	106	$300	$31,800
In-Line Injector Pumps (lot)	1	$12,000	$12,000
Header System (lot)	1	$42,000	$42,000
Storage Sheds (lot)	1	$20,000	$20,000
Direct Bury Pressure Pipe (lot)	1	$500,000	$500,000
Injection Setup (hours)	800	$60	$48,000
Injection Setup - Per Diem (lot)	1	$9,920	$9,920
Injection Setup - Cargo Van Rental / Gas (lot)	1	$8,000	$8,000
Injection Program (hours)	1,600	$60	$96,000
Injection Program - Per Diem (lot)	1	$19,840	$19,840
Injection Program - Rental Vehicle (lot)	1	$16,600	$16,600
Sodium Permanganate Materials (event)	4	$860,000	$3,440,000
Installation Report (ea)	1	$30,000	$30,000
Verification Sampling & Analysis			
Sampling Labor (event)	5	$3,600	$18,000
Per Diem (event)	5	$744	$3,720
Cargo Van Rental / Gas (event)	5	$400	$2,000
Sample materials (event)	5	$459	$2,295
Sample equipment (event)	5	$1,000	$5,000

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 5 - In Situ Reductive Declorination
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total
Verification Sampling & Analysis			
Analytical Cost (event)	5	$2,725	$13,625
Sample Shipment (event)	5	$100	$500
Data Management (event)	5	$1,840	$9,200
IDW Disposal (event)	5	$1,790	$8,950
Reporting			
Final Review and Confirmation Report (ea)	1	$18,000	$18,000
Monitoring Wells			
Mob/Site Preparation (ea)	1	$6,000	$6,000
Shallow Wells (ea)	2	$3,377	$6,754
Intermediate Wells (ea)	2	$8,244	$16,487
Deep Wells (ea)	2	$10,328	$20,655
IDW Disposal (drums)	46	$62	$2,852
Transportation (ls)	1	$1,415	$1,415
IDW Sampling (ea)	7	$425	$2,975
Development Equip, H&S Equip (wk)	2	$525	$1,050
Reporting			
Work Plan (ea)	1	$15,000	$15,000
Subtotal			$6,113,050
Design		6%	$366,783
Office Overhead		5%	$305,652
Field Overhead		15%	$916,957
Subtotal			$7,702,443
Profit		6%	$462,147
Contingency		25%	$1,925,611
Total			$10,090,200

Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
Dissolved Phase Plume Area Option 5 - In Situ Reductive Declorination
Cost Estimate

OPERATION AND MAINTENANCE			$1,492,256
Activity (unit)	**Quantity**	**Unit Cost**	**Total Cost**
O&M Sampling & Analysis			
Sampling Labor (event)	22	$9,600	$211,200
Per Diem (event)	22	$1,984	$43,648
Cargo Van Rental / Gas (event)	22	$900	$19,800
Sample materials (event)	22	$838	$18,443
Sample equipment (event)	22	$2,500	$55,000
Analytical Cost (event)	22	$5,250	$115,500
Sample Shipment (event)	22	$350	$7,700
Data Management (event)	22	$3,360	$73,920
IDW Disposal (event)	22	$1,539	$33,858
Reporting			
Initial Baseline Report (ea)	1	$18,000	$18,000
Annual Reports (ea)	5	$9,000	$45,000
5-Year Reports (ea)	16	$9,000	$144,000
Monitoring Well Abandonment			
Abandon Monitoring Well (lot)	1	$118,000	$118,000
Subtotal O&M			$904,069
Design		6%	$54,244
Office Overhead		5%	$45,203
Field Overhead		15%	$135,610
Subtotal			$1,139,127
Profit		6%	$68,348
Contingency		25%	$284,782
Total			$1,492,256

TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost)	$11,582,456

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