**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

**14 November 2008**

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
Under Contract W912HN-07-D-0029
Delivery Order Number 0001

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14 November 2008

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## *LIST OF 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 |
| DCE | dichloroethene |
| 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 |
| 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 |

## *LIST OF ACRONYMS (CONTINUED)*

| | |
|---|---|
| ORC | oxygen-releasing compound |
| ORP | oxidation-reduction potential |
| ORW | Outstanding Resource Waters |
| PCE | tetrachloroethene |
| PVC | 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 |
| SAP | Sampling and Analysis Plan |
| SARA | Superfund Amendment and Reauthorization Act of 1986 |
| scfm | standard cubic feet per minute |
| 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 |

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## *ES.0 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 finalized by TerranearPMC, LLC (TPMC) under Contract No. W912HN-07-D-0029, Delivery Order No. 0001; based on a draft document prepared by Science Applications International Corporation (SAIC) Engineering.

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 Rite Aid (formerly Eckerd Drug) Company. Five former tank sites and two other areas of operation comprise the CAMP investigation area.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) Phase I and II Remedial Investigations (RIs) were conducted at the site by Metcalf and Eddy (M&E), on behalf of the U. S. Army Corps of Engineers (USACE), in 1996 through 1997 and 1999 through 2000, respectively. Two supplemental groundwater investigations were conducted by SAIC in 2001 and 2003. Following the 2003 groundwater investigation, a pilot study was conducted to evaluate the use of chemical oxidation to reduce volatile organic compound (VOC) concentrations in groundwater at the Former CAMP site. Sodium permanganate was selected as the chemical oxidant to be injected based on a preliminary screening of alternatives for the CAMP site. Conclusions from these investigations are summarized in the following paragraphs.

*RI and Supplemental Groundwater 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 (SZ) is characterized by the unconsolidated residuum and saprolitic soils. The transition zone (TZ) is identified as the zone of transition along the overburden/bedrock interface. This zone consists of partially weathered parent material. The bedrock zone (BZ) 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 micrograms per liter (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 TZ.

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 SZ.

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 BZ. 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 VOCs, 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 groundwater 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 $1 \times 10^{-6}$ 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 discharge 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. Prior to the April 2007 stakeholders meeting, the North Carolina Department of Environment and Natural Resources (NCDENR) and the USACE–Savannah District had agreed that Hot Spot No. 1 was 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. However, during discussions at the 2007 stakeholders meeting following the performance of a pilot study at the site, it was agreed to also address Hot Spot No. 2 during remedial actions at the Former CAMP. Therefore, Hot Spot No. 2 has been addressed in the revised fate and transport modeling and a cost estimate developed based on the results of the CAMP pilot study. The costs for addressing Hot Spot No. 2 under Alternative 5 are included as an option to Alternative 5. Hot Spot No. 3 will not be specifically addressed within this FS as it is located within the footprint of Hot Spot No. 1, and 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. Hot Spot No. 2 will also be addressed but has only been included in the revised analysis of Alternative 5. Although the RAO addresses only shallow groundwater contamination, 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 TCE concentrations are below the NCAC 2L standards of 2.8 μg/L (anticipated to be 8 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 TCE concentrations are below the NCAC 2L standards of 2.8 μg/L (anticipated to be 8 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 (anticipated to be 2 years). Once treatment operations have been completed, the groundwater would be monitored every 5 years until the TCE concentrations are below the NCAC 2L standards of 2.8 µg/L. (anticipated to be 8 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 gallons per minute (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 reduce the TCE concentrations in the groundwater to 100µg/L in similar time periods (2 years). The permeable reactive barrier would require the longest time to meet the RAO at 160 years. However, Alternative 5 (ISCO) would reduce the TCE concentrations to below the NCAC 2L standards of 2.8 µg/ in the shortest amount of time (anticipated to be 8 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 ($2.5 million) followed by Alternative 2, Bioaugmentation ($5.9 million), Alternative 4, Permeable Reactive Barrier ($5.4 million), and Alternative 5, In situ Oxidation ($10.0 million).

Alternative 4 (Permeable Reactive Barrier) has a high cost and long-term monitoring and operation and maintenance requirements. Alternatives 2, 3, and 5 will achieve the RAO 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. Alternative 2 also has significant uncertainties, especially given the geochemical nature of the aquifer (oxidizing conditions).

Although Alternative 5 has a much higher cost than the other Alternatives, the pilot study results (see discussion below) indicated that Alternative 5 was successful in reducing TCE concentrations and the sodium permanganate was persistent in the aquifer. Revised fate and transport modeling also indicated that ISCO would reduce the TCE concentrations to below the NCAC 2L standards of 2.8 μg/ in the shortest amount of time (10 total years). Therefore, the preferred alternative for achieving the RAO at the former CAMP site is Alternative 5, In situ chemical oxidation using sodium permanganate.

**Pilot Study**

Due to the site-specific geologic, hydrogeologic, and groundwater geochemical conditions at the CAMP, a pilot study was recommended following the initial alternatives evaluation to determine the effectiveness of the chemical oxidation technology (Alternative 5). The pilot study was conducted in 2005 to evaluate the use of chemical oxidation ($NaMnO_4$ in this case) for reducing concentrations of TCE and the associated daughter products as a remedial approach at the Former CAMP and to better understand the site-specific aquifer hydraulics. The pilot study focused on a limited area where the highest concentrations of TCE had been detected at the site.

The primary objectives of the pilot study were to:

- Determine the injection radius of influence in the shallow and transition zones;
- Determine the travel distances of $NaMnO_4$ under ambient conditions (i.e., after injection has ceased);
- Determine possible preferential flow paths within each aquifer zone;
- Develop a measure of comparison to apply the results of the pilot test across the site during full-scale remedial implementation; and
- Determine if TCE concentrations decrease with treatment by $NaMnO_4$.

Four new monitoring wells were utilized with existing monitoring wells to make up the injection and observation network for the pilot study. As summarized in the Pilot Study Report (USACE 2005), a total of approximately 6,500 gal of dilute sodium permanganate at approximately 2.7 wt.% were injected into monitoring well SAIC-10 from March 2, 2005, to March 8, 2005. Groundwater sampling was conducted as one baseline (pre-injection) event and five post-injection events. The sampling events were scheduled at 1, 2, 4, 8, and 12 weeks post-injection.

Baseline groundwater sampling occurred in four TZ monitoring wells (SAIC-10, SAIC-17, SAIC-20, and SAIC-21) and three SZ monitoring wells (SAIC-16, SAIC-22, and SAIC-23). Each of the wells selected for baseline groundwater sampling is representative of the shallow and transition zones being evaluated. In each zone, a source area or area of high TCE concentrations was sampled along with at least two downgradient locations. This configuration provided sufficient data to determine the radius of influence of the injectate in each aquifer zone.

During the injection process, $NaMnO_4$ was observed in downgradient monitoring well SAIC-20 within the first 2 hours of the injection process. The $NaMnO_4$ was not observed in any other observation well during the injection cycle. During the first and second performance monitoring events, $NaMnO_4$ was only observed in monitoring wells SAIC-10 (the injection well) and SAIC-20, the nearest downgradient TZ well. During the third sampling event, a brown color was observed in monitoring well SAIC-21 (located approximately 15 ft downgradient of the injection well). It is likely that the discoloration is a result of the $NaMnO_4$ oxidation occurring near this well (e.g., the precipitant of $NaMnO_4$ oxidation is a brown $MnO_2$).

During the fourth sampling event, shallow monitoring well SAIC-23 (furthest downgradient shallow observation well) exhibited the distinct purple coloring of the $NaMnO_4$. During the fifth and final performance monitoring event, $NaMnO_4$ was present in three (SAIC-20, SAIC-17, and SAIC-23) of the downgradient observation wells. The presence of $NaMnO_4$ in monitoring well SAIC-17 is a good indication of the hydraulic transport mechanisms at the site. This TZ monitoring well is positioned so that the top of the well screen is approximately 8 ft below the bottom of the well screen of injection well SAIC-10. As $NaMnO_4$ density is greater than water, it was anticipated that a downward diffusion would occur. However, the $NaMnO_4$ was not observed in monitoring well SAIC-17 until approximately 83 days after injection. This, in conjunction with the observance in shallow monitoring well SAIC-23 (approximately 56 days), demonstrates a preferential flow in the shallower portion (approximately 20 to 30 ft below ground surface) of the aquifer. Although preferential flow was demonstrated through the detection of $NaMnO_4$, at the most downgradient location, the complexities of the subsurface lithologic profile are difficult to evaluate with respect to localized flow paths due to the extreme heterogeneity of the overburden material.

**Conclusions and Recommendations of the Pilot Study**

Based on the performance monitoring results, the pilot test has proven successful in that:

- The injection radius of influence of $NaMnO_4$ was greater than anticipated;
- The travel distances of $NaMnO_4$ under ambient conditions (i.e., after injection has ceased) were greater than anticipated;
- Preferential flow paths were noted in the transition and shallow zones; and
- TCE concentrations were observed to decrease significantly in the affected monitoring wells.

Based on the above criteria, the initial treatment design, including the percent $NaMnO_4$ used (between 2.5 % and 4%), and the volumes injected were adequate to reduce the TCE concentrations within the expected treatment area. Injection rates were optimum at monitoring well SAIC-10; however, pumping rates observed during the potable water injection indicate a sustained rate of 2 to 3 gpm cannot be attained across the site. During the remedial design phase, all data gathered during the pilot study must be fully evaluated to develop a successful remedial program for the Former CAMP.

Although the pilot study was a success, a few uncertainties still existed, such as the retention time of the $NaMnO_4$ and the potential for contaminant rebound. Residence times for the $NaMnO_4$ vary significantly based on site-specific aquifer characteristics and are difficult to predict. It should be noted however, that as long as the $NaMnO_4$ is present in the subsurface, it will actively treat the organic contaminants encountered.

Any enhanced remediation technique offers the potential for rebound. With $NaMnO_4$, rebound would typically occur when not all of the contaminant is treated due to inadequate distribution within the aquifer and all of the $NaMnO_4$ is expended. Residual contamination would then diffuse out of un-remediated zones. As with the $NaMnO_4$ persistence rates, rebound characteristics are highly variable, site specific, and difficult to predict.

Because of the uncertainties described above, the pilot study recommended that additional screening for the presence of $NaMnO_4$ be performed to evaluate the potential for rebound and determine the site-specific residence time for $NaMnO_4$ at the Former CAMP (SAIC 2005). The recommended activities would include a final round of groundwater sample collection from the monitoring wells utilized in the pilot study with all samples being analyzed for VOCs.

**Summary of 2006 Groundwater Data**

As mentioned above, the pilot study recommended that additional screening for the presence of $NaMnO_4$ be performed to evaluate the potential for rebound and determine the site-specific residence time for $NaMnO_4$ at the Former CAMP (SAIC 2005).

The purpose of the August 2006 sampling event conducted at the Former CAMP site was to collect groundwater analytical data from the monitoring wells utilized in the pilot study to answer the following questions.

1) Is $NaMnO_4$ still present in the groundwater at the Former CAMP site?
2) Is contaminant rebound occurring?

All analytical data as reported by the analytical laboratory are included in the sampling report (USACE 2007). During the last sampling event of the pilot study (May 2005), the $NaMnO_4$ was still present at elevated concentrations in monitoring wells SAIC-10, SAIC-20, and SAIC-23, and the retention time of the $NaMnO_4$ was presented as an uncertainty in the Pilot Study Report (USACE 2005). Therefore, during the focused sampling event conducted on August 28, 2006, groundwater samples were collected from 13 monitoring wells to check for the presence of $NaMnO_4$. A distinct purple coloring was noted in monitoring wells SAIC-10 and SAIC-23, and a distinct reddish brown coloring was noted in SAIC 20 and SAIC 21 (see Chapter 7.0) during the August 2006 sampling events.

As summarized in Chapter 7.0, permanganate was present in and near the original injection well SAIC-10 and the downgradient well SAIC-23 in August 2006. There also was an indication of the reaction byproduct manganese dioxide in downgradient wells SAIC-20 and SAIC-21. The apparent presence of permanganate in SAIC-10 and manganese dioxide in SAIC-20 and SAIC-21 (and associated TCE concentrations) indicates a continued residual of oxidant near SAIC-10 and a continued oxidation near or immediately upgradient of SAIC-20 and SAIC-21.

Based on available hydraulic conductivity data and with an estimated radius of influence during the injections, the leading edge of the dilute sodium permanganate hypothetically may have influenced TCE concentrations as far as downgradient monitoring well SAIC-15. Since preferential flow paths are highly likely in the heterogeneous subsurface and the sodium permanganate will be depleted by reaction, the actual zone of advection and influence may be significantly different, which may explain field observation of sodium permanganate in SAIC-23 during the August 2006 sampling event but no observations in the slightly upgradient SAIC-16 and SAIC-22

Another uncertainty presented in the Pilot Study Report (USACE 2005) was the potential for contaminant rebound following treatment. Any enhanced remediation technique offers the potential for rebound. With $NaMnO_4$, rebound would typically occur when not all of the contaminant is treated due to inadequate distribution within the aquifer and all of the $NaMnO_4$ is expended. Residual contamination would then diffuse out of un-remediated zones. As with the $NaMnO_4$ persistence rates, rebound characteristics are highly variable, site specific, and difficult to predict.

As summarized in Chapter 7.0, TCE concentrations in SAIC-10 continued to be significantly reduced from 768 μg/L to non-detect in 2006, and that sodium permanganate continued to persist near the screen interval of SAIC-10 approximately 17 months after the injection. After significant decreases in TCE immediately following the injections at SAIC-10, the permanganate appears to be depleted in the vicinity of SAIC-20 and SAIC-21, and TCE concentrations appear to have rebounded to pre-injection levels based on the August 2006 sampling results. Rebound of TCE is likely due to the limited volume of permanganate injected and the limited injection interval used for the pilot study.

TCE concentrations were also significantly reduced in wells SAIC-22, SAIC-23, and SAIC-15 from pre-injection concentrations (see Chapter 7.0) with minimal indications of either permanganate or manganese dioxide in these wells. The reduction in groundwater concentrations at these three wells likely represents a zone of treated groundwater that is migrating downgradient from SAIC-10. Rebounding TCE concentrations in SAIC-16 and SAIC-17 may indicate the trailing edge of this suspected treated groundwater slug as it continues to advect downgradient.

**Revised Fate and Transport Model**

Based on the results of the pilot study and subsequent sampling results, the fate and transport model developed for the Former CAMP (see Appendix A) was revised using these data. The revised modeling report addresses the No Action Alternative, source reduction using sodium permanganate, and monitored natural attenuation following source reduction. The revised modeling report is summarized in Chapter 7.0 and included as Appendix B.

To address the source reduction scenario for the shallow and transition zones at Hot Spot No. 1, the model was calibrated by matching the 2006 (post-injection) maximum concentrations observed and projected in six shallow wells and six TZ wells (see Appendix B). Based on the modeled parameters, the concentrations of TCE in the SZ will be reduced to 100 µg/L within 2 years, and the concentrations of TCE in the TZ will be reduced to 100 µg/L within 3 years due to source reduction with the injection of sodium permanganate. The model was then calibrated to 100 µg/L (i.e., the active clean-up concentration) at a downgradient location in both the shallow and transition zones. The results indicate that concentrations of TCE in the SZ and TZ at Hot Spot No. 1 will be reduced to 2.8 µg/L within 8 years due to natural attenuation after source reduction to 100 µg/L (see Appendix B).

There is some uncertainty regarding the number of injection points since the last round of comprehensive groundwater sampling was conducted in 2003. Based on attenuation rates observed at the site, it is possible that the areas of the plumes have decreased. It is recommended that prior to installing injection points, a baseline, comprehensive groundwater monitoring event be conducted to better ascertain the current nature and extent of the TCE plumes.

In addition, as mentioned previously, at the April 2007 stakeholders meeting held in Charlotte, North Carolina, a request was made to also address groundwater contamination at Hot Spot No. 2 in this FS. In response to this request, fate and transport modeling was also performed for Hot Spot No. 2 (see Appendix B). Based on the revised model, four (4) injection wells will be needed for the injection of sodium permanganate for source reduction to 100 µg/L at Hot Spot No. 2. Injection operations and sampling and analysis will be conducted as described for Hot Spot No. 1, and will be conducted contemporaneously with Hot Spot No. 1.

# 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 finalized by TerranearPMC, LLC (TPMC) under Contract No. W912HN-07-D-0029, Delivery Order No. 0001; based on a draft document prepared by Science Applications International Corporation (SAIC) Engineering.

## 1.1 PURPOSE AND ORGANIZATION

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 eight 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 summarizes the results of the pilot study conducted in 2005, the subsequent sampling program conducted in 2006, and presents the revised costs associated with Alternative 5 based on those results. Chapter 8.0 provides full citations for documents used in the preparation of this report.

## 1.1 SITE BACKGROUND

### 1.1.1 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 former Eckerd Drug Company (now Rite Aid). 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 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 the Rite Aid Company (formerly Eckerd Drug) 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.

### 1.1.2 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 the Rite Aid Company (formerly Eckerd Drug), MV Hercules LLC, Bancroft Realty Co., Fred D. Godley, Jerry L. and Joyce Dellinger, and Real Rock Holdings, LLC.

## *1.2 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 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:

- No further action for in situ soil since petroleum-impacted soils were below the March 1993 action levels of 180 milligrams per liter (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.

## 1.3 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.

### 1.3.1 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 North Carolina Department of Environment and Natural Resources (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.

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 1-4) 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.

### 1.3.2 *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 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.

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 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.

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 micrograms per liter (μg/L)] exceeded the Federal drinking water maximum contaminant level (MCL) of 5.0 μg/L.

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.

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.

## 1.4 *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. Following completion of the groundwater investigations, a pilot study and subsequent sampling and analysis of a limited number of monitoring wells were also performed by SAIC at the Former CAMP.

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 groundwater investigations conducted by SAIC are summarized below. The results of the pilot study are presented in Chapter 7.0.

### *1.4.1 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 available data through 2003 for each monitoring well.

#### *1.4.1.1 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).

#### *1.4.1.2 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.

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.

#### *1.4.1.3 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.

#### *1.4.1.4 2005 Pilot Study*

A pilot study was conducted at the Former CAMP from January to March of 2005 to evaluate the use of chemical oxidation ($NaMnO_4$ in this case) for reducing concentrations of TCE and the associated daughter products as a remedial approach at the Former CAMP and to better understand the site-specific aquifer hydraulics. The pilot study focused on a limited area where the highest concentrations of TCE had been detected (SAIC-10 and SAIC-17) [see Figures 1-5 and 1-6]. The Former CAMP pilot study is described in more detail in Chapter 7.0.

The primary objectives of the pilot study were to:

- Determine the injection radius of influence in the shallow and transition zones;

- Determine the travel distances of $NaMnO_4$ under ambient conditions (i.e., after injection has ceased);
- Determine possible preferential flow paths within each aquifer zone;
- Develop a measure of comparison to apply the results of the pilot test across the site during full-scale remedial implementation; and
- Determine if TCE concentrations decrease with treatment by $NaMnO_4$.

Two shallow (SAIC-22 and SAIC-23) and two transition zone wells (SAIC-20 and SAIC-21) were installed during the drilling activities (Figure 1-4). A summary of the well construction details and the monitoring well construction diagrams and borehole logs are presented in the Final Pilot Study Report (USACE 2005). The new monitoring wells were utilized with existing monitoring wells SAIC-10, SAIC-15, SAIC-17 (TZ wells) and SZ monitoring well SAIC-16 to make up the injection and observation network for the pilot study (Figure 1-4).

As summarized in the Pilot Study Report (USACE 2005), a total of approximately 6,500 gal of dilute sodium permanganate at approximately 2.7 wt.% was injected into monitoring well SAIC-10 from March 2, 2005, to March 8, 2005. Groundwater sampling was conducted as one baseline (pre-injection) event and five post-injection events.

During the injection process, $NaMnO_4$ was observed in downgradient monitoring well SAIC-20 within the first 2 hours of the injection process. The $NaMnO_4$ was not observed in any other observation well during the injection cycle. During the first and second performance monitoring events, $NaMnO_4$ was only observed in monitoring wells SAIC-10 (the injection well) and SAIC-20, the nearest downgradient TZ well. During the third sampling event, a brown groundwater color was observed in monitoring well SAIC-21 (located approximately 15 ft downgradient of the injection well), and consequently sampled. Monitoring well SAIC-21 was then sampled during all subsequent monitoring events. It is likely that the discoloration is a result of the $NaMnO_4$ oxidation occurring near this well (e.g., the precipitant of $NaMnO_4$ oxidation is a brown $MnO_2$).

During the fourth sampling event, shallow monitoring well SAIC-23 (furthest downgradient shallow observation well) exhibited the distinct purple coloring of the $NaMnO_4$ and was subsequently sampled. During the fifth and final performance monitoring event, $NaMnO_4$ was present in three (SAIC-20, SAIC-17, and SAIC-23) of the downgradient observation wells. The presence of $NaMnO_4$ in monitoring well SAIC-17 is a good indication of the hydraulic transport mechanisms at the site. This TZ monitoring well is positioned so that the top of the well screen is approximately 8 ft below the bottom of the well screen of injection well SAIC-10. As $NaMnO_4$ density is greater than water, it was anticipated that a downward diffusion would occur. However, the $NaMnO_4$ was not observed in monitoring well SAIC-17 until approximately 83 days after injection. This, in conjunction with the observance in shallow monitoring well SAIC-23 (approximately 56 days), demonstrates a preferential flow in the shallower portion (approximately 20 to 30 ft bgs) of the aquifer. Although preferential flow was demonstrated through the detection of $NaMnO_4$, at the most downgradient location, the complexities of the subsurface lithologic profile are difficult to evaluate with respect to localized flow paths due to the extreme heterogeneity of the overburden material.

Based on the performance monitoring results, the pilot test has proven successful in that:

- The injection radius of influence of $NaMnO_4$ was greater than anticipated;
- The travel distances of $NaMnO_4$ under ambient conditions (i.e., after injection has ceased) were greater than anticipated;
- Preferential flow paths were noted in the transition and shallow zones; and
- TCE concentrations were observed to decrease significantly in the affected monitoring wells.

Based on the above criteria, the initial treatment design, including the percent $NaMnO_4$ used (between 2.5 % and 4%), and the volumes injected were adequate to reduce the TCE concentrations within the expected treatment area. Injection rates were optimum at monitoring well SAIC-10. During the remedial design phase, all data gathered during the pilot study must be fully evaluated to develop a successful remedial program for the Former CAMP.

Although the pilot study was a success, a few uncertainties still existed, such as the retention time of the $NaMnO_4$. During the last pilot study sampling event (May 2005), the $NaMnO_4$ was still present at elevated concentrations detected in monitoring wells SAIC-10, SAIC-20, and SAIC-23. Residence times for the $NaMnO_4$ vary significantly based on site-specific aquifer characteristics and are difficult to predict. It should be noted however, that as long as the $NaMnO_4$ is present in the subsurface, it will actively treat the organic contaminants encountered.

Another uncertainty was the potential for contaminant rebound. Any enhanced remediation technique offers the potential for rebound. With $NaMnO_4$, rebound would typically occur when not all of the contaminant is treated due to inadequate distribution within the aquifer and all of the $NaMnO_4$ is expended. Residual contamination would then diffuse out of un-remediated zones. As with the $NaMnO_4$ persistence rates, rebound characteristics are highly variable, site specific, and difficult to predict.

Because of the uncertainties described above, the pilot study recommended that additional screening for the presence of $NaMnO_4$ be performed to evaluate the potential for rebound and determine the site-specific residence time for $NaMnO_4$ at the Former CAMP (SAIC 2005). The recommended activities would include a final round of groundwater sample collection from the monitoring wells utilized in the pilot study with all samples being analyzed for VOCs.

### *1.4.1.5 2006 Sampling Results*

The pilot study recommended that additional screening for the presence of $NaMnO_4$ be performed to evaluate the potential for rebound and determine the site-specific residence time for $NaMnO_4$ at the Former CAMP (SAIC 2005).

The purpose of the August 2006 sampling event conducted at the Former CAMP site was to collect groundwater analytical data from the monitoring wells utilized in the pilot study to answer the following questions.

1) Is $NaMnO_4$ still present in the groundwater at the Former CAMP site?
2) Is contaminant rebound occurring?

Groundwater samples were collected from the following wells:

- SAIC-10,
- SAIC-15,
- SAIC-16,
- SAIC-17,
- SAIC-20,
- SAIC-21,
- SAIC-22, and
- SAIC-23.

In addition to collecting groundwater samples in the eight monitoring wells, visual observations of the color of the groundwater were also noted to check for the presence of NaMnO4 (i.e., purple color). The color of the groundwater was also checked in five additional downgradient monitoring wells (SAIC-08, SAIC-14, MW01, MW1A, and COEMW29). This was accomplished by lowering a clear bailer into the monitoring well prior to purging and noting the color of the water when the bailer was retrieved from the well.

During the last sampling event of the pilot study (May 2005), the $NaMnO_4$ was still present at elevated concentrations in monitoring wells SAIC-10, SAIC-20, and SAIC-23, and the retention time of the $NaMnO_4$ was presented as an uncertainty in the Pilot Study Report (USACE 2005). Therefore, during the focused sampling event conducted on August 28, 2006, groundwater samples were collected from 13 monitoring wells to check for the presence of $NaMnO_4$. A distinct purple coloring was noted in monitoring wells SAIC-10 and SAIC-23, and a distinct reddish brown coloring was noted in SAIC-20 and SAIC-21 during the August 2006 sampling events. The sodium permanganate is a distinctive purple color, while the reaction product manganese dioxide is a distinctive red-brown color.

The apparent presence of permanganate in SAIC-10 and manganese dioxide in SAIC-20 and SAIC-21 (and associated TCE concentrations) indicates a continued residual of oxidant near SAIC-10 and a continued oxidation near or immediately upgradient of SAIC-20 and SAIC-21. The leading edge of the dilute sodium permanganate hypothetically may have influenced TCE concentrations as far as downgradient monitoring well SAIC-15. Since preferential flow paths are highly likely in the heterogeneous subsurface and the sodium permanganate will be depleted by reaction, the actual zone of advection and influence may be significantly different, which may explain field observation of sodium permanganate in SAIC-23 during the August 2006 sampling event but no observations in the slightly upgradient SAIC-16 and SAIC-22

Another uncertainty presented in the Pilot Study Report (USACE 2005) was the potential for contaminant rebound. Any enhanced remediation technique offers the potential for rebound. With $NaMnO_4$, rebound would typically occur when not all of the contaminant is treated due to inadequate distribution within the aquifer and all of the $NaMnO_4$ is expended. Residual contamination would then diffuse out of un-remediated zones. As with the $NaMnO_4$ persistence rates, rebound characteristics are highly variable, site specific, and difficult to predict. Figures 1-8 and 1-9 indicate the TCE concentrations observed in SZ and TZ wells, respectively, since 2003 (results for well SAIC 10 indicate the June 2001 concentration because this well was not sampled in 2003).

As indicated in Figures 1-7 and 1-8, TCE concentrations have been significantly reduced in wells SAIC-22, SAIC-23, and SAIC-15 from pre-injection concentrations with minimal indications of either permanganate or manganese dioxide in these wells. The reduction in groundwater concentrations at these three wells likely represents a zone of treated groundwater that is migrating downgradient from SAIC-10. Rebounding TCE concentrations in SAIC-16 and SAIC-17 may indicate the trailing edge of this suspected treated groundwater slug as it continues to advect downgradient.

As shown on Figure 1-8, TCE concentrations in SAIC-10 continued to be significantly reduced from 768 μg/L to non-detect in 2006. Sodium permanganate continued to persist near the screen interval of SAIC-10 approximately 17 months after the injection. After significant decreases in TCE immediately following the injections at SAIC-10, the permanganate appears to be depleted in the vicinity of SAIC-20 and SAIC-21, and TCE concentrations appear to have rebounded to pre-injection levels based on the August 2006 sampling results. Due to the limited volume of permanganate injected and the injection interval, the rebounded TCE in the vicinity of SAIC-20 and SAIC-21 likely is the result of:

- Downward flux of dissolved-phase TCE from the overlying saprolite clay and associated ground that was not treated (the top of the screened interval of SAIC-10 was approximately 15 ft below the top of the groundwater table).
- Dissolution of TCE that is present in the clay and bedrock matrix.
- Flux of TCE from cross- and upgradient sources not treated by the initial injection zone of influence (e.g., well COEMW13).
- Leaching of TCE from vadose zone sources.
- Low stoichiometric ratios of permanganate for localized areas of TCE dense nonaqueous-phase liquid (DNAPL).

### 1.4.2 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.

### 1.4.3 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 1-10). 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 15 NCAC 02B.0208(2)(B)(xv) for surface water. It should be noted that a sample taken from the storm sewer outfall did not exceed the regulatory criteria. Alternatives for preventing groundwater seepage into the storm sewer were not evaluated in this FS.

### 1.4.4 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.

## 1.5 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.

### 1.5.1 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).

#### 1.5.1.1 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 1-11.

#### *1.5.1.2 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 1-11). 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, no water entered the boring (USACE 2002). Further confirmation of the limited fracture zones within the bedrock material was reported during the geophysical borehole logging activities conducted in 2001 (Century 2001) [SAIC 2002].

As illustrated on Figure 1-10, the depth to the top of the bedrock is highly variable across the site with a general increase in depth toward the northwest. Within Hot Spot No. 1, the depth to bedrock ranges from approximately 55 to 85 ft bgs. The undulating bedrock surface is typical of the weathered plutonic parent material.

### ***1.5.2 Groundwater Hydrogeology***

The groundwater flow regime identified at the CAMP has been subdivided into three hydrogeologic zones, the shallow, transition, and bedrock. The SZ is characterized by the unconsolidated residuum and saprolitic soils. The TZ is identified as the zone of transition along the overburden/bedrock interface. This zone consists of partially weathered parent material. The BZ is characterized by the presence of water-bearing fractures within the competent diorite. The hydrogeologic characteristics of each zone are described below.

### 1.5.2.1 *Shallow Zone Potentiometric Surface*

Shallow groundwater at the CAMP was typically encountered between 4 and 10 ft bgs. The 2003 SZ potentiometric surface is represented in Figure 1-11. The groundwater data collected to date have been successful in providing the information necessary to develop a comprehensive shallow groundwater flow regime. In general, the shallow groundwater flow direction is toward the northwest, with a more northerly component identified in the center of the site (Figure 1-11).

The shallow groundwater flow gradient was calculated as 0.02. This gradient is assumed consistent across the hot spot areas and assumed consistent across the site. The hydraulic conductivities in the SZ during the Phase II RI (USACE 2000) ranged between 1.58 (COEMW05) and 39.77 (COEMW08) ft/day, as presented in Table 1-2.

Based on the hydraulic conductivity measurements obtained and the estimated effective porosity of the subsurface materials, the seepage velocity was estimated to be 593 ft/year in the SZ (USACE 2000). The highly variable conductivities may be attributed to the heterogeneous nature of the shallow overburden material as described in Section 1.6.1.

### 1.5.2.2 *Transition Zone Potentiometric Surface*

The 2003 TZ potentiometric surface is represented in Figure 1-12. In general, the TZ groundwater flow is toward the northwest with a northerly component being identified in the center of the site. The TZ was found to exhibit the highest yields of groundwater during monitoring well installation and development. However, at several locations where wells were installed along the overburden/bedrock interface and where the TZ was essentially absent, groundwater yield was significantly reduced (e.g., SAIC-08). The saprolitic material identified in boring SAIC-08 was consistent until the competent bedrock was encountered, with no partially weathered bedrock material observed. The flow rates achieved during development of this well were only 0.1 gallons per minute (gpm), below the average sustained pumping rate of 0.8 gpm for other TZ wells located in Hot Spot No. 1.

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).

#### 1.5.2.3 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).

### 1.5.3 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.

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.

### 1.5.4 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.

### 1.5.5 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.

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.

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.

## *1.6 CONTAMINANT PLUME CONFIGURATION*

Based upon the analytical, chemical, and physical findings from the Phase I and Phase II RIs and the 2001 and 2003 supplemental investigations, the groundwater distribution of TCE at the CAMP has been categorized into hot spot areas relative to potential remedial actions. Based on the fate and transport modeling and agreements with the USACE-Savannah District and NCDENR, 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 SZ (SAIC-16 north to COEMW06) (Figure 1-13) and contains the majority of TCE mass identified. This hot spot is characterized by concentrations of TCE > 500 μg/L with historical peak concentrations of up to 7,500 μg/L. The vertical distribution of TCE > 500 μg/L in this area extends from the SZ through the TZ [SAIC-10 (east end of Building 1) north to SAIC-18 (south side of Building 2)] (Figure 1-14) and into the underlying BZ (Hot Spot No. 3) (Figure 1-15).

Hot Spot No. 2 is located along the eastern end of Building 2 (Figure 1-13). 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.

Hot Spot No. 3 is located beneath the BZ along the northeast corner of Building 1 and is located within the footprint of Hot Spot No. 1 (Figure 1-15). 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 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.

## *1.7 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 1-19 illustrates the CSM that has been developed for the CAMP.

### *1.7.1 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 1-19) indicate this area is most likely an initial entry location.

### *1.7.2 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).

## *1.8 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 of the initial modeling and the subsequent modeling that was performed using information obtained during the pilot study. A complete discussion of the revised modeling effort is presented in Appendix A.

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?

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.

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 1-13 and 1-14. 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 1-13 and 1-14 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.

### *1.8.1 Revised Fate and Transport Model*

In February 2005, a pilot study was conducted at the CAMP site to evaluate sodium permanganate (NaMnO4) as an in situ groundwater treatment option to remediate the identified TCE and associated daughter products. Based on the results of the pilot study and subsequent sampling results from 2006, the initial fate and transport model developed for the Former CAMP was revised using these data. The revised modeling report is included as Appendix A. The revised modeling report addresses the No Action alternative, source reduction using sodium permanganate, and monitored natural attenuation following source reduction using sodium permanganate. Table 1-5 summarizes the scenarios modeled and the results of the modeling performed using the results of the pilot study.

Based on the results of the revised model, the No Action scenario will result in TCE concentrations reaching the NC 2L standard within 20 years in the SZ and 18 years in the TZ (see Table 1-5). By reducing TCE concentrations to 100 μg/L through the injection of sodium permanganate, the NC 2L standard will be reached at Hot Spot No. 1 within 8 years following completion of the injection process.

In addition, as mentioned previously, at the April 2007 stakeholders meeting held in Charlotte, North Carolina, a request was made to also address groundwater contamination at Hot Spot No. 2 in this FS. In response to this request, fate and transport modeling was also performed for Hot Spot No. 2 (see Appendix B). The modeling addressed the injection of a sodium permanganate solution until the TCE concentration reaches 100 μg/L. Once treatment operations have been completed, the groundwater would be monitored every year until the TCE concentrations are below the NCAC 2L standards of 2.8 μg/L (anticipated to be 7 years).

Based on the revised model evaluation and the attenuation rates observed at the site, it is possible that the areas of the plumes have decreased. It is recommended that prior to installing injection points, a baseline, comprehensive groundwater monitoring event be conducted to better ascertain the current nature and extent of the TCE plumes.

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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 in 2001 and 2003 for the FS/remedial design for subsurface soil, groundwater, and stormwater. A pathway analysis was conducted to evaluate the potential exposure and risk associated with the contaminants detected in the environmental media (SAIC 2006a). The pathways analysis included all data and considered the results of the initial Phase I and Phase II assessment. The pathways analysis was conducted in two steps: (1) identification of COPCs based on comparison of site data to conservative risk-based screening values including NCAC groundwater standards and the EPA Region 9 PRGs and (2) identification of potential exposure pathways following EPA guidance. Results of the initial Phase I and Phase II assessment, along with the pathways analysis, are provided in the following sections.

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*

The Pathway Analysis Report (SAIC 2006a) was utilized in the preparation of this section. 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 2.2.

#### 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*

The Pathway Analysis Report (SAIC 2006a) was utilized in the preparation of this section. 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 $1 \times 10^{-6}$. The estimated risk associated with TCE at Building 48 is $1 \times 10^{-6}$. 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 $2 \times 10^{-6}$.

- 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 collected in 2001 and 2003 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 80 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 $1 \times 10^{-6}$ 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

The Pathway Analysis Report (SAIC 2006a) was utilized in the preparation of this section. 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, the data collected to supplement this FS, and the Pathways Analysis Report (SAIC 2006a) 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 47 of 61 monitoring wells but has not been detected above the federal MCL for trihalomethanes of

80 μg/L in any wells. TCE has been detected in 45 of 61 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 $1 \times 10^{-6}$ 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. Prior to the April 2007 stakeholders meeting held in Charlotte, North Carolina, it was agreed between the NCDENR and the USACE–Savannah District on July 28, 2003, that Hot Spot No. 1 would be the only hot spot to be considered for treatment within this FS. It was agreed that treatment would consist of reducing 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 would not be specifically addressed within this FS, as they are considered localized and impracticable to treat at that 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.

However, at the stakeholders meeting held in Charlotte, North Carolina on April 19, 2007, it was agreed that Hot Spot No. 2 would also be considered for treatment within this FS. However, for the purposes of this FS, costing for this RAO has only been addressed under the chemical oxidation alternative (Alternative 5), and these costs are presented as an additional option to Alternative 5.

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 Nos. 1 and 2 (Hot Spot No. 2 is only addressed under Alternative 5) 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 the NCAC 2L criterion of 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.

#### 3.2.1.1 Groundwater

Federal MCLs [40 *Code of Federal Regulations* (*CFR*) 141] and NCAC 2L.0202 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, Section.0202). 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 *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.

#### 3.2.2.4 *Stormwater Management Standards and Sedimentation Control*

Should remedial actions on-site involve storm sewer disturbance via "Dig and Replace," the State Stormwater Management Program would be 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.

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. None were identified on the CAMP.

Due to the industrial setting of the site, there are no known sensitive areas (i.e., wetlands, floodplains, etc.) to be encountered.

This review of location-specific ARARs indicates that none were identified.

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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 (Chapters 1.0 and 2.0),
- 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.

### 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 physical barriers | Administrative controls, deed restrictions, and |
| Monitoring and Maintenance and maintenance | Long-term monitoring and physical surveillance |
| 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 Record of Decision (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, 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 20 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, ethane, 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 because of its wider use and application; its long-term persistence in the subsurface; its ability to diffuse readily into low permeability materials; and its greater capacity for distribution over a larger area. 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.

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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; and
- 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 3-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.

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 year for the first 5 years and once again after 3 years when the NCAC 2L standard for TCE is expected to be achieved.

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 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 year for the first 5 years and once again after 3 years when the NCAC 2L standard for TCE is expected to be achieved.

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 7 events of post-treatment monitoring would occur including a baseline event, annually for the first 5 years, and a final event after 8 years when the NCAC 2L standard is expected to be achieved.) Six additional downgradient groundwater-monitoring wells would be installed to complete the groundwater-monitoring network (Figure 5-1). 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 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 year for the first 5 years and once again after 3 years when the NCAC 2L standard for TCE is expected to be achieved. 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 deeper transition zone 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 year for the first 5 years, and every 3 years thereafter, following 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 7 events of post-treatment monitoring would occur including a baseline event, annually for the first 5 years, and a final event after 8 years when the NCAC 2L standard is expected to be achieved.) 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 NCAC 2L standard for TCE is ultimately achieved. Three-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.

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# 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 INDIVIDUAL ANALYSIS OF ALTERNATIVES

### 6.3.1 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.

#### 6.3.1.1 *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.

### 6.3.2 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 to reduce contaminant concentrations in the resource groundwater to meet the drinking water standards.

#### 6.3.2.1 *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.

#### 6.3.2.2 *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.

#### 6.3.2.3 *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).

#### 6.3.2.4 *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.

#### 6.3.2.5 *Cost*

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

### 6.3.3 *Alternative 2 – Bioaugmentation*

#### 6.3.3.1 *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 8 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 ISCO). 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.

#### 6.3.3.2 *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.

#### 6.3.3.3 *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 8 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.

#### 6.3.3.4 *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.

#### 6.3.3.5 *Short-Term Effectiveness*

The alternative would be effective in the short-term because it will reduce the plume thus reducing the potential exposure to contaminants. During implementation of the alternative, workers and the community would be protected by limiting exposure through access controls and the implementation of health and safety procedures/controls for workers on site as stipulated by OSHA.

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 resulting in reduced risk to human health and the environment. 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 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. 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 µg/L in a period of approximately one year.

#### 6.3.3.6 *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.

#### 6.3.3.7 *Costs*

Construction and injection costs for bioaugmentation were estimated to be $5,160,000. Subsequent O&M monitoring costs for 8 years were estimated at $770,000.

The total cost for this alternative is estimated at $5,940,000.

### 6.3.4 ***Alternative 3 – Biostimulation***

#### 6.3.4.1 *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 8 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.

#### *6.3.4.2 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.

### 6.3.4.3 *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 8 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.

### 6.3.4.4 *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.

#### 6.3.4.5 *Short-Term Effectiveness*

The alternative would be effective in the short-term because it will reduce the plume thus reducing the potential exposure to contaminants. During implementation of the alternative, workers and the community would be protected by limiting exposure through access controls and the implementation of health and safety procedures/controls for workers on site as stipulated by OSHA.

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.

#### 6.3.4.6 *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 the 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 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 3 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 become readily 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.

#### *6.3.4.7 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 (8 years) were estimated at $540,000.

The total cost for this alternative is estimated at $2,500,000.

### 6.3.5 Alternative 4 – Permeable Reactive Barrier

#### *6.3.5.1 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.

#### *6.3.5.2 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.

#### *6.3.5.3 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.

#### 6.3.5.4 *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.

#### 6.3.5.5 *Short-Term Effectiveness*

The alternative would be effective in the short-term because it will reduce the plume thus reducing the potential exposure to contaminants. During implementation of the alternative, workers and the community would be protected by limiting exposure through access controls and the implementation of health and safety procedures/controls for workers on site as stipulated by OSHA.

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.

#### 6.3.5.6 *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.

#### 6.3.5.7 *Costs*

Construction costs for installation of the permeable reactive barrier were estimated to be $3,090,000. The O&M costs were estimated at $2,280,000.

The total cost for this alternative is estimated at $5,360,000.

### 6.3.6 *Alternative 5 – In situ Chemical Oxidation*

#### 6.3.6.1 *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 be approximately 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 8 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.

### *6.3.6.2 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.

### 6.3.6.3 *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 8 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). The pilot study described in detail in Chapter 7.0 indicated the removal efficiency of chemical oxidation, and that 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. The pilot study results indicate that the permanganate will diffuse throughout the aquifer and that downgradient TCE concentrations would be mitigated for some distance. The pilot study also indicated that the permanganate is persistent in the aquifer.

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 groundwater. This uncertainty would be further evaluated during subsequent remedial design and remedial action implementation.

#### 6.3.6.4 *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 some distance downgradient from the treatment zone.

#### 6.3.6.5 *Short-Term Effectiveness*

The alternative would be effective in the short-term because it will reduce the plume thus reducing the potential exposure to contaminants. During implementation of the alternative, workers and the community would be protected by limiting exposure through access controls and the implementation of health and safety procedures/controls for workers on site as stipulated by OSHA.

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 2-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. However, fate and transport modeling based on the pilot study results indicates that the NCAC 2L standard will be met within 8 years following source reduction to 100 µg/L.

#### 6.3.6.6 *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.

The results of the pilot study conducted in 2005 using sodium permanganate indicate that ISCO is a viable alternative for groundwater remediation at the Former CAMP. The pilot study showed that injection of sodium permanganate can be accomplished at the Former CAMP, and it was found to be very effective in reducing TCE concentrations and was persistent in the aquifer.

##### *6.3.6.7 Costs*

Construction costs for installation of the injection wells were estimated to be $9,190,00. The O&M costs for the treatment operations (2 years), as well as the natural attenuation period (8 years), were estimated at $770,000.

The total cost for this alternative is estimated at $9, 970,000.

## *6.4 COMPARATIVE EVALUATION OF ALTERNATIVES*

### *6.4.1 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.

### 6.4.2 *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 2 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.

### 6.4.3 *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.

### 6.4.4 *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. Alternative 3 is capable of treating the contaminant plume beneath buildings through the use of horizontal treatment wells.

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.

### 6.4.5 *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 (Alternative 2) and ISCO (Alternative 5) have been demonstrated to achieve, on average, less destruction of chlorinated hydrocarbons than use of methane biostimulation (Alternative 3) or zero valence iron reactive media (Alternative 4). However, the pilot study results indicate destruction of chlorinated hydrocarbons is accomplished by the application of ISCO (Alternative 5) at the site.

### 6.4.6 *Short-term Effectiveness*

All alternatives would achieve some short-term effectiveness in preventing potential community exposure by limiting site access. Alternatives 2 through 5 would achieve short-term effectiveness for protection of workers by implementing health and safety procedures and controls.

The No Action alternative is not effective in the short-term in reducing contaminant concentrations although there would be no worker exposure due to inactivity and access controls. Alternative 4 would achieve only slight reductions in contaminant concentrations. 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.

### 6.4.7 *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 2 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.

### 6.4.8 *Costs*

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

- Alternative 1- No Action, $0;
- Alternative 2 - Bioaugmentation, $5,940,000
- Alternative 3 - Biostimulation, $2,500,000;
- Alternative 4 – Permeable Reactive Barrier, $5,360,000; and
- Alternative 5 In Situ Chemical Oxidation, $9,970,000.

### 6.4.9 *Preferred Alternative*

The preferred alternative for achieving the RAO at the CAMP site is Alternative 5, In situ chemical oxidations using sodium permanganate. This alternative was selected for several reasons. In particular:

- This alternative was selected because it will achieve the RAO in a reasonable amount of time.

- Each of the three alternatives that are expected to achieve the RAO in the shortest time are relatively new remedial technologies for groundwater treatment. However, this remedial technology was proven to be successful in reducing the TCE concentration effectively, as demonstrated during the pilot study (see discussion in Chapter 7).

- This alternative provides the highest overall protection of human health and the environment by reducing the TCE concentrations in groundwater to below the NCAC 2L standards of 2.8 μg/L in the shortest amount of time (10 total years).

- The oxidant being used moves faster than TCE in the aquifer and is persistent, meaning residual contamination will continue to be treated after achieving the RAO.

- With this alternative, there is no potential for altering groundwater flow from biomass buildup.

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# 7.0 PILOT STUDY

A pilot study was conducted at the Former CAMP from January to March of 2005 to evaluate the use of chemical oxidation ($NaMnO_4$ in this case) for reducing concentrations of TCE and the associated daughter products as a remedial approach at the Former CAMP and to better understand the site-specific aquifer hydraulics. The pilot study focused on a limited area where the highest concentrations of TCE had been detected (SAIC-10 and SAIC-17) [see Figures 1-5 and 1-6].

The primary objectives of the pilot study were to:

- Determine the injection radius of influence in the shallow and transition zones;
- Determine the travel distances of $NaMnO_4$ under ambient conditions (i.e., after injection has ceased);
- Determine possible preferential flow paths within each aquifer zone;
- Develop a measure of comparison to apply the results of the pilot test across the site during full-scale remedial implementation; and
- Determine if TCE concentrations decrease with treatment by $NaMnO_4$.

All field activities were performed in accordance with the Sampling and Analysis Plan (SAP) (SAIC 2005) and consisted of the following primary tasks:

1. Install four new monitoring wells (SAIC-20, SAIC-21, SAIC-22, and SAIC-23).
2. Execute a potable water injection program.
3. Conduct baseline groundwater sampling.
4. Inject $NaMnO_4$ into the transition zone.
5. Inject a bromide solution into the shallow zone.
6. Conduct performance monitoring for a period of 3 months.
7. Perform a civil survey of all newly installed monitoring wells

The new monitoring wells were utilized with existing monitoring wells SAIC-10, SAIC-15, and SAIC-17 (TZ wells) and SZ monitoring well SAIC-16 to make up the injection and observation network for the pilot study (Figure 7-1).

Two shallow (SAIC-22 and SAIC-23) and two transition zone wells (SAIC-20 and SAIC-21) were installed during the drilling activities. A summary of the well construction details and the monitoring well construction diagrams and borehole logs are presented in the Final Pilot Study Report (USACE 2005).

Upon completion of the monitoring well installation and prior to the $NaMnO_4$ injection, a potable water injection test was performed in existing monitoring wells SAIC-10, SAIC-14, SAIC-16, SAIC-17, SAIC-18, and COEMW06. This data were used to further define sustainable injection rates for the pilot test and provided a measure of comparison to apply the results of the pilot study across the contaminant plume during full-scale remedial implementation.

As summarized in the Pilot Study Report (USACE 2005), a total of approximately 6,500 gal of dilute sodium permanganate at approximately 2.7 wt.% were injected into monitoring well SAIC-10 from March 2, 2005, to March 8, 2005. Groundwater sampling was conducted as one baseline (pre-injection) event and five post-injection events. The sampling events were scheduled at 1, 2, 4, 8, and 12 weeks post-injection.

Baseline groundwater sampling occurred in four TZ monitoring wells (SAIC-10, SAIC-17, SAIC-20, and SAIC-21) and three SZ monitoring wells (SAIC-16, SAIC-22, and SAIC-23). Each of the wells selected for baseline groundwater sampling is representative of the shallow and transition zones being evaluated. In each zone, a source area or area of high TCE concentrations was sampled along with at least two downgradient locations. This configuration provided sufficient data to determine the radius of influence of the injectate in each aquifer zone. During the baseline sampling event, all groundwater samples were analyzed for VOCs, chemical oxygen demand (COD), and TAL metals and chloride.

During each performance sampling event, a bailer was dropped into each of the TZ wells included in the pilot study (SAIC-10, SAIC-17, SAIC-20, and SAIC-21) and observed for the presence of the distinct purple coloring of the $NaMnO_4$. Groundwater samples were not collected from a transition well until the $NaMnO_4$ was observed in that well. That is, if the $NaMnO_4$ had not traveled to intercept that well, it is unlikely that the TCE concentrations would have appreciably changed from baseline concentrations. Once the $NaMnO_4$ was observed in a particular well, the well was sampled during each subsequent performance monitoring event. All TZ wells were sampled during the final performance monitoring event in post-injection week 12 regardless of the visual detection of the $NaMnO_4$.

During the injection process, $NaMnO_4$ was observed in downgradient monitoring well SAIC-20 within the first 2 hours of the injection process. The $NaMnO_4$ was not observed in any other observation well during the injection cycle. During the first and second performance monitoring events, $NaMnO_4$ was only observed in monitoring wells SAIC-10 (the injection well) and SAIC-20, the nearest downgradient TZ well. During the third sampling event, a brown groundwater color was observed in monitoring well SAIC-21 (located approximately 15 ft downgradient of the injection well), and consequently sampled. Monitoring well SAIC-21 was then sampled during all subsequent monitoring events. It is likely that the discoloration is a result of the $NaMnO_4$ oxidation occurring near this well (e.g., the precipitant of $NaMnO_4$ oxidation is a brown $MnO_2$).

During the fourth sampling event, shallow monitoring well SAIC-23 (furthest downgradient shallow observation well) exhibited the distinct purple coloring of the $NaMnO_4$ and was subsequently sampled. During the fifth and final performance monitoring event, $NaMnO_4$ was present in three (SAIC-20, SAIC-17, and SAIC-23) of the downgradient observation wells. The presence of $NaMnO_4$ in monitoring well SAIC-17 is a good indication of the hydraulic transport mechanisms at the site. This TZ monitoring well is positioned so that the top of the well screen is approximately 8 ft below the bottom of the well screen of injection well SAIC-10. As $NaMnO_4$ density is greater than water, it was anticipated that a downward diffusion would occur. However, the $NaMnO_4$ was not observed in monitoring well SAIC-17 until approximately 83 days after injection. This, in conjunction with the observance in shallow monitoring well SAIC-23 (approximately 56 days), demonstrates a preferential flow in the shallower portion (approximately 20 to 30 ft bgs) of the aquifer. Although preferential flow was demonstrated through the detection of $NaMnO_4$, at the most downgradient location, the complexities of the subsurface lithologic profile are difficult to evaluate with respect to localized flow paths due to the extreme heterogeneity of the overburden material.

**Conclusions and Recommendations of the Pilot Study**

Based on the performance monitoring results, the pilot test has proven successful in that:

- The injection radius of influence of $NaMnO_4$ was greater than anticipated;
- The travel distances of $NaMnO_4$ under ambient conditions (i.e., after injection has ceased) were greater than anticipated;
- Preferential flow paths were noted in the transition and shallow zones; and
- TCE concentrations were observed to decrease significantly in the affected monitoring wells.

Based on the above criteria, the initial treatment design, including the percent $NaMnO_4$ used (between 2.5 % and 4%), and the volumes injected were adequate to reduce the TCE concentrations within the expected treatment area. Injection rates were optimum at monitoring well SAIC-10; however, pumping rates observed during the potable water injection indicate a sustained rate of 2 to 3 gpm cannot be attained across the site. During the remedial design phase, all data gathered during the pilot study must be fully evaluated to develop a successful remedial program for the Former CAMP.

Although the pilot study was a success, a few uncertainties still existed, such as the retention time of the $NaMnO_4$. During the last pilot study sampling event (May 2005), the $NaMnO_4$ was still present at elevated concentrations detected in monitoring wells SAIC-10, SAIC-20, and SAIC-23. Residence times for the $NaMnO_4$ vary significantly based on site-specific aquifer characteristics and are difficult to predict. It should be noted however, that as long as the $NaMnO_4$ is present in the subsurface, it will actively treat the organic contaminants encountered.

Another uncertainty is the potential for contaminant rebound. Any enhanced remediation technique offers the potential for rebound. With $NaMnO_4$, rebound would typically occur when not all of the contaminant is treated due to inadequate distribution within the aquifer and all of the $NaMnO_4$ is expended. Residual contamination would then diffuse out of un-remediated zones. As with the $NaMnO_4$ persistence rates, rebound characteristics are highly variable, site specific, and difficult to predict.

Because of the uncertainties described above, the pilot study recommended that additional screening for the presence of $NaMnO_4$ be performed to evaluate the potential for rebound and determine the site-specific residence time for $NaMnO_4$ at the Former CAMP (SAIC 2005). The recommended activities would include a final round of groundwater sample collection from the monitoring wells utilized in the pilot ptudy with all samples being analyzed for VOCs.

**Summary of 2006 Groundwater Data**

As mentioned above, the pilot study recommended that additional screening for the presence of $NaMnO_4$ be performed to evaluate the potential for rebound and determine the site-specific residence time for $NaMnO_4$ at the Former CAMP (SAIC 2005).

Field activities were performed in August 2006 in accordance with the SAP (SAIC 2006b) and consisted of the following primary tasks:

- Collecting and analyzing groundwater samples from a total of 8 groundwater monitoring wells for VOC analytes (Figure 7-1).
- Visually inspecting the groundwater from 13 wells for the presence of $NaMnO_4$ (Figure 7-1).

Groundwater samples were collected from the following wells using low-flow purging techniques to reduce turbidity and decrease the amount of generated IDW:

- SAIC-10,
- SAIC-15,
- SAIC-16,
- SAIC-17,
- SAIC-20,
- SAIC-21,
- SAIC-22, and
- SAIC-23.

In addition to collecting groundwater samples in the eight monitoring wells, visual observations of the color of the groundwater were also noted to check for the presence of NaMnO4 (i.e., purple color). The color of the groundwater was also checked in five additional downgradient monitoring wells (SAIC-08, SAIC-14, MW01, MW1A, and COEMW29). This was accomplished by lowering a clear bailer into the monitoring well prior to purging and noting the color of the water when the bailer was retrieved from the well.

The purpose of the August 2006 sampling event conducted at the Former CAMP site was to collect groundwater analytical data from the monitoring wells utilized in the pilot study to answer the following questions.

1) Is $NaMnO_4$ still present in the groundwater at the Former CAMP site?
2) Is contaminant rebound occurring?

The following provides a discussion of the data obtained and observations made during the sample collection activities as they relate to answering these questions.

All analytical data as reported by the analytical laboratory is included in the sampling report (USACE 2007).

During the last sampling event of the pilot study (May 2005), the $NaMnO_4$ was still present at elevated concentrations in monitoring wells SAIC-10, SAIC-20, and SAIC-23, and the retention time of the $NaMnO_4$ was presented as an uncertainty in the Pilot Study Report (USACE 2005). Therefore, during the focused sampling event conducted on August 28, 2006, groundwater samples were collected from 13 monitoring wells to check for the presence of $NaMnO_4$. A distinct purple coloring was noted in monitoring wells SAIC-10 and SAIC-23, and a distinct reddish brown coloring was noted in SAIC 20 and SAIC 21 (Table 7-1) during the August 2006 sampling events.

The sodium permanganate is a distinctive purple color, while the reacted manganese dioxide is a distinctive red-brown color. Visual observations of the groundwater color can be used to provide a qualitative indication of reaction progress or depletion of reagents. Manganese dioxide is insoluble, would not be expected to advect with the groundwater, and eventually would be purged from a monitoring well during development or settle out in the aquifer. Any visual indication of manganese dioxide in a monitoring well would be an indication of localized sodium permanganate oxidation. Sodium permanganate is very soluble in groundwater and would be expected to advect with groundwater until reacted. The density of permanganate solutions also is slightly heavier than groundwater, and they have a tendency to sink during advection in the subsurface (baring preferential flow paths in the transition zone).

The oxidation chemistry for sodium permanganate with TCE can be summarized as follows:

$$C_2HCl_3 + 2NaMnO_4 \Rightarrow 2CO_2 + 2MnO_2 + Na^+ + H^+ + 3Cl^-$$

where

$C_2HCl_3$ = TCE,
$NaMnO_4$ = sodium permanganate,
$CO_2$ = carbon dioxide,
$MnO_2$ = manganese dioxide,
$Na^+$ = sodium ion,
$H^+$ = hydronium ion,
$Cl^-$ = chloride ion.

As summarized in Table 7-1, permanganate was present in and near the original injection well SAIC-10 and the downgradient well SAIC-23 in August 2006. There also was an indication of the reaction byproduct manganese dioxide in downgradient wells SAIC-20 and SAIC-21. The initial injection of 6,500 gal of dilute sodium permanganate would have equated to an immediate and approximate 17-ft initial radius of influence, assuming an effective porosity of 0.25 and an injection interval thickness of 15 ft. This is consistent with field observation during the initial injection that indicated a purple color in monitoring well SAIC-20 (approximately 8 ft laterally downgradient) but not SAIC-21 (approximately 21 ft laterally downgradient), even though both wells are screened at a similar elevation to SAIC-10. The apparent presence of permanganate in SAIC-10 and manganese dioxide in SAIC-20 and SAIC-21 (and associated TCE concentrations) indicates a continued residual of oxidant near SAIC-10 and a continued oxidation near or immediately upgradient of SAIC-20 and SAIC-21.

The average hydraulic conductivity of the TZ was measured at approximately 6.9 ft/day with a calculated hydraulic gradient of 0.02 ft/ft (*Draft Final Feasibility Study for the Former Charlotte Army Missile Plant (CAMP), Mecklenburg County, Charlotte, North Carolina* (SAIC 2004). Assuming no flow retardation, depletion by reaction, or preferential flow paths, the injected sodium permanganate may have advected downgradient up to 95 ft from SAIC-10 from March 2005 to August 2006. With an estimated initial 17-ft radius of influence during the injections, the leading edge of the dilute sodium permanganate hypothetically may have influenced TCE concentrations as far as downgradient monitoring well SAIC-15. Since preferential flow paths are highly likely in the heterogeneous subsurface and the sodium permanganate will be depleted by reaction, the actual zone of advection and influence may be significantly different, which may explain field observation of sodium permanganate in SAIC-23 during the August 2006 sampling event but no observations in the slightly upgradient SAIC-16 and SAIC-22.

Another uncertainty presented in the Pilot Study Report (USACE 2005) was the potential for contaminant rebound. Any enhanced remediation technique offers the potential for rebound. With $NaMnO_4$, rebound would typically occur when not all of the contaminant is treated due to inadequate distribution within the aquifer and all of the $NaMnO_4$ is expended. Residual contamination would then diffuse out of un-remediated zones. As with the $NaMnO_4$ persistence rates, rebound characteristics are highly variable, site specific, and difficult to predict.

As summarized in Table 7-1 and shown on Figure 7-1, TCE concentrations in SAIC-10 continued to be significantly reduced from 768 μg/L to non-detect in 2006, and that sodium permanganate continued to persist near the screen interval of SAIC-10 approximately 17 months after the injection. After significant decreases in TCE immediately following the injections at SAIC-10, the permanganate appears to be depleted in the vicinity of SAIC-20 and SAIC-21, and TCE concentrations appear to have rebounded to pre-injection levels based on the August 2006 sampling results. Due to the limited volume of permanganate injected and the injection interval, the rebounded TCE in the vicinity of SAIC-20 and SAIC-21 likely is the result of:

- Downward flux of dissolved-phase TCE from the overlying saprolite clay and associated ground that was not treated (the top of the screened interval of SAIC-10 was approximately 15 ft below the top of the groundwater table).
- Dissolution of TCE that is present in the clay and bedrock matrix.
- Flux of TCE from cross- and upgradient sources not treated by the initial injection zone of influence (e.g., well COEMW13).
- Leaching of TCE from vadose zone sources.
- Low stoichiometric ratios of permanganate for localized areas of TCE DNAPL.

As summarized in Table 7-1, TCE concentrations also have been significantly reduced in wells SAIC-22, SAIC-23, and SAIC-15 from pre-injection concentrations with minimal indications of either permanganate or manganese dioxide in these wells. The reduction in groundwater concentrations at these three wells likely represents a zone of treated groundwater that is migrating downgradient from SAIC-10. Rebounding TCE concentrations in SAIC-16 and SAIC-17 may indicate the trailing edge of this suspected treated groundwater slug as it continues to advect downgradient.

*Revised Fate and Transport Modeling*

Based on the results of the pilot study and subsequent sampling results, the fate and transport model developed for the Former CAMP (Appendix A) was revised using these data. The revised modeling report addresses the No Action Alternative, source reduction using sodium permanganate, and monitored natural attenuation following source reduction. The revised modeling report is included as Appendix B. Table 7-2 summarizes the scenarios modeled using the revised model and the results of the modeling performed using the results of the pilot study.

To address the source reduction scenario for the shallow zone at Hot Spot No. 1, the model was calibrated by matching the 2006 (post-injection) maximum concentrations observed and projected in wells COEMW13, SAIC22, SAIC23, COEMW06, COEMW12, and COEMW18 (see Appendix B). Based on the modeled parameters, the concentrations of TCE in the SZ will be reduced to 100 μg/L within 2 years due to source reduction with the injection of sodium permanganate. The model was then calibrated to 100 μg/L (i.e., the active clean-up concentration) near COEMW12 (downgradient location), and the results indicate that concentrations of TCE in the SZ at Hot Spot No.1 will be reduced to 2.8 μg/L within 8 years due to natural attenuation after source reduction to 100 μg/L (see Appendix B).

For the TZ, the model was calibrated by matching the 2006 (post-injection) maximum concentrations observed and projected in wells SAIC04, SAIC20, SAIC08, SAIC14, SAIC18, and COEMW27. The results of the modeling indicate that the concentrations of TCE in the TZ will be reduced to 100 μg/L within 3 years due to source reduction with the injection of sodium permanganate. The model was then calibrated to 100 μg/L (i.e., the active clean-up concentration) near COEMW27 (downgradient location), and the model indicates that the concentrations of TCE in the TZ will be reduced to 2.8 μg/L within 8 years due to natural attenuation after source reduction to 100 μg/L (see Appendix B).

Based on attenuation rates observed at the site, it is possible that the areas of the plumes have decreased and that fewer injection points would be required. It is recommended that prior to installing injection points, a baseline, comprehensive groundwater monitoring event be conducted to better ascertain the current nature and extent of the TCE plumes.

## 7.1 *HOT SPOT NO. 2 OPTION*

In addition, as mentioned previously, at the April 2007 stakeholders meeting held in Charlotte, North Carolina, a request was made to also address groundwater contamination at Hot Spot No. 2 in this FS. In response to this request, fate and transport modeling was also performed for Hot Spot No. 2 (see Appendix B). Based on the revised model, eight (8) injection wells at 4 locations will be needed for the injection of sodium permanganate for source reduction to 100 μg/L at Hot Spot No. 2 (see Figure 7-2). Once treatment operations have been completed, the groundwater would be monitored every year until the RAO is achieved (anticipated to be 7 years). A summary of the remedial alternative for Hot Spot No. 2 is provided in Table 7-3.

The injection wells for Hot Spot No. 2 would include 4 shallow wells with an approximate depth of 25 ft and 4 intermediate wells with an approximate depth of 45 ft. The bottom 10 ft of each well would be screened. In general, each injection location would consist of a cluster of a shallow and an intermediate well. A 40% permanganate solution would be metered into the injection wells over the course of 1 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 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.

The estimated total cost for application of Alternative 5 at Hot Spot No. 2 is $801,000.

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USACE 2005. *Final Pilot Study Report for the Feasibility Study/Remedial Design at the Former Charlotte Army Missile Plant, Mecklenburg County, Charlotte, North Carolina*, prepared by Science Applications International Corporation for the USACE–Savannah District, October.

USACE 2007. *Sitewide Groundwater Sampling Report for the Feasibility Study/Remedial Design at the Former Charlotte Army Missile Plant, Mecklenburg County, Charlotte, North Carolina*, prepared by Science Applications International Corporation for the USACE–Savannah District, June.

# *FIGURES*

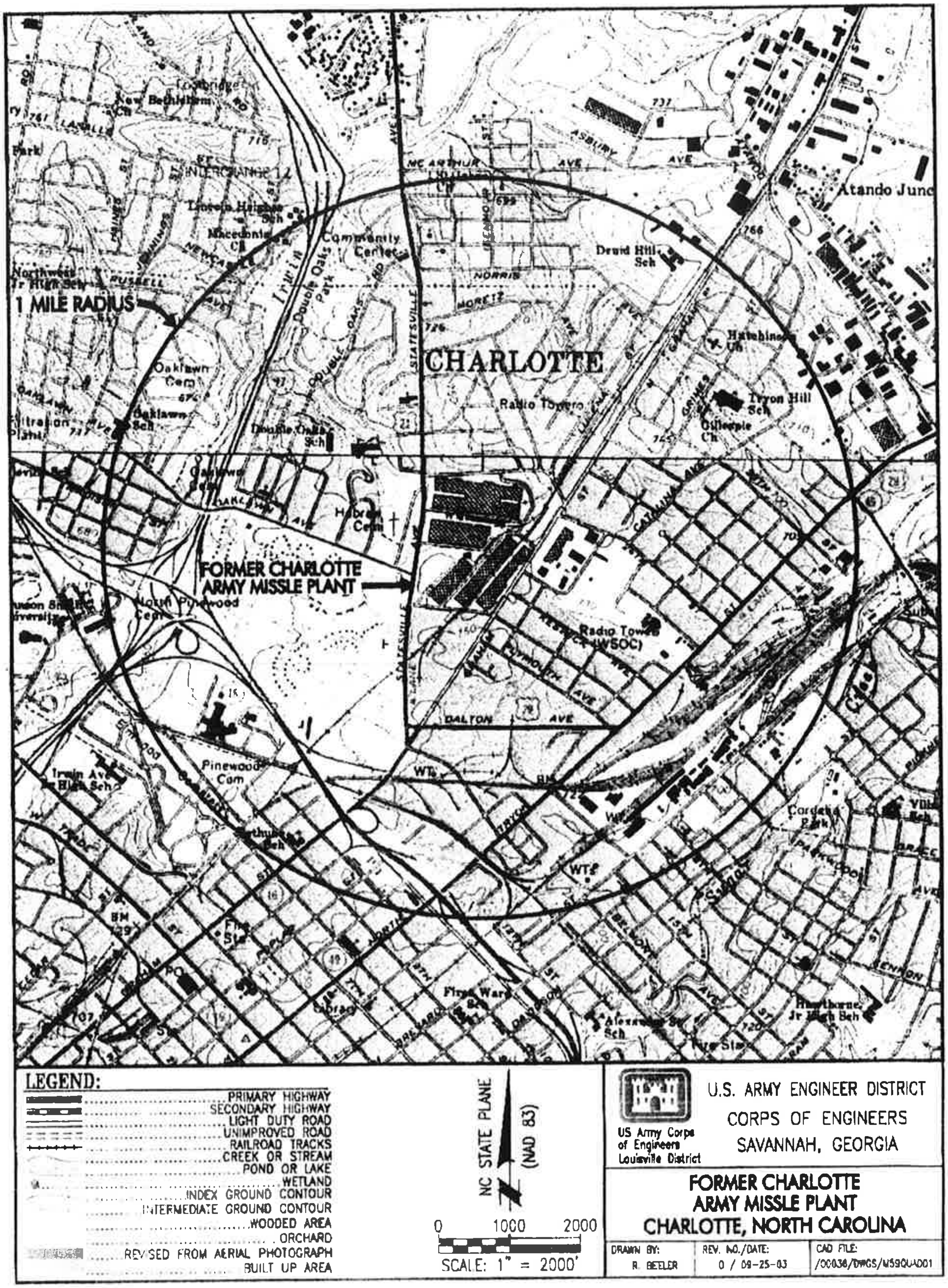



**Figure 1-1. Site Location Map**

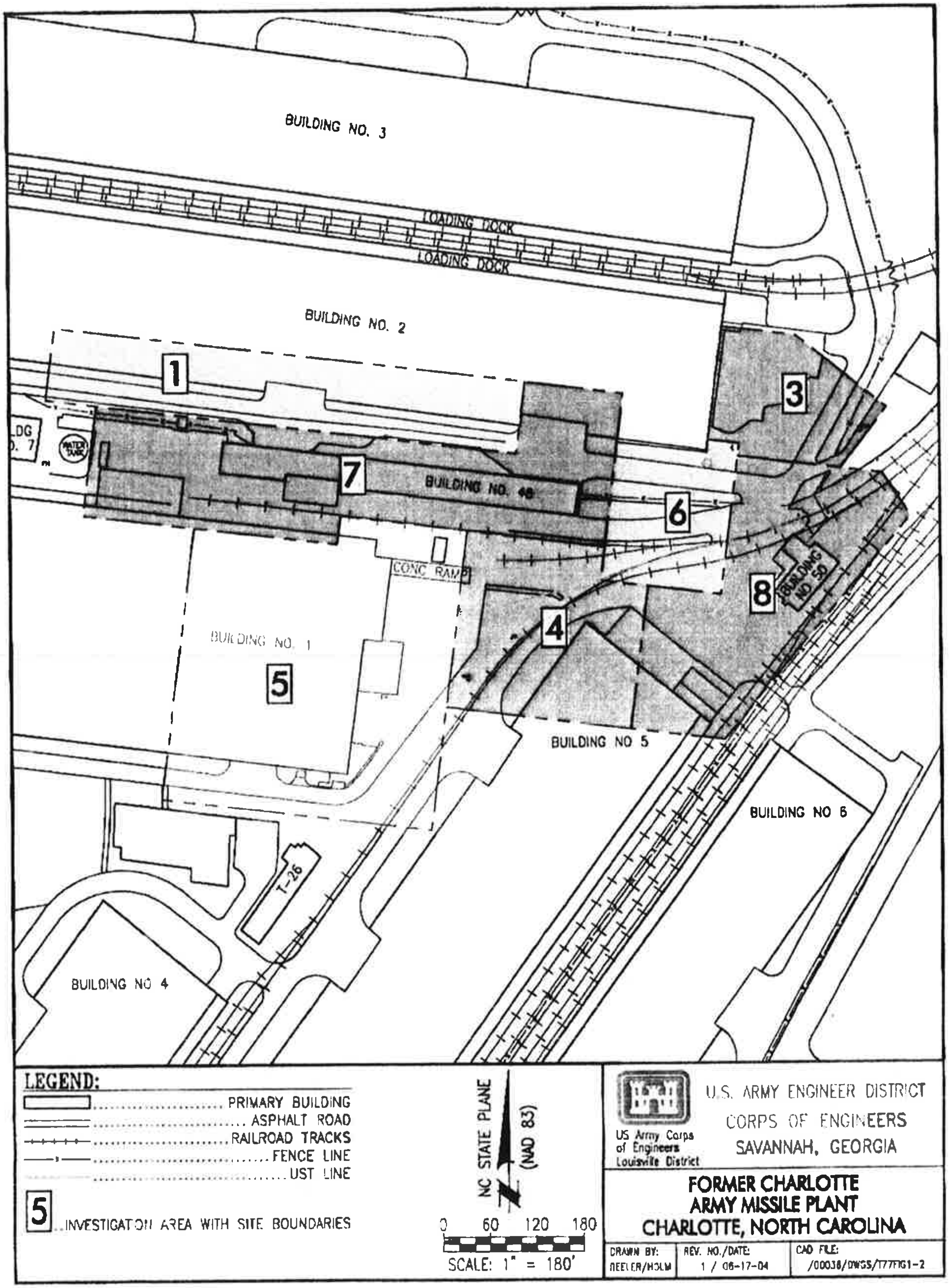



Figure 1-2. Investigation Area Site Boundaries

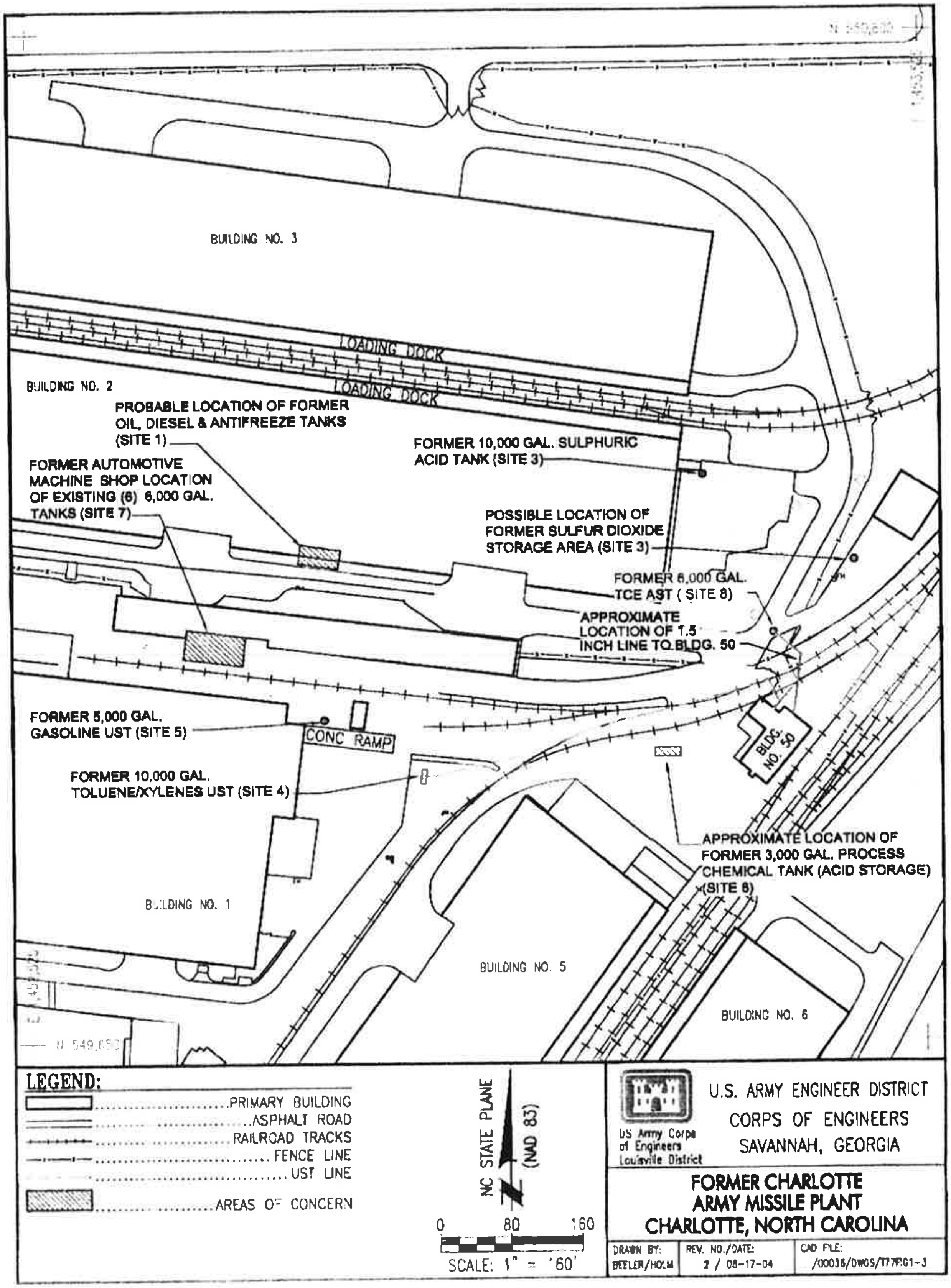



Figure 1-3. Possible Source Areas of Concern (as derived from M&E 2000)

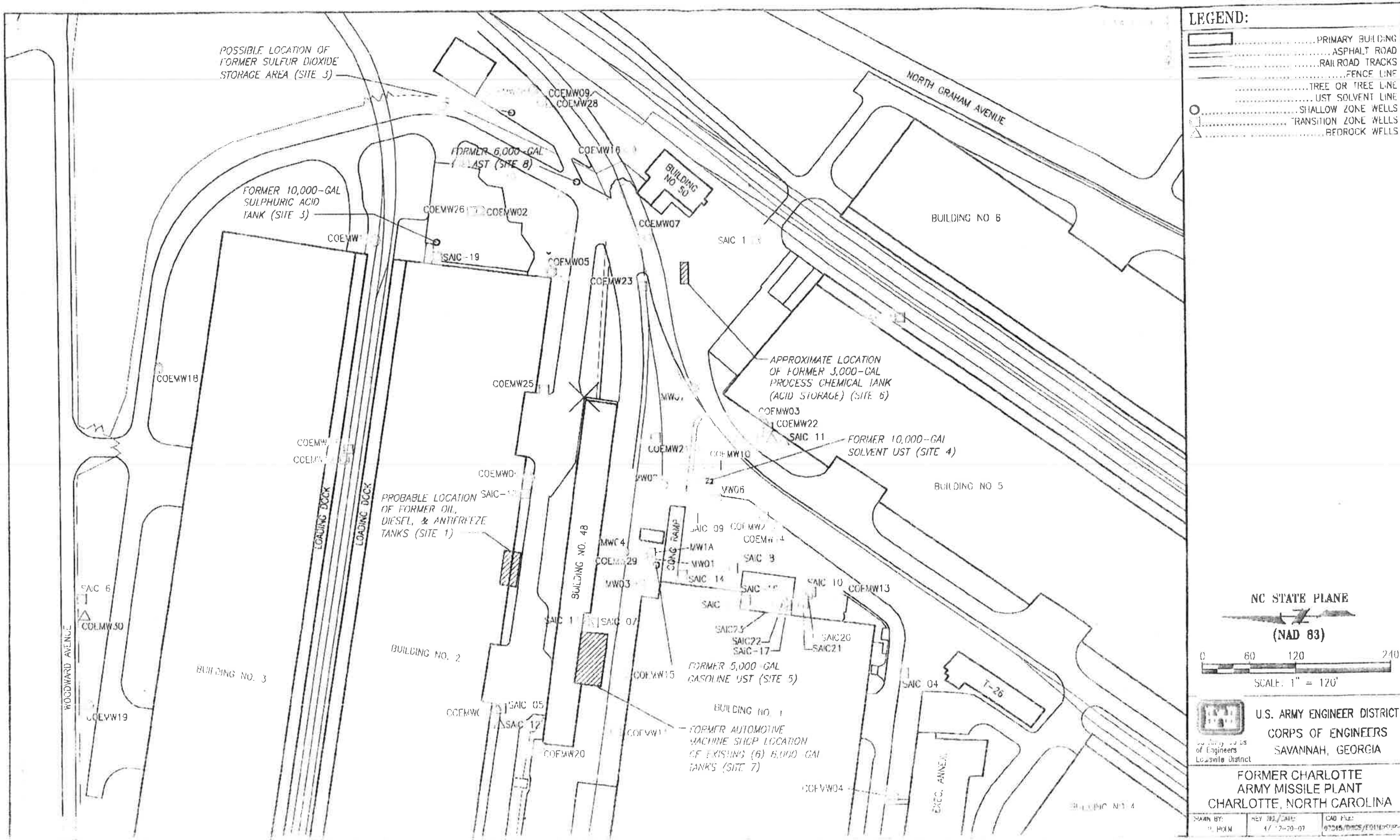



Figure 1-4. Site Map/Monitoring Well Locations

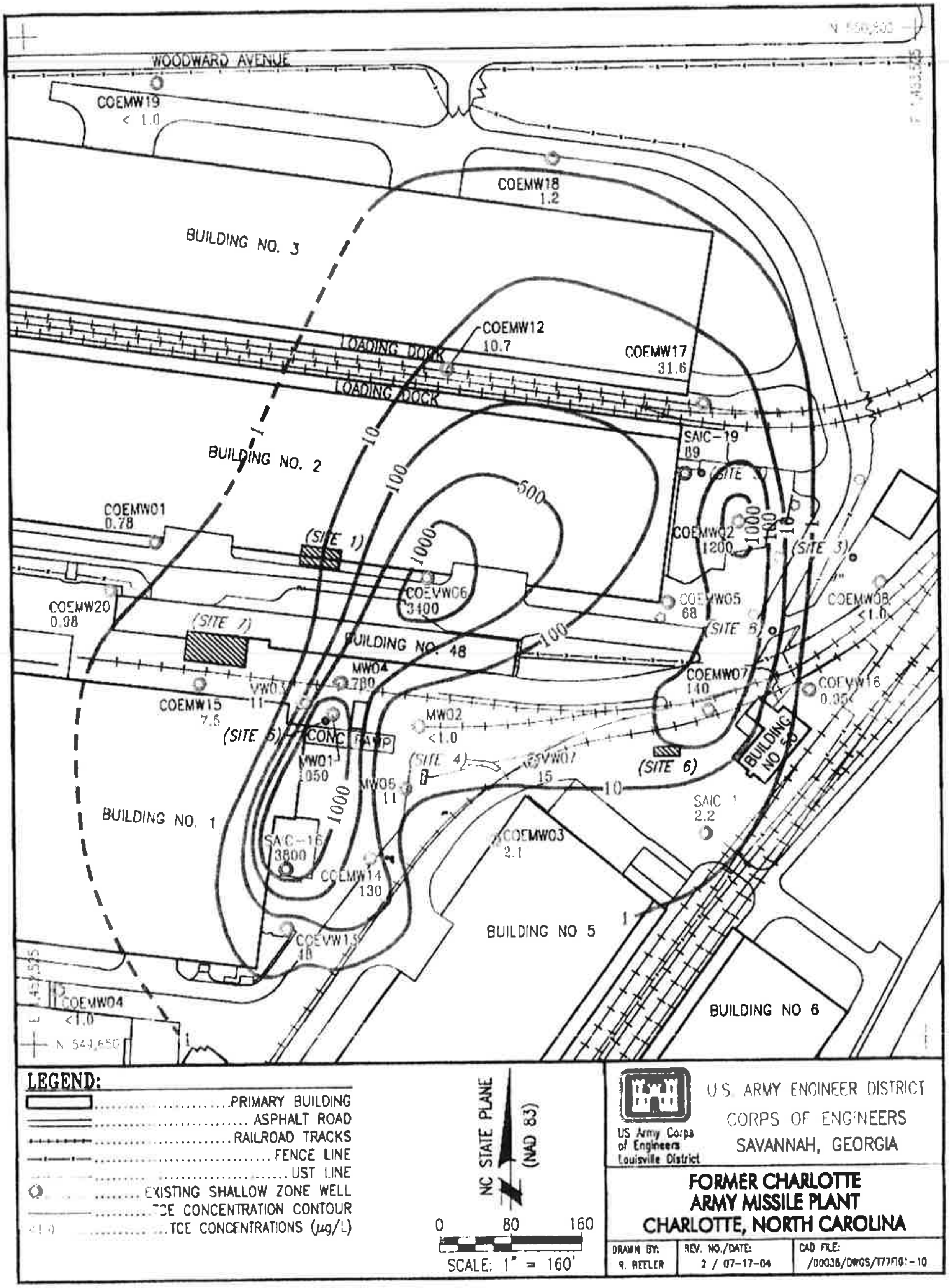



**Figure 1-5. TCE Concentrations in Shallow Zone Wells**

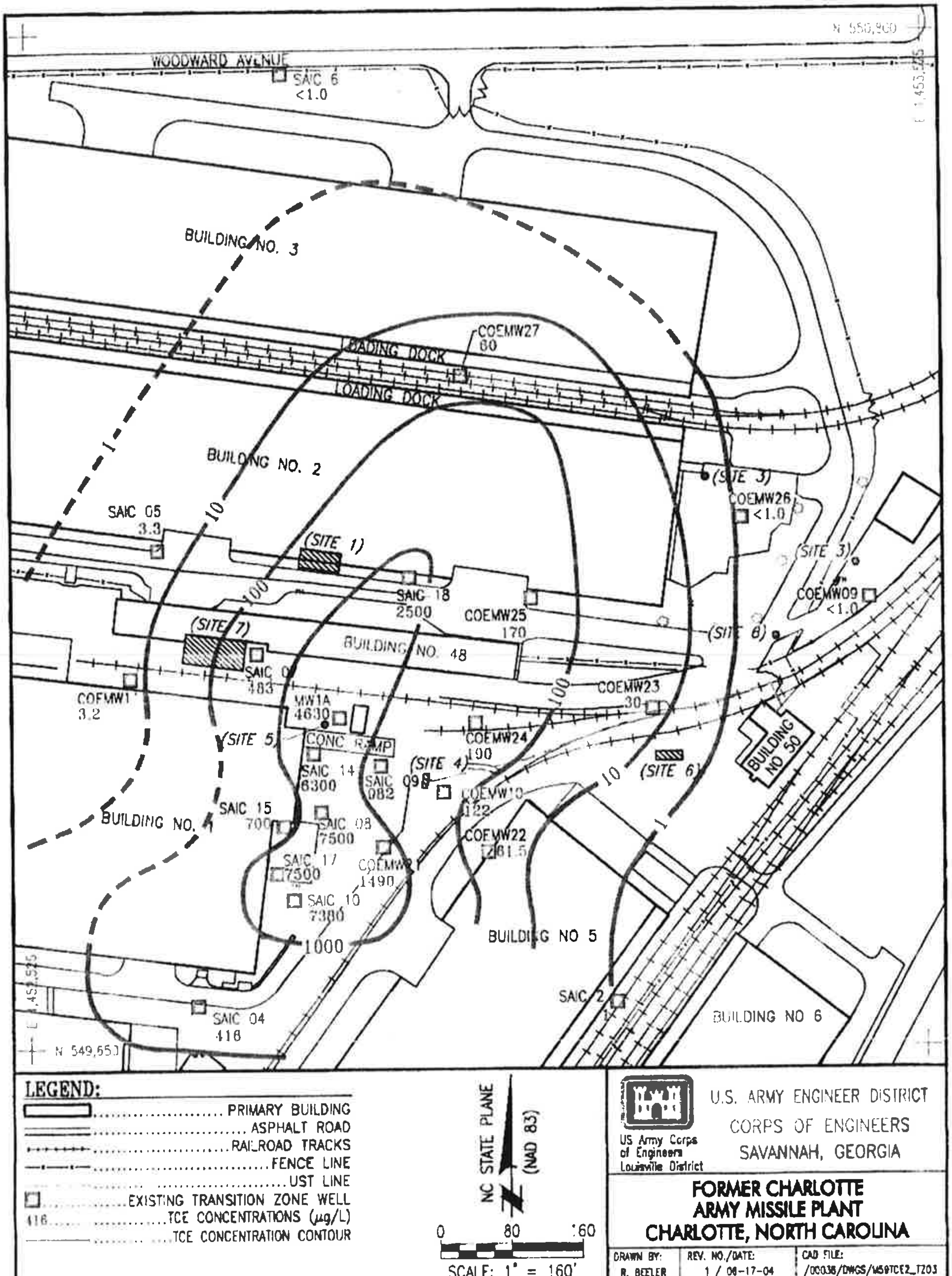



**Figure 1-6. TCE Concentrations inTransition Zone Wells, February 2003**

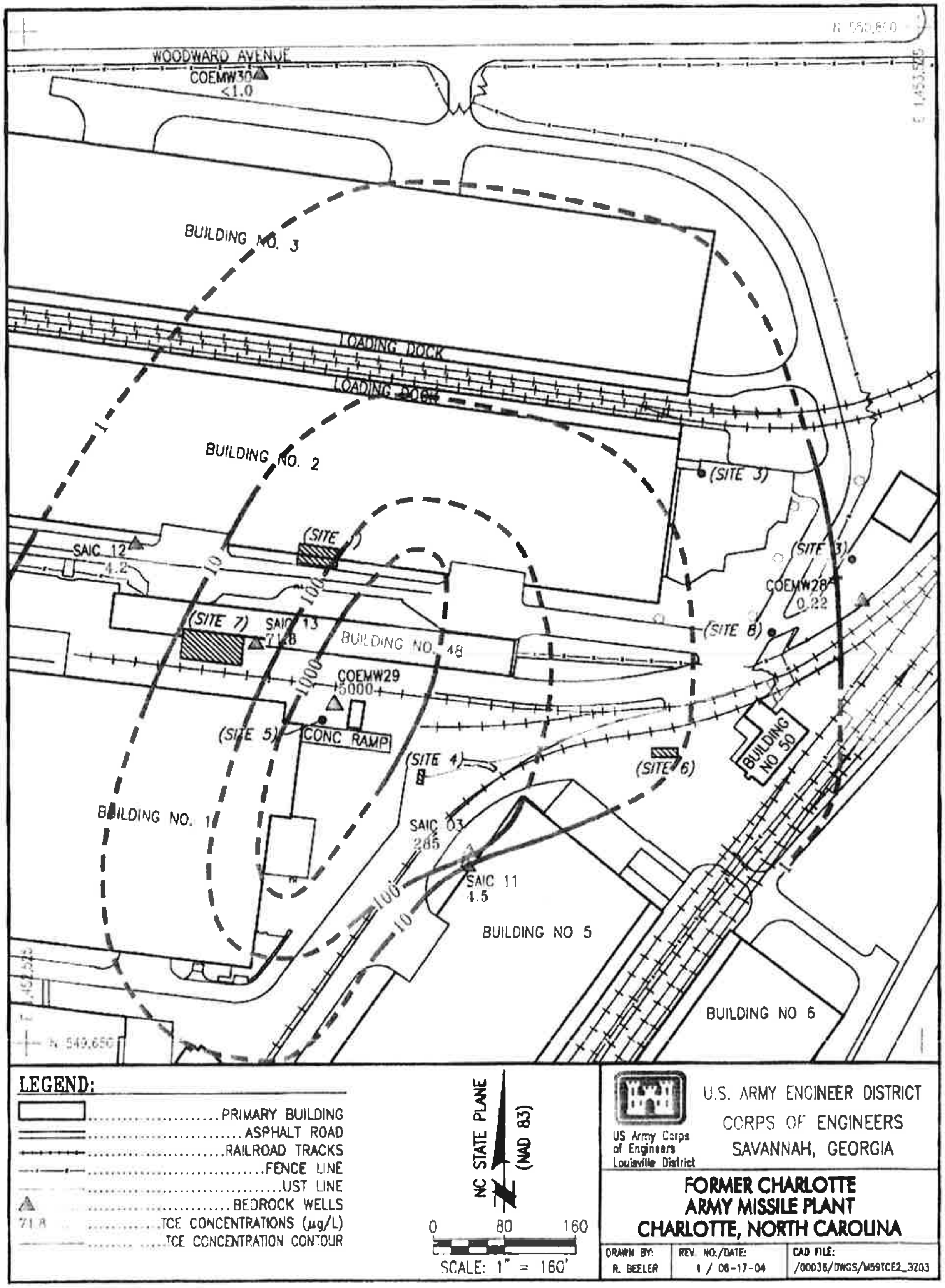



**Figure 1-7. TCE Concentrations in Bedrock Wells, February 2003**

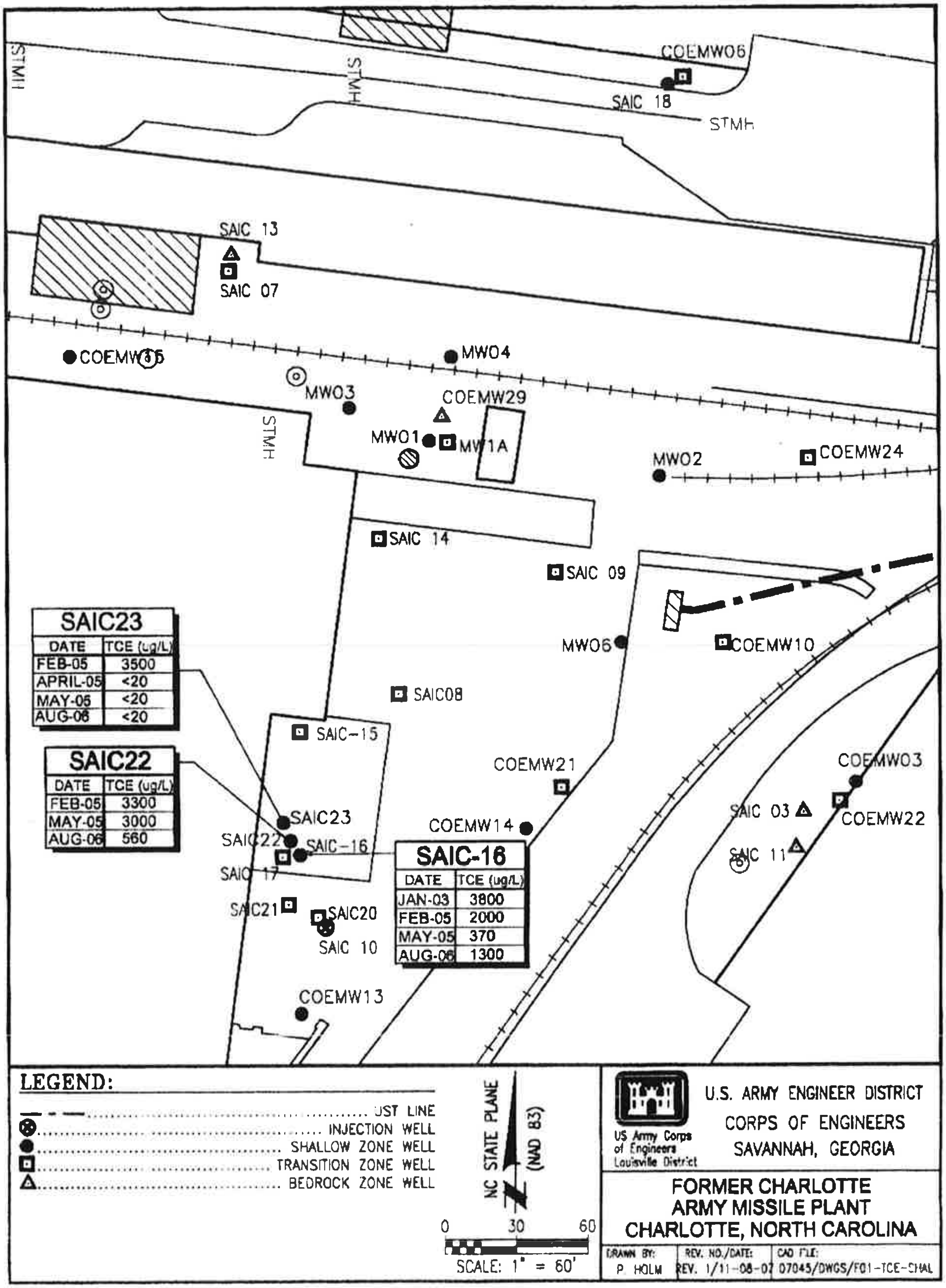



Figure 1-8. TCE concentrations - Shallow zone wells, August, 2006.

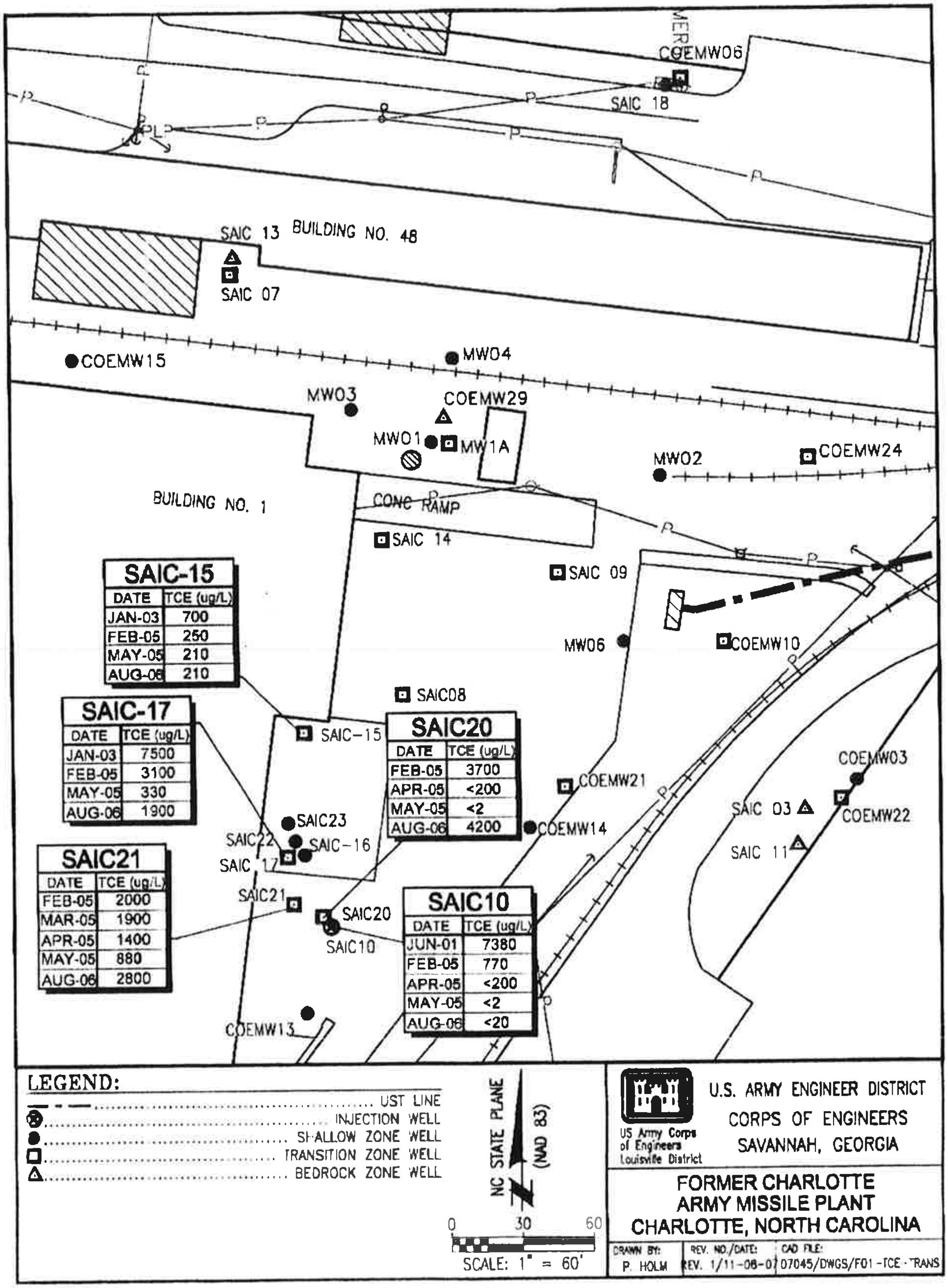



**Figure 1-9. TCE concentrations - Transition zone wells, August, 2006.**

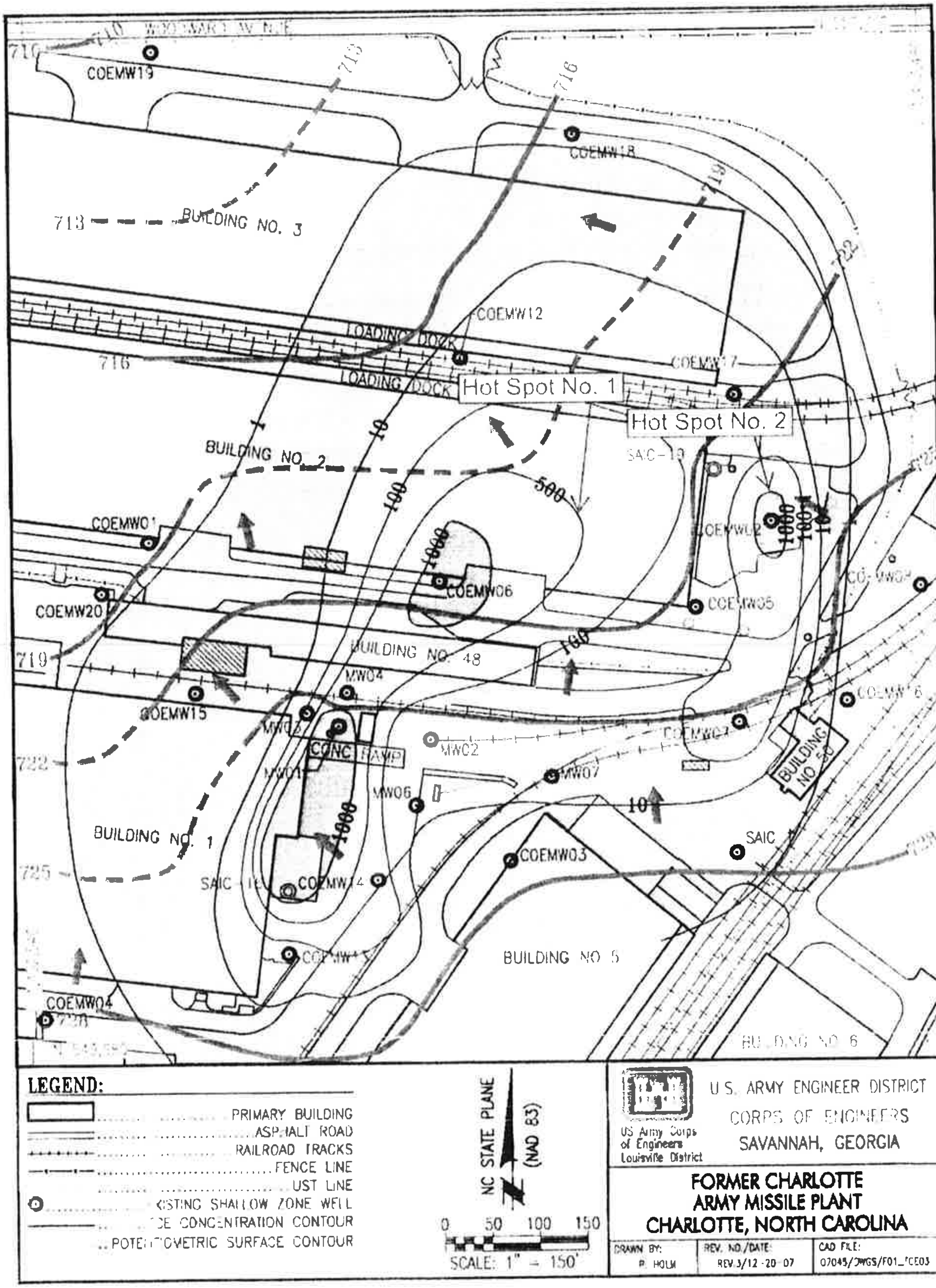



Figure 1-13. Shallow Zone Potentiometric Surface, February 2003, and TCE Concentrations

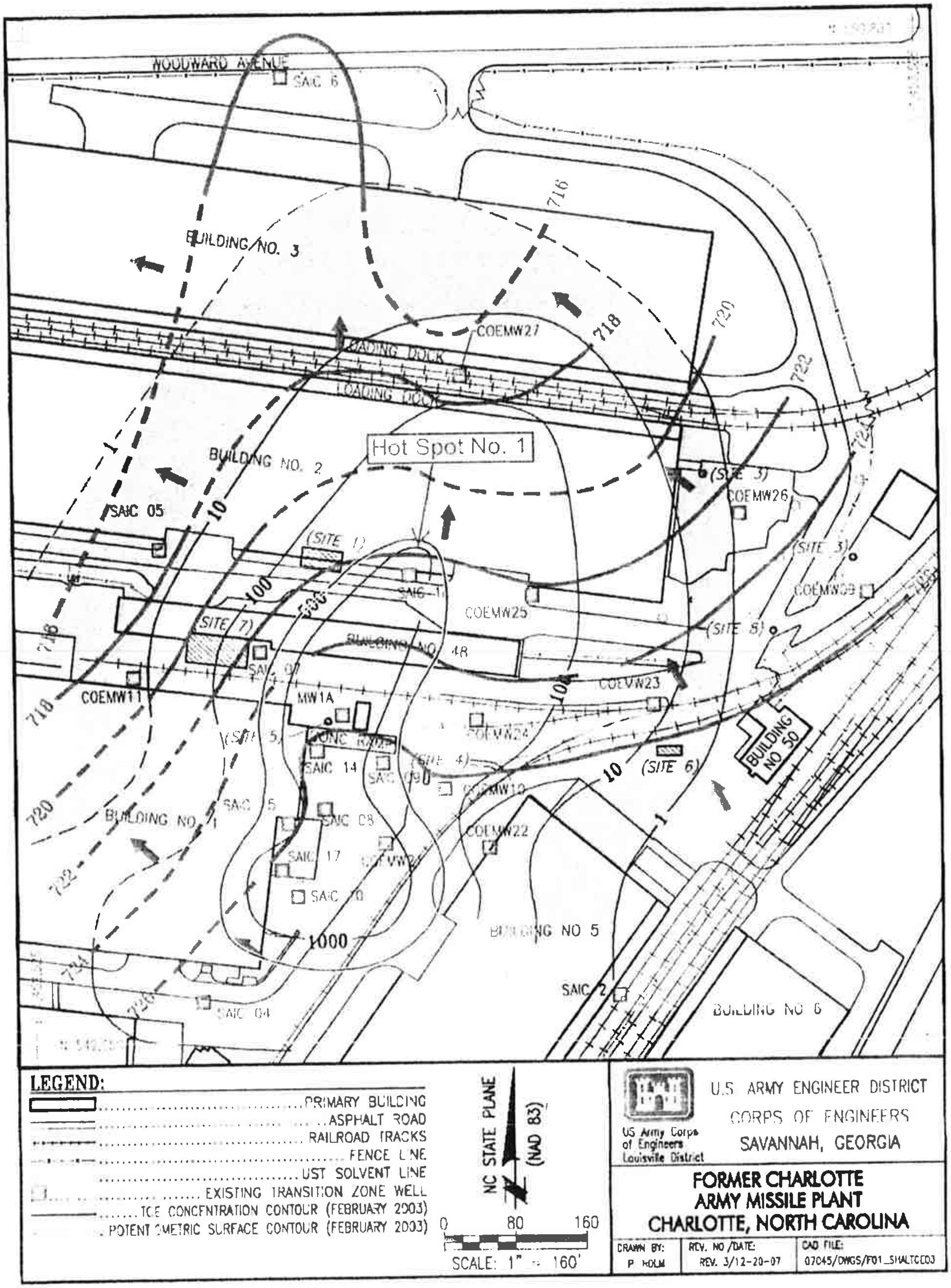



**Figure 1-14. Transition Zone Potentiometric Surface, February 2003**

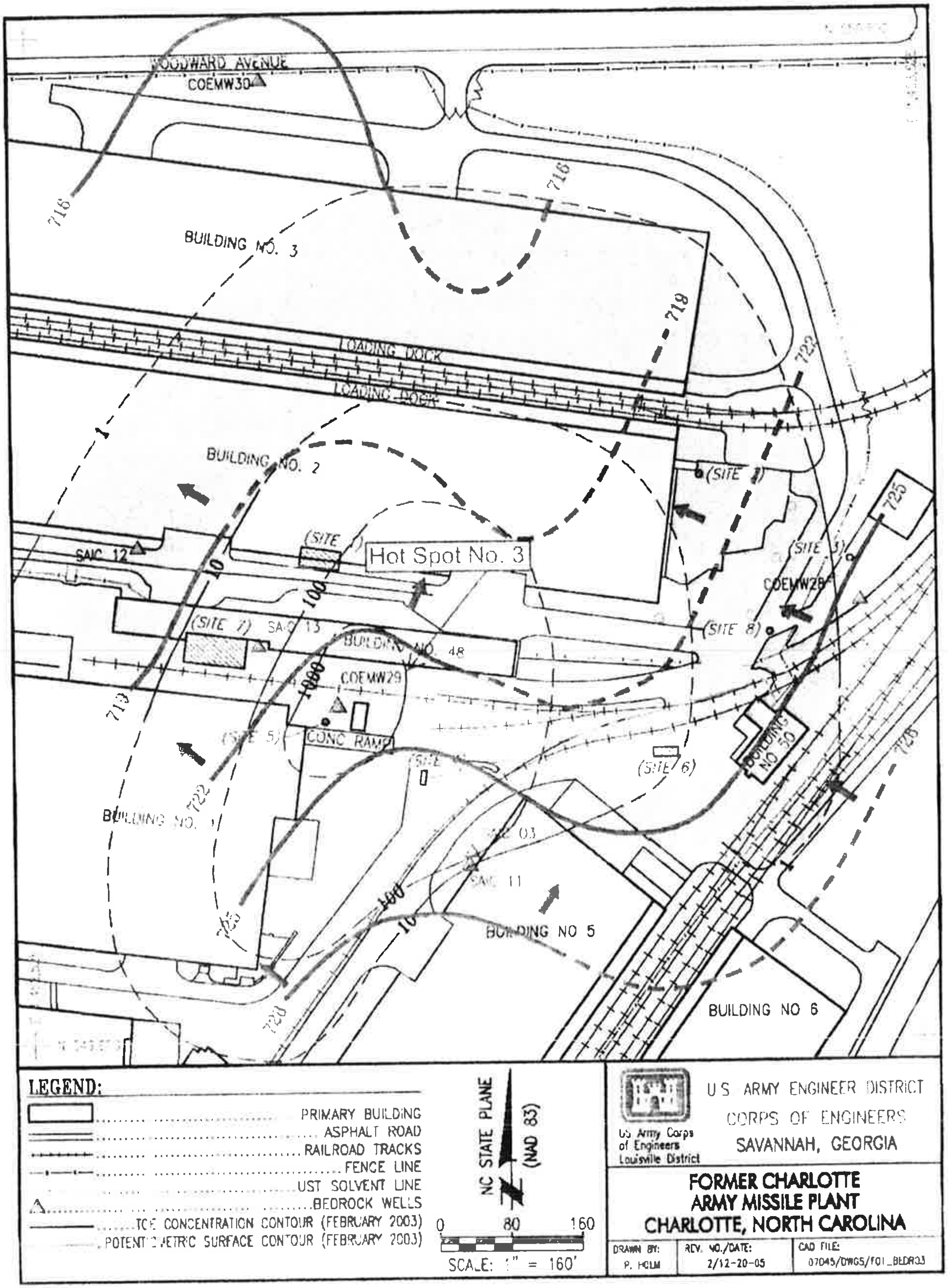



**Figure 1-15. Bedrock Zone Potentiometric Surface, February 2003**

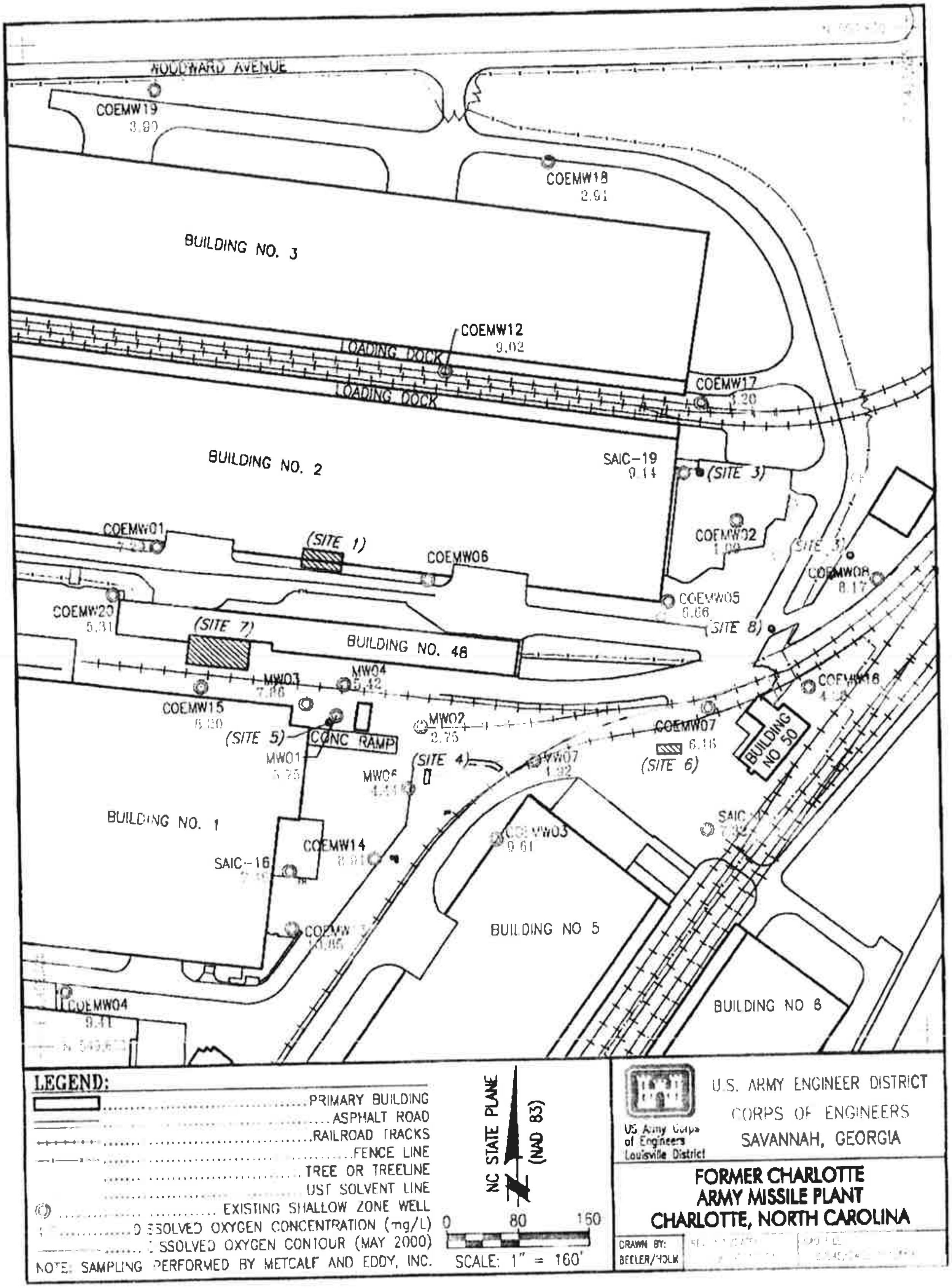



**Figure 1-16. Shallow Zone Dissolved Oxygen Concentrations**

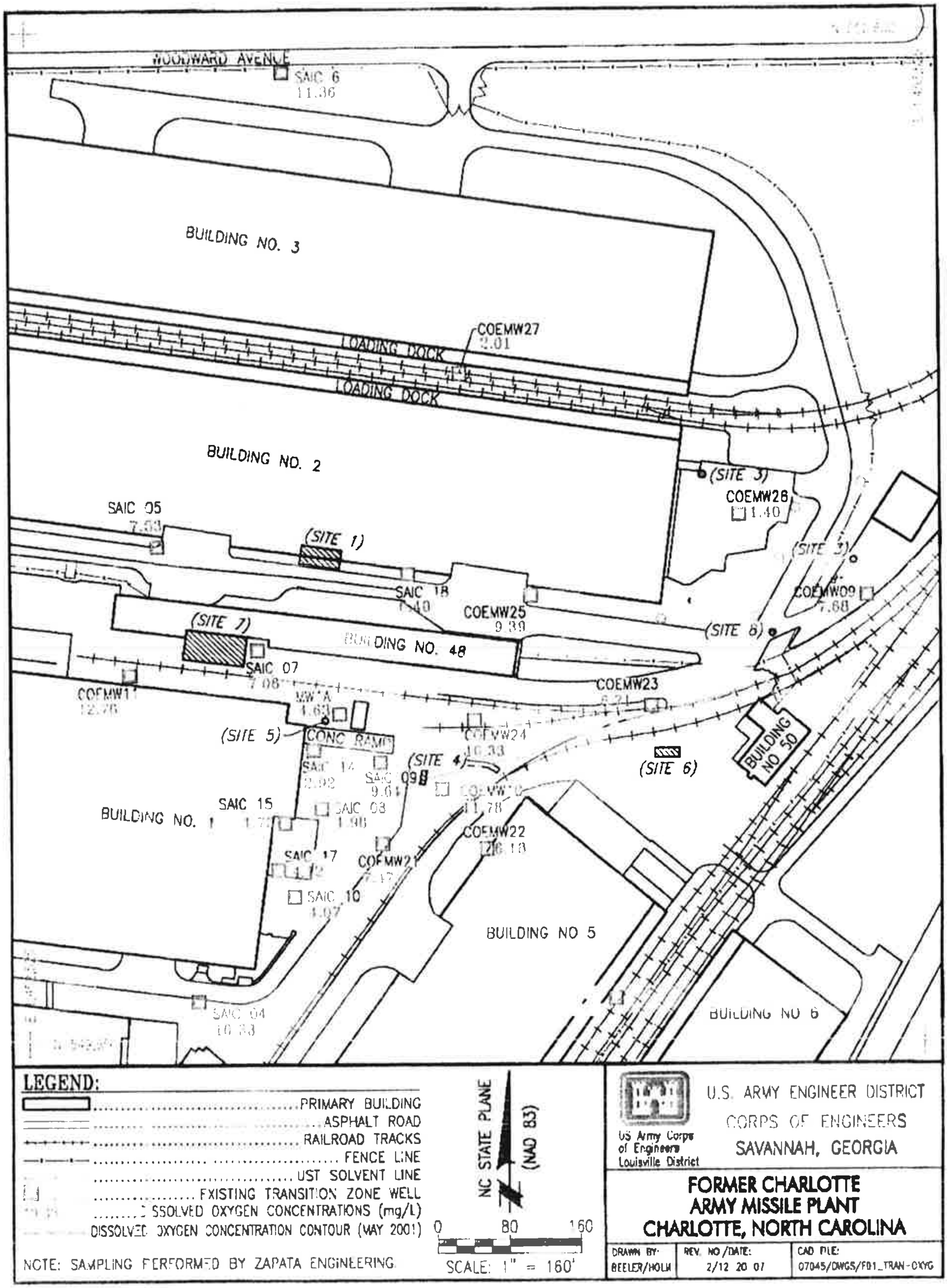



**Figure 1-17. Transition Zone Dissolved Oxygen Concentrations**

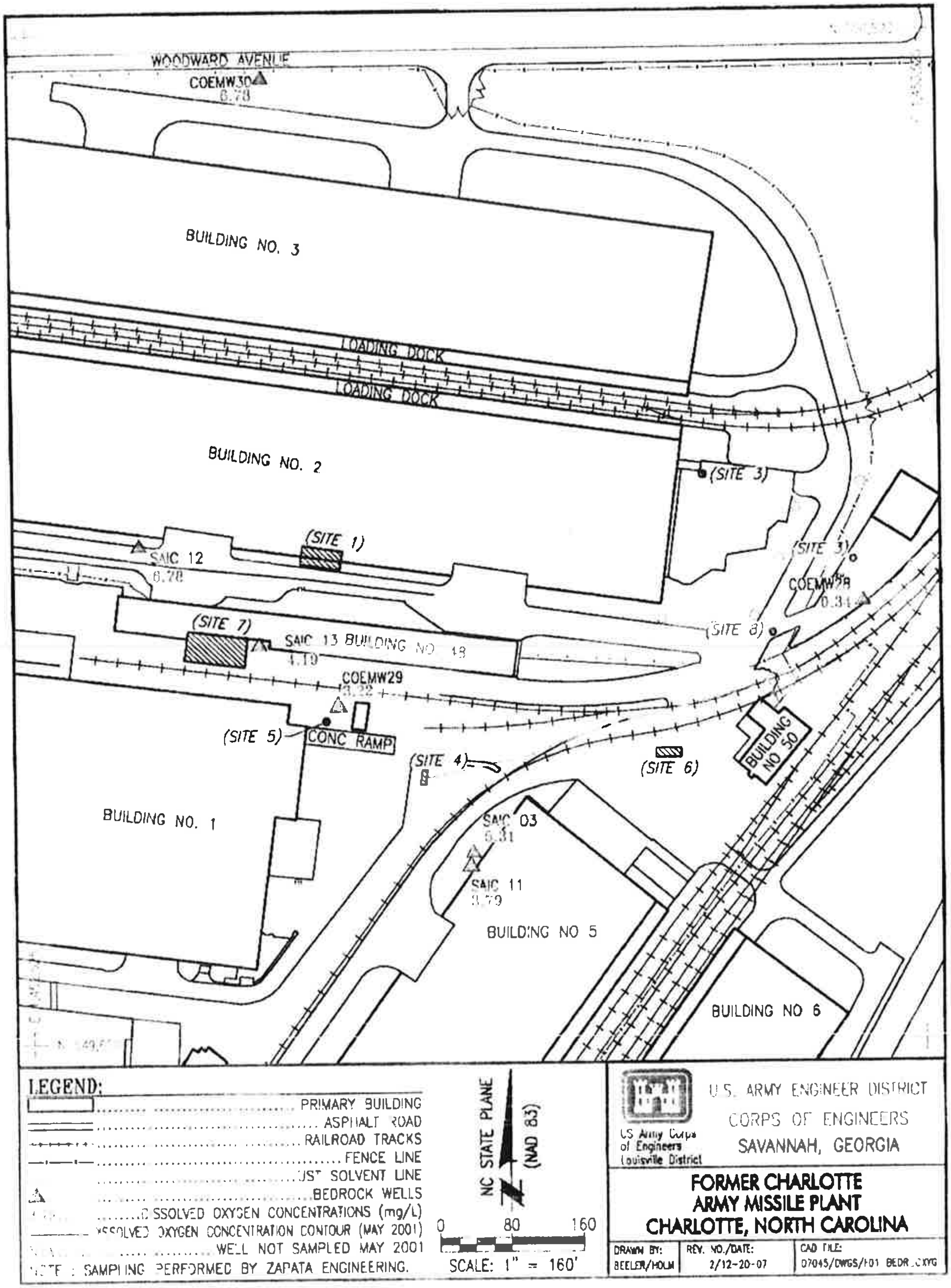
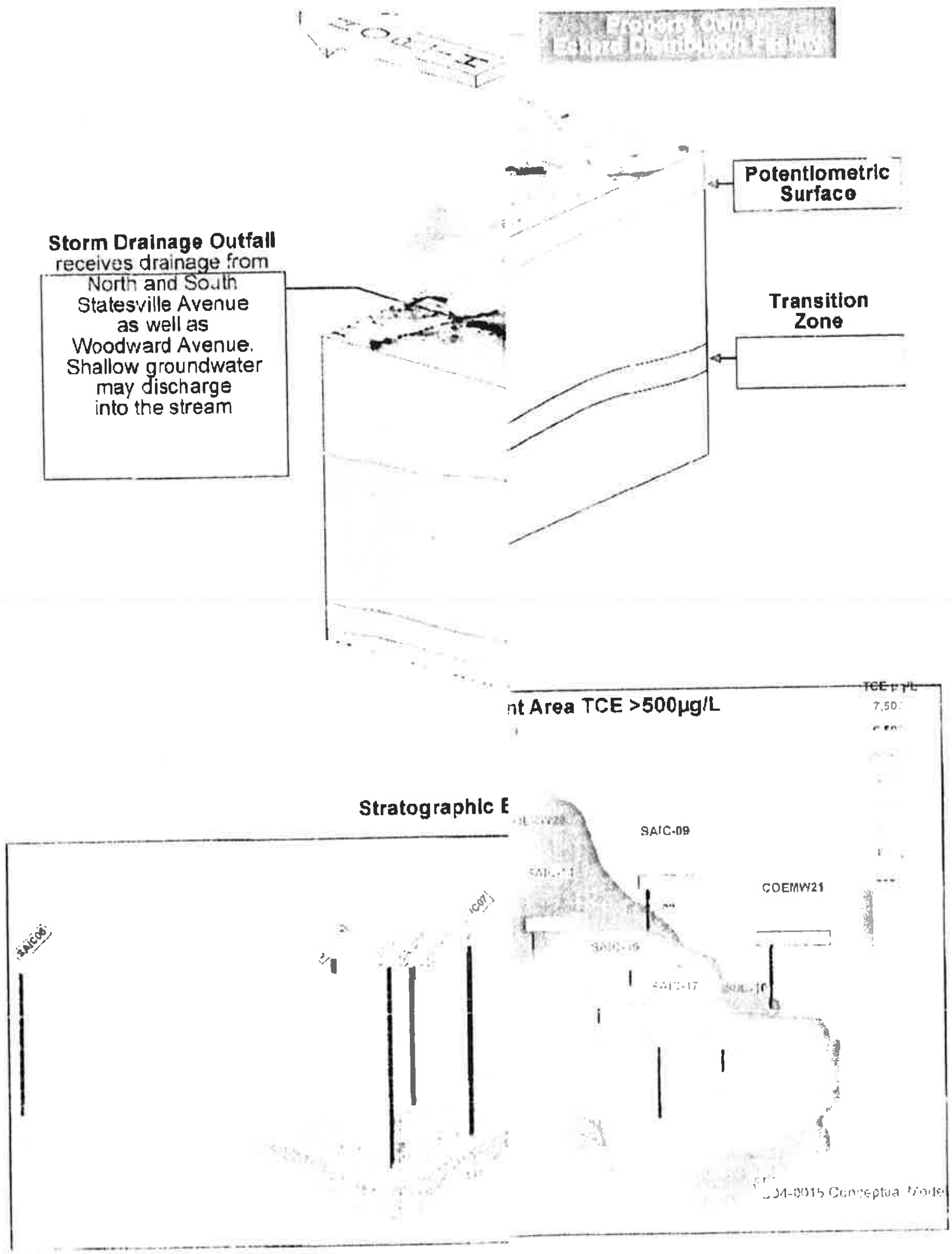



**Figure 1-18. Bedrock Zone Dissolved Oxygen Concentrations**


Potentiometric Surface
Storm Drainage Outfall
receives drainage from North and South Statesville Avenue as well as Woodward Avenue. Shallow groundwater may discharge into the stream
Transition Zone
nt Area TCE >500µg/L
Stratographic E
SAIC-09
COEMW21
SAIC06

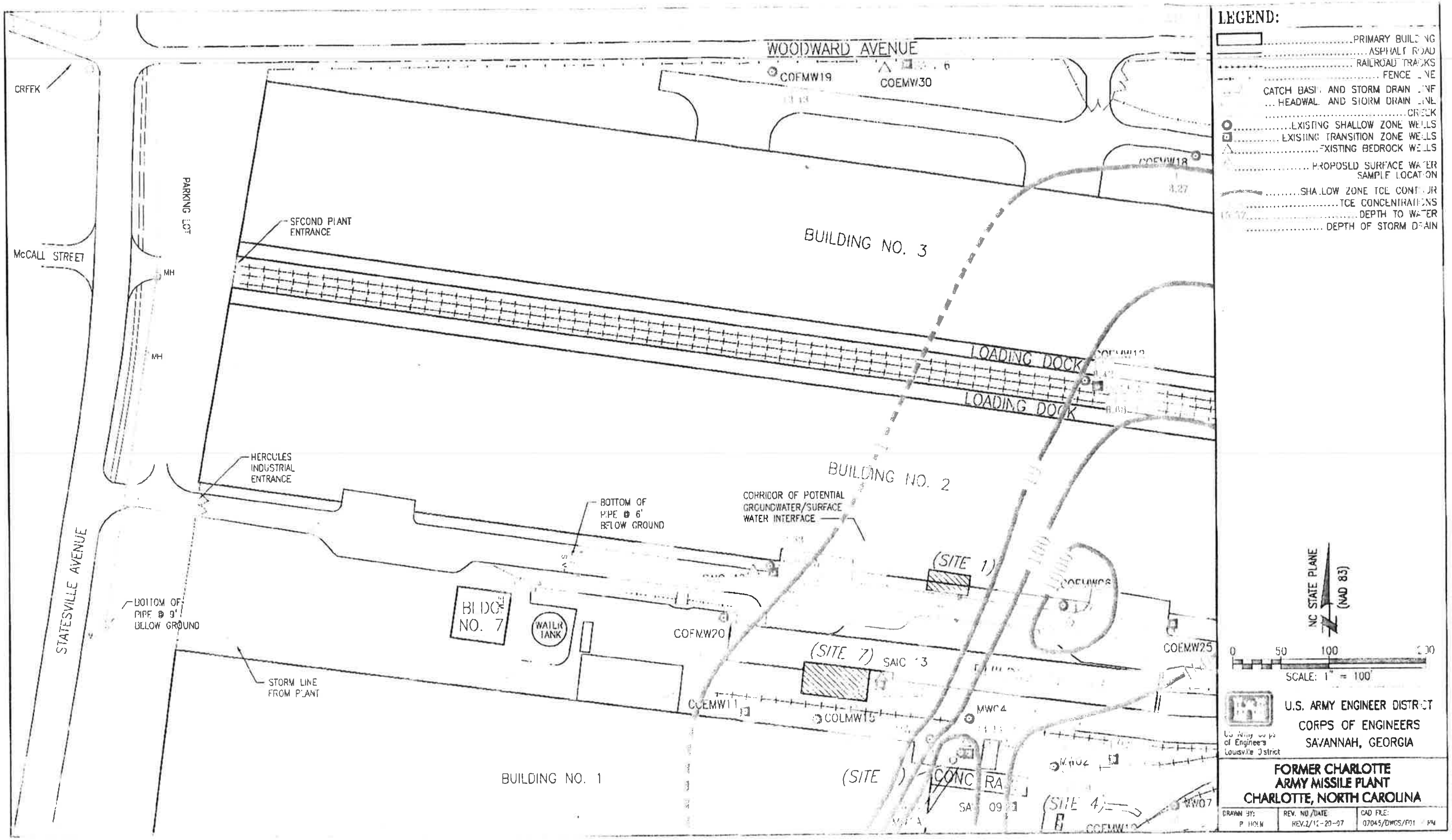



**Figure 1-10. Stormwater Drainage Pathways**

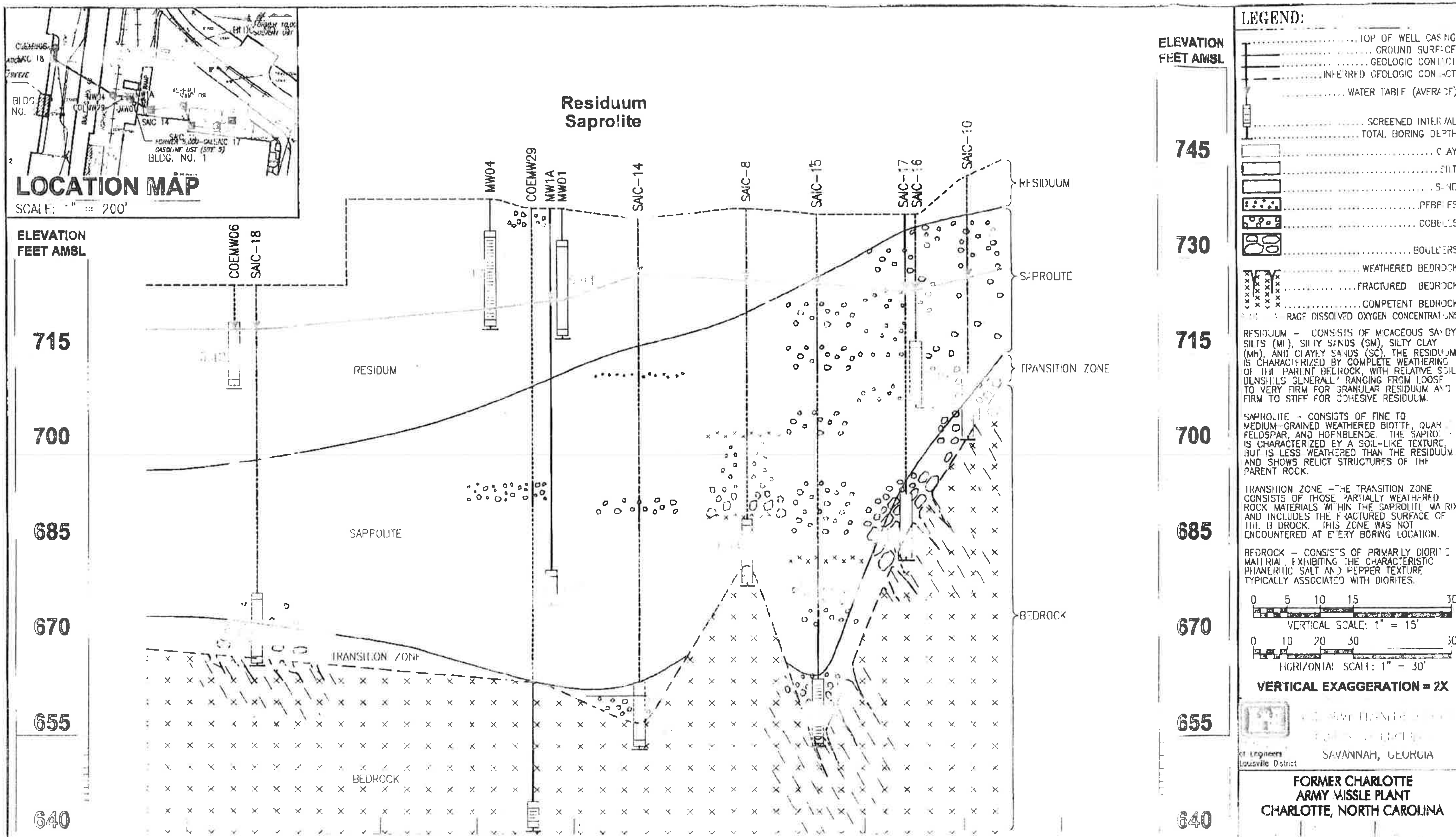



Figure 1-11. Site Cross Section

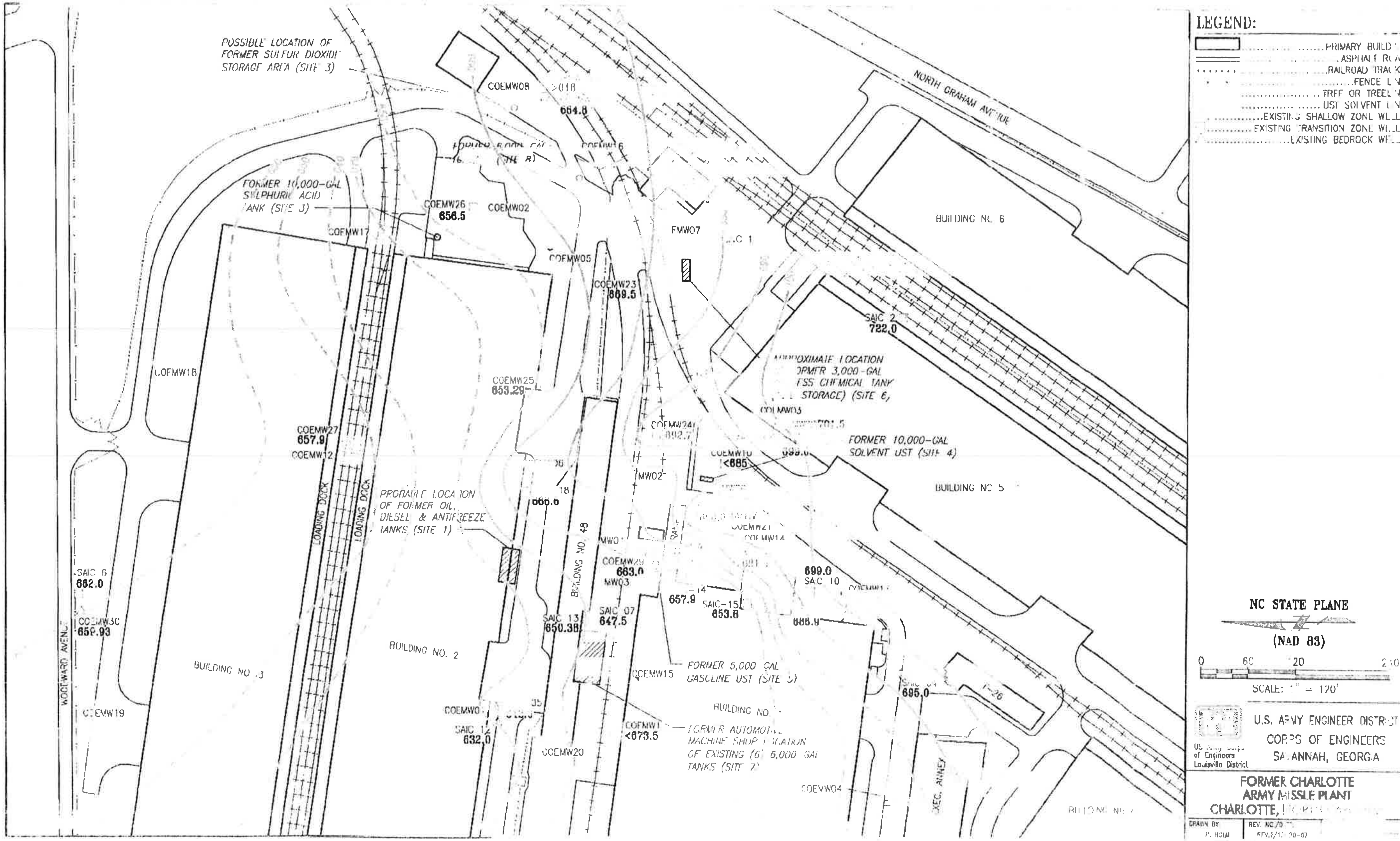



Figure 1-12. Top of Bedrock Isopleth

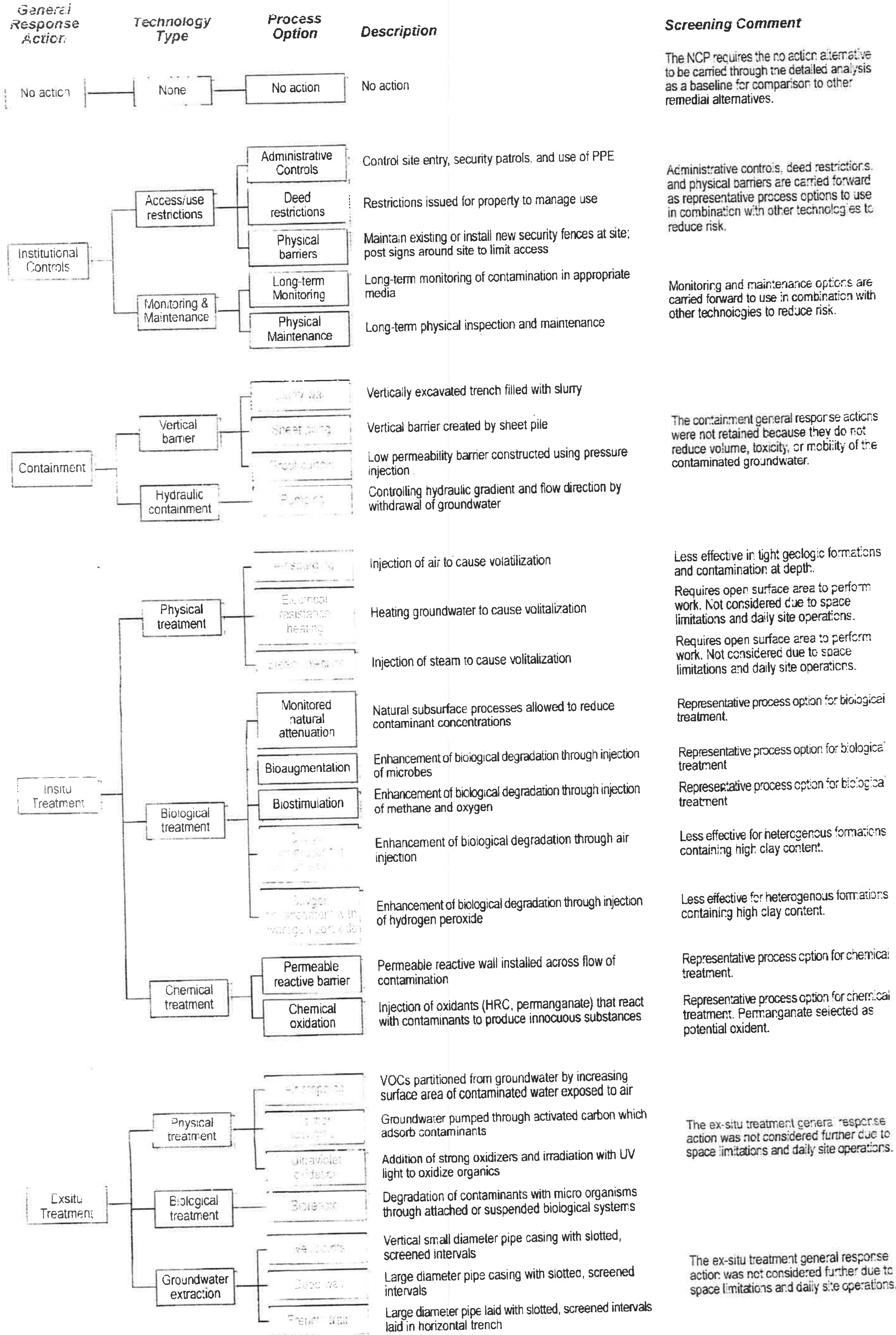



**Figure 4-1. Summary of Representative Technology Types and Process Options**

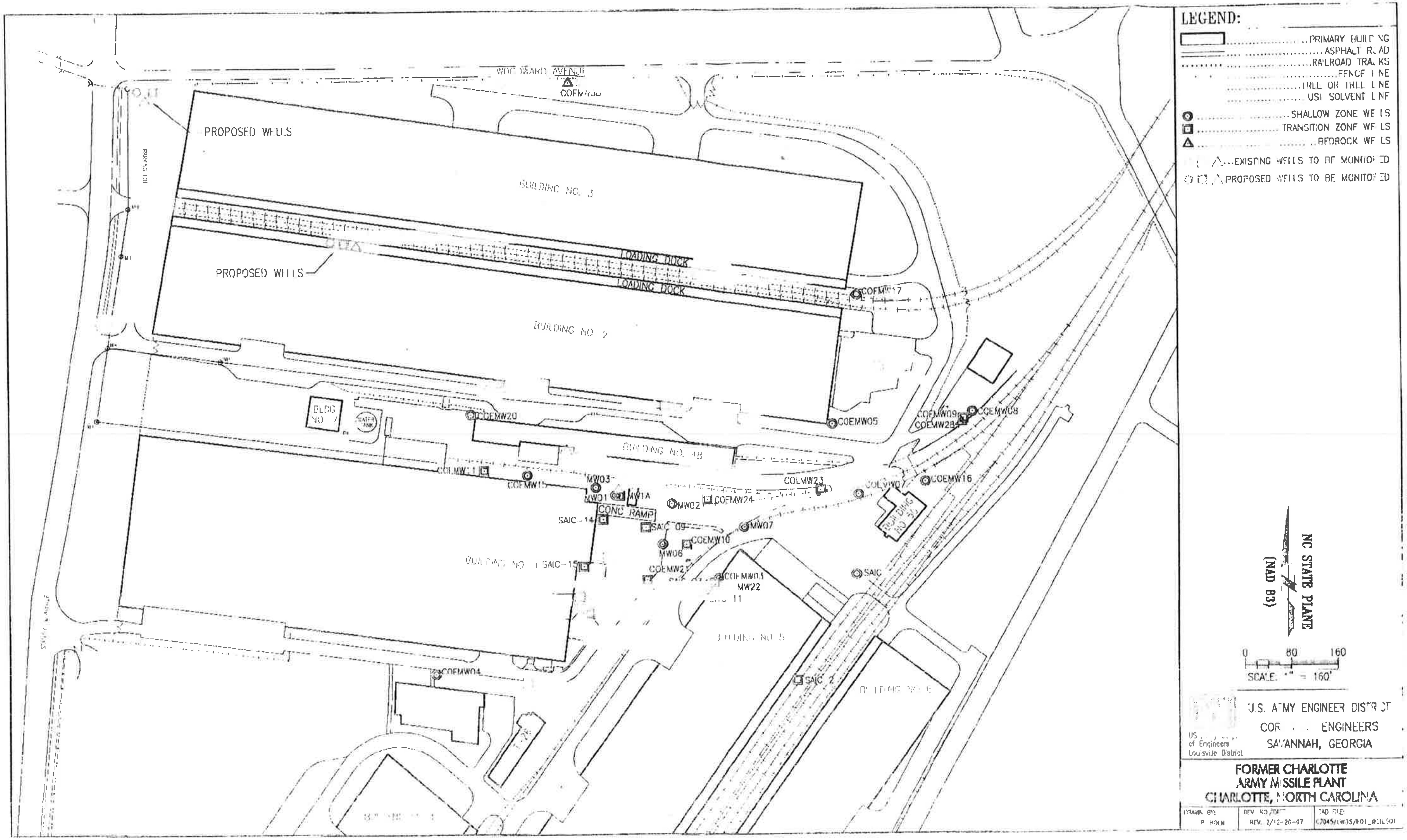



Figure 5-1. Existing and Proposed Monitoring Well Locations for Monitoring Natural Attenuation

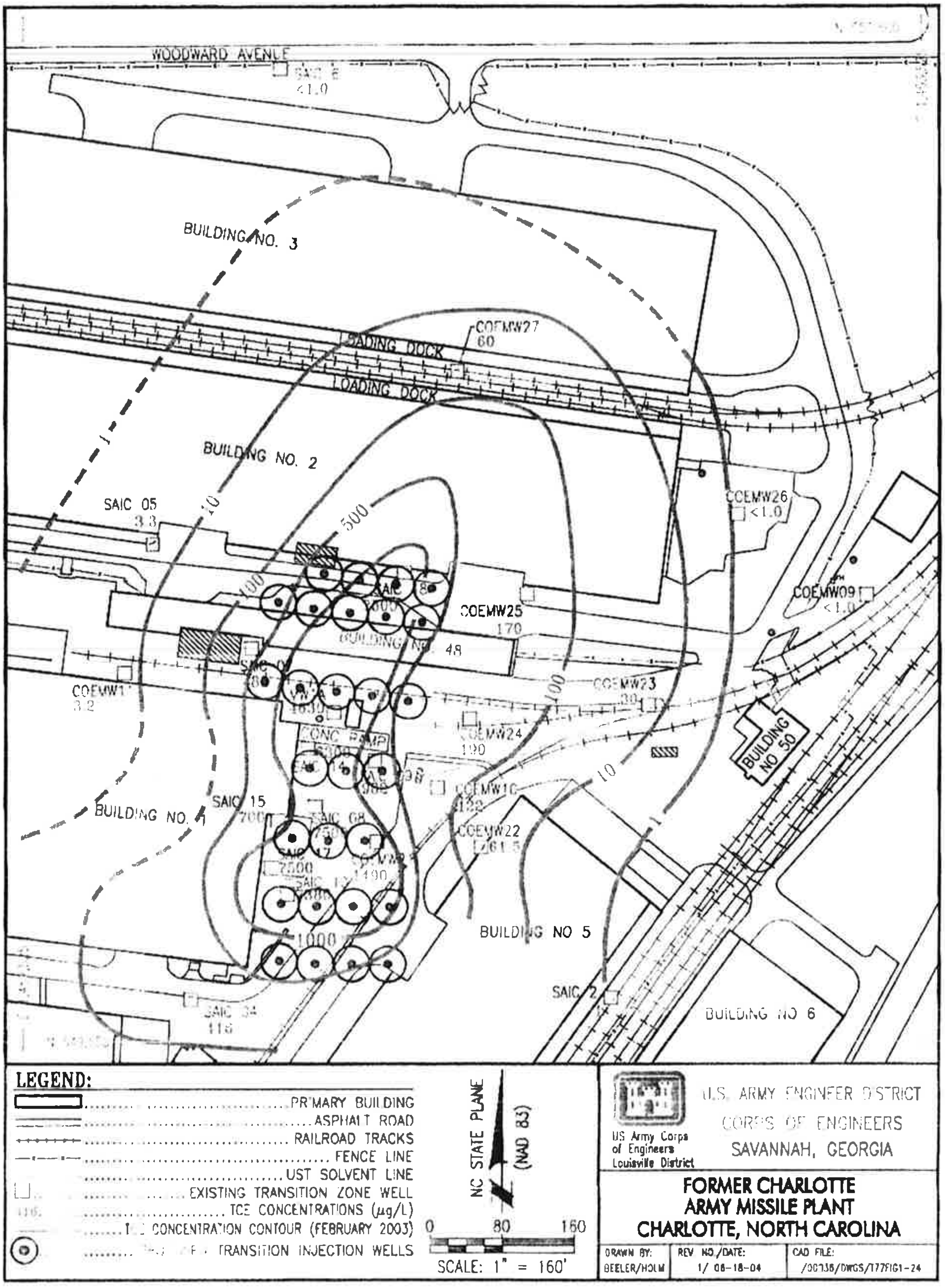



**Figure 5-2. TCE Concentrations in Transition Zone Wells**

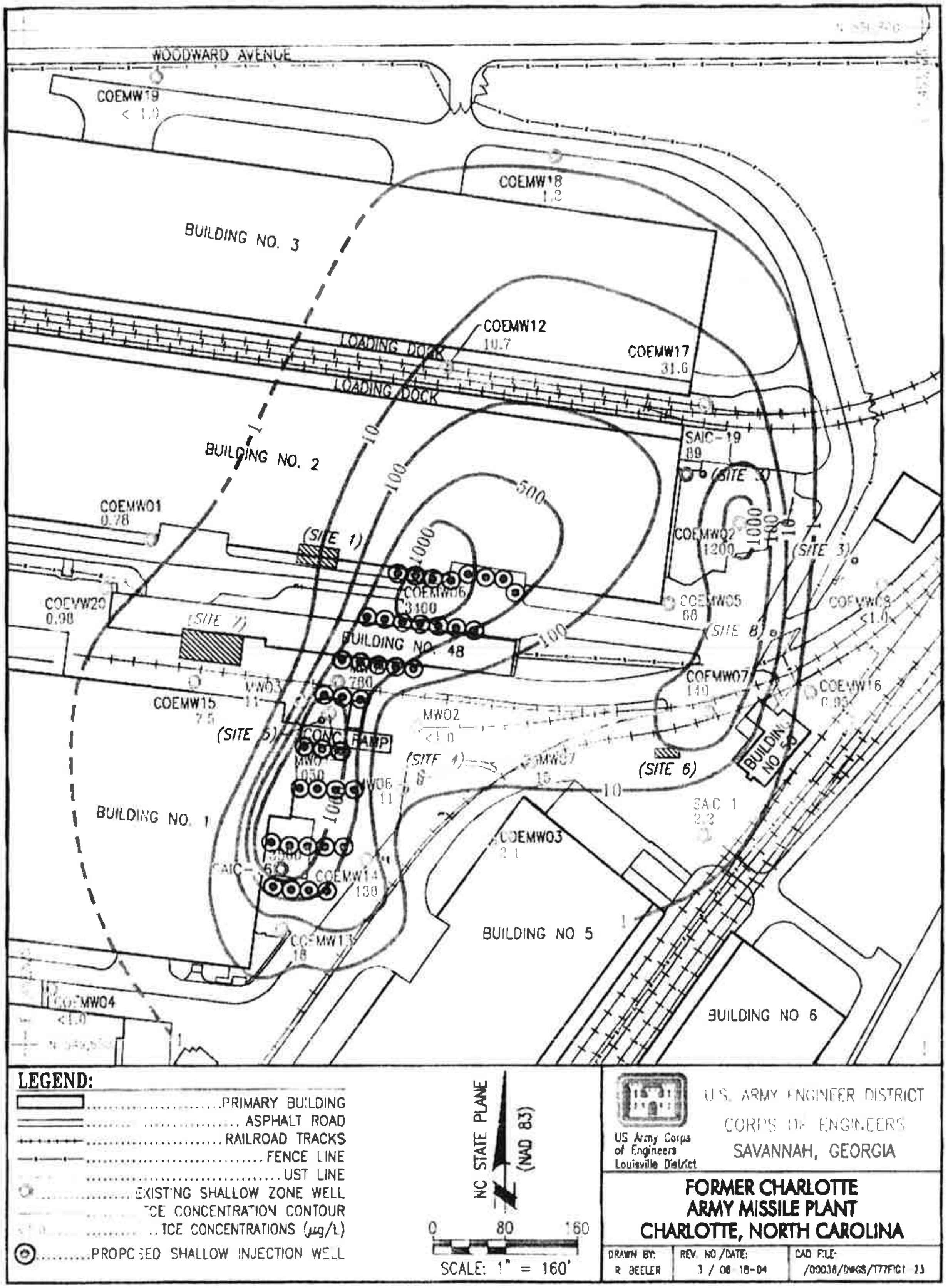



**Figure 5-3. TCE Concentrations in Shallow Zone Wells**

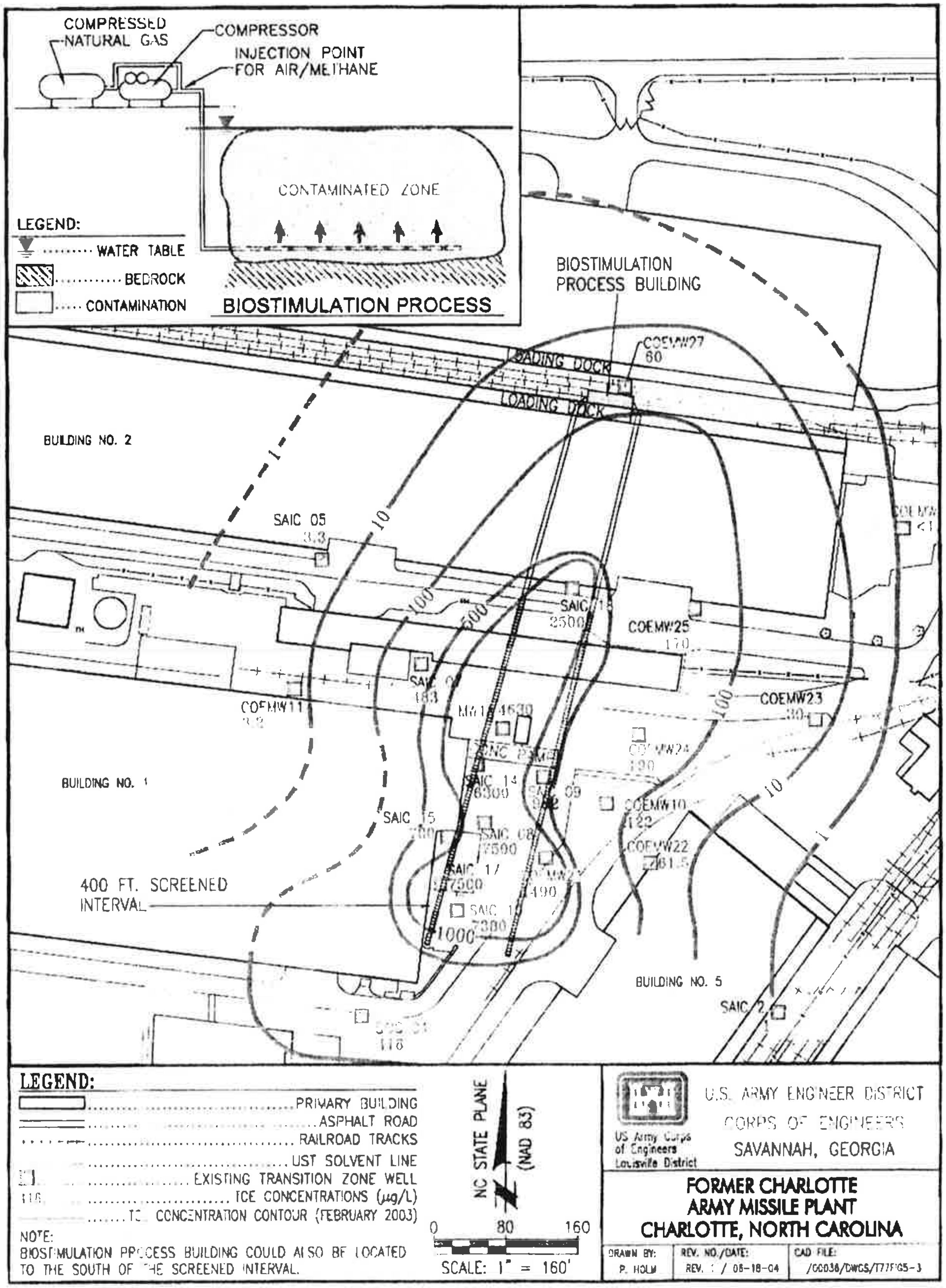



**Figure 5-4. Biostimulation Well Locations**

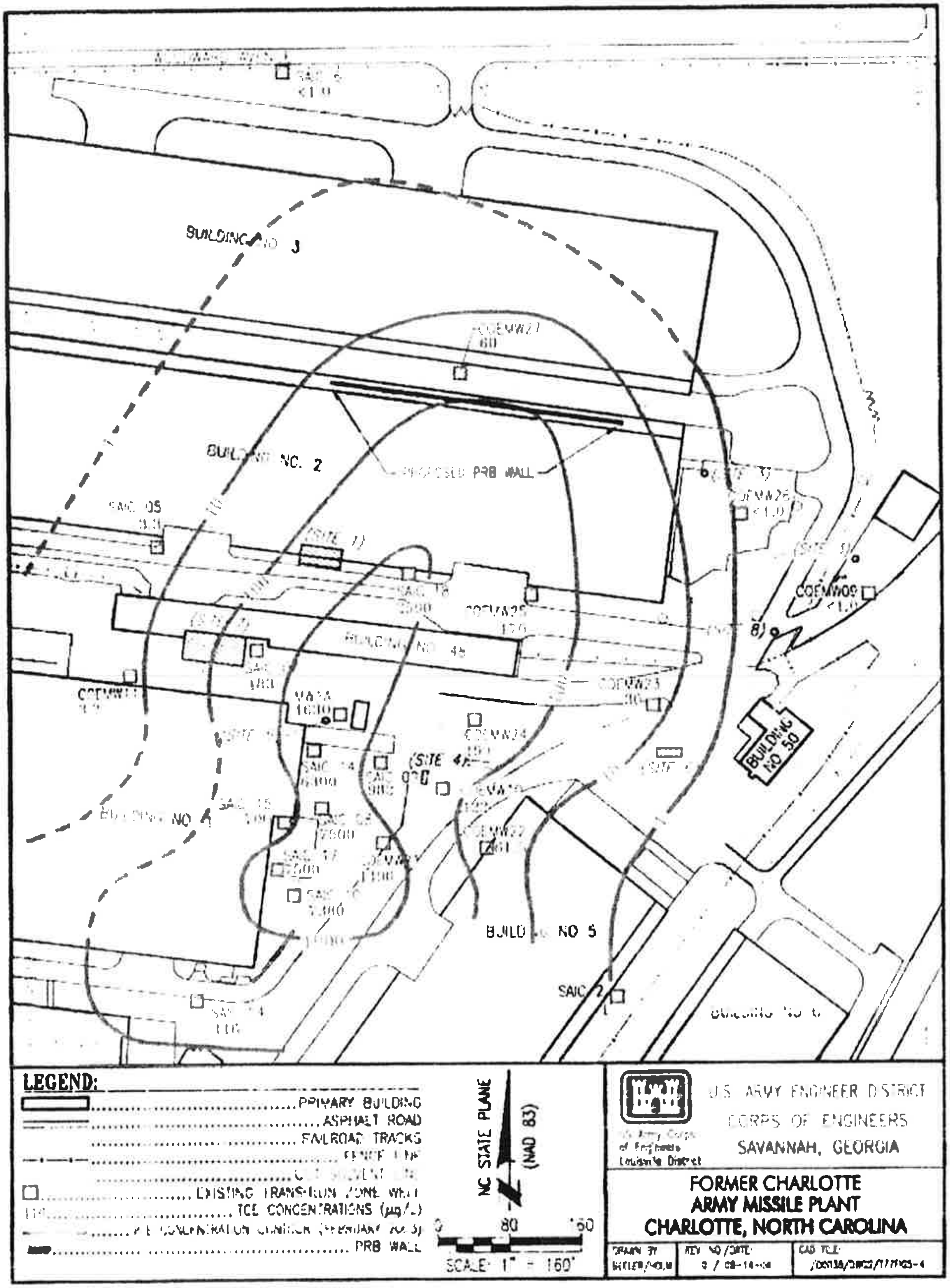



**Figure 5-5. Proposed Permeable Reactive Barrier Alternative Location**

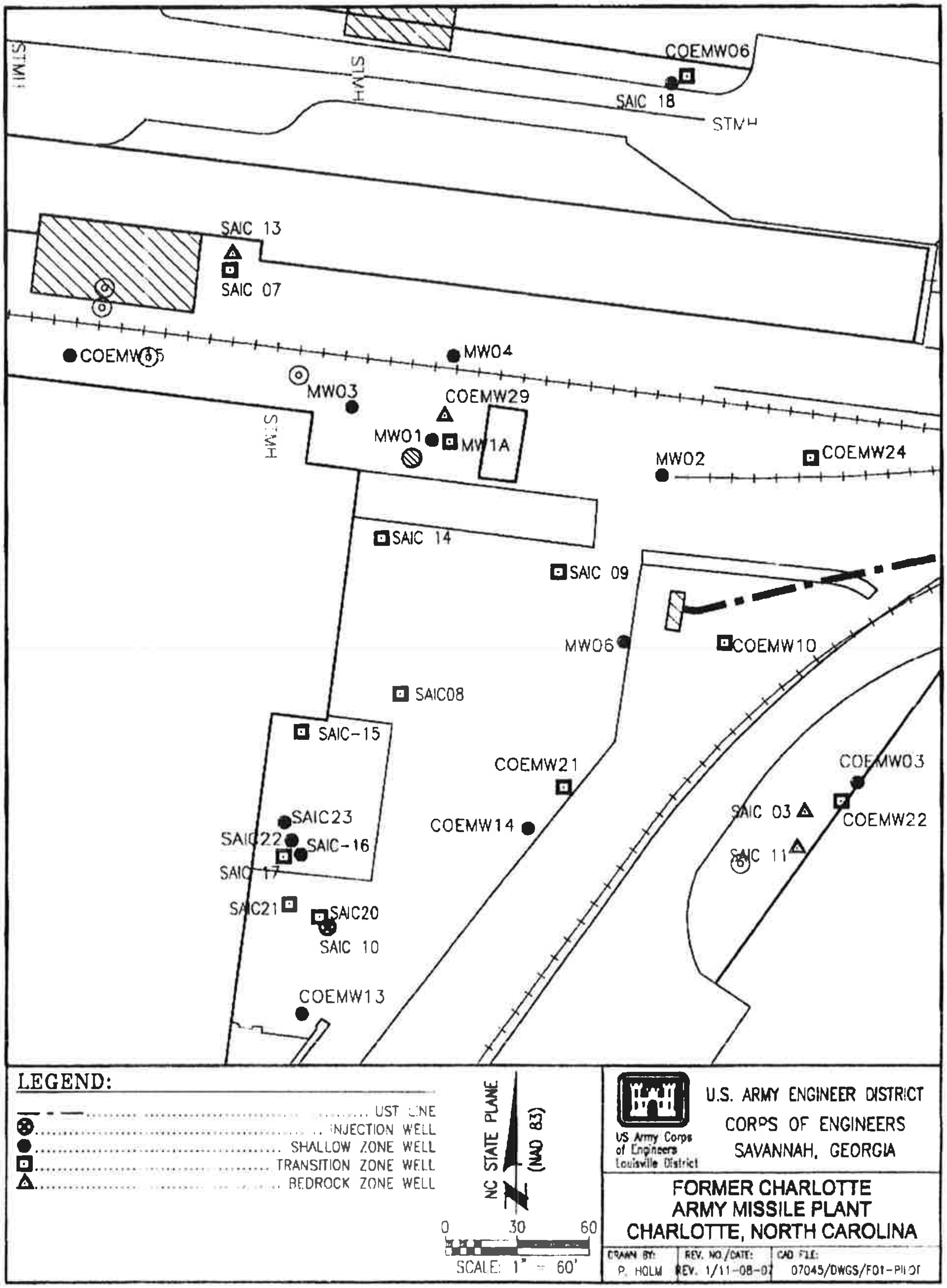



Figure 7-1. Pilot Study location

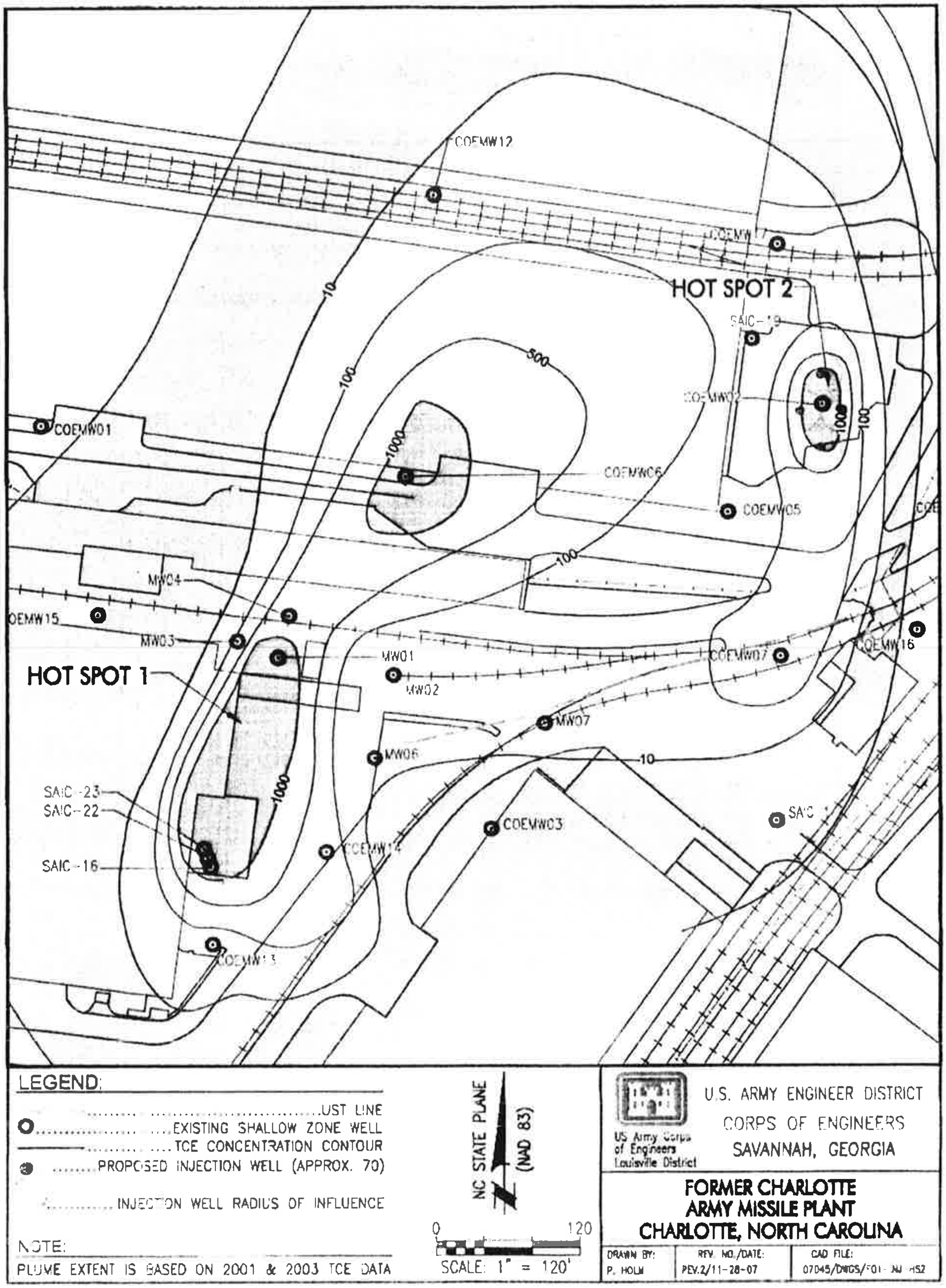



**Figure 7-2. Proposed Shallow Zone Injection Wells at Hot Spot No. 2**

# *TABLES*

## *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** | **1,900** |
| 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

## *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

## *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

## *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 | 8 | N/A | N/A |

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

## *Table 1-5*
## *Revised Modeling 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) |
|---|---|---|---|---|
| 1 | No Action/MNA | SZ | 790 | 20 |
| | No Action/MNA | TZ | 1,100 | 18 |
| 2 | Hot Spot No.1 >/= 500 µg/L reduced to 100 µg/L | SZ | 365 | 8 |
| | Hot Spot No. 1 >/= 500 µg/L reduced to 100 µg/L | TZ | 575 | 8 |
| 3 | Hot Spot No.2 >/= 500 µg/L reduced to 100 µg/L | SZ | 330 | 7 |

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

# *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 I [a] | Tier II | | |
| | 2000 | 2001 | 2003 | Well | | $10^{-4}$ | $10^{-5}$ | $10^{-6}$ |
| 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.

CAMP = Charlotte Army Missile Plant
COE = Corps of Engineers
COPC = Chemical of potential concern
MW = Monitoring well
NA = Not analyzed
ND = Non-detect (< detection limit)
NS = Not sampled
SAIC = Science Applications International Corporation

## *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.
CAMP = Charlotte Army Missile Plant
COPC = Chemical of potential concern

## *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 $g/cm\text{-}s^2$ | 40 $g/cm\text{-}s^2$ | 40 $g/cm\text{-}s^2$ | Default (EPA 2003). |
| Enclosed space floor length | 35,433 cm (1162.5 ft) | 35,433 cm (1162.5 ft) | 13,716 cm (450 ft) | From USACE (2002) Figures 5 and 6. |
| Enclosed space floor width | 5,143.5 cm (168.75 ft) | 5,143.5 cm (168.75 ft) | 1,143 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
COE = Corps of Engineers
MH = Silt of high plasticity, elastic silt
ML = Micaceous sandy silt
MW = Monitoring well
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
SAIC = Science Applications International Corporation
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.

## *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[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<br>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] NA = Not applicable to this study or not specified in regulations and
[e] NS = Not specified,
* Indicates Federal Secondary Drinking Water Standards
CAMP = Charlotte Army Missile Plant
COPC = Contaminant of potential concern
FS = Feasibility Study
MCL = Maximum contaminant level

## *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 |
| | | Steam 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

## *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. |
| 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. |

## *Table 4-2*
## *Summary of Preliminary Screening of Process*

| Alternative | Effectiveness | Implementable | Approximate Costs | Comments |
|---|---|---|---|---|
| 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). Pilot study results indicate that effective distribution of the oxidant throughout the formation can be attained. | Implementable over most of the site.<br>This option relies upon standard well installation and injection technologies. The chemical oxidant is commercially available. | High | Retained.<br>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.

***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 $g/cm\text{-}s^2$ | 40 $g/cm\text{-}s^2$ | 40 $g/cm\text{-}s^2$ | Default (EPA 2003). |
| Enclosed space floor length | 35,433 cm (1162.5 ft) | 35,433 cm (1162.5 ft) | 13,716 cm (450 ft) | From USACE (2002) Figures 5 and 6. |
| Enclosed space floor width | 5,143.5 cm (168.75 ft) | 5,143.5 cm (168.75 ft) | 1,143 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
COE = Corps of Engineers
MH = Silt of high plasticity, elastic silt
ML = Micaceous sandy silt
MW = Monitoring well
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
SAIC = Science Applications International Corporation
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.

## *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[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<br>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] NA = Not applicable to this study or not specified in regulations and
[e] NS = Not specified,
* Indicates Federal Secondary Drinking Water Standards
CAMP = Charlotte Army Missile Plant
COPC = Contaminant of potential concern
FS = Feasibility Study
MCL = Maximum contaminant level

## *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 |
| | | Steam 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

## *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.<br><br>Can achieve the RAO. |
| 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. |

## *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 once again after 3 years when the NCAC 2L standard is expected to be achieved. |
| 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 once again after 3 years when the NCAC 2L standard is expected to be achieved. |
| 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 once again after 3 years when the NCAC 2L standard is expected to be achieved. |

NA = Not applicable
NC = North Carolina
TCE = Trichloroethylene

## *Table 6-1*
## *Comparative Analysis of Remedial Alternatives*

| Remedial Alternative | Protection of Human Health and Environment | Complianc e 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<br>Permanently biodegrades TCE<br>TCE concentrations reduced to the NCAC 2L standards in 8 years<br>80 to 95% effectiveness estimated due to site constraints | Toxicity and mass of TCE reduced through biodegradatio n processes<br>90% reduction estimated<br>Long mass of TCE reduced through natural attenuation | Effective in the short-term<br>Would reduce 500 µg/L TCE to 100 µg/L in two years | Implementable<br>Treatment vendors and equipment readily available<br>Installation of injection wells would require coordination with property owners with greater disruption to ongoing operations<br>Additional wells easily installed | $5,940,000 |
| 3. Biostimulation | Protective of human health and the environment | Complies with ARARs | Effective in the long-term<br>Permanently biodegrades TCE<br>TCE concentrations reduced to the NCAC 2L standards in 8 years<br>80to 95% effectiveness estimated due to site constraints<br>Most effective at treating TCE contamination under buildings | Toxicity and mass of TCE reduced through biodegradatio n process<br>95% reduction estimated<br>Long mass of TCE reduced through natural attenuation | Effective in the short-term<br>Would reduce 500 µg/L of TCE to 100 µg/L in 2 years | Implementable<br>Treatment vendors and equipment readily available<br>Installation of injection wells would require coordination with property owners.<br>Additional wells easily implementable | $2,500,000 |

**_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 |
|---|---|---|---|---|---|---|---|
| 4. Permeable Reactive Barrier | Protective of human health and the environment | Complies with ARARs | Effective in the long-term<br>Effective because barrier would intercept entire plume<br>Permanently destroys TCE but requires plume to migrate to barrier<br>TCE concentrations reduced to NCAC 2L Standards | Toxicity and mass of TCE reduced through reductive chlorination<br>Long-term mass of TCE reduced through natural attenuation<br>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<br>Treatment vendors and equipment readily available<br>Installation of injection wells would require coordination with property owners<br>Additional wells easily installed | $5,360,000 |
| 5. In situ Chemical Oxidation | Protective of human health and the environment | Complies with ARARs | Effective in the long-term<br>TCE concentrations reduced to the NCAC 2L standards in 8 years<br>80 to 95% effectiveness estimated due to site constraints | Toxicity and mass of TCE reduced through ISCO<br>Greater than 90% reduction estimated<br>Long-term mass of TCE reduced through natural attenuation | Effective in the short-term<br>Would reduce 500 µg/L TCE to 100 µg/L in 2 years | Implementable<br>Treatment vendors and equipment readily available<br>Installation of injection wells would require coordination with property owners<br>Additional wells easily installed | $9,970,000 |

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

## *Table 7-1*
## *Summary of TCE Concentrations in Groundwater*

| Station ID | Well Type | Sampling Event | Date Sampled | TCE (µg/L) |
|---|---|---|---|---|
| SAIC-10[a] | Transition Zone | Baseline | 2/4/2005 | **768** |
| | | Event 1[b] | 2/16/2005 | <200.0 |
| | | Event 2[b] | 2/23/2005 | <200.0 |
| | | Event 4 | 4/6/2005 | <200.0 |
| | | Event 5 | 5/2/2005 | <2.0 |
| | | Event 6[b] | 08/28/06 | <20.0 |
| SAIC-15 | Transition Zone | Baseline | 2/4/2005 | **250** |
| | | Event 5 | 5/2/2005 | **210** |
| | | Event 6 | 08/28/06 | **21.0** |
| SAIC-16 | Shallow Zone | Baseline | 2/2/2005 | **2,000** |
| | | Event 5 | 5/2/2005 | **370** |
| | | Event 6 | 08/25/06 | **1,300** |
| SAIC-17 | Transition Zone | Baseline | 2/2/2005 | **3,059** |
| | | Event 5[b] | 5/2/2005 | **330** |
| | | Event 6 | 08/28/06 | **1,900** |
| SAIC-20 | Transition Zone | Baseline | 2/3/2005 | **3,700** |
| | | Event 1[b] | 2/16/2005 | <200.0 |
| | | Event 2[b] | 2/23/2005 | <200.0 |
| | | Event 4 | 4/6/2005 | <200.0 |
| | | Event 5[b] | 5/2/2005 | <2.0 |
| | | Event 6[c] | 08/28/06 | **4,200** |
| SAIC-21 | Transition Zone | Baseline | 2/1/2005 | **2,000** |
| | | Event 3[c] | 3/14/2005 | **1,900** |
| | | Event 4 | 4/6/2005 | **1,400** |
| | | Event 5 | 5/2/2005 | **880** |
| | | Event 6[c] | 08/28/06 | **2,800** |
| SAIC-22 | Shallow Zone | Baseline | 2/3/2005 | **3,298** |
| | | Event 5 | 5/2/2005 | **3,000** |
| | | Event 6 | 08/28/06 | **560** |
| SAIC-23 | Shallow Zone | Baseline | 2/2/2005 | **3,498** |
| | | Event 4[b] | 4/6/2005 | <20 |
| | | Event 5[b] | 5/2/2005 | <2.0 |
| | | Event 6[b] | 08/28/06 | <20.0 |

[a] Permanganate Injection Well.
[b] Purple (i.e., permanganate) color observed in groundwater sample.
[c] Red-brown (i.e., manganese dioxide) color observed in groundwater sample.
ID = Identification
SAIC = Science Applications International Corporation
TCE = Trichloroethene/Trichloroethane

## *Table 7-2*
## *Revised Modeling 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) |
|---|---|---|---|---|
| 1 | No Action/MNA | SZ | 790 | 20 |
| | No Action/MNA | TZ | 1,100 | 18 |
| 2 | Hot Spot No.1 >/= 500 µg/L reduced to 100 µg/L | SZ | 365 | 8 |
| | Hot Spot No. 1 >/= 500 µg/L reduced to 100 µg/L | TZ | 575 | 8 |
| 3 | Hot Spot No.2 >/= 500 µg/L reduced to 100 µg/L | SZ | 330 | 7 |

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

## *Table 7-3*
## *Summary of Remedial Action Alternative for Hot Spot No. 2*

| Remedial Alternative | Active Treatment Activities | Groundwater Monitoring Required During Treatment | Long-Term Groundwater Monitoring Required |
|---|---|---|---|
| Hot Spot No. 2 Option | Installation of 8 injection wells and injection of a sodium permanganate solution | Performance monitoring during treatment operations, including baseline and semiannual sampling of 5 wells for VOCs and natural attenuation parameters. | Monitoring 7 wells annually for the first 5 years, then every 3 years thereafter, for years 5 through 8 |

# APPENDIX A
# FATE AND TRANSPORT MODELING FOR THE FORMER CAMP

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# CONTENTS

# FIGURES



# TABLES

# 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 the preferred remedial alternative (injection of sodium permanganate [$NaMnO_4$]) presented in the Feasibility Study (FS) report.

In February 2005, a pilot test was conducted at the CAMP site to evaluate sodium permanganate (NaMnO4) as an in-situ groundwater treatment option to remediate the identified trichloroethene (TCE) and associated daughter products. The updated fate and transport evaluations provided in this appendix are based on historical groundwater data, as well as data collected as part of the pilot study.

The groundwater sampling data used in the analysis were analytical data obtained up to August 2006. 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., $DAF_{S-L} = C_S/C_L$, 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 a trend analysis on the groundwater analytical data to determine the appropriate attenuation rate to use for monitored natural attenuation. The calculated attenuation rate for MNA is based on all groundwater analytical data collected prior to the pilot study.

5. Determine the attenuation rate to use for the remedial alternative modeling. This attenuation rate is based on the baseline groundwater analytical data collected prior to the pilot study and the performance monitoring conducted following the injections.

6. 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.

7. 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

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. During model calibration of the SZ, the hydraulic conductivity was reduced to 1.22 ft/day in order to match the SZ TCE plumes. 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 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 (SZ – Hot Spot #1), A.2 (SZ – Hot Spot #2), and A.3 (TZ – Hot Spot #1). As can be seen from these figures, a close match is obtained in for all three scenarios.

For the MNA evaluation, an attenuation rate was calculated based on the historical, pre-injection groundwater analytical data collected from monitoring wells SAIC15, SAIC16, SAIC17, and MW1A.

Based on an average attenuation rate (0.38 1/yr) the calculated half life for the MNA evaluation is 2.13 years. For the sodium permanganate evaluation, an attenuation rate is calculated for monitoring well SAIC22 based on the baseline groundwater analytical data collected prior to the pilot study and the performance monitoring conducted following the injections. Based on the attenuation rate for SAIC22 (1.17 1/yr) the calculated half life for the sodium permanganate evaluation is 0.6 years.

The chemical-specific model parameters include the organic carbon partition coefficient, the soil-water distribution coefficient, and diffusion coefficients in water. 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. In addition, two distinct hot spots were evaluated for the SZ. 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 – Hotspot #1

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. Regarding the source loading, it was assumed that contaminant loading was started 35 years ago and reached a steady-state loading that stopped 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 = 15 m × 4 m located between SAIC22 and COEMW06
Saturated thickness = 12.2 m
Hydraulic gradient = 0.02 m/m toward north (see figure)
Hydraulic conductivity = 0.0155 m/hr (calibrated)
Longitudinal dispersivity = 7 m (calibrated)
Transverse dispersivity = 2 m (calibrated)
Vertical dispersivity = 0.8 m (calibrated)
Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 0.0 |
| 10–20 | 0.12 |
| 10–30 | 0.056 |
| 30–end | 0.0 |

Bulk density = 1.5 g/cc (EPA default)
Effective porosity = 0.20 (Mills et al. 1985)
Fraction Organic Carbon (foc) = 0.002 (EPA default)
Koc for TCE = 94 mL/g (EPA 1996)
Kd for TCE = 0.188 mL/g (Koc (foc))
Molecular diffusion coefficient for TCE = 3.27E-6 $m^2$/hr

Decay constant for TCE = 0.38 1/yr (based on average attenuation rate from SAIC15, SAIC16, SAIC17, and MW1A prior to pilot study injections)
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 observed and projected (based on the calculated attenuation rate) 2005 concentrations observed in wells COEMW13, SAIC22, SAIC23, COEMW06, COEMW12, and COEMW18 (Table A.1). The concentrations of TCE in the SZ of hotspot #1 will be reduced to 2.8 μg/L within 20 years due to natural attenuation (Table A.2). Also, TCE is predicted to migrate to a downgradient distance of approximately 240 m from SAIC23 before being reduced to 2.8 μg/L through natural attenuation.

**Scenario 2: Source Reduction to 100 μg/L Based on Injections of Sodium Permanganate – Shallow Zone – Hotspot #1**

Assumptions and Input Parameters: To simulate this scenario the AT123D No Action Model, with revised source size, loading, and attenuation rate was utilized. All of the calibrated parameters from the previous model (i.e., No Action Alternative model), except source loading, source size, and attenuation rate 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 stopped after 30 years from the start of loading. The model was calibrated to the 2006 observed and projected concentrations. The revised parameters are shown below:

Source dimension = 47 m x 4 m located between wells SAIC23 and COEMW12
Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 0.0 |
| 10–20 | 0.32 |
| 10–30 | 0.15 |
| 30–end | 0.0 |

Decay constant for TCE = 1.17 1/yr (based on attenuation rate from SAIC22 following pilot study injections)

The model was calibrated by matching the 2006 (post-injection) maximum concentrations observed and projected in wells COEMW13, SAIC22, SAIC23, COEMW06, COEMW12, and COEMW18 (Table A.1). 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 100 μg/L within 2 years due to source reduction with the injection of sodium permanganate (Table A.2).

**Scenario 3: Monitored Natural Attenuation following Source Reduction to 100 μg/L – Shallow Zone – Hotspot #1**

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 stopped 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 downgradient location COEMW12. The revised parameters are shown below:

Source dimension = 109 m × 4 m located between wells SAIC23 and COEMW12

Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 0.0 |
| 10–20 | 0.0011 |
| 10–30 | 0.00054 |
| 30–end | 0.0 |

Decay constant for TCE = 0.38 1/yr (based on average attenuation rate from SAIC15, SAIC16, SAIC17, and MW1A prior to pilot study injections)

The model was calibrated to 100 µg/L (i.e., the active clean-up concentration) near COEMW12 (downgradient location). The concentrations of TCE in the SZ will be reduced to 2.8 µg/L within 8 years due to natural attenuation after source reduction to 100 µg/L (Table A.2). Also, TCE is predicted to migrate to a downgradient distance of approximately 111 m from COEMW12 before being reduced to 2.8 µg/L through natural attenuation.

**Scenario 4: Supporting No Action Alternative – Shallow Zone – Hotspot #2**

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. Regarding the source loading, it was assumed that contaminant loading was started 35 years ago and reached a steady-state loading that stopped 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 = 13 m × 4 m located between COEMW07 and COEMW02
Saturated thickness = 12.2 m
Hydraulic gradient = 0.02 m/m toward north (see figure)
Hydraulic conductivity = 0.0155 m/hr (calibrated)
Longitudinal dispersivity = 10 m (calibrated)
Transverse dispersivity = 2 m (calibrated)
Vertical dispersivity = 1 m (calibrated)
Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 0.0 |
| 10–20 | 0.0034 |
| 10–30 | 0.0016 |
| 30–end | 0.0 |

Bulk density = 1.5 g/cc (EPA default)
Effective porosity = 0.20 (Mills et al. 1985)
Fraction Organic Carbon (foc) = 0.002 (EPA default)
Koc for TCE = 94 mL/g (EPA 1996)
Kd for TCE = 0.188 mL/g (Koc (foc))
Molecular diffusion coefficient for TCE = 3.27E-6 $m^2$/hr
Decay constant for TCE = 0.38 1/yr (based on average attenuation rate from SAIC15, SAIC16, SAIC17, and MW1A prior to pilot study injections)
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 observed and projected (based on the calculated attenuation rate) 2005 concentrations observed in wells COEMW07, COEMW01, and SAIC19 (Table A.1). The concentrations of TCE in the SZ of hotspot #2 will be reduced to 2.8 µg/L within 11 years due to natural attenuation (Table A.2). Also, TCE is predicted to migrate to a downgradient distance of approximately 140 m from COEMW02 before being reduced to 2.8 µg/L through natural attenuation.

**Scenario 5: Source Reduction to 100 µg/L Based on Injections of Sodium Permanganate – Shallow Zone – Hotspot #2**

Assumptions and Input Parameters: To simulate this scenario the AT123D No Action Model, with revised source size, loading, and attenuation rate was utilized. All of the calibrated parameters from the previous model (i.e., No Action Alternative model), except source loading, source size, and attenuation rate 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 stopped after 30 years from the start of loading. The model was calibrated to the 2006 observed and projected concentrations. The revised parameters are shown below:

Source dimension = 5 m × 4 m located between wells COEMW07 and COEMW02

Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 0.0 |
| 10–20 | 0.0031 |
| 10–30 | 0.0015 |
| 30–end | 0.0 |

Decay constant for TCE = $1.33 \times 10^{-4}$ 1/hr (based on attenuation rate from SAIC22 following pilot study injections)

The model was calibrated by matching the 2006 (post-injection) maximum concentrations observed and projected in wells COEMW07, COEMW02, and SAIC19 (Table A.1). 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 100 µg/L within 1.5 years due to source reduction with the injection of sodium permanganate (Table A.2).

**Scenario 6: Monitored Natural Attenuation following Source Reduction to 100 µg/L – Shallow Zone – Hotspot #2**

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 stopped 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 downgradient location SAIC19. The revised parameters are shown below:

Source dimension = 46 m × 4 m located between wells COEMW07 and SAIC19

Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 0.0 |
| 10–20 | 0.00026 |
| 10–30 | 0.00012 |
| 30–end | 0.0 |

Decay constant for TCE = 0.38 1/yr (based on average attenuation rate from SAIC15, SAIC16, SAIC17, and MW1A prior to pilot study injections)

The model was calibrated to 100 µg/L (i.e., the active clean-up concentration) near SAIC19 (downgradient location). The concentrations of TCE in the SZ will be reduced to 2.8 µg/L within 7 years due to natural attenuation after source reduction to 100 µg/L (Table A.2). Also, TCE is predicted to migrate to a downgradient distance of approximately 100 m from SAIC19 before being reduced to 2.8 µg/L through natural attenuation.

**Scenario 7: 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. Regarding the source loading, it was assumed that contaminant loading was started 35 years ago and reached a steady-state loading that stopped after 30 years from the start of loading. These assumptions were made to calibrate the existing TCE plume in the transition zone. The calibrated parameters for the TZ, including all other AT123D model parameters, are shown below:

Source dimension = 5 m × 4 m located d between wells SAIC04 and SAIC20
Saturated thickness = 4.3 m
Hydraulic gradient = 0.023 m/m toward north (see figure)
Hydraulic conductivity = 0.018 m/hr (calibrated)
Longitudinal dispersivity = 15 m (calibrated)
Transverse dispersivity = 5 m (calibrated)
Vertical dispersivity = 1.7 m (calibrated)
Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 1.36 |
| 10–20 | 0.061 |
| 10–30 | 0.029 |
| 30–end | 0.0 |

Bulk density = 1.5 g/cc (EPA default)
Effective porosity = 0.20 (EPA 1985)
Fraction Organic Carbon (foc) = 0.002 (EPA default)
Koc for TCE = 94 mL/g (EPA 1996)
Kd for TCE = 0.188 mL/g (Koc (foc))
Molecular diffusion coefficient for TCE = 3.27E-6 $m^2$/hr
Decay constant for TCE = 0.38 1/yr (based on average attenuation rate from SAIC15, SAIC16, SAIC17, and MW1A prior to pilot study injections)
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 observed and projected (based on the calculated attenuation rate) 2005 concentrations observed in wells SAIC04, SAIC20, SAIC08, SAIC14, SAIC18, and COEMW27 (Table A.1). The concentrations of TCE in the TZ will be reduced to 2.8 µg/L within 18 years due to natural attenuation (Table A.2). Also, TCE is predicted to migrate to a downgradient distance of approximately 330 m from SAIC08 before being reduced to 2.8 µg/L through natural attenuation.

**Scenario 8: Source Reduction to 100 μg/L Based on Injections of Sodium Permanganate – Transition Zone**

Assumptions and Input Parameters: To simulate this scenario the AT123D No Action Model, with revised source size, loading, and attenuation rate was utilized. All of the calibrated parameters from the previous model (i.e., No Action Alternative model), except source loading, source size, and attenuation rate 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 stopped after 30 years from the start of loading. The model was calibrated to the 2006 observed and projected concentrations. The revised parameters are shown below:

Source dimension = 65 m × 4 m located d between wells SAIC04 and SAIC08

Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 1.18 |
| 10–20 | 0.053 |
| 10–30 | 0.025 |
| 30–end | 0.0 |

Decay constant for TCE = $1.33 \times 10^{-4}$ 1/hr (based on attenuation rate from SAIC22 following pilot study injections)

The model was calibrated by matching the 2006 (post-injection) maximum concentrations observed and projected in wells SAIC04, SAIC20, SAIC08, SAIC14, SAIC18, and COEMW27 (Table A.1). The results of the modeling are presented in Figure A.6. As can be seen from this figure, the concentrations of TCE in the TZ will be reduced to 100 μg/L within 3 years due to source reduction with the injection of sodium permanganate (Table A.2).

**Scenario 9: Monitored Natural Attenuation following Source Reduction to 100 μg/L – Transition 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 stopped 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 downgradient location COEMW27. The revised parameters are shown below:

Source dimension = 120 m × 4 m located between wells SAIC14 and COEMW27

Source loadings (calibrated):

| Period (yr) | Loading (kg/hr) |
|---|---|
| 0–10 | 0.025 |
| 10–20 | 0.0011 |
| 10–30 | 0.00053 |
| 30–end | 0.0 |

Decay constant for TCE = 0.38 1/yr (based on average attenuation rate from SAIC15, SAIC16, SAIC17, and MW1A prior to pilot study injections)

The model was calibrated to 100 μg/L (i.e., the active clean-up concentration) near COEMW27 (downgradient location). The concentrations of TCE in the TZ will be reduced to 2.8 μg/L within 8 years due to natural attenuation after source reduction to 100 µg/L (Table A.2). Also, TCE is predicted to migrate to a downgradient distance of approximately 175 m from COEMW27 before being reduced to 2.8 µg/L through natural attenuation.

### A.1.6 LIMITATIONS/ASSUMPTIONS

Listed below are important assumptions used in this analysis:

- The use of $K_d$ and $R_d$ to describe the reaction term of the transport equation assumes that an equilibrium relationship exists between the solid- and solution-phase concentrations and that the relationship is linear and reversible.
- An average attenuation rate for TCE was used for the MNA analysis that was based on historical groundwater analytical data collected from monitoring wells SAIC15, SAIC16, SAIC17, and MW1A prior to pilot study injections.
- An attenuation rate used in the sodium permanganate analysis was based on the groundwater analytical data collected from monitoring well SAIC22 following the pilot study injections.
- 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, two plumes of TCE contaminating the groundwater were 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.

Previously, capture zone modeling was conducted to evaluate the radius of influence of the proposed injections. However, since the initial modeling was conducted, a pilot study was conducted and the results form the study indicate the area of influence of the individual injection well is approximately 1,055 $ft^2$.

Based on attenuation rates observed at the site, it is assumed that the areas of the plumes may have decreased since the last comprehensive sampling event at the site. It is recommended that prior to installing injection points, a baseline, comprehensive groundwater monitoring event be conducted to better ascertain the current nature and extent of the TCE plumes.

### 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.7). 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.7.

### 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.8). 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.8). 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.9). 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.10). 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.11). 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.

# A.3 REFERENCES


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Yeh, G. T. 1992. *AT123D: Analytical Transient One-, Two-, and Three-Dimensional Simulation of Waste Transport in the Aquifer System*, Publication No. 1439, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN.

# FIGURES

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**Shallow Zone**
**Scenario 1 [No action]**
**X=0 at SAIC 23**

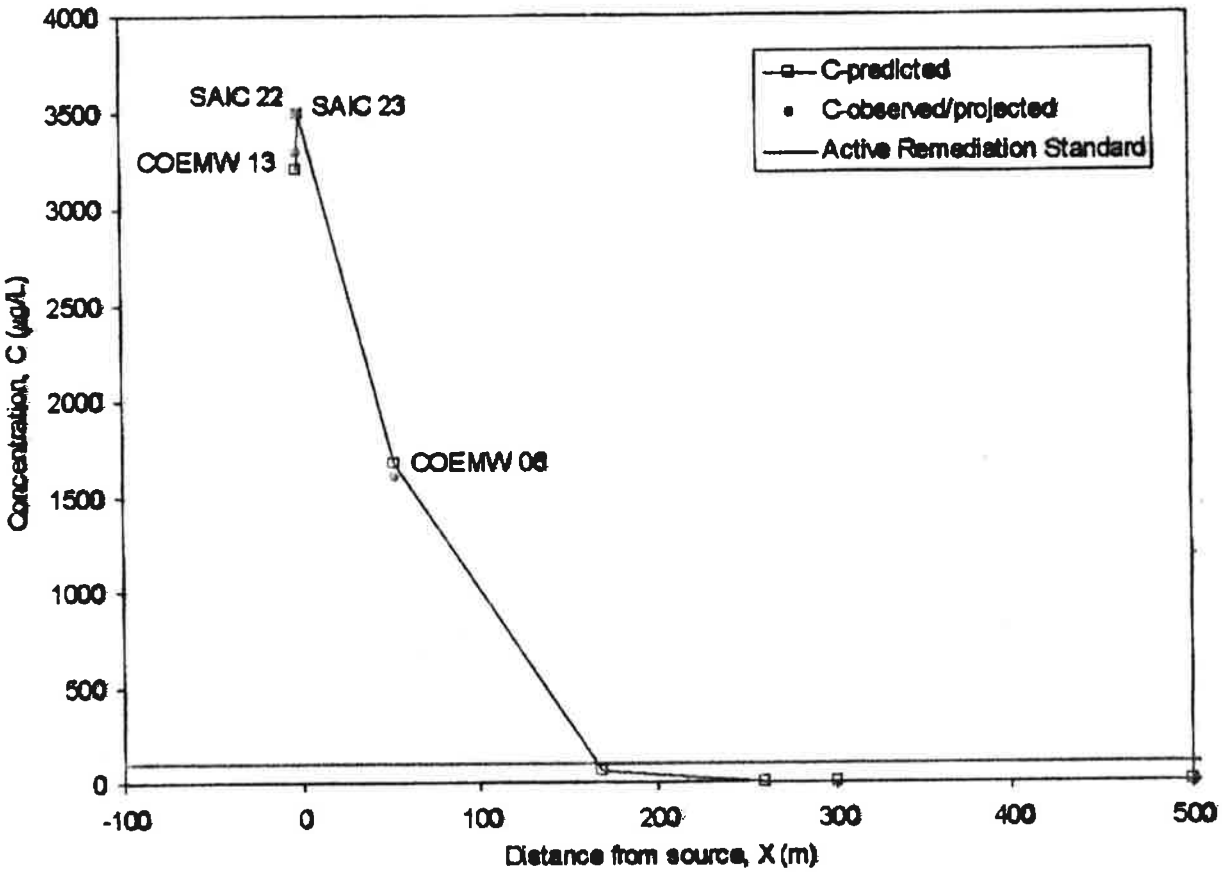



**Figure A.1. AT123D Simulation Results for the Shallow Zone (Hot Spot #1)**

**Shallow Zone - Hotspot #2**
**Scenario 1 [No action]**
**X=0 at COEMW 02**

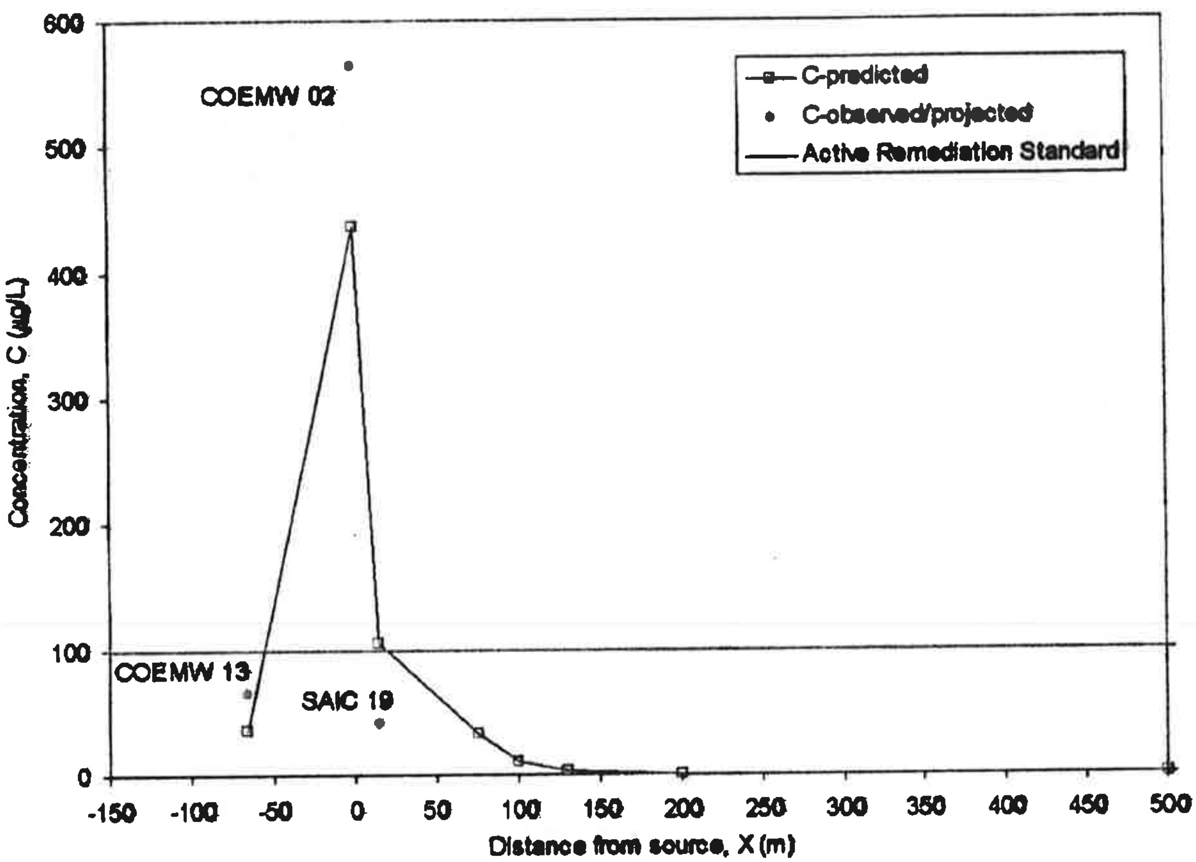



**Figure A.2. AT123D Simulation Results for the Shallow Zone (Hot Spot #2)**

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

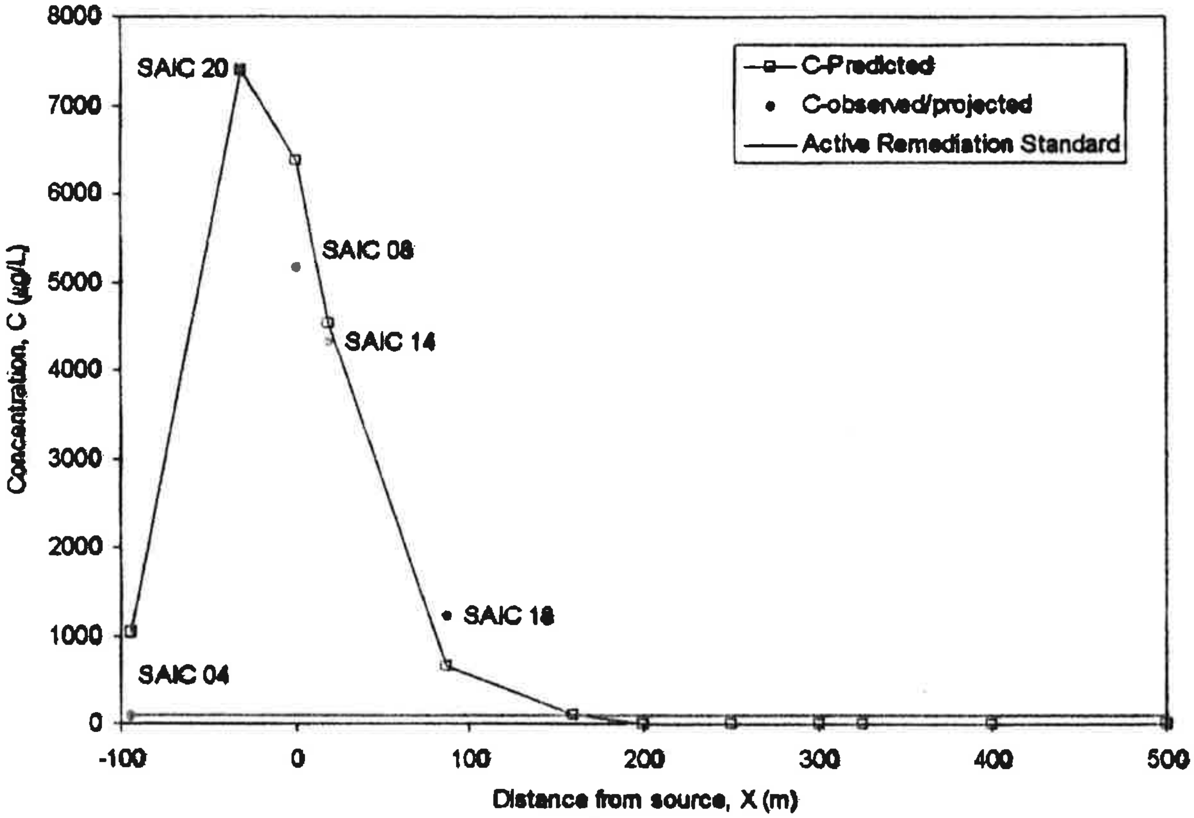



**Figure A.3. AT123D Simulation Results for the Transition Zone**

**Shallow Zone - Hotspot #1**
**Scenario 2 (Injection)**
**X=0 at SAIC 23**

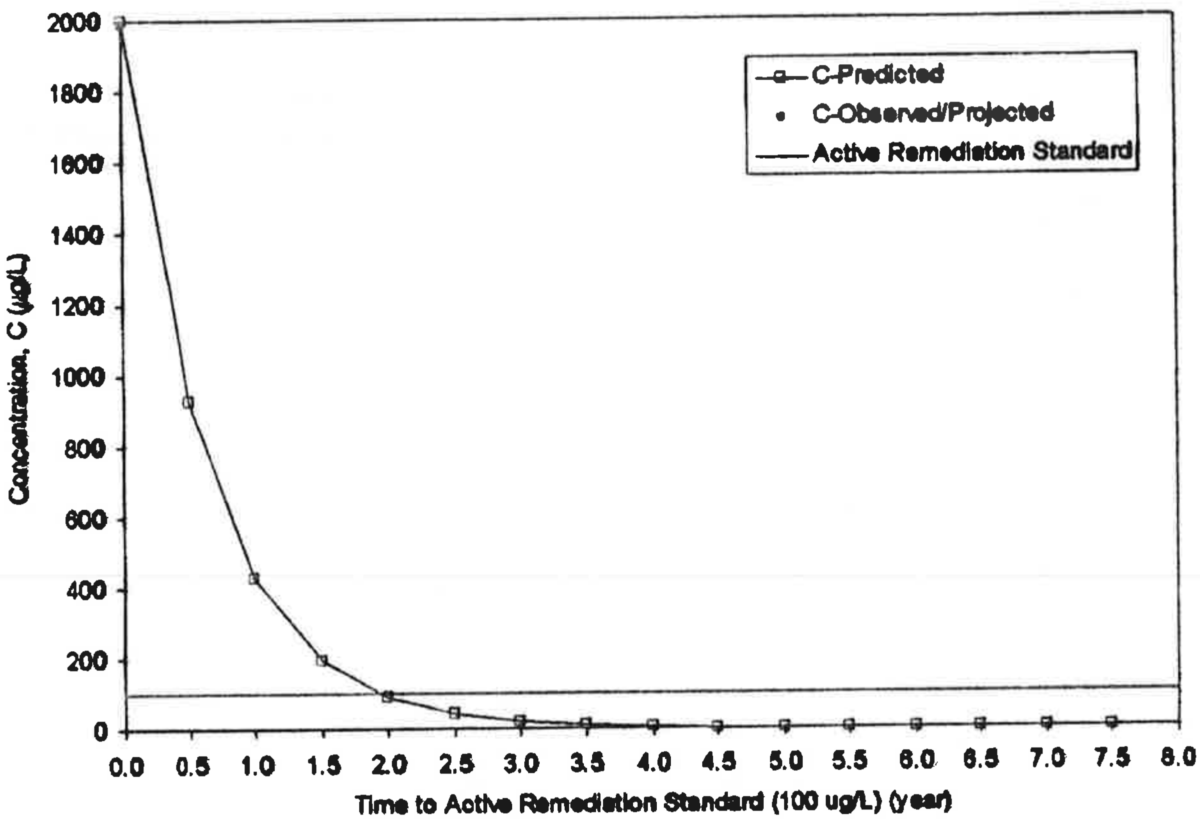



**Figure A.4. Time to Active Remediation Standard for the Shallow Zone - Hot Spot #1**

**Shallow Zone - Hotspot #2**
**Scenario 5 (Injection)**
**X=0 at COEMW 02**

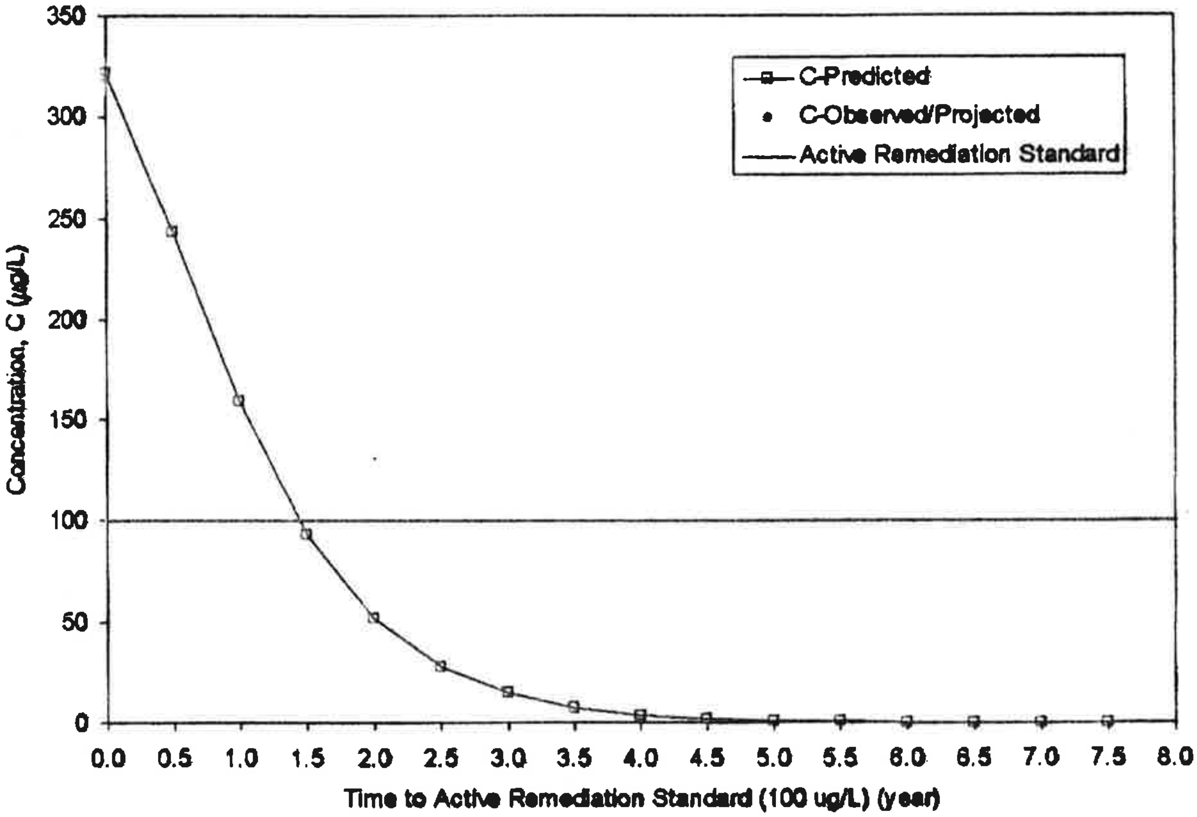



**Figure A.5. Time to Active Remediation Standard for the Shallow Zone - Hot Spot #2**

Transition Zone
Scenario 8 (Injection)
X=0 at SAIC 08

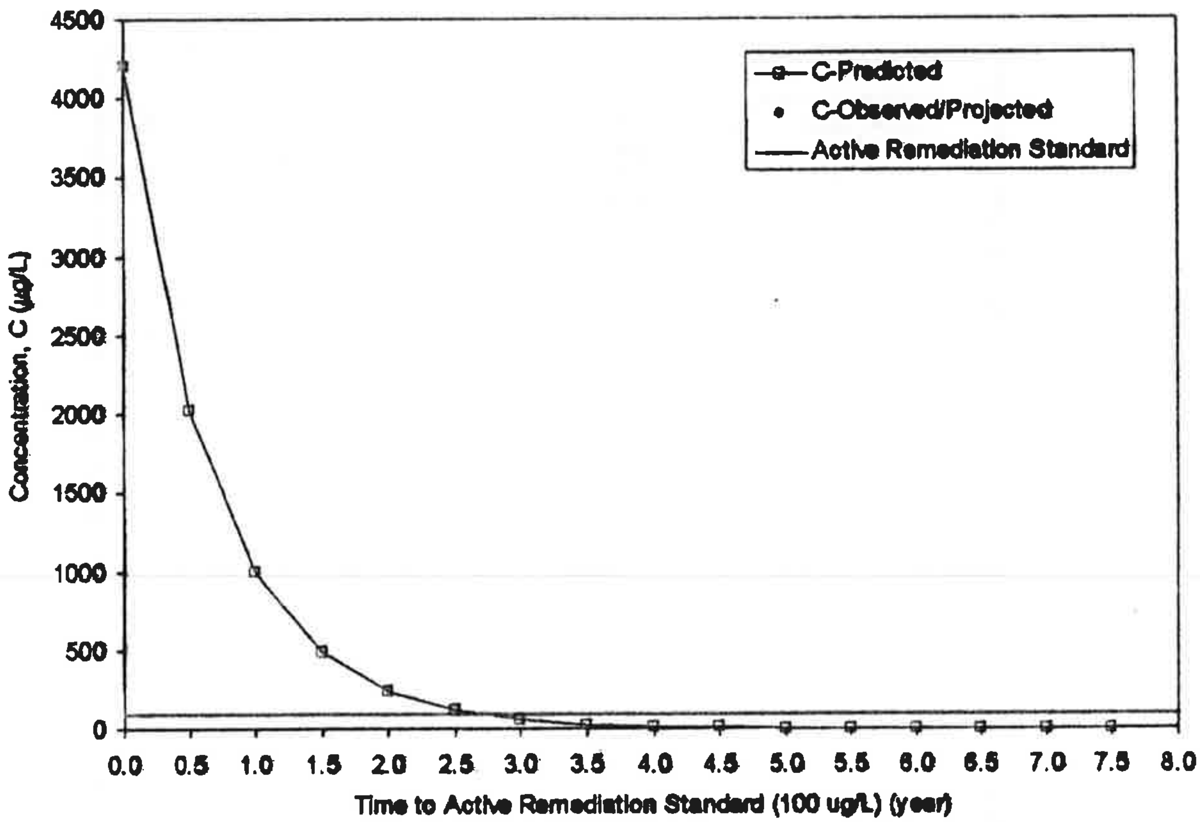
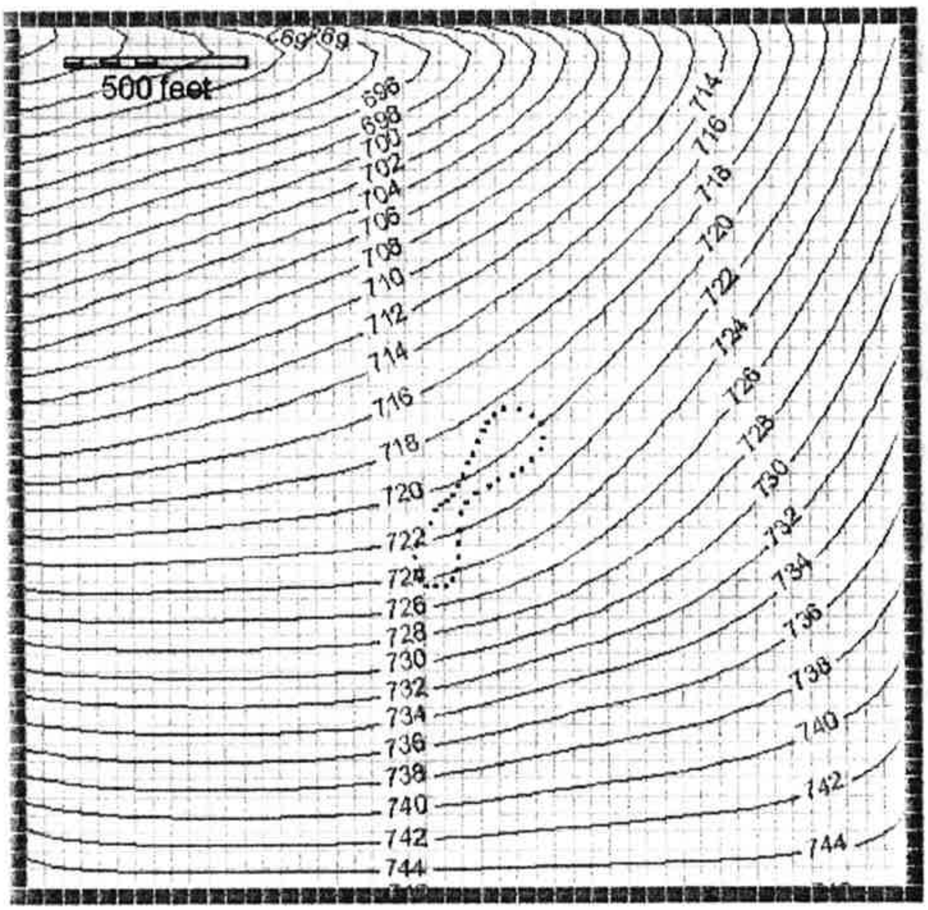



**Figure A.6. Time to Active Remediation Standard for the Transition Zone**

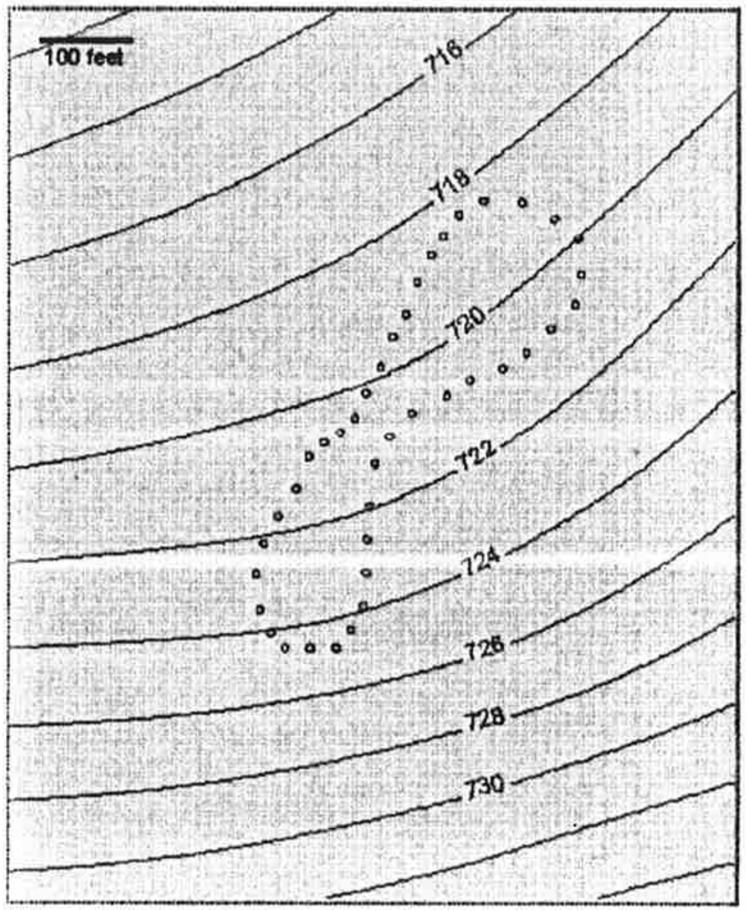
**A01**




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

**Figure A.7. Initial grid for MODFLOW set-up**

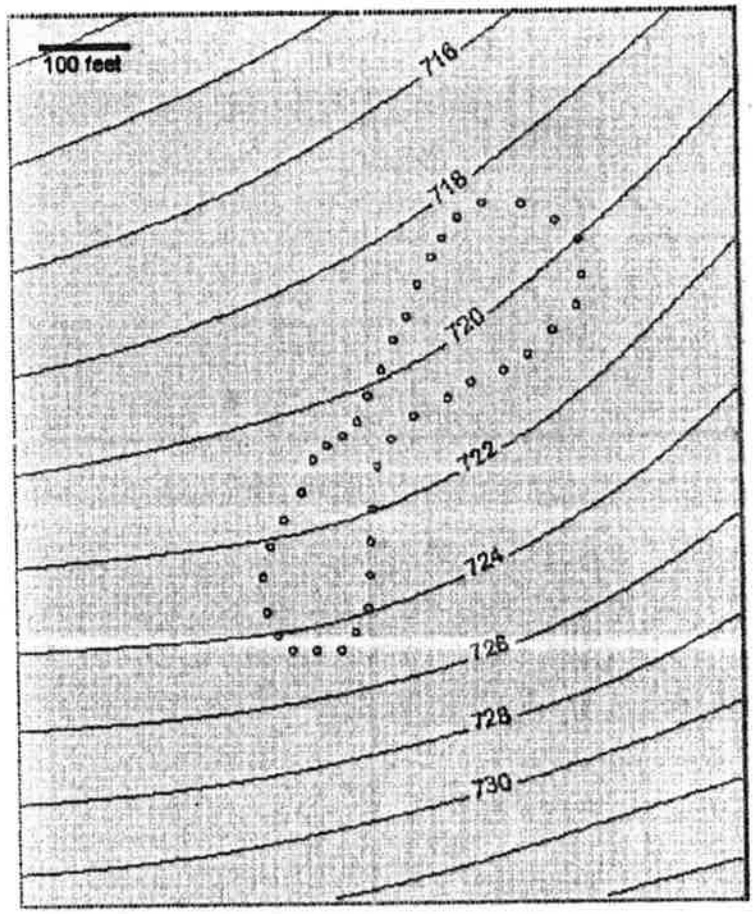
**A02**




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

**Figure A.8. Refined grid for MODFLOW set-up developed using telescopic mesh refinement (TMR) technique**

A03




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

Figure A.9. Refined grid for MODFLOW set-up developed refining TMR grid

**B01**

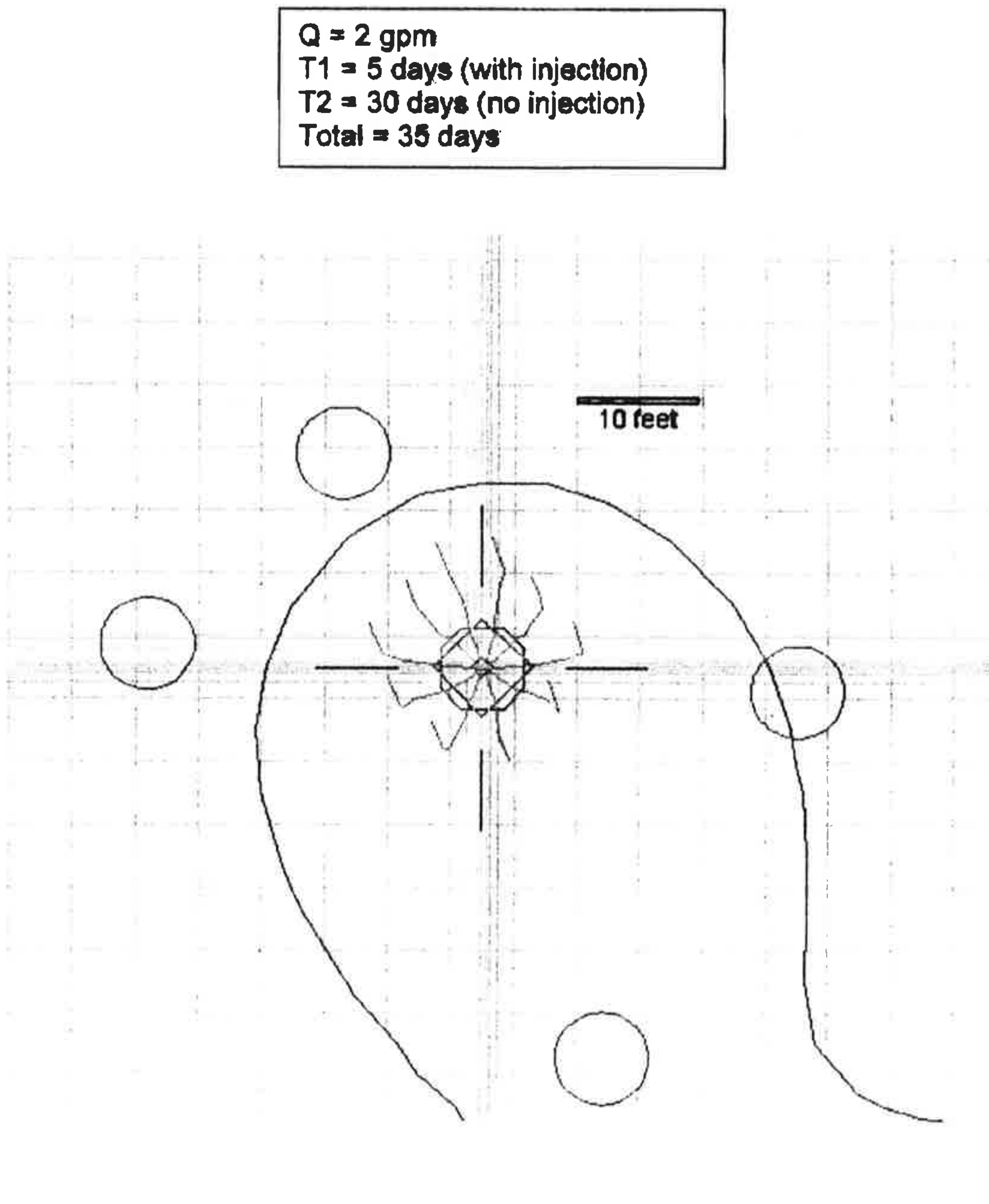



**Figure A.10. Particle tracks in shallow zone under injection**

**C03**

Q = 3 gpm
T1 = 5 days
T1 = 30 days
Total = 35 days

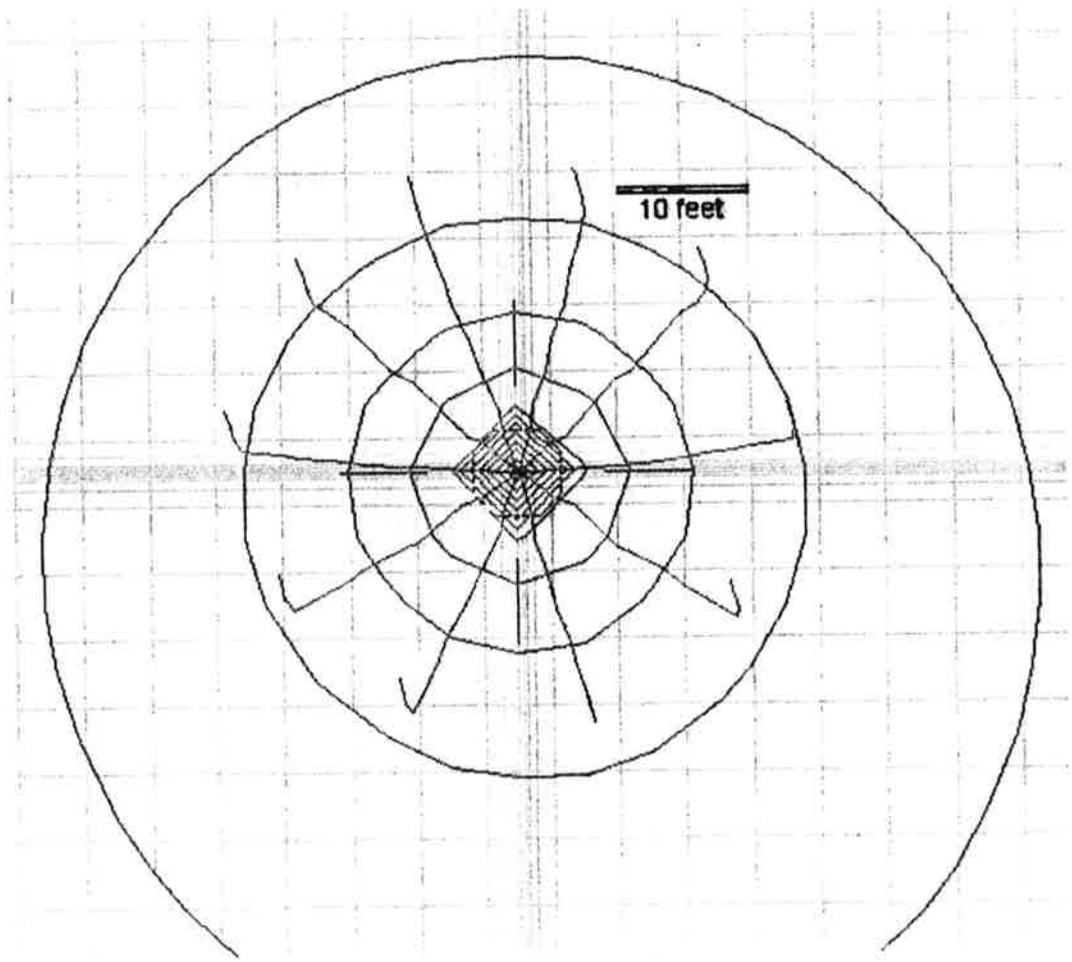



**Figure A.11. Particle tracks in transition zone under injection**

**Table A.1. Observed and Projected TCE Concentrations**

| Location | X (m) | Y (m) | Concentration in 2000 (mg/L) | Concentration in 2001 (mg/L) | Concentration in 2003 (mg/L) | Concentration in 2005 (mg/L) | Concentration in 2006 (mg/L) |
|---|---|---|---|---|---|---|---|
| **Shallow Zone - Hotspot #1** | | | | | | | |
| COEMW13 | -22 | 12 | 390 | NA | 48 | 22.6 | 12.8 |
| SAIC22 | -1 | 1 | NA | NA | NA | 3300 | 560/1874 |
| SAIC23 | 0 | 0 | NA | NA | NA | 3500 | ND/1988 |
| COEMW06 | 110 | 0 | 660 | 3500 | 3400 | 1600 | 909 |
| COEMW12 | 179 | 8 | 18 | 110 | NA | NA | NA |
| COEMW18 | 260 | 0 | 0.6 | 1.2 | NA | NA | NA |
| **Shallow Zone - Hotspot #2** | | | | | | | |
| COEMW07 | -66 | 0 | 140 | NA | 140 | 66 | 37 |
| COEMW02 | 0 | 0 | 1600 | 1050 | 1200 | 565 | 320 |
| SAIC19 | 15 | 20 | NA | NA | 89 | 42 | 23 |
| **Transition Zone - Hotspot #1** | | | | | | | |
| SAIC04 | -95 | 18 | NA | 416 | NA | 92 | 52 |
| SAIC20 | -31 | 0 | NA | NA | NA | 3700/7400 | 4200 |
| SAIC08 | 0 | 0 | NA | NA | 7500 | 5150 | 2926 |
| SAIC14 | 19 | 0 | NA | NA | 6300 | 4320 | 2454 |
| SAIC18 | 86 | 0 | NA | NA | 2500 | 1220 | 693 |
| COEMW27 | 160 | 0 | 60 | NA | NA | NA | NA |

Red text indicates a calculated projected value.

**Table A.2. AT123D Simulation Results**

| COC | MCL (mg/L) | MNA Half-Life (year) | MNA Time Below MCL (year) | ARS (mg/L) | Active Remediation Half-Life (year) | Active Remediation Time ARS (year) | MNA Time After Active Remediation (year) |
|---|---|---|---|---|---|---|---|
| **Shallow Zone - Hot Spot #1** | | | | | | | |
| Trichloroethene (TCE) | 2.8 | 2.1 | 20 | 100 | 0.275 | 2 | 8 |
| **Shallow Zone - Hot Spot #2** | | | | | | | |
| Trichloroethene (TCE) | 2.8 | 2.1 | 11 | 100 | 0.275 | 1.5 | 7 |
| **Transition Zone - Hot Spot #1** | | | | | | | |
| Trichloroethene (TCE) | 2.8 | 2.1 | 18 | 100 | 0.275 | 3 | 8 |

ARS = Active remediation standard.
MNA = Monitored natural attenuation.
MCL = North Carolina groundwater quality standard.
MNA half-life based on average attenuation rate calculated from SAIC15, SAIC16, SAIC17, and MW1A prior to pilot test injection.
Active remediation half-life based on attenuation rate calculated for SAIC22.

# *APPENDIX B*
# *COST ESTIMATES FOR THE FORMER CAMP*

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

[redacted]

| Dissolved Phase Plume Options | | Option Duration (yr) | Non Discounted Cost | | |
|---|---|---|---|---|---|
| | | | Capital Cost | O&M Cost | Total |
| 1 | No Action | 0 | $0 | $0 | $0 |
| 2 | Bioaugmentation (CL-Out) | 10 | $5,163,885 | $773,717 | $5,937,603 |
| 3 | Biostimulation (In Situ Co-metabolic Biodegradation) | 10 | $1,954,163 | $544,284 | $2,498,447 |
| 4 | Permeable Reactive Barrier | 160 | $3,086,603 | $2,275,169 | $5,361,771 |
| 5 | In Situ Chemical Oxidation - Revised | 10 | $9,193,594 | $773,717 | $9,967,311 |
| | Hot Spot No. 2 Treatment Option - In Situ Chemical Oxidation | 10 | $673,770 | $127,517 | $801,288 |

**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 well |
| IDW - Hazardous Disposal | $/drum | 375 | 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 |
| Injection Labor | $/hr | 70 | travel. Total effort = 2 FTE x 6 events x 15 days x 10 hrs/day |
| 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 CL-Out injection. Includes baseline |
| Sampling Labor | hrs/event | 60 | (prior to injection) and after each injection (7 total). Assume 10 |
| Sampling Labor | $/hr | 60 | injection/monitoring wells sampled during each event. Includes 1 day travel and app |
| 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 |
| Sample materials | $/ea | 19.96 | materials. |
| 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 |
| Shallow Wells | $/ea | 2,426 | completion, driller perdiem. |
| 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 |
| Intermediate Wells | $/ea | 6,972 | completion, driller perdiem. |
| 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 |
| Bedrock Wells | $/ea | 8,626 | completion, driller perdiem. |
| 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 |
| IDW - Nonhazardous Disposal | $/drum | 62 | installed. Includes nonhazardous soil & water combined. |

**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 | 7 | Assume a 10-year monitoring period (based on a cMAX of 100 ug/L in the transition zone). Includes baseline and annual sampling in Years 0-5, then periodiocally every 5-years in Year 10. 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 106 injection and 35 monitoring wells. Assume $1,000 mob and $1500/well to grout. |
| Abandon Monitoring Wells | $/lot | 212,500 | |

[redacted]

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

[redacted]

| 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** **$773,717**

| Activity (unit) | Quantity | Unit Cost | Total Cost |
|---|---|---|---|
| **O&M Sampling & Analysis** | | | |
| Sampling Labor (event) | 7 | $9,600 | $67,200 |
| Per Diem (event) | 7 | $1,984 | $13,888 |
| Cargo Van Rental / Gas (event) | 7 | $900 | $6,300 |
| Sample materials (event) | 7 | $838 | $5,868 |
| Sample equipment (event) | 7 | $2,500 | $17,500 |
| Analytical Cost (event) | 7 | $5,250 | $36,750 |
| Sample Shipment (event) | 7 | $350 | $2,450 |
| Data Management (event) | 7 | $3,360 | $23,520 |
| IDW Disposal (event) | 7 | $1,539 | $10,773 |
| **Reporting** | | | |
| Initial Baseline Report (ea) | 1 | $18,000 | $18,000 |
| Annual Reports (ea) | 5 | $9,000 | $45,000 |
| 5-Year Reports (ea) | 1 | $9,000 | $9,000 |
| **Monitoring Well Abandonment** | | | |
| Abandon Monitoring Well (lot) | 1 | $212,500 | $212,500 |
| Subtotal O&M | | | $468,749 |
| Design | | 6% | $28,125 |
| Office Overhead | | 5% | $23,437 |
| Field Overhead | | 15% | $70,312 |
| Subtotal | | | $590,624 |
| Profit | | 6% | $35,437 |
| Contingency | | 25% | $147,656 |
| Total | | | $773,717 |

**TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost)** **$5,937,603**

**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.<br>2 injection wells @ 400 cf/minute/well.<br>Methane = 3% or 12 cf/min/well or 34,560 cf/day for both wells.<br>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 | |
| Sampling Labor | wells | 10 | Includes sampling to monitor effectiveness of co-metabolic injection. Includes baseline (prior to injection) and semi-annual sampling for 2 years (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 | 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 | 7 | Assume a 10-year monitoring period (based on a cMAX of 100 ug/L in the transition zone). Includes baseline and annual sampling in Years 0-5, then periodiocally every 5-years in Year 10. 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** **$544,284**

| Activity (unit) | Quantity | Unit Cost | Total Cost |
|---|---|---|---|
| **O&M Sampling & Analysis** | | | |
| Sampling Labor (event) | 7 | $9,600 | $67,200 |
| Per Diem (event) | 7 | $1,984 | $13,888 |
| Cargo Van Rental / Gas (event) | 7 | $900 | $6,300 |
| Sample materials (event) | 7 | $838 | $5,868 |
| Sample equipment (event) | 7 | $2,500 | $17,500 |
| Analytical Cost (event) | 7 | $5,250 | $36,750 |
| Sample Shipment (event) | 7 | $350 | $2,450 |
| Data Management (event) | 7 | $3,360 | $23,520 |
| IDW Disposal (event) | 7 | $1,539 | $10,773 |
| **Reporting** | | | |
| Initial Baseline Report | 1 | $18,000 | $18,000 |
| Annual Reports | 5 | $9,000 | $45,000 |
| 5-Year Reports | 1 | $9,000 | $9,000 |
| **Monitoring Well Abandonment** | | | |
| Abandon Monitoring Well (lot) | 1 | $73,500 | $73,500 |
| Subtotal O&M | | | $329,749 |
| Design | | 6% | $19,785 |
| Office Overhead | | 5% | $16,487 |
| Field Overhead | | 15% | $49,462 |
| Subtotal | | | $415,484 |
| Profit | | 6% | $24,929 |
| Contingency | | 25% | $103,871 |
| Total | | | $544,284 |

**TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost)** **$2,498,447**

**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, 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 | 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 | 37 | Assume an 160-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 - 160. 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 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 |
| Abandon Monitoring Wells | $/lot | 53,500 | grout. |

**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** **$2,275,169**

| 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 | 32 | $9,000 | $288,000 |
| **Well Abandonment** | | | |
| Abandon Monitoring Wells (lot) | 1 | $53,500 | $53,500 |
| Subtotal O&M | | | $1,378,389 |
| Design | | 6% | $82,703 |
| Office Overhead | | 5% | $68,919 |
| Field Overhead | | 15% | $206,758 |
| Subtotal | | | $1,736,770 |
| Profit | | 6% | $104,206 |
| Contingency | | 25% | $434,192 |
| Total | | | $2,275,169 |

**TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost)** **$5,361,771**

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area Option 5 - In Situ Chemical Oxidation - Revised**
**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** | | | |
| 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, driller per diem. Based on historical cost. |
| Shallow Wells | $/ea | 2,791 | |
| 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, driller per diem. Based on historical cost. |
| Intermediate Wells | $/ea | 4,181 | |
| 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, driller per diem. Based on historical cost. |
| Deep Wells | $/ea | 8,236 | |
| 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 well installed. Includes nonhazardous soil & water combined. |
| IDW - Hazardous Disposal | $/drum | 375 | |
| Transportation | ea | 12 | Based on historical IDW disposal cost. Includes mob, forklift, and transportation. |
| Transportation | $/event | 1,415 | |
| IDW Sampling | ea | 123 | Samples for TCLP, VOCs, SVOCs, and Metals. Assumes composite sample every 7 drums. |
| IDW Sampling | $/ea | 425 | |
| 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. |
| 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). |

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

**Key Parameters and Assumptions:**

| Item | Unit | Value | Notes |
|---|---|---|---|
| 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.<br>106 injection wells @ 3 gpm = approx 318 gpm<br>Total system flow = 318 gpm<br><br>Total gallons = 120 hours x 60 minutes/hr x 318 gallons/minute = 2,289,600 gallons<br>Assume 0.5% permanganate by volume = 11,448 gallons<br>of 40% permanganate (as delivered to site) required 11,448 / 0.4 = 28,620 gallons<br>($3/lb) - Approx. $30.00/gallon = $860,000 / per 5 day injection |
| Sodium Permanganate Materials | $/event | 860,000 | |
| 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. |
| 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. |

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

**Key Parameters and Assumptions:**

| Item | Unit | Value | Notes |
|---|---|---|---|
| IDW - Nonhazardous Soil/water | drums | 46 | Assume 4 drums shallow, 9 drums intermediate, and 10 drums deep for each |
| IDW - Nonhazardous Disposal | $/drum | 62 | 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 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. |

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

**Key Parameters and Assumptions:**

| Item | Unit | Value | Notes |
|---|---|---|---|
| **O&M** | | | |
| **Site Wide Sampling & Analysis** | | | |
| Sampling Labor | events | 7 | Assume a 10-year monitoring period (based on a cMAX of 100 ug/L in the transition zone). Includes baseline and annual sampling in Years 0-5, then periodiocally every 5-years in Year 10. 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 106 injection and 35 monitoring wells. Assume $1,000 mob and $1500/well to grout. |
| Abandon Monitoring Wells | $/lot | 212,500 | |

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area Option 5 - In Situ Chemical Oxidation - Revised**
**Cost Estimate**

| CAPITAL COST | | | $9,193,594 |
|---|---|---|---|
| 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 Chemical Oxidation** | | | |
| 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 |

[redacted]

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area Option 5 - In Situ Chemical Oxidation - Revised**
**Cost Estimate**

[redacted]

| 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 | | | $5,569,850 |
| Design | | 6% | $334,191 |
| Office Overhead | | 5% | $278,492 |
| Field Overhead | | 15% | $835,477 |
| Subtotal | | | $7,018,011 |
| Profit | | 6% | $421,081 |
| Contingency | | 25% | $1,754,503 |
| Total | | | $9,193,594 |

## Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
## Dissolved Phase Plume Area Option 5 - In Situ Chemical Oxidation - Revised Cost Estimate

**OPERATION AND MAINTENANCE** **$773,717**

| Activity (unit) | Quantity | Unit Cost | Total Cost |
|---|---|---|---|
| **O&M Sampling & Analysis** | | | |
| Sampling Labor (event) | 7 | $9,600 | $67,200 |
| Per Diem (event) | 7 | $1,984 | $13,888 |
| Cargo Van Rental / Gas (event) | 7 | $900 | $6,300 |
| Sample materials (event) | 7 | $838 | $5,868 |
| Sample equipment (event) | 7 | $2,500 | $17,500 |
| Analytical Cost (event) | 7 | $5,250 | $36,750 |
| Sample Shipment (event) | 7 | $350 | $2,450 |
| Data Management (event) | 7 | $3,360 | $23,520 |
| IDW Disposal (event) | 7 | $1,539 | $10,773 |
| **Reporting** | | | |
| Initial Baseline Report (ea) | 1 | $18,000 | $18,000 |
| Annual Reports (ea) | 5 | $9,000 | $45,000 |
| 5-Year Reports (ea) | 1 | $9,000 | $9,000 |
| **Monitoring Well Abandonment** | | | |
| Abandon Monitoring Well (lot) | 1 | $212,500 | $212,500 |
| Subtotal O&M | | | $468,749 |
| Design | | 6% | $28,125 |
| Office Overhead | | 5% | $23,437 |
| Field Overhead | | 15% | $70,312 |
| Subtotal | | | $590,624 |
| Profit | | 6% | $35,437 |
| Contingency | | 25% | $147,656 |
| Total | | | $773,717 |

| | |
|---|---|
| **TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost)** | **$9,967,311** |

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area Hot Spot No. 2 Treatment Option - In Situ Chemical Oxidation**
**Key Parameters and Assumptions**

**Key Parameters and Assumptions:**

Note: This option was assumed to be implemented with Alternative 5, so only the additional cost were included. Cost elements with "Alt 5" listed were included in the Alternative 5 cost.

| 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 | Alt 5 | Based on historical survey cost to establish control. Assume 2 ea. |
| Surveyor Deliverables | $/ls | Alt 5 | Based on historical survey cost. Data submittal, Drawings, etc. |
| Utility Locate | $/ea | Alt 5 | Based on historical locating services |
| Water | $/lot | Alt 5 | Assumed cost to extend water supply to injection control building. |
| Electric | $/lot | Alt 5 | Extend electric & install temp transformer at injection control building. |
| Rehabilitate Existing Sewer | $/ls | Alt 5 | Based on relining the existing sewer system. Engineering Estimate |
| **In Situ Chemical Oxidation** | | | |
| Injection Well Installation | | | |
| Mob/Site Preparation | $/lot | Alt 5 | Based on historical drilling cost. Inc mob/demob, and decon pad. |
| Shallow Wells | ea | 4 | Assume TD 25' (8" Boring) - Screened 15'-25' - Inc drill, install well, well vault, driller per diem. Based on historical cost. |
| Shallow Wells | $/ea | 2,791 | |
| SAIC Geologist | $/ea | 858 | Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document |
| Intermediate Wells | ea | 4 | Assume TD 45' (8" Boring) - Screened 35'-45' - Inc drill, install well, well vault, driller per diem. Based on historical cost. |
| Intermediate Wells | $/ea | 4,181 | |
| SAIC Geologist | $/ea | 827 | Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document |
| Deep Wells | ea | 0 | Assume TD 65' (8" Boring) - Screened 55'-65' - Inc drill, install well, well vault, driller per diem. Based on historical cost. |
| Deep Wells | $/ea | 8,236 | |
| SAIC Geologist | $/ea | 827 | Based on historical cost. Inc Travel, Per Diem, Install, Develop, Document |
| IDW - Hazardous Soil/water | drums | 48 | Assume 5 drums shallow, 7 drums intermediate, and 14 drums deep for each well installed. Includes nonhazardous soil & water combined. |
| IDW - Hazardous Disposal | $/drum | 375 | |
| 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 | 1 | 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 | 4 | 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 | 8 | |
| Injector Installation Matls | $/well | 300 | Engineer Estimate |
| Injection Program - Fixed Cost | | | Includes fixed equipment cost. |
| Metering Pump | $/lot | 6,000 | 1 each @ $6,000, up to 10 gpm @ 100 psi, Engineer Estimate |
| Header System | $/lot | 3,500 | 1 each @ $3,500, Engineer Estimate |
| Storage Sheds | $/lot | Alt 5 | 1 each @ 20,000, Heated, Engineer Estimate |
| Direct Bury Pressure Pipe | $/lot | 37,500 | Includes additional 1,500 lf of 2" HDPE pipe with direct bury installation @ $25/lf. |
| Injection Setup | hours | 80 | One time setup. Assume 2 field techs for 4 days @ 10 hour/day to setup prior to injection. |
| Injection Setup | $/hour | 60 | |
| Per Diem | $/event | 992 | (2 people x 4 days x $124/day) |
| Cargo Van Rental / Gas | $/event | 800 | (2 trucks x 4 days x $100/day). |

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area <u>Hot Spot No. 2 Treatment Option</u> - In Situ Chemical Oxidation**
**Key Parameters and Assumptions**

**Key Parameters and Assumptions:**

Note: This option was assumed to be implemented with Alternative 5, so only the additional cost were included. Cost elements with "Alt 5" listed were included in the Alternative 5 cost.

| Item | Unit | Value | Notes |
|---|---|---|---|
| Injection Program | days | 80 | Assume 2 injections each in Years 1 and 2. Total = 4 injections. Assume 2 field techs for 2 days @ 10 hour/day per injection (covers travel, setup, and injection). Total = 8 days or 160 hrs for technicians. |
| Injection Program | hours | 160 | |
| Injection Program | $/hour | 60 | |
| Per Diem | $/event | 1,984 | (2 people x 8 days x $124/day) |
| Cargo Van Rental / Gas | $/event | 1,700 | (2 trucks x 8 days x $100/day) Add $100 for gas.. |
| Sodium Permanganate Materials | event | 4 | Pumping duration 5 days = 120 hours.<br>8 injection wells @ 3 gpm = approx 24 gpm<br>Total system flow = 24 gpm<br><br>Total gallons = 120 hours x 60 minutes/hr x 24 gallons/minute = 172,800 gallons<br>Assume 0.5% permanganate by volume = 864 gallons<br>of 40% permanganate (as delivered to site) required 864 / 0.4 = 2,160 gallons |
| Sodium Permanganate Materials | $/event | 64,800 | ($3/lb) - Approx. $30.00/gallon = $64,800 / per 5 day injection |
| Installation Report | $/report | 3,000 | Estimate Includes an additional 40 hrs @ $75/hour. |
| **<u>Verification Sampling & Analysis</u>** | 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 2 injection/monitoring wells sampled during each event. Includes 1 day travel and approximately 5 wells/day. Includes 2 FTE for 0.5 days @ 10 hrs/day. |
| Sampling Labor | wells | 2 | |
| Sampling Labor | hrs/event | 10 | |
| Sampling Labor | $/hr | 60 | |
| Per Diem | $/event | 124 | (2 people x 0.5 days x $124/day) |
| Cargo Van Rental / Gas | $/event | 100 | (1 van x 0.5 days x $100/day). Add $50 for gas. |
| Sample materials | ea/event | 5 | Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials. |
| Sample materials | $/ea | 19.96 | |
| Sample equipment | $/event | 200 | Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase. |
| Analytical Cost | $/event | 595 | Analyze GW samples from 2 wells VOCs (3 @ $125) and natural attenuation parameters (2 @ $110). Includes 10% duplicate, 5% rinsate, and trip blanks. |
| Sample Shipment | $/event | 50 | 1 coolers @ $50 ea. |
| Data Management | hrs | 5 | 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 | Alt 5 | Based on historical IDW disposal cost. |
| **<u>Reporting</u>** | | | |
| Injection and Monitoring Report | $/event | 3,000 | Based on historical cost. Assume additional 40 hrs @ $75/hr. |
| **<u>Monitoring Wells</u>** | | | No additional monitoring wells required for the hot spot treatment. |

## Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina
## Dissolved Phase Plume Area Hot Spot No. 2 Treatment Option - In Situ Chemical Oxidation
## Key Parameters and Assumptions

**Key Parameters and Assumptions:**

Note: This option was assumed to be implemented with Alternative 5, so only the additional cost were included. Cost elements with "Alt 5" listed were included in the Alternative 5 cost.

| Item | Unit | Value | Notes |
|---|---|---|---|
| **O&M** | | | |
| **Site Wide Sampling & Analysis** | | | |
| Sampling Labor | events | 7 | Assume a 10-year monitoring period (based on a cMAX of 100 ug/L in the transition zone). Includes baseline and annual sampling in Years 0-5, then periodically every 5-years in Year 10. Assume an average of 7 additional wells per sampling event. Includes travel in Alt 5 and approximately 5 wells/day. |
| Sampling Labor | wells | 7 | |
| Sampling Labor | hrs/event | 60 | |
| Sampling Labor | $/hr | 60 | Includes 2 FTE for 1.5 days @ 10 hrs/day. |
| Per Diem | $/event | 744 | (2 people x 1.5 days x $124/day) |
| Cargo Van Rental / Gas | $/event | 250 | (1 van x 1.5 days x $100/day). Add $100 for gas. |
| Sample materials | ea/event | 10 | Reference ECHOS 33 02 0401/0402 for disposable sampling and decon materials. |
| Sample materials | $/ea | 19.96 | |
| Sample equipment | $/event | 500 | Drums, water quality parameter equipment, pumps, misc tools and sampling equipment rental/purchase. |
| Analytical Cost | $/event | 1,250 | Analyze GW samples from 30 wells for VOCs (10 @ $125). Includes 10% duplicate, 5% rinsate, and trip blanks. |
| Sample Shipment | $/event | 50 | 1 coolers @ $50 ea. |
| Data Management | hrs | 10 | Assume 1 hour/sample. |
| Data Management | $/hr | 80 | |
| IDW - Nonhazardous Soil/water | drum | 1 | Assume 1 drums for additional wells. |
| IDW - Nonhazardous Disposal | $/drum | 62 | Based on historical IDW disposal cost. |
| IDW Transportation | $/event | Alt 5 | Based on historical IDW disposal cost. |
| **Reporting** | | | |
| Initial Baseline Report | $/event | 4,500 | Estimate based on historical costs and includes monitoring well installation details. Includes an additional 60 hrs @ $75/hour. |
| Annual Reports | $/event | 1,500 | Estimate based on historical costs. Includes an additional 20 hrs @ $75/hr. |
| 5-Year Reports | $/event | 1,500 | Estimate based on historical costs. Includes an additional 20 hrs @ $75/hr. |
| **Well Abandonment** | | | |
| Abandon Monitoring Wells | lot | 1 | Assume an additional 8 injection and 0 monitoring wells. Assume mob included in Alt 5 and $1500/well to grout. |
| Abandon Monitoring Wells | $/lot | 12,000 | |

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area Hot Spot No. 2 Treatment Option - In Situ Chemical Oxidation**
**Cost Estimate**

**CAPITAL COST** **$673,770**

| Activity (unit) | Quantity | Unit Cost | Total |
|---|---|---|---|
| **Site Work** | | | |
| Civil Survey (well) | 8 | $90 | $720 |
| Civil Survey (monument) | Inc. in Alt 5 | $0 | $0 |
| Surveyor Deliverables (ls) | Inc. in Alt 5 | $0 | $0 |
| Utility Locate | Inc. in Alt 5 | $0 | $0 |
| Water (lot) | Inc. in Alt 5 | $0 | $0 |
| Electric (lot) | Inc. in Alt 5 | $0 | $0 |
| Rehabilitate Existing Sewer (ls) | Inc. in Alt 5 | $0 | $0 |
| **In Situ Chemical Oxidation** | | | |
| Mob/Site Preparation (lot) | Inc. in Alt 5 | $0 | $0 |
| Shallow Wells (ea) | 4 | $3,649 | $14,596 |
| Intermediate Wells (ea) | 4 | $5,008 | $20,032 |
| Deep Wells (ea) | 0 | $9,063 | $0 |
| IDW Disposal (drums) | 48 | $375 | $18,000 |
| Transportation (ls) | 1 | $1,415 | $1,415 |
| IDW Sampling (ea) | 7 | $425 | $2,914 |
| Development Equip, H&S Equip (wk) | 1 | $525 | $525 |
| Injection System Setup | | | |
| Injector Installation Labor (days) | 4 | $700 | $2,800 |
| Injector Installation Materials (well) | 8 | $300 | $2,400 |
| In-Line Injector Pumps (lot) | 1 | $6,000 | $6,000 |
| Header System (lot) | 1 | $3,500 | $3,500 |
| Storage Sheds (lot) | Inc. in Alt 5 | $0 | $0 |
| Direct Bury Pressure Pipe (lot) | 1 | $37,500 | $37,500 |
| Injection Setup (hours) | 80 | $60 | $4,800 |
| Injection Setup - Per Diem (lot) | 1 | $992 | $992 |
| Injection Setup - Cargo Van Rental / Gas (lot) | 1 | $800 | $800 |
| Injection Program (hours) | 160 | $60 | $9,600 |
| Injection Program - Per Diem (lot) | 1 | $1,984 | $1,984 |
| Injection Program - Rental Vehicle (lot) | 1 | $1,700 | $1,700 |
| Sodium Permanganate Materials (event) | 4 | $64,800 | $259,200 |
| Installation Report (ea) | 1 | $3,000 | $3,000 |
| **Verification Sampling & Analysis** | | | |
| Sampling Labor (event) | 5 | $600 | $3,000 |
| Per Diem (event) | 5 | $124 | $620 |
| Cargo Van Rental / Gas (event) | 5 | $100 | $500 |
| Sample materials (event) | 5 | $100 | $499 |
| Sample equipment (event) | 5 | $200 | $1,000 |

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area Hot Spot No. 2 Treatment Option - In Situ Chemical Oxidation**
**Cost Estimate**

| Activity (unit) | Quantity | Unit Cost | Total |
|---|---|---|---|
| **Verification Sampling & Analysis** | | | |
| Analytical Cost (event) | 5 | $595 | $2,975 |
| Sample Shipment (event) | 5 | $50 | $250 |
| Data Management (event) | 5 | $400 | $2,000 |
| IDW Disposal (event) | 5 | $375 | $1,875 |
| **Reporting** | | | |
| Final Review and Confirmation Report (ea) | 1 | $3,000 | $3,000 |
| Subtotal | | | $408,197 |
| Design | | 6% | $24,492 |
| Office Overhead | | 5% | $20,410 |
| Field Overhead | | 15% | $61,230 |
| Subtotal | | | $514,329 |
| Profit | | 6% | $30,860 |
| Contingency | | 25% | $128,582 |
| Total | | | $673,770 |

**Former Charlotte Army Missile Plant Feasibility Study, Charlotte, North Carolina**
**Dissolved Phase Plume Area Hot Spot No. 2 Treatment Option - In Situ Chemical Oxidation**
**Cost Estimate**

**OPERATION AND MAINTENANCE** **$127,517**

| Activity (unit) | Quantity | Unit Cost | Total Cost |
|---|---|---|---|
| **O&M Sampling & Analysis** | | | |
| Sampling Labor (event) | 7 | $3,600 | $25,200 |
| Per Diem (event) | 7 | $744 | $5,208 |
| Cargo Van Rental / Gas (event) | 7 | $250 | $1,750 |
| Sample materials (event) | 7 | $200 | $1,397 |
| Sample equipment (event) | 7 | $500 | $3,500 |
| Analytical Cost (event) | 7 | $1,250 | $8,750 |
| Sample Shipment (event) | 7 | $50 | $350 |
| Data Management (event) | 7 | $800 | $5,600 |
| IDW Disposal (event) | Inc. in Alt 5 | $0 | $0 |
| **Reporting** | | | |
| Initial Baseline Report (ea) | 1 | $4,500 | $4,500 |
| Annual Reports (ea) | 5 | $1,500 | $7,500 |
| 5-Year Reports (ea) | 1 | $1,500 | $1,500 |
| **Monitoring Well Abandonment** | | | |
| Abandon Monitoring Well (lot) | 1 | $12,000 | $12,000 |
| Subtotal O&M | | | $77,255 |
| Design | | 6% | $4,635 |
| Office Overhead | | 5% | $3,863 |
| Field Overhead | | 15% | $11,588 |
| Subtotal | | | $97,342 |
| Profit | | 6% | $5,840 |
| Contingency | | 25% | $24,335 |
| Total | | | $127,517 |

**TOTAL ALTERNATIVE CAPITAL AND O&M COST (Non Discounted Cost)** **$801,288**