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Final

Feasibility Study Report for Site 21

St. Juliens Creek Annex
Chesapeake, Virginia

Contract Task Order 0057

February 2009

Prepared for

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Naval Facilities Engineering Command
Mid-Atlantic

Under the

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Prepared by

CH2MHILL

Virginia Beach, Virginia

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Acronyms and Abbreviations

amsl	above mean sea level
AOC	Area of Concern
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
COC	contaminant of concern
CSM	conceptual site model
CTO	Contract Task Order
CVOC	chlorinated volatile organic compound
DCE	dichloroethene
DHC	*Dehalococcoides*
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DPT	Direct Push Technology
DRMO	Defense Reutilization and Marketing Office
ERD	enhanced reductive dechlorination
EVO	emulsified vegetable oil
EZVI	emulsified zero valent iron
FS	Feasibility Study
ft	feet
ft^2	square feet
HHRA	Human Health Risk Assessment
HRC®	Hydrogen Release Compound®
IR	Installation Restoration
ISCO	in situ chemical oxidation
ISCR	in situ chemical reduction
LUC	land use control
µg/L	micrograms per liter
MARMC	Mid-Atlantic Regional Maintenance Center
MCL	maximum contaminant level
mg/L	milligramss per liter
MNA	monitored natural attenuation

NAVFAC	Naval Facilities Engineering Command
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NOD	natural oxidant demand
O&M	operations and maintenance
ORP	oxidation-reduction potential
PRB	permeable reactive barriers
PRG	Preliminary Remediation Goals
RAO	remedial action objective
RI	Remedial Investigation
RME	reasonable maximum exposure
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SJCA	St. Juliens Creek Annex
SPAWAR	Space and Naval Warfare Systems Command
TBC	to-be-considered
TCE	trichloroethene
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VC	vinyl chloride
VDEQ	Virginia Department of Environmental Quality
VFA	volatile fatty acid
VOC	volatile organic compound
ZVI	zero valent iron

SECTION 1
Introduction and Background

This report presents the Feasibility Study (FS) for Installation Restoration (IR) Site 21, St. Juliens Creek Annex (SJCA) in Chesapeake, Virginia. This FS report was prepared under the United States Navy, Naval Facilities Engineering Command (NAVFAC) Mid-Atlantic, Comprehensive Long-term Environmental Action Navy (CLEAN) III Contract N62470-02-D-3052, Contract Task Order (CTO) 0057 for submittal to NAVFAC, the United States Environmental Protection Agency (USEPA), and the Virginia Department of Environmental Quality (VDEQ).

The FS was prepared in accordance with the process outlined in the Navy's IR Program which is consistent with the National Contingency Plan (NCP) and Section 120 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA).

1.1 Objective

Previous investigations have identified potential human health risk associated with chlorinated volatile organic compounds (CVOCs) in shallow groundwater (Columbia aquifer) at Site 21 from potable use. The nature and extent of contamination and Human Health Risk Assessment (HHRA) are documented in the Site 21 Remedial Investigation (RI) report (CH2M HILL, 2008). The HHRA also evaluated the potential human health risks associated with current and future hypothetical industrial workers for inhalation of indoor air; however, an additional investigation is being planned to further assess this exposure pathway due to the uncertainties identified in the HHRA and the results of this additional investigation will be presented in a future addendum to the RI report. There are no unacceptable ecological risks identified at Site 21. In response to these findings, this FS was completed to develop and evaluate remedial alternatives to prevent unacceptable risk exposure to shallow groundwater at Site 21 through potable use. This FS develops remedial action objectives (RAOs) to protect human health and the environment and identifies applicable or relevant and appropriate requirements (ARARs) and to-be-considered (TBC) criteria. If potential risk is identified as a result of the additional vapor intrusion investigation currently being planned, the risk will be addressed separately.

1.2 SJCA Description and History

SJCA is approximately 490 acres and is situated at the confluence of St. Juliens Creek and the Southern Branch of the Elizabeth River in the City of Chesapeake, southeastern Virginia (**Figure 1-1**). Most of the surrounding area is developed and includes residences, schools, recreational areas, and shipping facilities for several large industries.

SJCA began operations as a naval ammunition facility in 1849. The facility was one of the largest ammunition depots in the United States involving wartime transfer of ammunitions to various other naval facilities. After ordnance operations ceased at SJCA in 1977, decontamination was performed in, around, and under ordnance-handling facilities by flushing the areas with chemical solutions and water. The SJCA facility has also been involved in non-ordnance services, including degreasing; operation of paint shops, machine shops, vehicle and locomotive maintenance shops, pest control shops, battery shops, printing shops, electrical shops, boiler plants, wash racks, and potable water and salt water fire-protection systems; fire-fighter training; and storage of oil and chemicals.

Activity at SJCA has decreased in recent years and many of the aging structures are being demolished. The current primary mission of SJCA is to provide a radar-testing range and various administrative and warehousing facilities and light industrial shops for nearby Norfolk Naval Shipyard and other local naval activities. Defense Reutilization and Marketing Office (DRMO) storage, Space and Naval Warfare Systems Command (SPAWAR), Mid-Atlantic Regional Maintenance Center (MARMC), and a cryogenics school are currently located within SJCA.

1.3 Site 21 Description and History

Site 21 is located in an industrial area in the south-central portion of SJCA (**Figure 1-2**)**.** The site vicinity, including the boundary, existing and demolished buildings, and other site features, are depicted on **Figure 1-3**. Although Site 21 was initially identified as Building 187, investigation data indicated the need to expand the boundary to encompass the CVOC groundwater plume that underlies a number of nearby industrial buildings.

Historically, the buildings at Site 21 were used as machine, vehicle, and locomotive maintenance shops; electrical shops; and munitions loading facilities. The outdoor areas were used for equipment and chemical storage. Several of these buildings and/or their surrounding areas were designated as former IR sites (Sites 9, 10, 11, 12, 13, 14, 18, and Area of Concern [AOC] E). In addition, a fuel service station, including two underground storage tanks (USTs), was located just south of Building 187, but has since been removed.

Currently, the existing buildings and the Site 21 area are used for storage and maintenance activities. Building 1556, constructed in 1992, is currently used as the MARMC warehouse. Many of the older buildings at the site have been demolished (**Figure 1-3**). The majority of the Site 21 ground surface is covered with asphalt, with the exception of a few small, unconnected grassy areas. A topographical survey has not been performed; however, based on surveyed monitoring well elevations, the topography is relatively flat, with ground surface elevations ranging from 7 to 9 feet (ft) above mean sea level (amsl). A storm sewer system runs through Site 21 and drains to a downstream inlet to St. Juliens Creek (IR Site 2). Shallow groundwater at Site 21 is generally encountered from 2 to 7 ft below ground surface (bgs) and flows southwest in the eastern portions of the site and southeast in the western portions of the site, toward the storm sewer system east of Building 1556 (**Figure 1-4**).

The subsurface geology at Site 21 consists of the fine to coarse silty and clayey sands of the Columbia aquifer (shallow groundwater), underlain by the high plasticity clay of the Yorktown confining unit. The Columbia aquifer extends to a depth of between 13.5 and 20 ft bgs. The Yorktown confining unit is approximately 17 ft thick and contiguous at Site 21 and lies above the fine to coarse shelly sands of the Yorktown aquifer (deep groundwater).

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Legend

St. Juliens Creek Annex

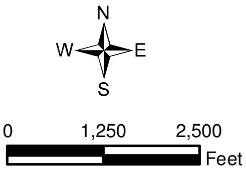

Figure 1-1
SJCA Location
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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Figure 1-2
Site 21 Location
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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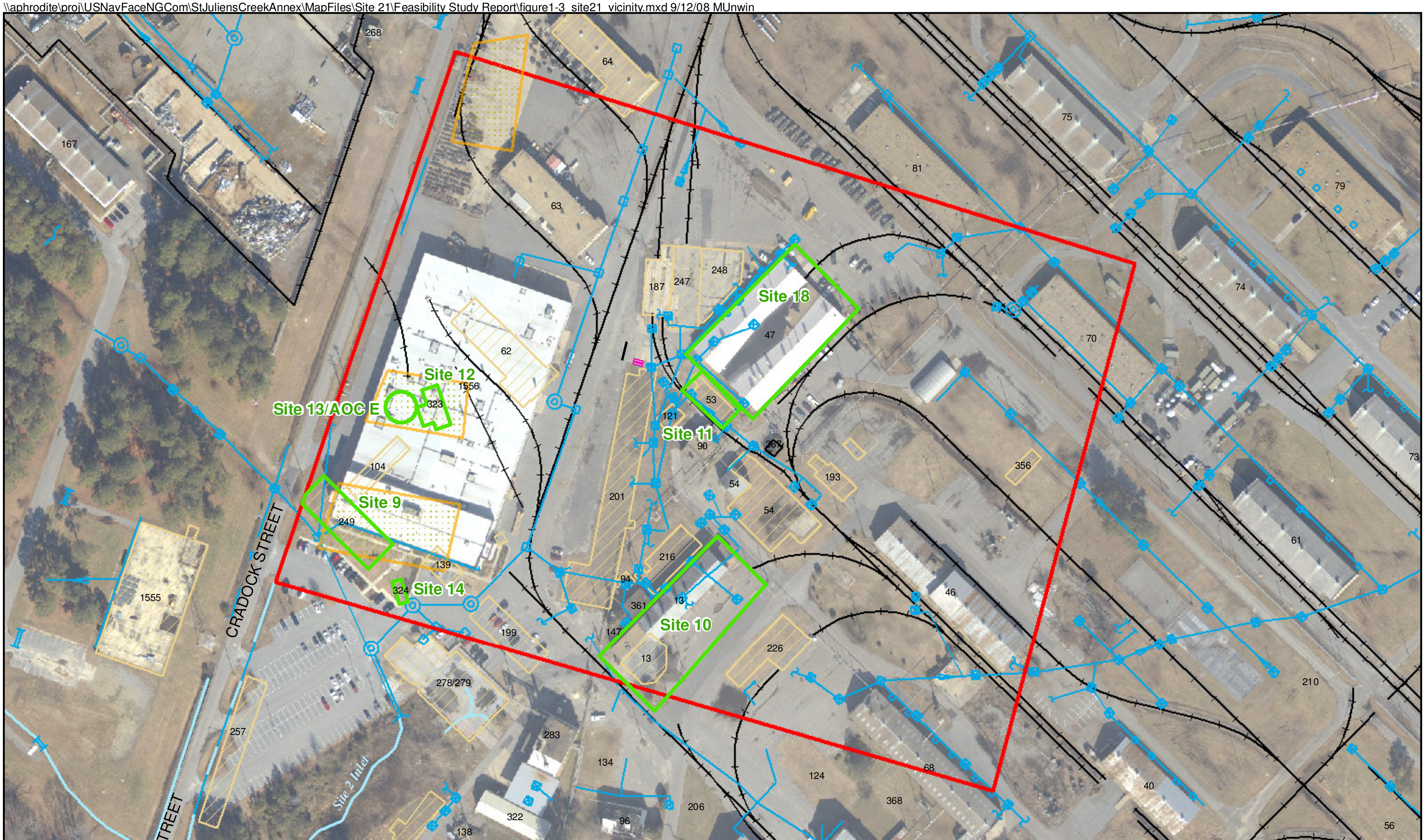

Legend

- Active IR Sites
- No Further Action IR Sites
- Demolished Buildings
- Approx. Areas of TPH Contaminated Soil Removal (1993)
- Approx. Locations of Former USTs
- Former Service Station
- Former Railroad Tracks
- Storm Sewer System

N W E S

0 100 200 Feet

Figure 1-3
Site 21 Vicinity
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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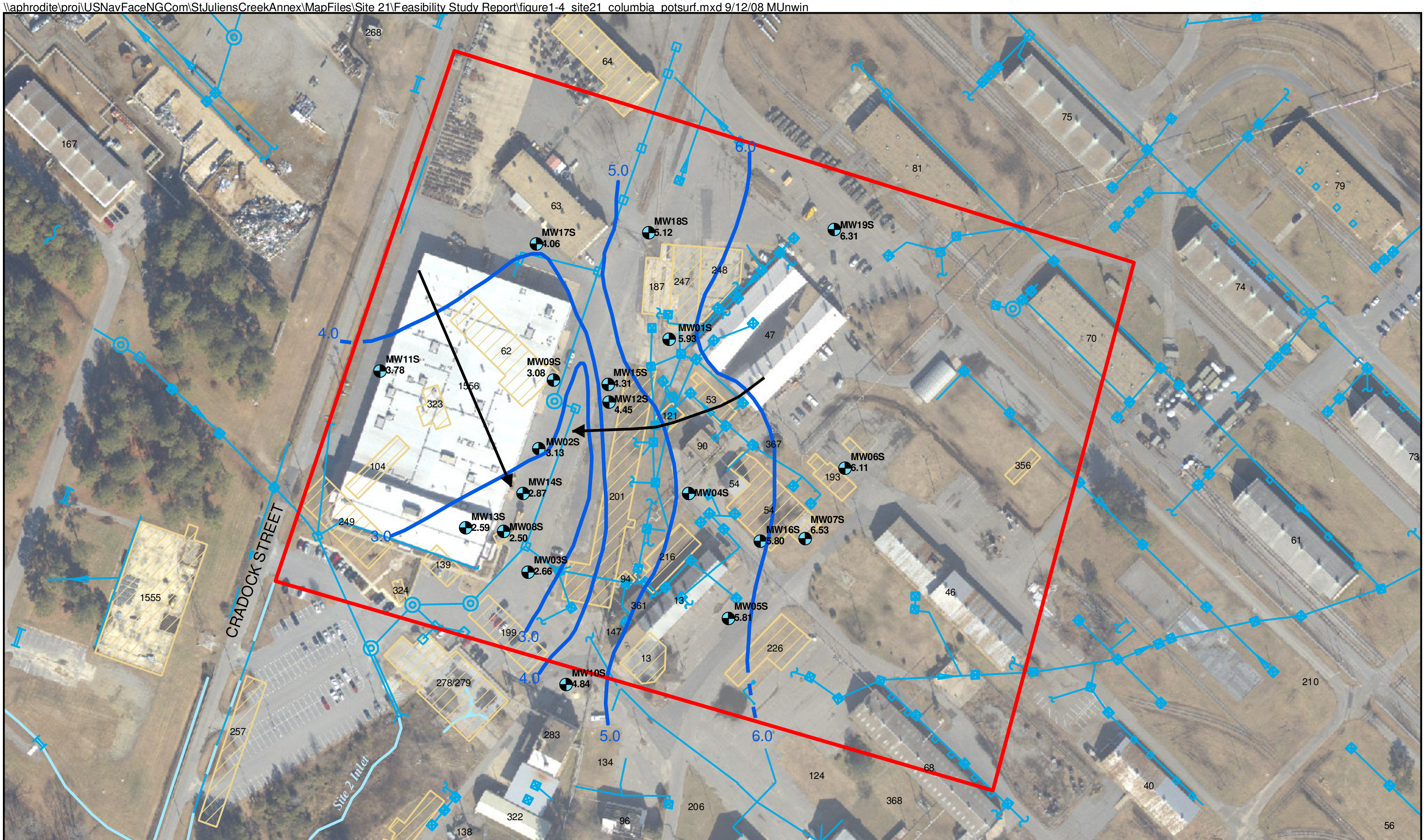

Legend

- Site 21 Boundary
- Shallow Monitoring Well Location
- Estimated Groundwater Flow Direction
- Demolished Buildings
- Potentiometric Contour Lines
- Inferred Potentiometric Contour Lines
- Storm Sewer System

3.28 Groundwater Elevation (feet above mean sea level)

N W E S

0 100 200 Feet

Figure 1-4
Columbia Aquifer Potentiometric Surface
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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SECTION 2

Results of Environmental Investigations

Several investigations have been conducted at Site 21, including the following:

- Resource Conservation and Recovery Act Facility Assessment (A. T. Kearney, 1989)
- Relative Risk Ranking System Data Collection (CH2M HILL, 1996)
- Site Screening Assessment (CH2M HILL, 2002)
- Site Investigation (CH2M HILL, 2004)
- Remedial Investigation (CH2M HILL, 2008)

The scope of these investigations included collection and evaluation of shallow and deep groundwater, surface and subsurface soil, storm water, and surface water. The evaluation identified a CVOC groundwater plume in shallow groundwater posing potential risk to human health. No potential human health or ecological risks were identified from exposure to deep groundwater, surface and subsurface soil, storm water, and surface water. The vapor intrusion pathway has not been fully assessed and is being evaluated separately. The results of the shallow groundwater investigation and risk assessment to be addressed as part of this FS are presented in the RI report (CH2M HILL, 2008) and summarized in the following subsections.

2.1 Nature and Extent of Contamination

A shallow groundwater CVOC plume has been identified at Site 21. Trichloroethene (TCE) and its degradation products were the most frequently detected contaminants in the shallow aquifer. Based on the analytical results, the TCE plume at Site 21 has an areal extent of approximately 8 acres, and extends laterally within the Columbia aquifer from the parking lot south of Building 64 (north) to the south side of Building 201 (south) and from the southwest side of Building 1556 (west) to Building 46 (east) (**Figure 2-1**)**.** The orientation of the plume for cis-1,2-dichloroethene (DCE) (**Figure 2-2**) closely resembles that of the TCE plume and extends over 8.1 acres. The orientation of the vinyl chloride (VC) plume (**Figure 2-3**) also resembles that of the TCE plume, although it is of lesser extent (2.7 acres).

The maximum concentrations of TCE detected in shallow groundwater at Site 21 are 16,000 micrograms per liter (µg/L) at SJS21-MW15S and 13,000 µg/L at SJS21-MW16S, indicating the likely presence of dense non-aqueous phase liquid (DNAPL). Depth-specific groundwater samples collected at the bottom of the Columbia aquifer at select monitoring wells (SJS21-MW07S, -MW12S, and -MW13S) identified CVOC concentrations 2 to 7 times higher than in groundwater samples collected over the entire screened interval and further support the conclusion that DNAPL is likely present.

2.2 Fate and Transport of Contamination

As depicted in the conceptual site model (CSM) (**Figure 2-4**), the current primary migration pathways of CVOCs at Site 21 are comprised of:

- Dissolved contaminant migration downgradient with groundwater flow (advection)
- Groundwater discharge to the leaking storm sewer system and to the south toward St. Juliens Creek
- DNAPL desorbing from the top of the Yorktown confining unit into shallow groundwater
- Potential vapor intrusion from shallow groundwater into indoor air (volatilization)

The mechanisms responsible for the fate of contaminants include:

- Sorption of contaminants to soil surfaces, which affects advection rates and the extent of lateral spreading
- Natural degradation through different pathways (predominantly breakdown by biological processes), which play a significant role in the length of time the contaminants will exist in the subsurface
- Volatilization of contaminants from groundwater into the gas phase, which results in a decrease of contaminant mass from the saturated zone; however, the net effect of volatilization on overall contaminant mass removal from the saturated zone will likely be fairly insignificant.

2.3 Human Health Risk Assessment

The HHRA was conducted to evaluate the potential human health risks associated with current receptors (industrial workers) and hypothetical future receptors (construction worker, adult resident, child resident, lifetime resident) and exposure scenarios (ingestion, dermal contact, inhalation [showering], inhalation [indoor air]) if no remedial action is implemented for shallow aquifer groundwater. A summary of the reasonable maximum exposure (RME) risks are provided in **Table 2-1**. The HHRA also evaluated the potential human health risks associated with current and future hypothetical industrial workers for inhalation of indoor air; however, an additional investigation is being planned to further assess this exposure pathway due to the uncertainties identified in the HHRA; the results of this additional investigation will be presented in a future addendum to the RI report. If potential risk is identified, it will be addressed separately.

Future potable use of shallow aquifer groundwater may pose risk for future hypothetical residents associated with ingestion of TCE, cis-1,2-DCE, VC, benzene, and arsenic; inhalation of TCE while showering; and dermal contact with TCE.

Although potential risks were identified from exposure to benzene and arsenic at SJS21-MW09S, these compounds were only identified in the vicinity of the closed former UST site, are fuel-related, and are not treated under CERCLA based on the petroleum exclusion.

However, the development and evaluation of remedies should take into consideration the potential for mobilizing naturally occurring metals such as arsenic and include monitoring to confirm that if increased, concentrations return to a level that does not pose unacceptable risk to potential receptors.

TABLE 2-1
Summary of RME Cancer Risks and Hazard Indices
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

Receptor	Media	Exposure Route	Cancer Risk	Chemicals with Cancer Risks >10^{-4}	Hazard Index	Chemicals with HI>1
Future Construction Worker Adult	Shallow Groundwater	Ingestion	NA		NA	
		Dermal Contact	1.5E-06		5.9E-01	
		Inhalation	1.9E-07		1.4E-02	
		Total	1.6E-06		6.1E-01	
Future Resident Adult	Shallow Groundwater	Ingestion	NA		2.5E+01	Trichloroethene, Vinyl chloride, cis-1,2-dichlorothene, Arsenic
		Dermal Contact	NA		3.1E+00	Trichloroethene
		Inhalation/Shower	NA		8.6E-01	
		Total	NA		2.9E+01	Trichloroethene, Vinyl chloride, cis-1,2-dichlorothene, Arsenic
Future Resident Child	Shallow Groundwater	Ingestion	NA		5.8E+01	Benzene, Trichloroethene, Vinyl chloride, cis-1,2-dichlorothene, Arsenic
		Dermal Contact	NA		7.0E+00	Trichloroethene
		Inhalation/Shower	NA		NA	
		Total	NA		6.5E+01	Benzene, Trichloroethene, Vinyl chloride, cis-1,2-dichlorothene, Arsenic
Future Resident Lifetime (Adult/Child)	Shallow Groundwater	Ingestion	5.2E-03	Trichloroethene, Vinyl chloride, Arsenic	NA	
		Dermal Contact	2.3E-04		NA	
		Inhalation[1]/Shower	2.3E-04	Trichloroethene	NA	
		Total	5.6E-03	Benzene, Trichloroethene, Vinyl chloride, Arsenic	NA	

NA - Not applicable, pathway incomplete.
[1]Inhalation calculated for adult only.

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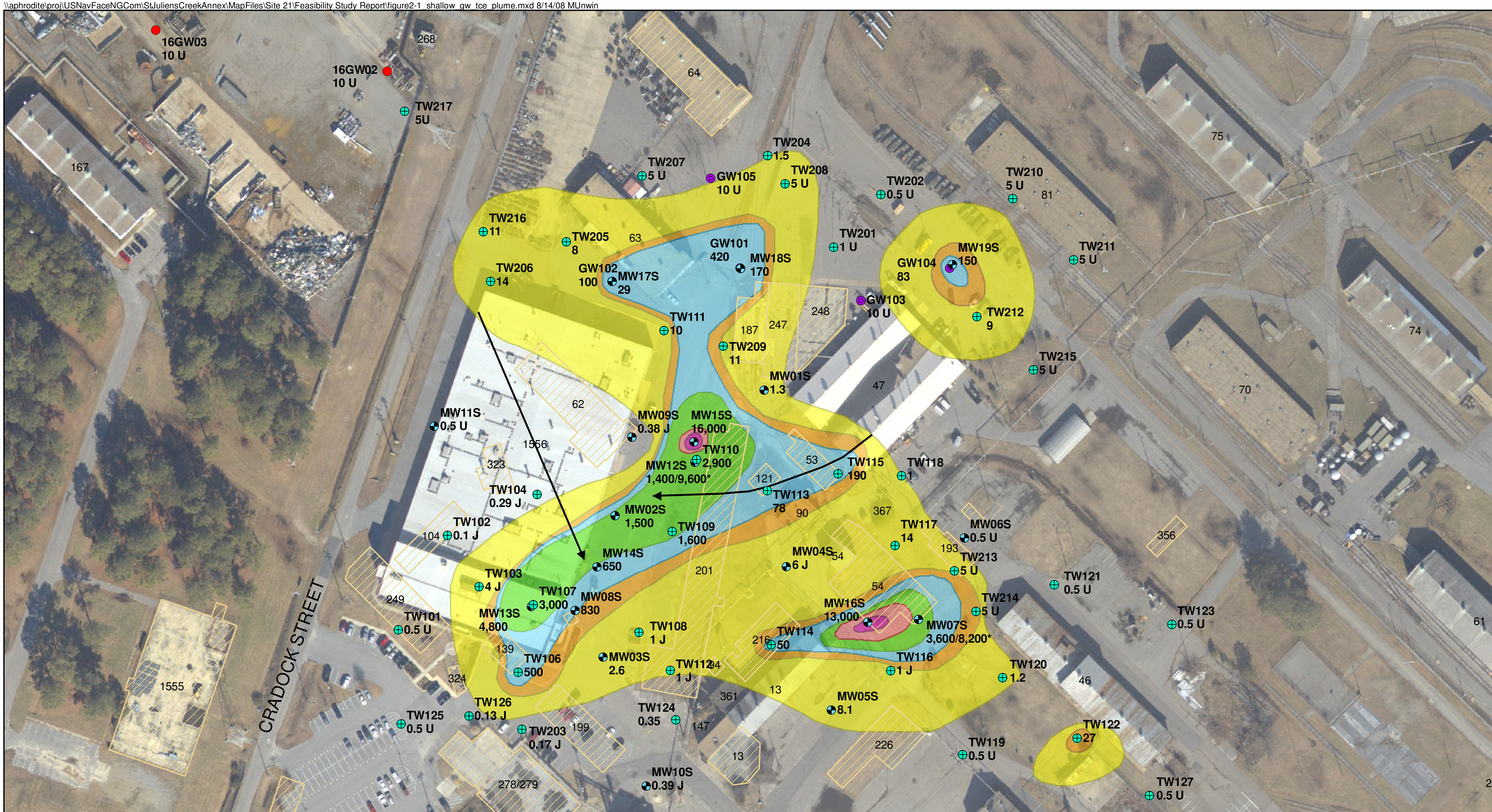

Legend

- Shallow Monitoring Well Location
- Temporary Monitoring Well Location
- Grab Groundwater Sample Location
- RRR Groundwater Sample Location
- Demolished Buildings
- Estimated Groundwater Flow Direction
- TCE Concentration 1 - 25
- TCE Concentration 26 - 49
- TCE Concentration 50 - 999
- TCE Concentration 1,000 - 4,999
- TCE Concentration 5,000 - 9,999
- TCE Concentration >= 10,000

All results are reported in µg/L
J - Reported value is estimated
U - No Detect
Concentrations shown are the most recent results, with the exception of MW09S, at which a previous result was used because the most recent detection limit was above the MCL.
* Concentrations from depth specific DPT GW sample collected at the bottom of the aquifer; not used to delineate the plume

N
W E
S

0 120 240
Feet

Figure 2-1
Shallow Groundwater TCE Plume
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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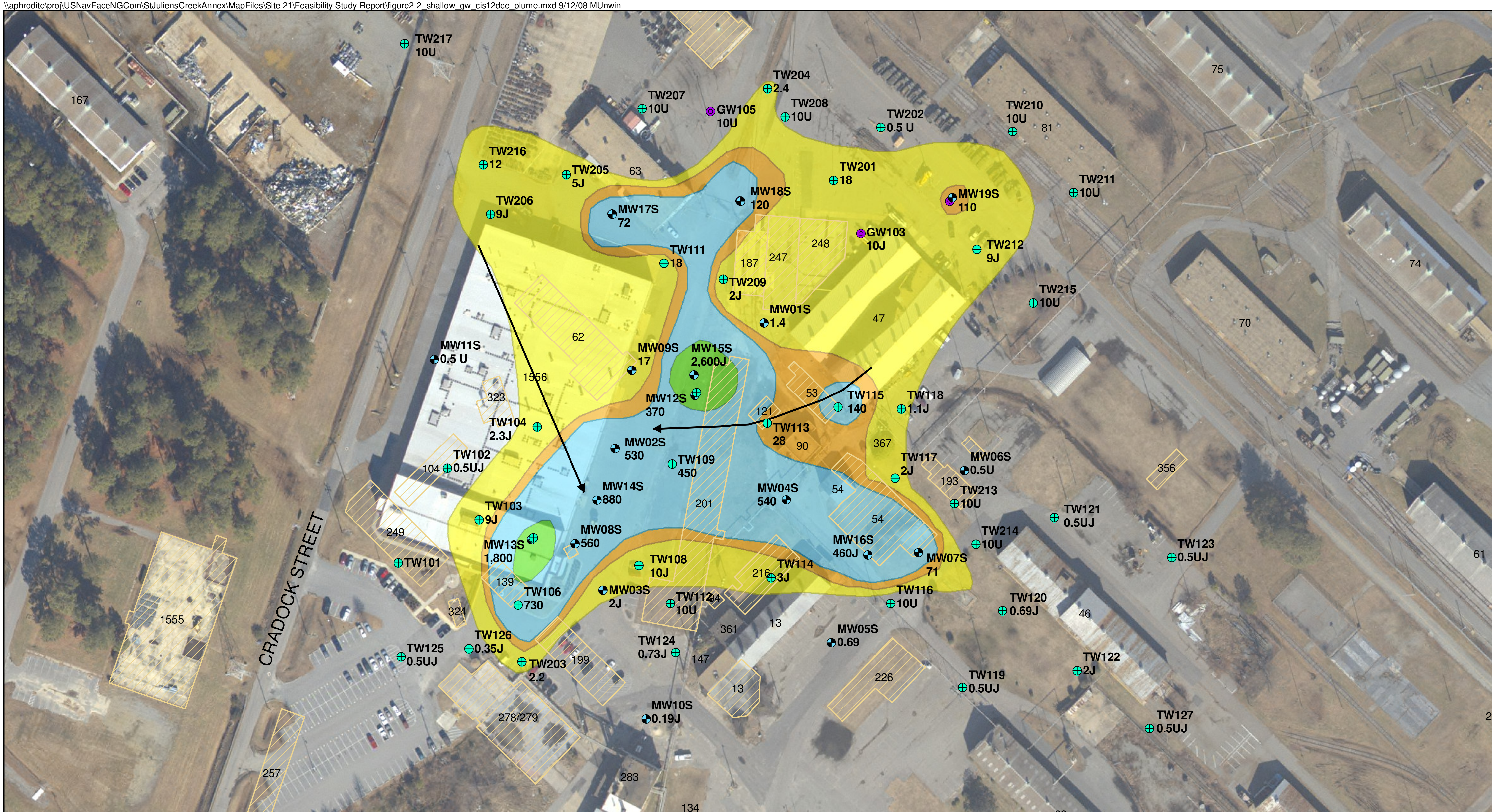

Legend

- Shallow Monitoring Well Location
- Temporary Monitoring Well Location
- Grab Groundwater Sample Location
- Demolished Building
- Estimated Groundwater Flow Direction
- cis-1,2-DCE Concentration 1 - 25
- cis-1,2-DCE Concentration 26-49
- cis-1,2-DCE Concentration 50-999
- cis-1,2-DCE Concentration >=1,000

All results are reported in µg/L.
J - Reported value is estimated
U - no detect
Concentrations shown are the most recent results.

N
W E
S

0 120 240
Feet

Figure 2-2
Shallow Groundwater cis-1,2-DCE Plume
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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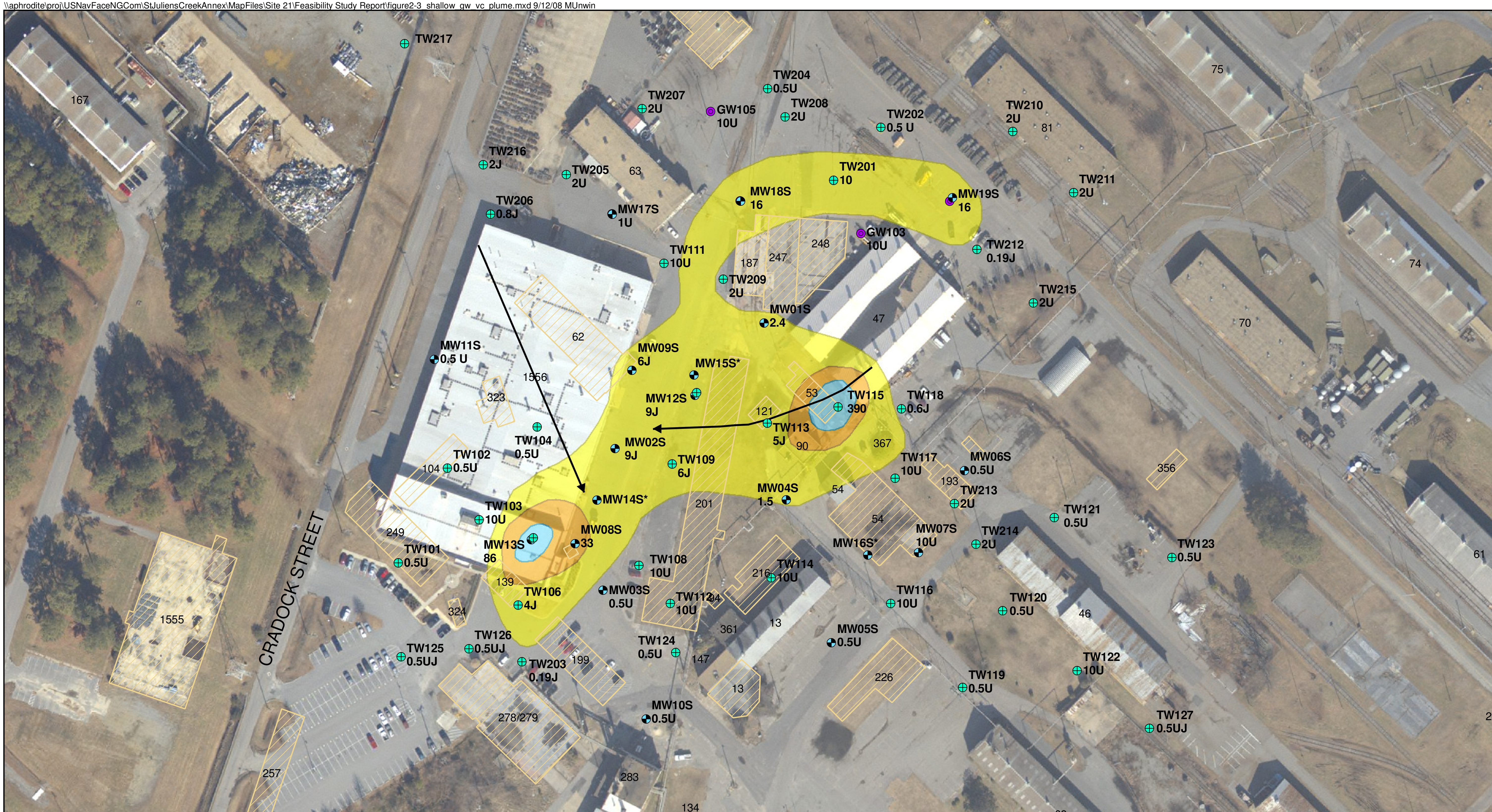

Legend

- Shallow Monitoring Well Location
- Temporary Monitoring Well Location
- Grab Groundwater Sample Location
- Demolished Building
- Estimated Groundwater Flow Direction
- VC Concentration 1-25
- VC Concentration 26-49
- VC Concentration >= 50

All results are reported in µg/L.
J - Reported value is estimated
U - No detect
Concentrations shown are the most recent results, with the exception of MW04S, at which a previous result was used because the most recent detection was above the MCL.
* Anomalous results due to high detection limits; were not used

N
W E
S

0 120 240
Feet

Figure 2-3
Shallow Groundwater VC Plume
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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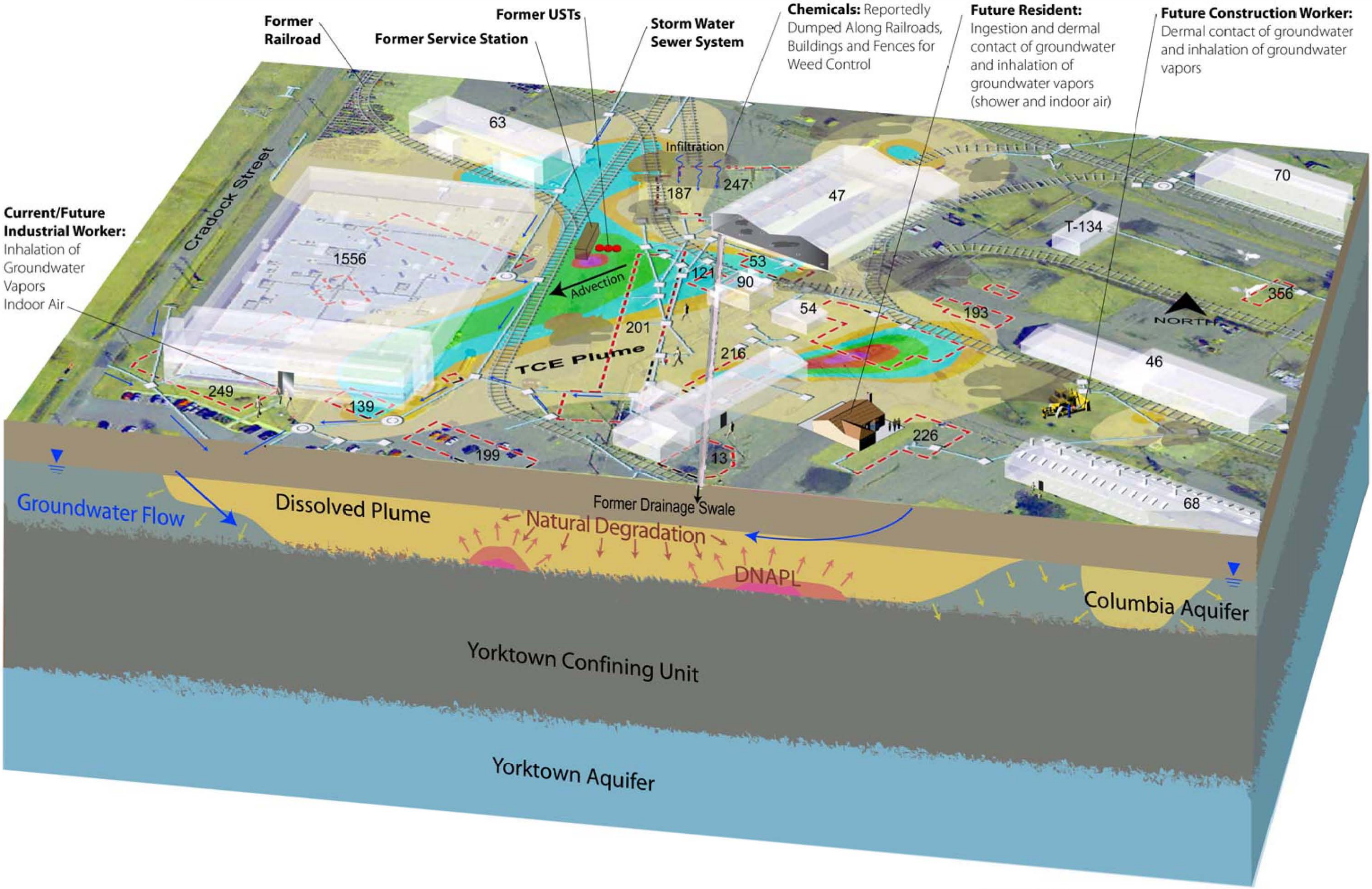

FIGURE 2-4
Conceptual Site Model
St. Juliens Creek Annex, Chesapeake, Virginia

SECTION 3

Remedial Action Objectives and Applicable or Relevant and Appropriate Requirements

This section discusses the NCP and CERCLA objectives and identifies the RAOs and ARARs for the remedial alternatives considered in this FS.

3.1 NCP and CERCLA Objectives

The NCP requires that the selected remedy meet the following:

- Each remedial action selected shall be protective of human health and the environment (40 Code of Federal Regulations [CFR] 300.430 [f][ii][A]).
- Onsite remedial actions that are selected must attain those ARARs that are identified at the time of the Record of Decision (ROD) signature (40 CFR 300.430 [f][ii][B]).
- Each remedial action selected shall be cost-effective, provided that it first satisfies the threshold criteria set forth in §300.430(f)(1)(ii)(A) and (B). A remedy shall be cost-effective if its costs are proportional to its overall effectiveness.
- Each remedial action shall use permanent solutions and alternative treatment technologies or resource-recovery technologies to the maximum extent practicable (40 CFR 300.430 [f][ii][E]).

The statutory scope of CERCLA was amended by SARA to include the following general objectives for remedial action at all CERCLA sites:

- Remedial actions "shall attain a degree of cleanup of hazardous substances, pollutants, and contaminants released into the environment and of control of further releases at a minimum which assures protection of human health and the environment" (§121[d][1]).
- Remedial actions in which treatment that "permanently and significantly reduces the volume, toxicity, or mobility of the hazardous substances, pollutants, and contaminants is a principal element are to be preferred" (§121[b][1]). If the treatment or recovery technologies selected are not a permanent solution, an explanation must be published (§121[b][1][G]).
- The least-favored remedial actions are those that include "offsite transport and disposal of hazardous substances or contaminated materials without treatment" where practicable treatment technologies are available (§121[b][1]).
- The selected remedy must comply with or attain the level of any standard, requirement, criteria, or limitation under Federal environmental law or any promulgated standard, requirement, criteria, or limitation under a State environmental or facility siting law that

is more stringent than any Federal standard, requirement, criteria, or limitation (§121[d][2][A]).

3.2 Remedial Action Objectives

RAOs consist of medium-specific goals for protecting human health and the environment. The only media of concern being addressed within this FS is shallow groundwater based on potential risk to human health.

The RAOs for the protection of human health at Site 21 are:

- Reduce contaminant concentrations in shallow groundwater to the maximum extent practicable
- Prevent exposure to shallow groundwater until contaminant concentrations allow for unlimited use and unrestricted exposure

3.2.1 Development of Risk-Based Preliminary Remediation Goals

Preliminary remediation goals (PRGs) were developed for constituents with concentrations contributing to unacceptable risks and hazards from exposure to shallow groundwater within Site 21. Based on the RI (CH2M HILL, 2008), contaminants of concern (COCs) were identified as those site-related constituents with cancer risks exceeding 10^{-4}, or hazard index exceeding 1. The COCs are TCE, cis-1,2-DCE, 1,1-DCE, and VC. To achieve RAOs for unlimited use and unrestricted exposure, PRGs are established as the maximum contaminant level (MCL). The total risk and hazard associated with use of MCLs as PRGs were calculated to confirm the selected PRGs are acceptable (**Appendix A**). The total risk level associated with the use of MCLs as the PRGs for TCE and vinyl chloride falls within the acceptable range of 10^{-4} to 10^{-6} and the hazard level associated with the use of the MCL as the PRG for cis-1,2-DCE is below the acceptable HI of 1. Therefore, the use of MCLs as the PRGs is appropriate, and achieving the MCLs will be protective of cumulative risk.The PRGs are presented in **Table 3-1**.

3.3 Applicable or Relevant and Appropriate Requirements

As required by Section 121 of CERCLA, remedial actions carried out under Section 104 or secured under Section 106 must attain the levels of standards of control for hazardous substances, pollutants, or contaminants specified by the ARARs of federal and state environmental laws and state facility-siting laws, unless waivers are obtained. According to USEPA guidance, remedial actions should also be based on non-promulgated TBC criteria or guidelines if the ARARs do not address a particular situation.

ARARs are identified by the USEPA as either being applicable to a situation or relevant and appropriate to it.

Applicable requirements are standards and other environmental protection requirements of federal or state law dealing with a hazardous substance, pollutant, contaminant, action being taken, location, or other circumstance at a CERCLA site.

Relevant and appropriate requirements are standards and environmental protection criteria of federal or state law that, although not "applicable" to a hazardous substance, pollutant, contaminant, action being taken, location, or other circumstance, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. A requirement that is relevant and appropriate must be met as if it were applicable. TBC criteria are non-promulgated advisories or guidance issued by federal or state government that are not legally binding, and do not have the status of potential ARARs. TBCs are evaluated along with ARARs and may be implemented by USEPA when ARARs are not fully protective of human health and the environment.

Onsite CERCLA response actions must meet substantive requirements but not administrative requirements. Substantive requirements are those dealing directly with actions or with conditions in the environment. Administrative requirements implement the substantive requirements by prescribing procedures such as fees, permitting, and inspection that make substantive requirements effective. This distinction applies to onsite actions only; offsite response actions are subject to all applicable standards and regulations, including administrative requirements such as permits.

Three classifications of requirements are defined by USEPA in the ARAR determination process: chemical-specific, location-specific, and action-specific. These classifications are described below. The remedial action alternatives developed in this FS were analyzed for compliance with the potential Federal and State ARARs, and are provided in **Appendix B**.

- **Chemical-specific ARARs** are health or risk management-based numbers or methodologies that result in the establishment of numerical values for a given medium that would meet the NCP "threshold criterion" of overall protection of human health and the environment. These requirements generally set protective cleanup concentrations for the chemicals of concern in the designated media, or set safe concentrations of discharge for response activity. Federal and Commonwealth of Virginia chemical-specific regulations that have been reviewed are summarized in **Appendix B**.
- **Location-specific ARARs** restrict response activities and media concentrations based on the characteristics of the surrounding environments. Location-specific ARARs may include restrictions on response actions within wetlands or floodplains, near locations of known endangered species, or on protected waterways. Federal and Commonwealth of Virginia location-specific regulations that have been reviewed are summarized in **Appendix B**.
- **Action-specific ARARs** are usually technology- or activity-based requirements or limitations on actions taken with respect to hazardous substances. Federal and Commonwealth of Virginia action-specific ARARs that may affect the development and conceptual arrangement of response alternatives are summarized in **Appendix B**.

TABLE 3-1
Summary of Shallow Groundwater PRGs
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

COC	PRG (μg/L)	SOURCE
1,1-Dichloroethene	7	MCL
cis-1,2-Dichloroethene	70	MCL
Trichloroethene	5	MCL
Vinyl chloride	2	MCL

SECTION 4

Development and Screening of Alternatives

General response actions are broad responses, remedies, or technologies developed to meet site-specific RAOs and address COCs, migration pathways, and exposure routes. The general response actions listed below have been identified for the remediation of Site 21:

- No Action
- In Situ Treatment
- Containment
- Administrative and Engineering controls
- Monitoring

The *No Action* response is included in accordance with the NCP to serve as a baseline for evaluation of the remedial actions.

In Situ Treatment response actions are in situ methods of reducing the toxicity, mobility, or volume of contaminants in groundwater. Treatment technologies include biological, chemical, and physical processes.

The *Containment* response actions are methods to reduce the toxicity of contaminants and prevent further migration of the contaminants. Containment technologies can be physical, chemical, or biological in nature.

Administrative and Engineering Controls consist of a number of alternatives that can be used alone or as part of another response action. Administrative land use controls (LUCs) include activities such as restricting groundwater use though land-use, deed, or access restrictions. Engineering controls physically limit access or land use on a property or exposure to contaminated media through engineered structures. Administrative or engineering controls costs are significantly lower relative to other technologies and can be very effective, especially in areas where there is limited exposure potential.

The *Monitoring* response action consists of groundwater sampling and analysis to assess the behavior of contaminants over time, natural processes attenuating the contaminants, and performance of an active remediation.

4.1 Development of Remedial Target Areas

Remedial action target areas were defined to support the development of the remedial alternatives. The target areas were divided into separate high-concentration and low-concentration zones to allow for flexibility in the assembly and selection of remedial alternatives. The criteria for the division for each of the zones are described below. The target areas are depicted on **Figures 4-1** and **4-2**. Area and volume estimates are summarized in **Table 4-1**.

4.1.1 High-Concentration Zones

The high-concentration zones correspond to areas where the highest dissolved phase concentrations (COC concentrations greater than 1,000 µg/L) were detected during the latest round of groundwater sampling. These areas are more likely to contain DNAPL and sorbed phase constituents. The high-concentration zones cover approximately 36,600 square feet (ft^2) (1 acre) and range vertically from approximately 5 to 17 ft bgs (**Figure 4-1**).

4.1.2 Low-Concentration Zones

The low-concentration zones correspond to areas where lower dissolved phase concentrations (COC concentrations greater than MCLs and less than 1,000 µg/L) were detected during the latest round of groundwater sampling. The low-concentration zones cover approximately 294,300 ft^2 (7 acres) and range vertically from approximately 5 to 17 ft bgs (**Figure 4-2**). The high-concentration zones are included within the low-concentration zone area because over time, as the COC concentrations are reduced, the high-concentration zones will become low-concentration zones.

4.2 Screening of Remedial Technologies

Remediation of COCs in groundwater at Site 21 is required to address potential unacceptable risks. These risks comprise potential potable use of shallow groundwater by future residents.

A screening of remedial technologies was conducted to evaluate groundwater remediation alternatives. The technologies were screened concurrently for the high- and low-concentration zones with consideration to which technologies would be the most effective and appropriate for each area. **Table 4-2** summarizes the results of the screening process.

This screening process incorporated the Navy's preference to select a remedy that would minimize impacts to current land use, meet proposed RAOs, and minimize timeframes that treatment technology would have to be operated and maintained. Also considered was the recent USEPA's initiative for consideration of sustainable environmental practices in remediation, which favors remedies with lower carbon footprints.

Technologies were screened out for a variety of reasons depending on their effectiveness, operating and maintenance (O&M) costs, and consistency with the established RAOs. Aerobic bioremediation via co-metabolism was screened out because of high O&M costs, lack of proven effectiveness on a large scale, and a large carbon footprint. Thermal technologies using electrical resistant heating were eliminated because of high costs associated with well replacement, high O&M costs, and a large carbon footprint. Air sparge/soil vapor extraction has large O&M costs and a large carbon footprint, and was therefore screened out. Flushing was rejected because of high O&M costs, less proven effectiveness, and a large carbon footprint. Pump and treat also had high O&M costs, a large carbon footprint, and required a very long time to reach cleanup objectives, and is inconsistent with Navy policy. Permeable reactive barriers (PRBs) were rejected because they do not provide area treatment. Without area treatment, large areas would remain above MCLs for a long period of time. Additionally the groundwater flow direction is not well defined and it would be difficult to place the PRB to capture all of the flow year round.

Technologies that were retained for further consideration included those that have the potential to significantly reduce contaminant concentrations with minimal impacts to land use, are cost effective, or compliment the naturally occurring aerobic/anaerobic conditions and resulting intrinsic biodegradation of the COCs. The following technologies were retained:

- **No Action**—Retained as a baseline comparison of alternatives.
- **In Situ Chemical Oxidation (ISCO)**—Retained for the high concentration zone due to its ability to effectively treat high CVOC concentrations.
- **In Situ Chemical Reduction (ISCR)**—Retained for high-concentration zone treatment due to relatively fast treatment and compatibility with other technologies.
- **Enhanced Reductive Dechlorination (ERD)**—Retained for low-concentration zone because it provides effective treatment with low costs and low safety hazard.
- **LUCs**—Retained for high- and low-concentration zones due to relatively low cost and effectiveness provided controls are properly maintained.
- **Monitored Natural Attenuation (MNA)**—Retained for high- and low-concentration zones. The capital cost is low for this technology, and the O&M costs are relatively low because the remedy utilizes naturally occurring attenuation and intrinsic biodegradation processes.

4.3 Description of Remedial Alternatives

Four remedial alternatives were developed from the technologies retained following the initial screening process presented in **Table 4-2**. These are:

Alternative 1 – No Action
Alternative 2—Monitored Natural Attenuation
Alternative 3—In Situ Chemical Reduction and Enhanced Reductive Dechlorination
Alternative 4—In Situ Chemical Oxidation and Enhanced Reductive Dechlorination

With the exception of Alternative 1 (No Action), each of the remedial alternatives includes groundwater monitoring and the implementation of LUCs to prevent unacceptable risk exposure.

In Alternatives 3 and 4, separate treatments are considered for the high- and low-concentration zones and could be implemented concurrently or in a phased approach, treating the high-concentration zones first, followed by the low-concentration zones. For Alternatives 2, 3, and 4, monitoring and LUCs would be maintained until MCLs are achieved, with 5-year statutory reviews to ensure protection of human health and the environment.

4.3.1 Alternative 1—No Action

Alternative 1 is the no-action alternative as required by the NCP. Under this scenario, no remedial actions are taken at Site 21 and contaminants would remain in the shallow groundwater. There are no costs associated with this alternative. Alternative 1 serves as the baseline against which the other alternatives are compared.

4.3.2 Alternative 2—Monitored Natural Attenuation

MNA is a passive response action where the reduction of contaminants occurs through natural biological, chemical, or physical processes. Site-specific MNA parameters were evaluated to determine if conditions are favorable for the intrinsic biodegradation of the COCs.

Biological reduction of chlorinated solvents requires a reducing environment where there is low dissolved oxygen (DO) and the presence of microorganisms that can reduce the parent compound to its daughter products. Low nitrate and sulfate make the environment even more reducing and may enhance degradation of COCs, but is not required.

Current MNA parameter data and analytical results suggest that biodegradation of the COCs is occurring at Site 21 and conditions are favorable for it to continue. DO (below 2 milligrams per liter [mg/L]), and nitrate (less than the reporting limit of 0.05 mg/L) concentrations are low. Sulfate concentrations are low at times, ranging from 1.1 to 110 mg/L. Groundwater samples from Site 21 show the presence of *Dehalococcoides* (DHC), which is a microorganism that has been shown to reduce TCE and its daughter products.

This alternative would be implemented in the high- and low-concentration zones. Implementation will involve developing a monitoring plan based on groundwater geochemistry and the historical data. Continued routine shallow groundwater sampling will provide data needed to monitor changes in COC concentrations, plume size, location, and compliance to RAOs. The specifics of the groundwater sampling program are outside of the scope of the FS, but for evaluation purposes for this alternative, it is assumed that five new sentinel wells and 10 existing wells will be included in a groundwater sampling program. Sampling frequency will be assumed to occur on a semiannual basis for 5 years followed by 25 years of annual sampling. Similar to the recent groundwater sampling events, the samples will be analyzed for volatile organic compounds (VOCs), chloride, nitrate, sulfate, dissolved iron, dissolved manganese, alkalinity, total organic carbon, methane, ethane, and ethene. DO and oxidation-reduction potential (ORP) will be included with the typical field parameters.

4.3.3 Alternative 3—In Situ Chemical Reduction and Enhanced Reductive Dechlorination

Alternative 3 comprises ISCR in the high-concentration zones (followed by ERD, if necessary) and ERD in the low-concentration zones. Because the technologies both rely on reducing conditions, the schedule for implementation of the technologies may be concurrent or sequential, as described below:

- **Concurrent:** ISCR in the high-concentration zones may be implemented concurrently with ERD in the low-concentration zones during the initial remedial action. Based on monitoring results, subsequent treatment can be implemented (ISCR or ERD) based on whether COC concentrations are high (greater than 1,000 µg/L) or low (less than 1,000 µg/L but greater than PRGs).
- **Sequential:** ISCR can be implemented in the high-concentration zones only during the initial remedial action. Based on the monitoring results, once the COC concentration

results are reduced to below 1,000 µg/L in the high-concentration zones (thereby making them low-concentration zones), ERD can be implemented across the site.

The actual sequencing and schedule would be determined during the Remedial Design based on consideration of funding, site conditions, and cost-effectiveness (e.g., whether implementation of two different technologies at the same time or potential additional mobilizations for ERD is more cost-effective).

High-Concentration Zone Treatment – In-situ Chemical Reduction

ISCR is a chemically driven process where compounds are reduced through an abiotic pathway. Zero-valent iron (ZVI) is the most commonly used chemical reductant for the site COCs. ZVI coated with an oil emulsion (EZVI) has shown promise for use in sites with DNAPL (Quinn et al., 1995); however, because this is an emerging technology it has great uncertainty which may pose numerous cost and implementability issues. Therefore, traditional ZVI will be considered as the reductant for this alternative.

As ZVI (Fe^0[s]) oxidizes to ferrous iron (Fe^{+2}), electrons are released and hydrogen gas is produced:

$$\mathrm{Fe}^0(\mathrm{s}) \rightarrow \mathrm{Fe}^{+2}(\mathrm{aq}) + 2e^-$$

$$\mathrm{Fe}^0(\mathrm{s}) + 2\mathrm{H}_2\mathrm{O} \rightarrow \mathrm{Fe}^{+2}(\mathrm{aq}) + 2\mathrm{OH}^- + \mathrm{H}_2(\mathrm{g})$$

The reaction tends to depress DO and the ORP and increase pH. Under properly catalyzed conditions, the reduction of CVOCs (dehalogenation) can be coupled with ZVI oxidation, resulting in replacement of halogen atoms with hydrogens produced by ZVI oxidation. The resulting reduced conditions may mobilize metals naturally present in soil, including arsenic.

Implementation of ISCR can be approached using direct injection, high-pressure injection, or soil mixing. Through direct injection, wells are installed and ZVI is pumped into the well as a slurry or powder and then followed by chase water to disperse the ZVI. However, because ZVI is a particulate it is difficult to push it out into aquifer from the injection point. Also, it can reduce the permeability near the injection well.

High-pressure injection is accomplished by injecting a compressed gas containing an atomized slurry, or a high-pressure liquid slurry, of ZVI at a pressure that exceeds the natural overburden in the soil. In tight soils this typically results in a fracture network containing ZVI at a much larger radius from the injection point than can be achieved by direct injection. The fractures can also improve the effective permeability of the treatment zone. In loose soils, high-pressure injection can disperse the injected slurry by expanding the pore space of the surrounding subsurface as a result of the high energy pressure burst. High-pressure injection is only practical for use at depths were the overburden is sufficient to prevent the gas from short circuiting (daylighting) to the surface. The amount of overburden required to prevent daylighting depends on the soil type and ground cover present, but is typically 5 ft or more.

Soil mixing involves directly auguring the ZVI into the soil. This allows for a more uniform distribution of ZVI throughout the soil and alleviates concerns with high-pressure injection short circuiting from insufficient overburden. Soil mixing also overcomes concerns regarding heterogeneity and low-permeability zones, offering the most control over reagent distribution, which increases the likelihood of success. However, this is a very labor intensive and expensive process and tends to be most practical when the treatment area is relatively small, such as in a permeable reactive barrier type application, and in inactive/ low-traffic areas. Because Site 21 is a large, active industrial area, soil mixing is not appropriate.

The use of ZVI is only being considered for treatment of the high-concentration areas due to reasonableness of cost. For this alternative, it is assumed that the ZVI will be emplaced using high-pressure injection. Direct-push technology (DPT) temporary injection points are assumed in order to control costs, due to the large number of injection points required. **Figure 4-3** shows the assumed injection strategy based on the expected radius of influence of 5.4 ft as provided by a vendor experienced with this type of application. For evaluation purposes, it was assumed that the injection pattern would not be influenced by the locations of existing buildings and underground utilities. As shown in **Figure 4-3**, the vast majority of the injections occur in open areas. Specific attention will need to be given to injections near buildings and utilities during the Remedial Design.

Once the concentrations of all COCs have been reduced to less than 1,000 µg/L in shallow groundwater for a sufficient period that it is apparent that rebound is not occurring, the high-concentration zone treatment can be discontinued and the area will transition to the low-concentration zone treatment approach. Details of the transition and the monitoring will be addressed during the Remedial Design. One injection round of ZVI is assumed to be sufficient to reduce contaminant concentrations to less than 1,000 µg/L due to the relatively long expected life of ZVI in the subsurface (likely on the order of a year or more). Subsequent ZVI injection(s), if necessary, will depend on individual site characteristics and need to be determined based on actual performance. Following implementation of the remedy, quarterly groundwater monitoring is assumed to evaluate effectiveness, though the specific monitoring plan would be determined during the Remedial Design.

It is assumed that the monitoring will be conducted at a total of 15 shallow groundwater monitoring wells (10 existing and 5 new), and will include the same analytes as Alternative 2 (MNA) with the addition of selected dissolved metals (including arsenic) due to the potential for the reducing conditions generated by this alternative to mobilize naturally occurring metals. More specific design criteria assumptions related to the implementation of ISCR in this alternative are specified in the cost estimate (**Appendix C**).

Low-Concentration Zone Treatment—Enhanced Reductive Dechlorination

ERD is a microbially-mediated, anaerobic process in which chlorine atoms on a parent CVOC molecule are sequentially replaced with hydrogen. In the reductive dechlorination process, electrons are transferred from an electron donor source to the CVOC compound, which functions as an electron acceptor. Therefore, an external electron donor source is required for the reaction to occur. Potential electron donor sources include biodegradable organic co-contaminants, native organic matter, or substrates intentionally added to the subsurface. Deeply anaerobic (reducing) conditions are required for reductive dechlorination of many CVOCs, and competing electron acceptors such as DO, nitrate, nitrite, manganese (IV), ferrous iron, and sulfate must be depleted. As with ISCR, the resulting reduced conditions may mobilize metals naturally present in soil, including arsenic.

The predominant parent COC at Site 21 is TCE. The principal anaerobic biodegradation pathway for TCE is:

$$TCE \rightarrow cis\text{-}1,2\text{-}DCE \rightarrow VC \rightarrow ethene$$

The transformation rate for each step varies but tends to become slower with progress along the breakdown sequence, often resulting in accumulation of cis-1,2-DCE and VC. Further breakdown from cis-1,2-DCE and VC to ethene and then to ethane varies and is based on site specific conditions and the microbial population present.

DHC gene analysis was conducted during the Remedial Investigation. Groundwater from four monitoring wells within the shallow CVOC groundwater plume were sampled for DHC deoxyribonucleic acid (DNA) BAV1, 195, and FL2 functional genes analysis to evaluate the capability of the indigenous microbial community to break down TCE all the way to ethene. Lack of these functional genes may result in a stall in the breakdown pathway at VC. Results indicate the presence of these functional genes in indigenous bacteria at three of the four locations sampled. Although not conclusive, this is a favorable indication that bioaugmentation may not be required at the site to result in complete breakdown to ethene. Therefore, it is assumed that bioaugmentation will not be conducted as part of this remedy. Groundwater monitoring will be conducted, and if VC is found to be accumulating, bioaugmentation may be considered in those areas.

The principle anaerobic biodegradation pathway for 1,1-DCE is similar to the TCE pathway starting at cis-1,2-DCE:

$$1,1\text{-}DCE \rightarrow VC \rightarrow ethene$$

Biological treatment of CVOCs is enhanced by adding a suitable carbon substrate (soluble or insoluble) to the subsurface. The introduced substrate serves multiple purposes: depleting competing electron acceptors, creating strongly reducing conditions, and producing an electron donor source for reductive dechlorination.

Commonly used insoluble substrates include Hydrogen Release Compound® (HRC) and emulsified vegetable oil (EVO). HRC is a viscous liquid that slowly releases lactic acid to act as a hydrogen donor to microorganisms that are able to carry out reductive dechlorination. EVO consists of linoleic and other long chain fatty acids that slowly solubilize in water over time and are broken down by native microorganisms to lower molecular weight fatty acids such as pyruvate and propionate. Ultimately, the EVO degrades to form acetic acid and hydrogen. The hydrogen and dissolved organic carbon from the acetic acid are then available to support reductive dechlorination of chlorinated solvents.

Soluble substrates include benzoate, lactate, acetate, propionate, butyrate, methanol, ethanol, sucrose, molasses, and hydrogen (H_2). These substrates are water soluble, degrade rapidly, and are transported with groundwater flow. Since these substrates degrade rapidly, they typically require more frequent injections than insoluble substrates and therefore are generally dispensed via permanent injection wells.

For the purpose of this FS conceptual design and cost estimate, EVO, a widely used and effectively insoluble substrate, was selected. Similar to the ZVI, it is assumed that the EVO will be emplaced using high-pressure injection at temporary DPT points. High-pressure injection will allow for rapid injection of the required volume at each DPT point and result in completion of injection round in a reasonable time frame. If daylighting from high-pressure injection becomes an issue during implementation, injection pressures may need to be reduced. This would increase the time of the injections, but may potentially result in a larger radius of influence.

The EVO will be injected and allowed to naturally advect through the subsurface to provide adequate coverage. In order to maintain reasonableness of cost for the large treatment area (nearly 300,000 ft^2), it is assumed that the injection wells will be placed such that injected EVO covers approximately one-quarter of the total area. The injection points will be oriented such that the natural flow of groundwater disperses the treatment product into the areas not directly within the radius of influence of the injections. **Figure 4-4** shows the assumed injection strategy based on the expected radius of influence of 6.5 ft as provided by a vendor experienced with this type of application. For evaluation purposes, a generic pattern was used and it was assumed that the injection pattern would not be influenced by the locations of existing buildings and underground utilities. As shown in **Figure 4-4**, the vast majority of the injections occur in open areas. Specific attention will need to be given to injections near buildings and utilities during the Remedial Design.

A single injection round of EVO across the entire site was assumed to be sufficient for reducing COC concentrations from 1,000 µg/L (or less) to the respective PRG during the estimated 5-year design life of the electron donor available for use by dechlorinating bacteria. Following implementation of the remedy, quarterly groundwater monitoring is assumed to evaluate if some areas may require a subsequent injection after 5 years. Monitoring will be continued as implemented following the ZVI injections with the addition of volatile fatty acids (VFAs) to the analytical parameters. More specific design criteria assumptions related to the implementation of ERD in this alternative are specified in the cost estimate (Appendix C).

4.3.4 Alternative 4—In Situ Chemical Oxidation and Enhanced Reductive Dechlorination

Alternative 4 comprises ISCO (followed by ERD) in the high-concentration zones and ERD in the low-concentration zones. Implementation of this remedial alternative will likely require more than one round of treatment, especially within the high-concentration zones. Because ISCO relies on oxidizing conditions and ERD relies on reducing conditions, the technologies will most likely be implemented sequentially. Initially, ISCO can be implemented in the high-concentration zones only. Based on the monitoring results, once the COC concentration results are reduced to below 1,000 µg/L in the high-concentration zones (thereby making them low-concentration zones), ERD can be implemented across the site.

The actual sequencing and schedule would be determined during the Remedial Design based on consideration of funding, site conditions, and cost-effectiveness (e.g., concurrent implementation of competing technologies to achieve more significant immediate reduction in contaminant mass, though potentially resulting in reduce effectiveness in the technology transition zone).

High-Concentration Zone Treatment—In Situ Chemical Oxidation

ISCO is based on the delivery of a chemical oxidant to contaminated media in order to oxidize CVOCs to innocuous compounds (carbon dioxide, chloride ions, and hydrogen ions). Oxidants can include permanganate, persulfate, peroxide, Fenton's reagent, percarbonate, and a variety of proprietary products. The most common oxidants applied in this process for the COCs at Site 21 are persulfate (as $Na_2S_2O_8$) and permanganate (as $KMnO_4$ or $NaMnO_4$).

Persulfate oxidizes CVOCs through the generation of a sulfate radical. The generation of this radical occurs through the addition of an activator such as heat, iron, hydrogen peroxide, and high pH. The activator that is best suited for a particular application is determined by site-specific conditions. The permanganate ion (MnO_4^-) is an oxidant that is commonly used to oxidize the types of CVOCs at Site 21.

The choice of whether to use persulfate or permanganate at a site can often be a difficult decision. However, for the purpose of this FS conceptual design and cost estimate, it is assumed that permanganate will be the chemical oxidant used at Site 21. The reasons behind assuming permanganate over persulfate include:

- Permanganate has been more widely used and studied
- Permanganate is more stable and will persist longer in the environment, giving more time to react with contaminants in the sorbed and DNAPL phases
- Permanganate does not require activation and is less sensitive to the particular groundwater chemistry of the site

The oxidation of TCE by permanganate requires two moles of permanganate per mole of TCE to drive the reaction. The reaction proceeds as follows:

$$C_2HCl_3 + 2MnO_4- \rightarrow 2CO_2 + 3Cl- + 2MnO_2 + H^+$$

On a mass basis this equates to 2.2 grams of sodium permanganate, or 2.4 grams of potassium permanganate per gram of TCE. However, these stoichiometric calculations do not include the oxidant reactions with the aquifer matrix, which generally far exceed the stoichiometric mass required to oxidize the COCs. Therefore, it is important that sufficient permanganate is injected to overcome natural oxidant demand (NOD) of the soil so that sufficient residual permanganate will remain to react with the COCs.

Soil samples were collected at varying depths adjacent to SJCA-MW02S and SJCA-MW04S, where high concentrations of TCE had been previously detected in shallow groundwater, for NOD analysis. Relatively low NOD was identified (less than 3 g/kg on a dry weight basis as $KMnO_4$ [less than 2.3 g/kg as MnO_4^-] (CH2M HILL, 2008). Typical values can range as high as 25 g/kg as MnO_4^-, particularly in soils high in organics and clay. A low NOD is favorable because less oxidant is required to overcome the NOD, and more of the added reagent is used for to treatment of the COCs, lowering the cost.

Manganese is an abundant element in the earth's crust and MnO_2 is naturally present in soils. Therefore, introduction of $KMnO_4$ or $NaMnO_4$ to soil or groundwater could raise the concentrations of manganese, and potentially other trace metals in the permanganate reagent, above their respective drinking water standards. Additionally, the oxidizing conditions created by the addition of permanganate may increase the solubility of certain forms of metals, such as hexavalent chromium. However, should any of these metals become significantly elevated, their mobility is generally limited and their concentrations tend to return to acceptable levels once the permanganate is depleted.

It is assumed that $NaMnO_4$ will be purchased premixed to a concentration of 6%, and will be emplaced using high-pressure injection at temporary DPT points. NaMnO4 was selected by the vendor over KMnO4 because it is more soluble and thus easier to prepare the reagent solution. High-pressure injection will allow for rapid injection of the required volume at each DPT point and result in completion of injection round in a reasonable time frame. If daylighting from high-pressure injection becomes an issue during implementation, injection pressures may need to be reduced. This would increase the time of the injections, but may potentially result in a larger radius of influence.

Figure 4-3 shows the assumed injection strategy based on the expected radius of influence of 6.5 ft as provided by a vendor experienced with this type of application. For evaluation purposes, it was assumed that the injection pattern would not be influenced by the locations of existing buildings and underground utilities. As shown in **Figure 4-3**, the vast majority of the injections occur in open areas. Specific attention will need to be given to injections near buildings and utilities during the Remedial Design.

Once the concentrations of all COCs have been reduced to less than 1,000 µg/L in shallow groundwater for a sufficient period that it is apparent that rebound is not occurring, the high-concentration zone treatment can be discontinued and the area will transition to the low-concentration zone treatment approach. Details of the transition and the monitoring will be addressed during the Remedial Design. Two injection rounds of $NaMnO_4$ are assumed to be sufficient to achieve the reduction in contaminant concentrations to below 1,000 µg/L due to the relative short effective life of $NaMnO_4$ in the subsurface (likely on the order of months). The actual number of ISCO injections required (more or less than two) will need to be determined based on actual performance.

Following implementation of the remedy, quarterly groundwater monitoring is assumed to evaluate effectiveness, though the specific monitoring plan will be determined during the Remedial Design. It is assumed that the quarterly sampling will be conducted at a total of 15 shallow groundwater monitoring wells (10 existing and 5 new), and will include the same analytes as Alternative 2 (MNA) with the addition of hexavalent chromium and selected dissolved metals (e.g., iron, manganese, arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver—the actual analytes will be determined during development of the groundwater monitoring plan).

More specific design criteria assumptions related to the implementation of ISCO in this alternative are specified in the cost estimate (**Appendix C**).

Low-Concentration Zone Treatment—Enhanced Reductive Dechlorination

Unlike ISCR, the oxidizing conditions established as a result of ISCO are not conducive for ERD. In the treatment train approach using ISCO for the high-concentration zones and ERD for the low-concentration zones, the oxidizing conditions created in the high-concentration zones will need to be allowed to diminish over time before attempting to stimulate the reducing bacteria used in ERD. Before the biological substrate is introduced for ERD, groundwater monitoring will be used to show that the permanganate is depleted and reducing conditions are becoming reestablished. If the biological substrate is injected prematurely, the residual permanganate could oxidize the substrate before it can be utilized by the microorganisms. It is also possible that the highly oxidizing conditions resulting from the permanganate injection could be inhibitory to some microorganisms.

It is difficult to anticipate how the effects of ISCO will impact the subsequent ERD effectiveness. However, for the purpose of this FS conceptual design and cost estimate, it is assumed that because a relatively low permanganate dose is proposed, the ERD implementation could take place approximately 1 year following the ISCO injections. It is assumed that additional EVO will not be required to achieve the necessary reducing conditions. It is also assumed that reducing conditions will become rapidly established following the ERD injection, and that the microbial population will be viable and subsequent bioaugmentation will not be required.

The use and details of ERD for the low-concentration zone are the same as discussed previously for Alternative 3.

Table 4-1
Treatment Area Summary
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

	Area (ft^2)	GW Volume (gal)	Soil Volume (yd^3)	Soil Mass (ton)
High Concentration Areas				
TCE	35600	798900	15800	26400
Cis-1,2-DCE	8600	193000	3800	6300
VC	NA	NA	NA	NA
1,1-DCE	NA	NA	NA	NA
Combined	36600	821300	16300	27200
Low Concentration Areas				
TCE	269400	6045300	119700	199900
Cis-1,2-DCE	113300	2542500	50400	84200
VC	138900	3116900	61700	103000
1,1-DCE	1500	33700	700	1200
Combined	294300	6604100	130800	218500

Assumptions:

Effective porosity =	0.25	
Saturated zone thickness =	12	feet
Soil dry bulk density =	1.67	ton/yd^3

TABLE 4-2
Screening of Remedial Technologies
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

General Response Actions	**Remedial Technology**	**Process Options**	**Descriptions**	**Effectiveness** Protection of Human Health and the Environment Compliance with ARARs Short-Term Effectiveness Long-Term Effectiveness Reduction of Toxicity, Mobility, and Volume through Treatment	**Implementability** Technical Implementability Administrative Implementability	**Relative Cost Range**	**Primary Screening**		
							Retain	**Reject**	**Screening Comment**
No Action	None	None	No action. May result in reduced COC concentrations over time as a result of naturally occurring processes.	**Low** • Evidence of natural degradation processes exists. However, time to achieve RAOs may be decades or more in some areas. • No short-term risk to remediation or site workers.	**High** • No work required; therefore easily implementable	**No cost**	X		Retained for baseline comparison
In-Situ Treatment	Chemical Treatment	In-Situ Chemical Oxidation (ISCO)	Aqueous injection of oxidizing agents (peroxide, persulfate, permanganate, or ozone) to promote abiotic in-situ oxidation of COCs. Oxidants react directly with the COCs producing innocuous substances such as carbon dioxide, water, and chloride.	**Moderate to High** • Effective for the COCs at Site 21. • Can reduce large concentrations quickly in the aqueous phase. • Requires good contact between COCs and reagent. • Aquifer heterogeneity, where present, would make uniform distribution difficult and would limit effectiveness. • Naturally occurring metals (such as chromium) may be temporarily mobilized under oxidizing conditions. • Handling of oxidants or storage of chemicals on site presents a short-term risk to remediation workers or site workers. • Oxidizing conditions produced are not conducive with other remedial technologies involving reducing conditions (ISCR, ERD).	**Moderate** • Accessibility to area is relatively high due to being a low-traffic area. • Presence of underground and overhead utilities, asphalt, concrete, and potentially building foundations may present challenges. • Presence of asphalt and concrete across much of the site may reduce potential for "daylighting" during implementation. • Relatively low soil NOD means chemical requirements will not be excessive; therefore, potentially effective with one application in low-concentration zones. • DNAPL areas would likely require multiple applications. • Effective life of treatment reagents is short	**Moderate** Relatively low for high-concentration. zone treatment when timeframe is considered. Probably less cost effective for low-concentration zones.	X (high-conc. zones)	X (low-conc. zones)	Retained for high-concentration zones due to relatively fast breakdown kinetics. Rejected for the low-concentration zones due to incompatibility with reducing present under natural conditions.
		In-Situ Chemical Reduction (ISCR)	Injection of reducing agents (zero-valent iron) to promote abiotic in-situ reduction of COCs. Can reduce compounds to ethene and chloride.	**Moderate to High** • Effective for the COCs at Site 21. • Can reduce large concentrations quickly in the aqueous phase; however, rates will be diffusion-limited for sorbed and DNAPL phases. • Requires good contact between COCs and reagent. • Aquifer heterogeneity, where present, would make uniform distribution difficult and would limit effectiveness. • Naturally occurring metals (such as iron, manganese, arsenic, vanadium) may be temporarily mobilized under reducing conditions. • Reducing conditions produced are ideal for other remedial technologies involving reducing conditions (ERD).	**Moderate to High** • Accessibility to area is relatively high due to being a low-traffic area. • Presence of underground and overhead utilities, asphalt, concrete, and potentially building foundations may present challenges. • Presence of asphalt and concrete across much of the site may reduce potential for "daylighting" during implementation. • Potentially effective with one application in low-concentration zones. • DNAPL areas may require retreatment. • Relatively long-lived treatment reagents.	**Moderate** Relatively low for high-concentration zone treatment. Relatively high for low-concentration zones.	X (high-conc. zones)	X (low-conc. zones)	Retained for high-concentration zones due to relatively fast breakdown kinetics and compatibility with other treatments. Not cost-effective for low-concentration areas.
	Biological Treatment	Enhanced Reductive Dechlorination (ERD)	Electron donor source, which is generally the limiting factor in the naturally occurring reductive dechlorination process, is injected into the subsurface. Common substrates are molasses, lactate, alcohols, emulsified vegetable oil, and other proprietary products (e.g., HRC, EHC).	**Moderate to High** • Effective for the COCs at Site 21. • Site 21 data indicates microbial population is capable of complete reductive dechlorination of COCs. • Can reduce large concentrations quickly in the aqueous phase; however, rates will be diffusion-limited for sorbed and DNAPL phases. • Naturally occurring metals (iron, manganese, arsenic, vanadium) may be mobilized under low redox conditions. • Exposure to substrate presents very low risk when using food grade substrate to construction and site workers.	**Moderate to High** • Accessibility to area is relatively high due to being a low-traffic area. • Presence of underground and overhead utilities, asphalt, concrete, and potentially building foundations may present challenges. • Presence of asphalt and concrete across much of the site may reduce potential for "daylighting" during implementation. • Potentially effective with one application in low-concentration areas if slow-release substrate is used. • High-concentration areas may require retreatment.	**Low to Moderate** More cost effective for low-concentration zones than other in-situ methods. Costs may increase if bioaugmentation or multiple injections are required.	X (low-conc. zones)	X (high-conc. zones)	Retained for low-concentration zones due to effectiveness, compatibility with site conditions, low safety hazard, and low cost. Rejected for high concentration zones due to relatively longer times to achieve RAOs relative to ISCR and ISCO.
		Aerobic Bioremediation via Co-Metabolism	Injection of dilute solution containing primary substrate (inducer, e.g., toluene, phenol, methane) to enhance cometabolic breakdown. Inducers serve as carbon sources that activate aerobic enzyme systems known to degrade COCs. Oxygen is supplied via oxygenated injection water or by air sparging.	**Moderate** • Considerable uncertainty on rate and extent of biodegradation that can be achieved. • Breakdown products may cause toxicity to microbes. • Extensive use of electricity results in a high carbon footprint.	**Low to Moderate** • In-situ application of this technology has not been demonstrated at a large scale. • Oxygen requirement makes this technology more difficult to implement than others. • Regulatory approval for use of specific inducer compounds may be required.	**High** Expensive to implement over a large area because of high O&M costs associated with oxygen supply.		X	Rejected for high O&M costs and lack of proof of effectiveness on large scale. Relatively large carbon footprint.
	Physical Treatment	Thermal Technologies (e.g., electrical resistance heating)	The subsurface is heated by delivering separate electric phases through electrodes to promote in-situ generation of steam to vaporize COCs. Resulting vapors and steam are extracted and treated.	**High** • Effective for the COCs at Site 21. • Greatly increases the rate of COC removal, and can remove DNAPL and sorbed phases if present. • Applicable in low permeability soils. • Extensive use of electricity results in a high carbon footprint. • Excessive heat may diminish the microbial population and/or diversity.	**Low to Moderate** • Significant infrastructure required and may impact area operations. • Will likely require off-gas treatment to minimize impacts from volatilization to ambient air for protection of workers. • Difficult to implement over a large treatment area. • Implementation may be constrained by existing buildings, and may result in vapor intrusion into site buildings.	**Moderate to Very High** Cost may be moderate for high-concentration zones due to short timeframe. Very costly to implement in large, low-concentration zones.		X	Rejected for high O&M costs. Large carbon footprint.
		Air Sparging/Soil Vapor Extraction (AS/SVE)	Air is injected into subsurface to remove COCs through volatilization. AS is usually coupled with SVE for collection/treatment of displaced COCs.	**Moderate** • Effective for the COCs at Site 21. • Could cause migration of DNAPL, if present. • Less effective when sparging saturated zones at depths less than 5 feet. • Requires tight well spacing in for the shallow groundwater zone at Site 21. • Aquifer heterogeneity, where present, would limit effectiveness.	**Moderate** • Difficult to implement over a large treatment area and for low-concentration zones.	**High** Not cost-effective for large areas low-concentration zones.		X	Rejected for high O&M costs. Relatively large carbon footprint.
		Flushing	Injection / extraction or recirculation of surfactants, cyclodextrin, cosolvents, or treated water.	**Moderate** • Increases the rate of mass removal by increasing solubility or mobility of COCs. • Heterogeneities and improperly designed extraction wells may result in the migration COCs. • Extensive use of electricity results in a high carbon footprint.	**Low to Moderate** • Large amounts of wastewater will need to be managed, treated, and disposed. • Regulatory approval may be required for use of some flushing agents.	**Moderate to High** Expensive and inappropriate for low-concentration zones.		X	Rejected. Potentially less effective than other treatments. O&M cost are high. Relatively large carbon footprint.

TABLE 4-2
Screening of Remedial Technologies
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

General Response Actions	Remedial Technology	Process Options	Descriptions	**Effectiveness** Protection of Human Health and the Environment Compliance with ARARs Short-Term Effectiveness Long-Term Effectiveness Reduction of Toxicity, Mobility, and Volume through Treatment	**Implementability** Technical Implementability Administrative Implementability	Relative Cost Range	Primary Screening		
							Retain	Reject	Screening Comment
Containment	Physical Treatment	Pump and Treat	Groundwater is extracted and treated in an ex-situ treatment system. Extraction system can be designed to achieve hydraulic containment (to prevent off-site migration of COCs) or for hotspot treatment.	**Low to Moderate** • Effective for the COCs at Site 21. • Rate of COC mass removal tends to decrease as concentrations decrease, resulting in long timeframe to achieve low cleanup goals. • Can prevent contaminant migration if properly engineered. • Extensive use of electricity results in a high carbon footprint.	**Moderate** • Requires onsite treatment system and O&M. • May require many years of operation unless source removal completed. • Well siting may be hampered by existing buildings/site activities.	**High** Expensive to implement over a large area because of high O&M costs associated with pumping and treatment system.		X	Rejected for high O&M costs and facility impacts. Technology not as effective as other treatments and not consistent with Navy policy. Relatively large carbon footprint.
	Bio-Chemical Treatment	Permeable Reactive Barrier (PRB)	Barriers are constructed in strategic locations to intercept and treat COCs and prevent downgradient migration. Treatment can be chemical (e.g., zero-valent iron barrier) or biological (e.g., emulsified oil bio-barrier). PRBs can be constructed by trenching or by injecting materials.	**Moderate** • Effective for the COCs at Site 21, but only provides treatment of aqueous-phase COCs flowing through the PRB. • Does not treat areas upgradient of the barrier; therefore, does achieve RAOs • Prevents COC migration. • Installation by trenching may result in the production of hazardous soil and groundwater for disposal and higher risk of worker exposure. • Remains effective if the subsurface is heterogeneous. However, inconsistencies in groundwater flow direction will limit the effectiveness of the PRB.	**Moderate to High** • Low area traffic could allow installation by trenching or direct-push technology. • Trenching approach may be constrained by depth or site infrastructure.	**Low to Moderate** Cost is relatively low compared to area treatment		X	Rejected because technology does not provide area treatment.
Administrative Controls	Land Use Controls	Deed Notifications and Permits	Deed notifications issued for property and/or area(s) exceeding the clean up goals to restrict groundwater and land use. Regulations promulgated to require a permit for various activities (i.e., excavation, installation of wells, etc.).	**Moderate** • Relies on proper enforcement for administrative control to be effective. • No short-term risk to remediation or site workers.	**High** • Easily implementable	**Low** No remediation undertaken.	X		Required for areas exceeding cleanup criteria after treatment.
Monitoring	Monitoring	Monitored Natural Attenuation (MNA) / Performance Monitoring	Regular, long-term monitoring is necessary to demonstrate that COC concentrations continue to decrease, to verify that potentially toxic transformation products are not created at levels that are a threat to human health; that the impacted area is not expanding; and, that there are no changes in hydrogeological, geochemical, or microbiological parameters that might reduce the effectiveness of the remedial action.	**Low** • Evidence of natural degradation processes exists. However, time to achieve RAOs may be decades or more in some areas. • Natural degradation processes will be slow due to limited substrate availability. Could be enhanced by upgradient or prior active treatment. • No short-term risk to remediation or site workers.	**High** • Easily implementable	**Low** No remediation undertaken.	X		Retained, MNA meets RAOs over long timeframe. Monitoring required for any alternative.

Notes:

COCs = contaminants of concern

DNAPL = dense non-aqueous phase liquid

O&M = operation and maintenance

RAOs = remedial action objectives

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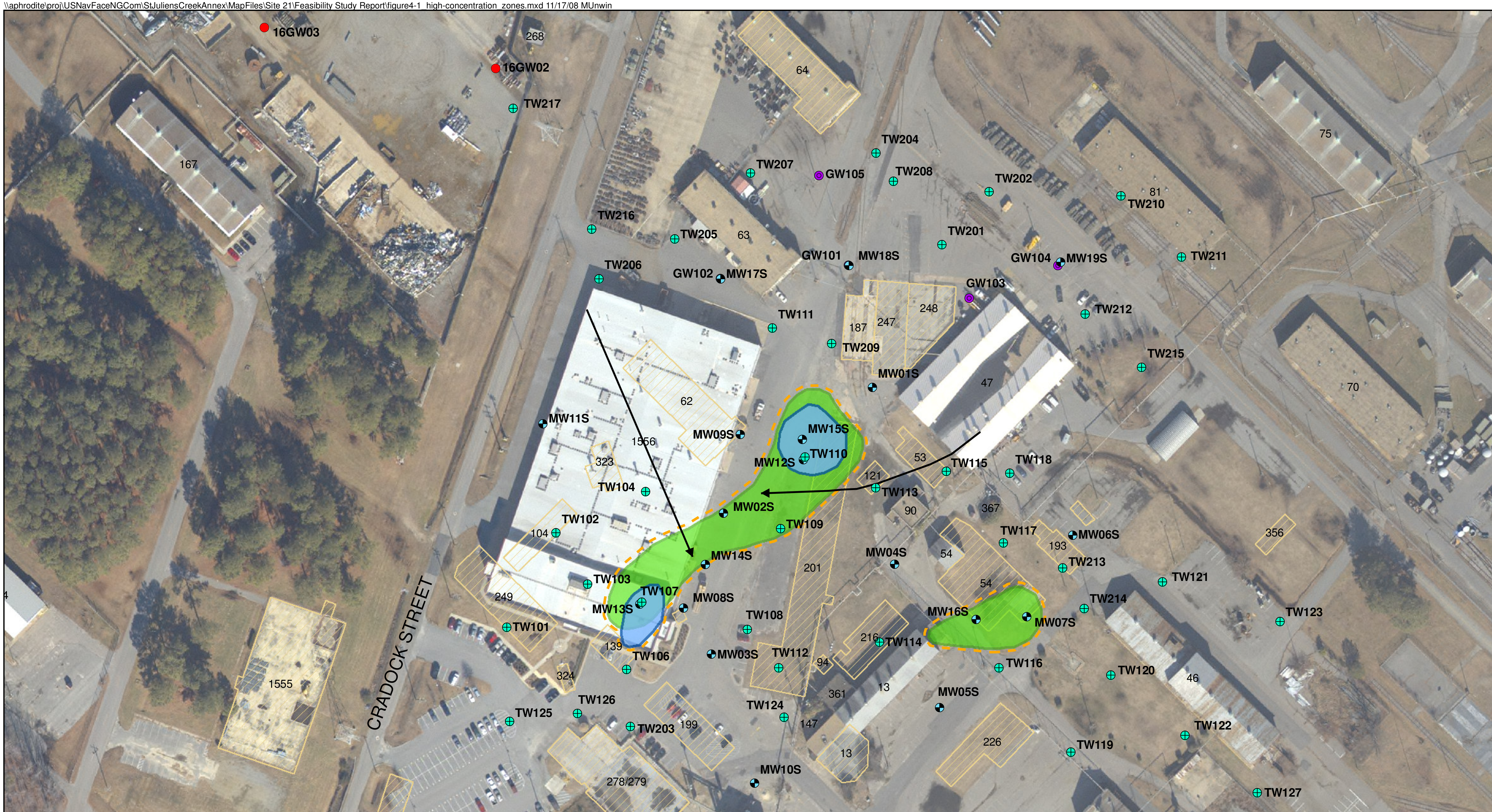

Legend

- Shallow Monitoring Well Location
- Temporary Monitoring Well Location
- Grab Groundwater Sample Location
- RRR Groundwater Sample Location
- Demolished Building
- Estimated Groundwater Flow Direction
- TCE Concentrations >= 1,000 µg/L (35,600 ft²)
- cis-1,2-DCE Concentrations >= 1,000 µg/L (8,600 ft²)
- High Concentration Zones Boundary (36,600 ft²)

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Feet

Figure 4-1
High-Concentration Zones
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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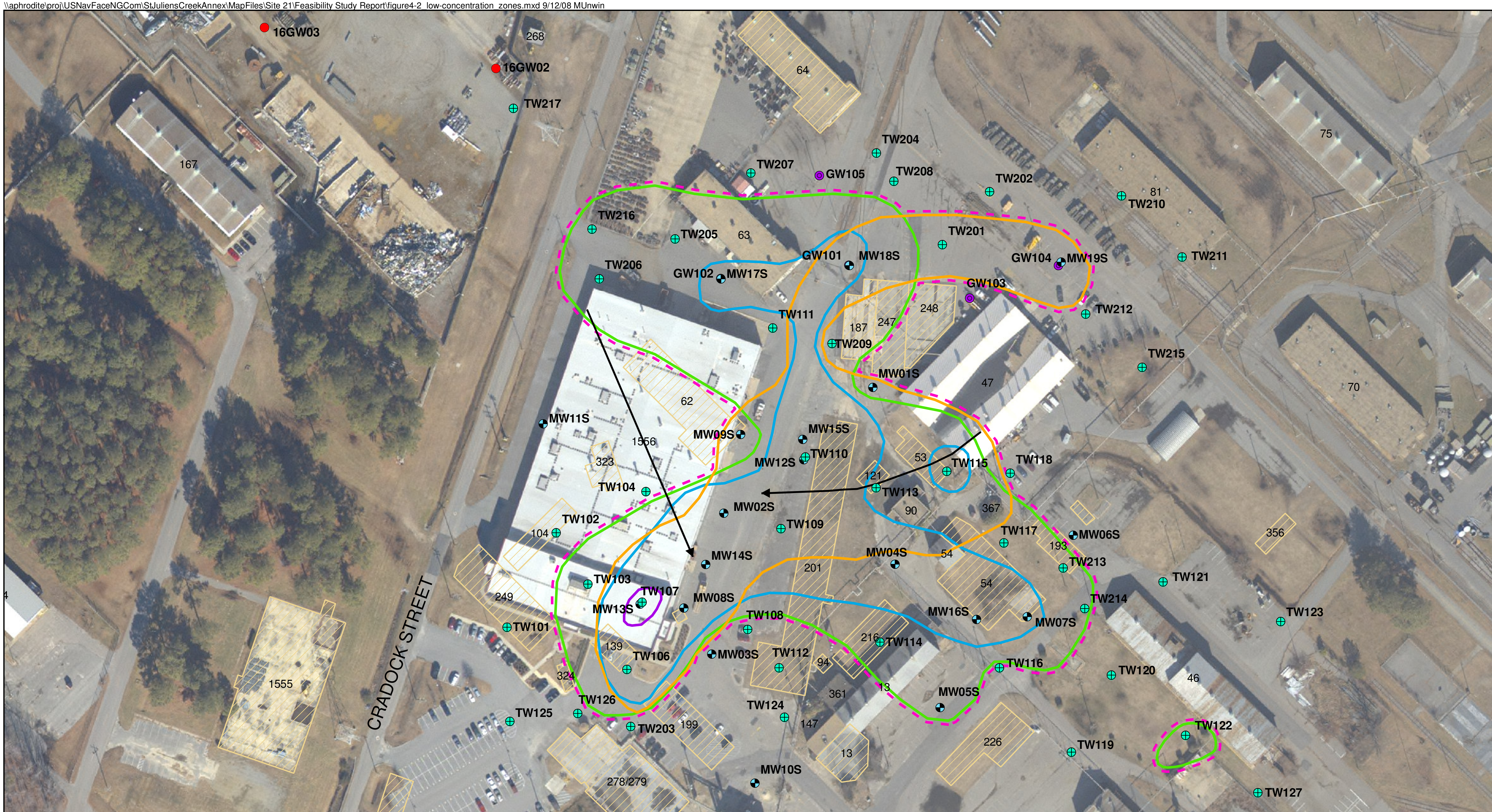

Legend

- Shallow Monitoring Well Location
- Temporary Monitoring Well Location
- Grab Groundwater Sample Location
- RRR Groundwater Sample Location
- Demolished Building
- Estimated Groundwater Flow Direction
- TCE Concentrations 5-999 µg/L (269,400 ft²)
- cis-1,2-DCE Concentrations 70-999 µg/L (113,300 ft²)
- VC Concentrations 2-999 µg/L (138,900 ft²)
- 1,1-DCE Concentrations 7-999 µg/L (1,500 ft²)
- Low Concentration Zones Boundary (294,300 ft²)

Note: Contours reflect estimated concentrations after high concentration areas have been treated.

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0 120 240 Feet

Figure 4-2
Low-Concentration Zones
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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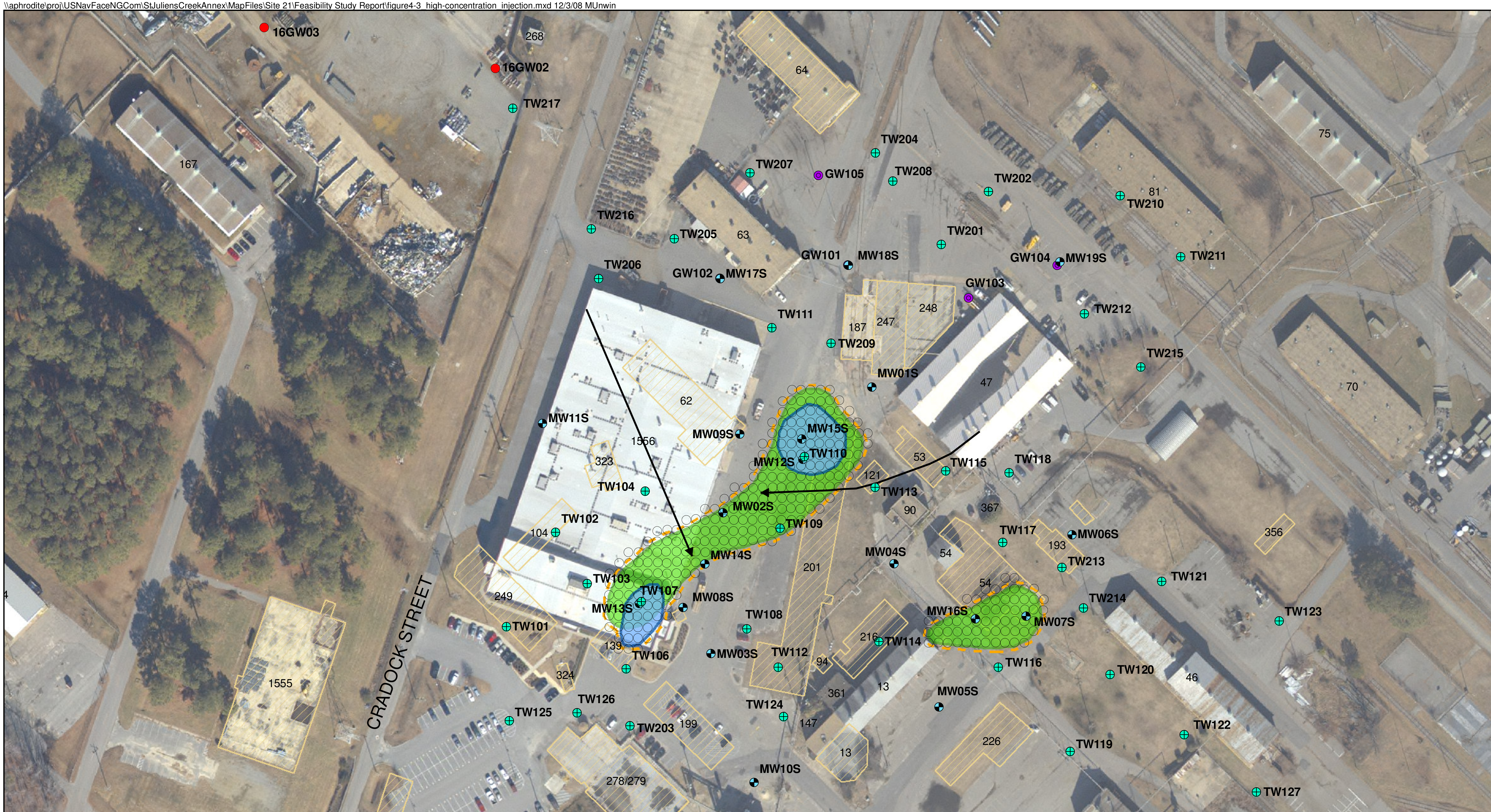

Legend

- Shallow Monitoring Well Location
- Temporary Monitoring Well Location
- Grab Groundwater Sample Location
- RRR Groundwater Sample Location
- Injection Point (radius of influence is approximate)
- Demolished Building
- Estimated Groundwater Flow Direction
- TCE Concentrations >= 1,000 µg/L (35,600 ft²)
- cis-1,2-DCE Concentrations >= 1,000 µg/L (8,600 ft²)
- High Concentration Zones Boundary (36,600 ft²)

Note: For evaluation purposes, it was assumed that the injection pattern would not be influenced by the locations of existing buildings and underground utilities. Specific attention will need to be given to injections near buildings and utilities during the Remedial Design.

N W E S

0 120 240 Feet

Figure 4-3
High-Concentration Zones Injection Points
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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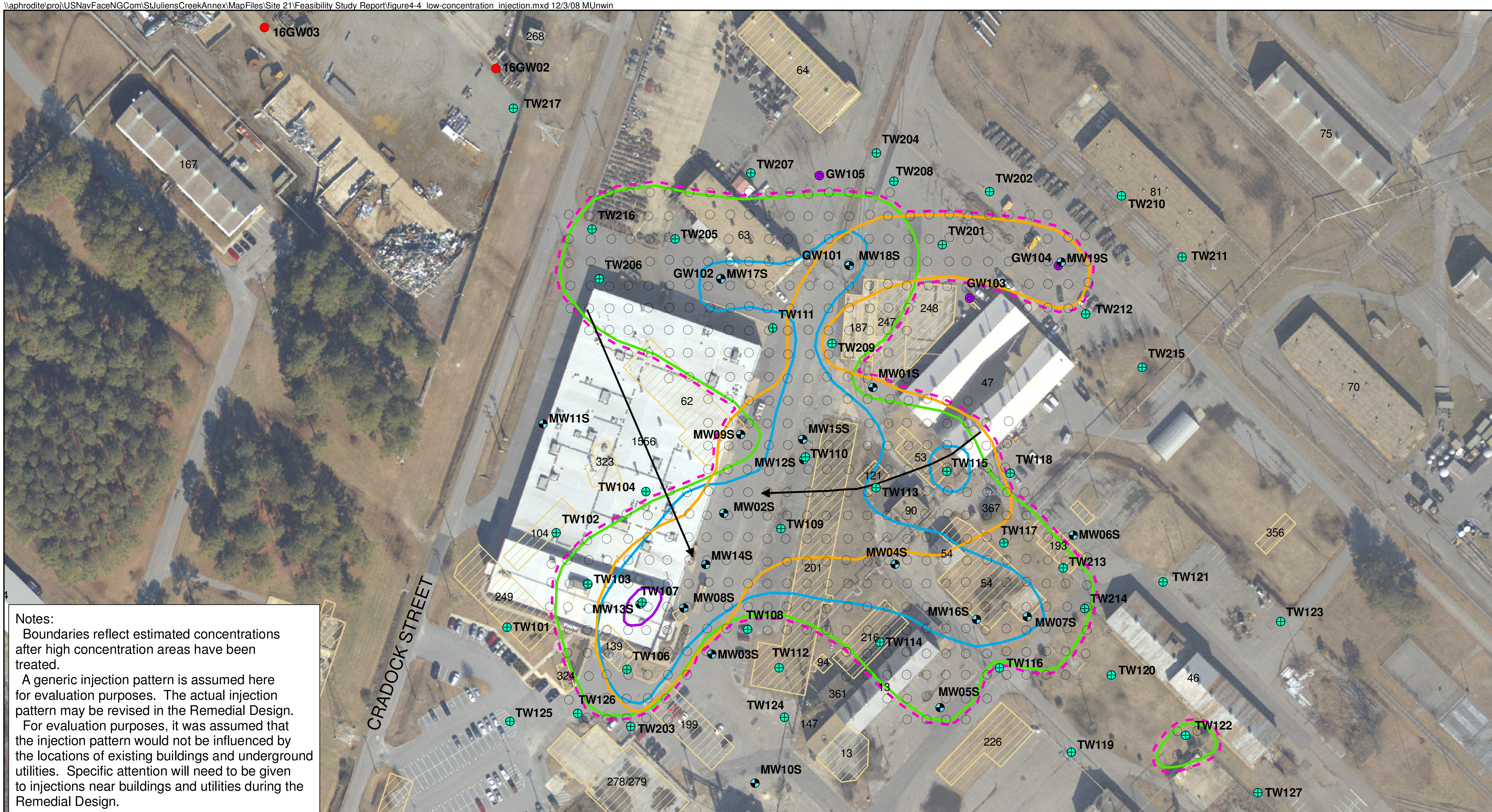

Notes:
Boundaries reflect estimated concentrations after high concentration areas have been treated.
A generic injection pattern is assumed here for evaluation purposes. The actual injection pattern may be revised in the Remedial Design.
For evaluation purposes, it was assumed that the injection pattern would not be influenced by the locations of existing buildings and underground utilities. Specific attention will need to be given to injections near buildings and utilities during the Remedial Design.

Legend

- Shallow Monitoring Well Location
- Temporary Monitoring Well Location
- Grab Groundwater Sample Location
- RRR Groundwater Sample Location
- Injection Point (radius of influence is approximate)
- Demolished Building
- Estimated Groundwater Flow Direction
- TCE Concentrations 5-999 µg/L (269,400 ft²)
- cis-1,2-DCE Concentrations 70-999 µg/L (113,300 ft²)
- VC Concentrations 2-999 µg/L (138,900 ft²)
- 1,1-DCE Concentrations 7-999 µg/L (1,500 ft²)
- Low Concentration Zones Boundary (294,300 ft²)

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Figure 4-4
Low-Concentration Zones Injection Points
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

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SECTION 5

Detailed Evaluation of Alternatives

In this section, the alternatives developed in the previous section are evaluated to provide a basis for selecting a remedy. Section 5.1 discusses the criteria used to evaluate the alternatives, and Section 5.2 contains the evaluations of the alternatives.

5.1 Evaluation Criteria for Remedial Alternatives

The remedial alternatives that have been developed are evaluated against a common set of criteria. Each alternative was developed to address threats to human health posed by contamination at Site 21. The NCP requires that the remedial alternatives be evaluated against nine criteria as listed below.

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, and volume through treatment
- Short-term effectiveness
- Implementability
- Cost
- State acceptance
- Community acceptance

The first two criteria are *threshold criteria* and must be achieved by alternatives at a minimum, and the next five are considered *primary balancing criteria*. These first seven criteria form the basis of the detailed evaluation of alternatives. The last two criteria, state and community acceptance, are *modifying criteria*, and will be addressed in the Proposed Plan and ROD for Site 21.

The detailed alternative analysis is the means for assembling and evaluating technical and policy considerations to develop the rationale for selecting a remedy. Each of the nine criteria is described below.

5.1.1 Overall Protection of Human Health and the Environment

This criterion provides a final check to assess whether each alternative provides adequate protection of human health and the environment. The overall assessment of protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence and short-term effectiveness. This evaluation focuses on whether each alternative achieves adequate protection and describes how site risks are being eliminated, reduced, or controlled. This criterion allows for consideration of whether an alternative poses any unacceptable short-term or cross-media impacts.

5.1.2 Compliance with ARARs

This criterion is used to determine whether each alternative will meet all of the Federal and State ARARs that have been identified. A discussion of ARARs was presented in Section 3.3. The following factors will be considered as each alternative is evaluated for this criterion on State and Federal levels:

- Compliance with location-specific ARARs
- Compliance with chemical-specific ARARs
- Compliance with action-specific ARARs
- Compliance with other criteria, advisories, or guidelines

5.1.3 Long-Term Effectiveness and Permanence

This criterion addresses the results of the remedial action in terms of risk remaining at the site after response objectives have been met. The primary focus of this evaluation is the extent and effectiveness of the controls that may be required to manage the risk posed by treatment residuals and/or untreated wastes. The following factors will be considered as each alternative is evaluated for this criterion:

- Magnitude of estimated residual risk
- Adequacy and reliability of controls

5.1.4 Reduction of Toxicity, Mobility, and Volume through Treatment

This criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of hazardous substances, and thereby reduce the principal threats at a site. The following factors will be considered as each alternative is evaluated for this criterion:

- Treatment processes used and materials treated
- Amount of hazardous material destroyed or treated
- Degree of expected reduction in toxicity, mobility, or volume
- Degree to which treatment is irreversible
- Type and quantity of residuals remaining after treatment
- Satisfaction of the statutory preference for treatment as a principal element

5.1.5 Short-term Effectiveness

This criterion addresses the effects of the alternative on human health and the environment during the construction and implementation phases until RAOs are met. The following factors will be considered as each alternative is evaluated for this criterion:

- Protection of community during remedial actions
- Protection of workers during remedial actions
- Environmental impacts
- Time to achieve the RAOs

5.1.6 Implementability

The evaluation of implementability includes the technical and administrative feasibility of implementing each alternative, as well as the availability of services and materials required for implementation. The following factors will be considered as each alternative is evaluated for this criterion:

- Technical feasibility
  - Ability to construct, operate, and monitor the technology
  - Reliability of the technology
  - Ease of undertaking additional remedial action, if necessary
  - Ability to monitor the effectiveness
- Administrative feasibility
  - Ability to coordinate with and obtain approvals from other agencies

Availability of equipment, specialists, technologies, off-property treatment, storage or disposal services, and capacity

5.1.7 Cost

This criterion evaluates alternatives based on the associated capital cost and operating and maintenance cost to achieve the RAOs. The estimated cost of each remedial option is expressed as present value based on an assumed discount rate of 4.9 percent over a 30-year operation period. The discount rate was selected based on the Federal Office of Management and Budget (http://www.whitehouse.gov/omb/fedreg/2008/013008_discountrate.pdf). Note that the 30-year O&M period is assumed for evaluation purposes only; the actual O&M period could be much longer in some cases. Total costs are expressed over a plus 50 to minus 30 percent range.

5.1.8 State Acceptance

This criterion evaluates the technical and administrative issues and concerns the state may have regarding each of the alternatives. This criterion is not discussed in this report but will be addressed in the ROD.

5.1.9 Community Acceptance

This criterion evaluates the technical and administrative issues and concerns the public may have regarding each of the alternatives. This criterion is not discussed in this report but will be addressed in the Proposed Plan and ROD.

5.2 Evaluation of Remedial Alternatives

The detailed analysis of remedial alternatives comprises individual and comparative evaluation of the remedial alternatives. During the individual evaluation, each alternative is assessed against the NCP criteria described in Section 5.1. The results are then arrayed to compare the alternatives and identify the key tradeoffs among them. This approach provides decision makers with sufficient information to adequately compare the alternatives, select an appropriate remedy for the site, and demonstrate satisfaction of the remedy selection requirements in the ROD. The individual evaluation of the alternatives is provided in **Table 5-1**.

The comparative evaluation is provided in the following sections. A qualitative comparative analysis was employed using a ranking system of 1 to 5, with 1 being the lowest valued metric and 5 being the highest. The results of the ranking for each alternative are included in **Table 5-2**.

Alternative 1, no action, is easily implemented, with no concerns for short term effectiveness and no associated cost. However, Alternative 1 does not provide protection of human health and the environment, does not comply with ARARs, is not effective in the long term, and does not reduce toxicity, mobility or volume through treatment. Alternative 1 serves only as a baseline and is therefore not discussed in the following sections.

5.2.1 Overall Protection of Human Health and the Environment

Alternative 2, 3, and 4 are all protective of human health and the environment. Alternative 2 is considered to be less protective than Alternatives 3 and 4 because it relies on natural degradation, which adds a higher degree of uncertainty. Alternatives 3 and 4 are similar in protectiveness because they each employ an active treatment. Monitoring will be conducted and LUCs will provide adequate protection of human health and the environmental by controlling exposure to shallow groundwater until the RAOs are achieved.

5.2.2 Compliance with ARARs

Alternatives 2, 3, and 4 are expected to comply with ARARs. Alternative 2 will have a longer timeframe associated with meeting the ARARs because it relies on natural degradation, whereas Alternatives 3 and 4, which are similar, employ active treatment and will therefore meet the ARARs in an accelerated timeframe.

5.2.3 Long-Term Effectiveness and Permanence

Alternatives 2, 3, and 4 are expected to effectively reduce concentrations of VOCs in shallow groundwater to allow for unlimited use and unrestricted exposure over time. Alternatives 3 and 4 are considered equally effective and will achieve a more rapid reduction in VOC concentrations because they employ active treatment, while Alternative 2 relies on natural degradation.

5.2.4 Reduction of Toxicity, Mobility, and Volume through Treatment

Alternatives 2, 3, and 4 are each expected to reduce toxicity, mobility, and volume. Only Alternatives 3 and 4 have treatment components, which is the statutory preference. While MNA is not considered a treatment, the natural reduction of contaminant concentrations through a variety of physical, chemical, or biological activities is expected over time.

5.2.5 Short-Term Effectiveness

The short-term effectiveness associated with Alternatives 3 and 4 are similar with regard to impacts to the community, as both treatments rely on direct injection technology for implementation. Alternatives 3 and 4 are also similar with consideration to environmental impacts, as each alternative has the potential to temporarily mobilize naturally occurring metals. Alternative 4 has a slightly higher risk to construction workers during implementation than Alternatives 2 and 3 due to the handling and potential exposure to oxidizing chemicals. Because Alternative 2 relies on natural degradation rather than employing an active treatment, it has the lowest impacts to the community; however, it also results in the lowest rate of reduction in COCs. Therefore, Alternative 3 provides the greatest short-term effectiveness.

5.2.6 Implementability

Alternatives 2, 3, and 4 can each be implemented using standard and widely available technologies. The implementability associated with Alternatives 3 and 4 are slightly lower than Alternative 2 due to the logistical challenges of working in an industrial area (e.g., the presence of buildings and utilities). Alternative 3 will be slightly easier to implement than Alternative 4 because Alternative 3 relies on naturally occurring reducing conditions, while Alternative 4 would require the reversal of the conditions to oxidizing for the initial phase of treatment (ISCO) then return to reducing for the second phase (ERD).

5.2.7 Cost

The estimated capital cost for implementation of Alternative 2 ($50 thousand) is less than Alternative 3 ($3.1 million) and 4 ($4.6 million). The estimated present value cost, factoring in a 30-year operation and maintenance period for each alternative, for Alternative 2 ($0.5 million) is less than Alternatives 3 ($3.9 million) and 4 ($5.3 million). The cost estimates are provided in **Appendix C.**

TABLE 5-1
Individual Evaluation of Remedial Alternatives
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

Evaluation Criteria	Alternative 1 No Action	Alternative 2 MNA	Alternative 3 ISCR & ERD	Alternative 4 ISCO & ERD
Overall Protection of Human Health & the Environment	**Not protective** Does not prevent exposure to contaminated groundwater or provide measures to reduce COC concentrations to achieve RAOs.	**Protective** COCs naturally degrade over time. Performance monitoring and LUCs implemented and maintained until groundwater RAOs are achieved.	**Protective** Actively treats COCs. Performance monitoring and LUCs implemented and maintained until groundwater RAOs are achieved.	**Protective** Actively treats COCs. Performance monitoring and LUCs implemented and maintained until groundwater RAOs are achieved.
Compliance with ARARs	**Does not meet**	**Meets** Extended timeframe.	**Meets** Accelerated cleanup timeframe.	**Meets** Accelerated cleanup timeframe.
Long-Term Effectiveness & Permanence	**Ineffective** Past groundwater monitoring suggests reductive dechlorination of VOCs is occurring naturally. However, with no treatment or monitoring, it is uncertain if/when RAOs will be achieved. Timeframe considered unacceptable. LUCs not in place to prevent exposure to COCs.	**Effective, maybe** Past groundwater monitoring suggests reductive dechlorination of VOCs is occurring naturally. However, the timeframe to achieve RAOs is uncertain. Performance monitoring would assess degradation and mobility of COCs. LUCs will prevent exposure to COCs.	**Effective, likely** Greatly reduces timeframe to achieve RAOs through both chemical reduction and accelerated natural degradation processes. Following termination of injection activities, aquifer conditioned for continued degradation; rebound risk reduced. LUCs will prevent exposure to COCs until RAOs are achieved.	**Effective, likely** Greatly reduces timeframe to achieve RAOs through both chemical oxidation and accelerated natural degradation processes. Following termination of injection activities, aquifer conditioned for continued degradation; rebound risk reduced. LUCs will prevent exposure to COCs until RAOs are achieved.
Reduction of Toxicity, Mobility, & Volume Through Treatment	**No treatment** Reduction would only gradually occur as a result of natural processes. Reduction and mobility of COCs would remain unknown and undocumented.	**No treatment** Reduction would gradually occur as a result of natural processes. Performance monitoring would be used to confirm reduction and that COCs remain on-site for extended timeframe.	**Treatment** Reduced at an accelerated rate.	**Treatment** Reduced at an accelerated rate.
Short-Term Effectiveness	**Not effective/No change** No short-term change in the level of risk posed by groundwater contamination would result.	**Not effective/No change** No short-term change in the level of risk posed by groundwater contamination would result.	**Effective/Manageable impacts** Reduced conditions may temporarily mobilize some metals (iron, manganese, arsenic) above background levels, but these are expected to not be very mobile and stabilize over time. Site workers will perform installation of injection points and chemical handling. Health and safety precautions would be required to protect workers and the community during activities. Impacts to the community, workers, and the environment are minimal because treatment is performed in-situ.	**Effective/Manageable impacts** The chemical oxidant and the oxidizing conditions produced may temporarily increase some metals (hexavalent chromium and manganese) above background levels, but these are expected to not be very mobile and are expected to stabilize over time. Site workers will perform installation of injection points and chemical handling. Health and safety precautions would be required to protect workers and the community during activities. The use and handling of oxidizing chemicals require additional health and safety precautions. Impacts to the community, workers, and the environment are minimal because treatment is performed in-situ.
Implementability	**No implementation**	**Straightforward** Performance monitoring and LUCs are easily implemented.	**Moderate** Proven technology. Challenges due to underground obstructions & buildings.	**Moderate** Proven technology. Challenges due to underground obstructions and buildings. Reversing of oxidizing conditions to reducing for ISCO to ERD may pose additional challenges.
Cost	**No cost**	**Capital Cost = $50K** **O&M PV = $434K** **Total Cost = $484K**	**Capital Cost = $3.1M** **O&M PV = $0.8M** **Total Cost = $3.9M**	**Capital Cost = $4.6M** **O&M PV = $0.7M** **Total Cost = $5.3M**

TABLE 5-2
Comparative Analysis of Remedial Alternatives
Site 21 Feasibility Study Report
St. Juliens Creek Annex
Chesapeake, Virginia

Evaluation Criteria	Alternative 1 No Action	Alternative 2 MNA	Alternative 3 ISCR & ERD	Alternative 4 ISCO & ERD
Overall Protection of Human Health and the Environment	1	2	5	5
Compliance with ARARs	1	2	5	5
Long-Term Effectiveness and Permanence	1	2	5	5
Reduction of Toxicity, Mobility, and Volume Through Treatment	1	2	5	5
Short-Term Effectiveness	1	2	4	3
Implementability	5	5	4	3
Cost	5	4	2	1
Total	15	19	30	27

Qualitative comparative analysis of alternatives using a rating scale of 1 through 5 (1 = lowest score, 5 = highest score)

SECTION 6

References

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Appendix A
PRG Calculations

TABLE GW-1
Preliminary Remediation Goals - Groundwater, Adult Residential Scenario
Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical	Chronic Oral RfD (RfDo) (mg/kg-day)	Chronic Dermal RfD (RfDd) (mg/kg-day)	Chronic Inhalation RfD (RfDi) (mg/kg-day)	Target Organ Ing/Inh	DAevent (L/cm^2-day)	Shower Exposure (L/day)	Noncarcinogen Groundwater PRG HQ = 0.1 (mg/L)	HQ = 0.5 (mg/L)	HQ = 1 (mg/L)	Applicable HQ[1] (mg/L)	Applicable PRG (mg/L)
cis-1,2-Dichloroethene	1.0E-02	1.0E-02	NA	Blood	5.6E-06	NA	3.5E-02	1.7E-01	3.5E-01	1	3.5E-01
Trichloroethene	NA	NA	NA	NA	1.1E-05	1.5E+00	NA	NA	NA	NA	NA
Vinyl chloride	3.0E-03	3.0E-03	2.9E-02	Liver	9.8E-09	2.2E+00	9.8E-03	4.9E-02	9.8E-02	1	9.8E-02

Noncarcinogenic calculations:

$$\text{Groundwater RBC (mg/L)} = \frac{THQ \times BW \times AT_{nc}}{EF \times ED \times (An + Bn + Cn)}$$

An = 1/RfDo x IR

Bn = 1/RfDd x SA x DAevent

Cn = 1/RfDi x Shower Exposure

EXPOSURE ASSUMPTIONS	
BW - Body weight (kilograms)	70
ATnc - Averaging time for noncarcinogens (days)	8760
ATc - Averaging time for carcinogens (days)	25,550
EF - Exposure frequency (days/year)	350
ED - Exposure duration (year)	24
IR - Ingestion rate (L/day)	2
SA - Skin surface area (cm^2)	18,000

NA - No reference dose or slope factor available.

TABLE GW-1a
Calculation of DAevent (Adult) -- Groundwater
Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical of Potential Concern	Permeability Constant (Kp) (cm/hr)	Lag Time (τ) (hr)	Duration of Event (tevent) (hr)	t* (hr)	B (dimensionless)	Fraction Absorbed Water FA (dimensionless)	DAevent (L/cm^2-event)	Eq
cis-1,2-Dichloroethene	7.7E-03	3.7E-01	5.8E-01	8.9E-01	2.9E-02	1.0E+00	5.6E-06	2
Trichloroethene	1.2E-02	5.8E-01	5.8E-01	1.4E+00	5.1E-02	1.0E+00	1.1E-05	2
Vinyl chloride	5.6E-03	2.4E-01	5.8E-01	5.7E-01	1.7E-02	1.0E+00	9.8E-09	3

Inorganics:
DAevent (L/cm2-event) =
Kp x tevent x 0.001 L/cm^3 (eq 1)

Organics:

tevent<t*: DAevent (L/cm2-event) =
2 x FA x Kp x (sqrt((6 x τ x tevent)/3.1415)) x 0.001 L/cm^3

tevent>t*: DAevent (L/cm2-event) =
FA x Kp x (t_{event}/(1+B) + 2 x τ_{event} x ((1 + 3xB + 3xB^2)/(1+B)^2) x 0.001 l/cm^3 (eq 3)

TABLE GW-1b
Inhalation Exposure Concentrations from Foster and Chrostowski Shower Model
Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical	Molecular weight (MW) (g/mole)	Henry's Law Constant (H) (atm-m^3/mole)	Kg (VOC) (cm/hr)	Kl(VOC) (cm/hr)	KL (cm/hr)	Kal (cm/hr)	Cwd	S (L/m^3 -min)	Exposure (InExp) (L/kg-shower)	Exposure (InExp X BW) (L/day)
Trichloroethene	131	1.0E-02	1.1E+03	1.2E+01	1.1E+01	1.5E+01	1.2E+02	1.0E+02	2.2E-02	1.5E+00
Vinyl chloride	63	2.7E-02	1.6E+03	1.7E+01	1.7E+01	2.2E+01	1.7E+02	1.4E+02	3.1E-02	2.2E+00

Variables	Units	Exposure Assumptions
Kg(VOC) = gas-film mass transfer coefficient	cm/hr	Solved by Eq 1
Kl(VOC) = liquid-film mass transfer coefficient	cm/hr	Solved by Eq 2
KL = overall mass transfer coefficient	cm/hr	Solved by Eq 3
Kal = adjusted overall mass transfer coeff.	cm/hr	Solved by Eq 4
Tl = Calibration temp. of water	K (20C +273)	293
Ts = Shower water temperature	k (45C)	318
Us = water viscosity at Ts	centipoise	0.596
Ul = water viscosity at Tl	cp	1.002
Cwd = conc. leaving droplets after time sdt		Solved by Eq 5
sdt = shower droplet drop time	sec	0.5
d = shower droplet diameter	mm	1
FR = shower water flow rate	l/min	10
SV = shower room air volume	m^3	12
S = indoor VOC generation rate	L/m^3-min	Solved by Eq 6
VR = ventilation rate	l/min	13.8
BW = body weight	kg	70
Ds = duration of shower	min	30
Dt = total duration in shower room	min	60
R = air exchange rate	min^{-1}	0.0083
Ca = indoor air concentration of VOCs	L-ug/mg-m^3	Solved by Eq 7
Einh = inhalation exposure per shower	L/kg-shower	Solved by Eq 8

Equation 1:	Kg(VOC) =	$3000 * (18 / MW)^{0.5}$
Equation 2:	Kl(VOC) =	$20 * (44 / MW)^{0.5}$
Equation 3:	KL =	$((1 / Kl(VOC)) + (0.024 / (Kg (VOC) * H)))^{-1}$
Equation 4:	Kal =	$(KL * (((Tl * Us) / (Ts * Ul))^{-0.5}))$
Equation 5:	Cwd =	((1-EXP((-1 * Kal * sdt)/(60 * d))))
Equation 6:	S =	(Cwd * FR / SV)
Equation 7:	see time series example on Table I-GW-6	
Equation 8:	Einh =	If t>Ds (((VR * S) / (BW * R * 1000000)) * ((Ds + (EXP(-R * Dt) / R)-(EXP(R * (Ds - Dt))) / R)))

TABLE GW-2
Preliminary Remediation Goals - Groundwater, Child Residential Scenario
Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical	Chronic Oral RfD (RfDo) (mg/kg-day)	Chronic Dermal RfD (RfDd) (mg/kg-day)	Target Organ Ing	DAevent (L/cm^2-day)	An (kg-L/mg)	Bn (kg-L/mg)	Noncarcinogen Groundwater PRG HQ = 0.1 (mg/L)	Noncarcinogen Groundwater PRG HQ = 0.5 (mg/L)	Noncarcinogen Groundwater PRG HQ = 1 (mg/L)	Applicable HQ[1] (mg/L)	Applicable PRG (mg/L)
cis-1,2-Dichloroethene	1.0E-02	1.0E-02	Blood	2.3E-08	1.0E+02	1.5E-02	1.6E-02	7.8E-02	1.6E-01	1	1.6E-01
Trichloroethene	NA	NA	NA	1.4E-05			NA	NA	NA	NA	NA
Vinyl chloride	3.0E-03	3.0E-03	Liver	1.7E-08	3.3E+02	3.7E-02	4.7E-03	2.3E-02	4.7E-02	1	4.7E-02

Noncarcinogenic calculations:

$$\text{Groundwater RBC (mg/L)} = \frac{THQ \times BW \times AT_{nc}}{EF \times ED \times (An + Bn)}$$

An = 1/RfDo x IR

Bn = 1/RfDd x SA x DAevent

EXPOSURE ASSUMPTIONS	
BW - Body weight (kilograms)	15
ATnc - Averaging time for noncarcinogens (days)	2190
ATc - Averaging time for carcinogens (days)	25,550
EF - Exposure frequency (days/year)	350
ED - Exposure duration (year)	6
IR - Ingestion rate (L/day)	1
SA - Skin surface area (cm^2)	6,600

NA - No reference dose or slope factor available.

TABLE GW-2a
Calculation of DAevent (Child) --Groundwater
Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical of Potential Concern	Permeability Constant (Kp) (cm/hr)	Lag Time (τ) (hr)	Duration of Event (tevent) (hr)	t* (hr)	B (dimensionless)	Fraction Absorbed Water FA (dimensionless)	DAevent (L/cm^2-event)	Eq
cis-1,2-Dichloroethene	7.7E-03	3.7E-01	1.0E+00	8.9E-01	2.9E-02	1.0E+00	2.3E-08	3
Trichloroethene	1.2E-02	5.8E-01	1.0E+00	1.4E+00	5.1E-02	1.0E+00	1.4E-05	2
Vinyl chloride	5.6E-03	2.4E-01	1.0E+00	5.7E-01	1.7E-02	1.0E+00	1.7E-08	3

Inorganics:
DAevent (L/cm2-event) =
Kp x tevent x 0.001 L/cm^3 (eq 1)

Organics:

tevent<t*: DAevent (L/cm2-event) =
2 x FA x Kp x (sqrt((6 x τ x tevent)/3.1415)) x 0.001 L/cm^3

tevent>t*: DAevent (L/cm2-event) =
FA x Kp x ($t_{event}/(1+B) + 2 \times \tau_{event} \times ((1 + 3xB + 3xB^2)/(1+B)^2)$) x 0.001 l/cm^3 (eq 3)

TABLE GW-3
Preliminary Remediation Goals - Groundwater, Lifetime Residential Scenario
Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical	Oral Slope Factor (CSFo) (kg-day/mg)	Dermal Slope Factor (CSFd) (kg-day/mg)	Inhalation Slope Factor (CSFi) (kg-day/mg)	DAevent-a (L/cm^2-day)	DAevent-c (L/cm^2-day)	Shower Exposure (L/day)	Carcinogen Ingestion PRG		
							Risk = 1E-06 (mg/L)	Risk = 1E-05 (mg/L)	Risk = 1E-04 (mg/L)
cis-1,2-Dichloroethene	NA	NA	NA	5.6E-06	2.3E-08	NA	NA	NA	NA
Trichloroethene	1.3E-02	1.3E-02	7.0E-03	1.1E-05	1.4E-05	1.5E+00	4.7E-03	4.7E-02	4.7E-01
Vinyl chloride	1.4E+00	1.4E+00	3.1E-02	9.8E-09	1.7E-08	2.2E+00	4.8E-05	4.8E-04	4.8E-03

Carcinogen calculations:

Groundwater RBC = (mg/L)

$$\frac{TR \times AT_c}{EF \times (Ac + Bc + Cc)}$$

Ac = CSFo x IRadj

Bc = CSFd x [(SAa x DAevent-a x EDa)/BWa + (SAc x DAevent-c X EDc)/BWc]

Cc = CSFi x Shower Exposure x EDa x 1/BWa

EXPOSURE ASSUMPTIONS	Lifetime	Adult (a)	Child (c)
BW - Body weight (kilograms)		70	15
ATc - Averaging time for carcinogens (days)		25,550	25,550
EF - Exposure frequency (days/year)		350	350
ED - Exposure duration (year)		24	6
IR - Ingestion rate (L/day)		2	1
IRdj - Ingestion rate (L-year/kg-day)	1.09		
SA - Skin surface area (cm^2)		18,000	6,600
ET - Exposure Time (hours/day)		0.58	1.00

TABLE GW-4
Recommended Risk-Based Preliminary Remediation Goals - Groundwater
Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical	Recommended Risk-Based Groundwater PRG (ug/L)	Basis
cis-1,2-Dichloroethene	1.6E+02	Child, HQ = 1
Trichloroethene	4.7E+01	Lifetime, CR = 10^{-5}
Vinyl chloride	4.8E-01	Lifetime, CR = 10^{-5}

Notes:
1. For constituents with basis of CR = 10^{-5}, PRG for CR =10^{-5} less than PRG for applicable HQ.
2. Used CR of 10^{-5} to keep overall carcinogenic risk below 10^{-4}.
3. Applicable HQ chosen to keep total HI for each target organ equal to or less than 1.
4. Based on above PRGs, total CR would be $2x10^{-5}$.
5. Based on above PRGs, HIs for individual target organs would be 1 or below.

TABLE GW-5

Risk-Based Preliminary Remediation Goals and MCLs - Groundwater

Site 21, St Juliens Creek Annex, Chesapeake, Virginia

Chemical	Recommended Risk-Based Groundwater PRG (ug/L)	Basis	MCL (ug/L)	Risk Level of MCL	Hazard Level of MCL
cis-1,2-Dichloroethene	1.6E+02	Child, HQ = 1	7.0E+01		4.5E-01
Trichloroethene	4.7E+01	Lifetime, CR = 10^{-5}	5.0E+00	1.1E-06	
Vinyl chloride	4.8E-01	Lifetime, CR = 10^{-5}	2.0E+00	4.2E-05	
1,1-Dichloroethene	NA		7.0E+00	2.1E-07	
Total Risk	2.0E-06	2.0E-05		4.3E-05	

Notes:

1. For constituents with basis of CR = 10^{-5}, PRG for CR =10^{-5} less than PRG for applicable HQ.
2. Used CR of 10^{-5} to keep overall carcinogenic risk below 10^{-4}.
3. Applicable HQ chosen to keep total HI for each target organ equal to or less than 1.
4. NA - not applicable since 1,1-dichloroethene not a COC based on the HHRA.

Appendix B
ARARs and TBCs

Table B-1
Federal Chemical-Specific ARARs and TBCs
Site 21 Feasibility Study
St. Juliens Creek Annex
Chesapeake, Virginia

Media	Requirement	Prerequisite	Citation	Alternative	ARAR Determination	Comment
Safe Drinking Water Act						
Groundwater	SDWA standards serve to protect public water systems. Primary drinking water standards consist of federally enforceable MCLs. MCLs are the highest level of a contaminant that is allowed in drinking water.	Impact to public water systems that have at least 15 service connections or serve at least 25 year-round residents. May also be cleanup standards for on-site ground or surface waters that are current or potential sources of drinking water.	40 CFR 141.11 to 141.16 and 141.61 to 141.66	2,3,4	Applicable	These remedial actions are being implemented with a target goal of achieving MCLs. However, the aquifer is not currently, nor reasonably anticipated in the future to be used as a potable water supply.
Groundwater	SDWA standards serve to protect public water systems. The MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.	Impact to public water systems that have at least 15 service connections or serve at least 25 year-round residents. May also be cleanup standards for on-site ground or surface waters that are current or potential sources of drinking water.	40 CFR 141.50 to 141.55	2,3,4	TBC	MCLGs are non-enforceable standards. These remedial actions are being implemented with a target goal of achieving MCLs. The aquifer is not currently, nor reasonably anticipated in the future to be used as a potable water supply.
Groundwater	National Secondary Drinking Water Regulations (NSDWRs or secondary standards) are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water.	Impact to public water systems that have at least 15 service connections or serve at least 25 year-round residents. May also be cleanup standards for on-site ground or surface waters that are current or potential sources of drinking water.	40 CFR 143	2,3,4	TBC	NSDWRs are non-enforceable standards. These remedial actions are being implemented with a target goal of achieving MCLs. The aquifer is not currently, nor reasonably anticipated in the future to be used as a potable water supply.

Notes:
Alternative 2 - MNA
Alternative 3 - ISCR and ERD
Alternative 4 - ISCO and ERD

Table B-2
Virginia Chemical-Specific ARARs and TBCs
Site 21 Feasibility Study
St. Juliens Creek Annex
Chesapeake, Virginia

Media	Requirement	Prerequisite	Citation	Alternative	ARAR Determination	Comment
***Environmental Health Services* [VA Code Ann. §§ 32.1-163 to 248.2]**						
Groundwater	Ensures that all water supplies destined for public consumption be pure water. Cleanup levels for potential drinking water sources must be based on PMCLs. In the absence of PMCLs, other health-based standards or criteria, or best professional judgment based on risk assessment, may be employed. Where groundwater that is a potential drinking water source discharges to surface water, the cleanup level at the discharge point would be the more stringent of either the PMCL or a discharge limit based on the *Water Quality Standards* .	Potential drinking water source.	*Waterworks Regulations* , 12 VAC 5-590-10 to 1280	2,3,4	Relevant and Appropriate	The aquifer is not currently, nor reasonably anticipated in the future to be used as a potable water supply. These remedial actions are being implemented with a target goal of achieving MCLs.
Groundwater	SMCLs are guidelines pertaining to aesthetic qualities of drinking water (i.e., color, odor, and taste).	Potential drinking water source.	*Waterworks Regulations* , 12 VAC 5-590-10 to 1280	2,3,4	TBC	SMCLs are non-enforceable guidelines. The aquifer is not currently, nor reasonably anticipated in the future to be used as a potable water supply. The remedial actions are being implemented with a target goal of achieving MCLs.
***Virginia Waste Management Act* [VA Code Ann. §§ 10.1-1400 to 1457 (2004)]**						
Waste/Soil/Water	Wastes to be managed must be sampled for TCLP analyses to determine the appropriate waste characterization. TCLP regulatory levels and definition of RCRA hazardous waste.	Management of wastes.	*Hazardous Waste Regulations,* 9 VAC 20-60-261.3	2,3,4	Applicable	These remedial actions will generate water and soil IDW which will be characterized for off site disposal. Based on site history, some IDW may be characterized as hazardous waste. If characterization results indicate this material is hazardous, it will be disposed of accordingly.
Waste/Soil/Water	Hazardous wastes shall not be disposed or managed in solid waste disposal facilities.	Management of solid waste.	*Solid Waste Management Regulations,* 9 VAC 20-80-240 (c)	2,3,4	Applicable	These remedial actions will generate water and soil IDW which will be characterized for off site disposal. Based on site history, some IDW may be characterized as hazardous waste. If characterization results indicate this material is hazardous, it will be disposed of accordingly.

Notes:
Alternative 2 - MNA
Alternative 3 - ISCR and ERD
Alternative 4 - ISCO and ERD

Table B-3
Federal Location-Specific ARARs and TBCs
Site 21 Feasibility Study
St. Juliens Creek Annex
Chesapeake, Virginia

Location	Requirement	Prerequisite	Citation	Alternative	ARAR Determination	Comment
Coastal Zone Management Act						
Coastal zone or area that will affect the coastal zone	Federal activities must be consistent with, to the area that will affect maximum extent practicable, State coastal zone management programs. Federal agencies must supply the State with a consistency determination.	Wetland, flood plain, estuary, beach, dune, barrier island, coral reef, and fish and wildlife and their habitat, within the coastal zone.	*Coastal Zone Management Act* , 16 USC 1451 et. seq.; 15 CFR 930.30; 15 CFR 930.34	2,3,4	TBC	Site 21 is excluded from the coastal zone as lands held in trust by the Federal Government are exempt.
Fish and Wildlife Coordination Act						
Floodplain	Action to avoid adverse effects, minimize potential harm, restore and preserve natural and beneficial values.	Action that will occur in a floodplain, i.e., lowlands, and relatively flat areas adjoining inland and coastal waters and other flood prone areas.	*Fish and Wildlife Coordination Act* , 16 USC 661 et. seq.; Executive Order 11988; 40 CFR 6, Appendix A; 40 CFR 6.302	2,3,4	Applicable	These remedial actions do not involve actions that will cause adverse affects to lowlands and coastal areas.
Area affecting stream or river	Requires that activities avoid, minimize, or compensate for impacts to fish and wildlife and their habitats.	Diversion, channeling or other activity that modifies a stream or river and affects fish or wildlife and their habitat.	*Fish and Wildlife Coordination Act,* 16 USC 661 et. seq.; 40 CFR 6.302	2,3,4	Not Applicable	Surface water is not present within Site 21. A surface water body is adjacent to Site 21; however, these remedial actions are not expected to impact that wetland.
Migratory Bird Treaty Act						
Migratory bird area	Protects almost all species of native birds in the United States from unregulated taking which can include poisoning at hazardous waste sites.	Presence of migratory birds.	*Migratory Bird Treaty Act* , 16 USC 703	2,3,4	Applicable	St. Juliens Creek Annex is located in the Atlantic Migratory Flyway.
Federal Executive Order 11900 (Floodplain Mgmt and Wetlands Mgmt)						
Federal Executive Order 11900 (Floodplain Mgmt and Wetlands Mgmt)	Protects wetlands and floodplains to avoid long and short term adverse impacts.	Applies to actions that are conducted in wetland and floodplain areas.	Federal Executive Order 11900 (Floodplain Mgmt and Wetlands Mgmt, 40 CFR Part 6 Appendix A	2,3,4	Applicable	A wetland is not present within Site 21. These remedial actions do not involve actions that will cause adverse affects to floodplain areas.

Notes:
Alternative 2 - MNA
Alternative 3 - ISCR and ERD
Alternative 4 - ISCO and ERD

Table B-4
Virginia Location-Specific ARARs and TBCs
Site 21 Feasibility Study
St. Juliens Creek Annex
Chesapeake, Virginia

Location	Requirement	Prerequisite	Citation	Alternative	ARAR Determination	Comment
***Chesapeake Bay Preservation Act* [VA Code Ann. §§ 10.1-2100 to 2116]**						
Chesapeake Bay and its tributaries	Criteria that provide for the protection of water quality of the Chesapeake Bay and its tributaries, that will also accommodate economic development in Tidewater Virginia. Under these requirements, certain locally designated tidal and nontidal wetlands, as well as other sensitive land areas, may be subject to limitations regarding land-disturbing activities, removal of vegetation, use of impervious cover, erosion and sediment control, storm water management, and other aspects of land use that may have effects on water quality.	Location is within a Chesapeake Bay Preservation Area.	*Chesapeake Bay Preservation Area Designation and Management Regulations* , 9 VAC 10-20-10 to 260	2,3,4	Applicable	Site 21 is located within the Chesapeake Bay watershed. However, these remedial actions will not involve or effect tributaries of the Chesapeake Bay.
***Groundwater Management Act of 1992* [VA Code Ann. §§ 62.1-254 to 62.1-279]**						
Groundwater management area	Regulates groundwater withdrawals in Ground Water Management Areas. Any person or entity wishing to withdraw 300,000 gallons per month or more in a declared management area must obtain a permit.	Location is in a Groundwater Management Area. Currently (June 2005), there are two Ground Water Management Areas in the state. The Eastern Virginia Ground Water Management Area comprises an area east of Interstate 95 and south of the Mattaponi and York rivers. The Eastern Shore Ground Water Management Area includes Accomack and Northampton counties.	*Groundwater Management Act of 1992,* VA Code Ann. §§ 62.1-254 to 62.1-270	2,3,4	Relevant and Appropriate	St. Juliens Creek Annex is located within a Groundwater Management Area. Excess of 300,000 gallons of groundwater per month will not been withdrawn; therefore, a permit is not necessary.

Notes:
Alternative 2 - MNA
Alternative 3 - ISCR and ERD
Alternative 4 - ISCO and ERD

Table B-5
Federal Action-Specific ARARs and TBCs
Site 21 Feasibility Study
St. Juliens Creek Annex
Chesapeake, Virginia

Action	Requirement	Prerequisite	Citation	Alternative	ARAR Determination	Comment
Safe Drinking Water Act						
Underground injection	Regulates the subsurface emplacement of liquids through the Underground Injection Control program, which governs the design and operation of five classes of injection wells in order to prevent contamination of underground sources of drinking water. The Underground Injection Control program regulates well construction, well operation, and monitoring.	Any dug hole or well that is deeper than it's largest surface dimension, where the principal function of the hole is in placement of fluids.	40 CFR 144.1G1, 144.3, 144.6, 144.11, 144.12a, 144.24a, 144.80e, 144.82, 144.83	3,4	Applicable	These remedial actions will include substrate injections. Permits are not applicable to on-site CERCLA injection wells; however, these remedial actions will comply with the substantive requirements o the regulation.
				2	Not Applicable	These remedial actions will not include substrate injections.

Notes:
Alternative 2 - MNA
Alternative 3 - ISCR and ERD
Alternative 4 - ISCO and ERD

Table B-6
Virginia Action-Specific ARARs and TBCs
Site 21 Feasibility Study
St. Juliens Creek Annex
Chesapeake, Virginia

Action	Requirement	Prerequisite	Citation	Alternative	ARAR Determination	Comment
***Virginia Waste Management Act* [VA Code Ann. §§ 10.1-1400 to 1457 (2004)]**						
Handling, storage, treatment, disposal, and/or transportation of hazardous waste IDW	Provides for the control of all hazardous wastes that are generated within, or transported to, the Commonwealth for the purposes of storage, treatment, or disposal or for the purposes of resource conservation or recovery. Any disposal facility must be properly permitted and in compliance with all operational and monitoring requirements of the permit and regulations.	Management of wastes that meet the definition of hazardous waste.	*Hazardous Waste Regulations*, 9 VAC 20-60-261.3, 262,263 Regulations Governing the Transportation of Hazardous Materials, 9 VAC 20-110-10 to 130	2,3,4	Applicable	These remedial actions will generate water and soi IDW which will be characterized for off site disposal. Based on site history, some IDW may be characterized as hazardous waste. If characterization results indicate this material is hazardous, it will be disposed of accordingly.
Handling, storage, treatment, disposal, and/or transportation of solid waste IDW	Establishes standards and procedures pertaining to the management of solid wastes, and siting, design construction, operation, maintenance, closure, and post-closure care of solid waste management facilities in this Commonwealth in order to protect the public health, public safety, the environment, an natural resources. Provides the means for identification of open dumping of solid waste and provides the means for prevention or elimination of open dumping of solid waste to protect the public health and safety and enhance the environment. Sets forth the requirements for undertaking corrective actions at solid waste management facilities. Any disposal facility must be properly permitted and in compliance with all operational and monitoring requirements of the permit and regulations.	Management of wastes that meet the definition of solid waste.	*Solid Waste Management Regulations*, 9 VAC 20-80-140 to 170	2,3,4	Applicable	These remedial actions will generate water and soi IDW which will be characterized for off site disposal.

Table B-7
Acronyms and Abbreviations
Site 21 Feasibility Study
St. Juliens Creek Annex
Chesapeake, Virginia

ARAR	Applicable or relevant and appropriate requirement
BTAG	Biological Technical Assistance Group
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
DCR	Virginia Department of Conservation and Recreation
DNH	Division of Natural Heritage
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
NAAQS	National Ambient Air Quality Standards
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NSDWRs	National Secondary Drinking Water Regulations
NSPS	New Source Performance Standards
OSWER	Office of Solid Waste and Emergency Response
PCB	Polychlorinated biphenyls
PMCL	Primary Maximum Contaminant Level
POTW	Publicly Owned Treatment Works
ppm	Parts per Million
RBC	Risk-Based Concentrations
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
SMCL	Secondary Maximum Contaminant Level
TCLP	Toxicity Characteristic Leaching Procedure
TSCA	Toxic Substance Control Act
UIC	Underground Injection Control
USACE	US Army Corps of Engineers
USC	United States Code
USEPA	United States Environmental Protection Agency
VAC	Virginia Administrative Code
VMRC	Virginia Marine Resource Commission
VPA	Virginia Pollutant Abatement
VPDES	Virginia Pollutant Discharge Elimination System

Notes:
Listing the statutes, policies, and citations for the ARARs does not indicate that the Navy accepts the entire statues or policies as potential ARARs; only substantive requirements of the specific citations are considered potential ARARs.

References

Commonwealth of Virginia, 2004. Preliminary Identification, Applicable or Relevant and Appropriate Requirements.

USEPA, 1998. *CERCLA Compliance with Other Laws Manual: Interim Final* . Office of Emergency and Remedial Response. EPA/540/G-89/006.

USEPA, 1998. *CERCLA Compliance with Other Laws Manual: Part II. Clean Air Act and Other Environmental Statutes.* Office of Emergency and Remedial Response. EPA/540/G-89/009.

USEPA, 1998. RCRA, Superfund & EPCRA Hotline Training Manual. Introduction to Applicable or Relevant and Appropriate Requirements. EPA540-R-98-020.

Appendix C
Cost Estimates

APPENDIX C

Final Cost Estimates[1]

St. Juliens Creek Annex Site 21

Remedial Alternative	Design Criteria	
1 - No Action		
2 - Monitored Natural Atten. (MNA)	Monitor wells in sampling program	15
	New monitor wells	5
	O&M time frame	30 yr
Includes:	APR	4.9%
Land Use Controls		
Semiann. GW Monitoring (yrs 1-5)		
Annual GW Monitoring (yrs 6-30)		

Capital Costs

Remedial Alternative	Description	Specifications	Rate	Source	Qty	Cost	
1 - No Action	There are no capital costs associated with this alternative						
2 - MNA	1) Install New Monitor Wells						**$ 33,325**
	a) Monitoring plan	Lump sum	$ 12,000	2	1	$ 12,000	
	b) Mobilize Equipment	Lump sum	$ 950	4	1	$ 950	
	c) Well components	2", 20 ft deep PVC well	$ 2,000	1	5	$ 10,000	
	d) Vaults, bollards, etc.	per well	$ 450	4	5	$ 2,250	
	e) Well development	per well	$ 325	1	5	$ 1,625	
	f) Disposal of generated wastes	per well	$ 1,000	1	5	$ 5,000	
	g) Surveying	Lump sum	$ 1,500	1	1	$ 1,500	
	2) Engineering Services						**$ 10,331**
	a) Design	6% Capital costs	6%	2	$ 33,325	$ 2,000	
	b) Construction Management	15% Capital costs	15%	2	$ 33,325	$ 4,999	
	c) Project Management	10% Capital costs	10%	2	$ 33,325	$ 3,333	
						Subtotal Capital Cost $	43,656
						Contingency @ 15% $	6,548
						Total Capital Cost $	**50,204**

Operation and Maintenance Costs

Remedial Alternative	Description	Specifications	Rate	Source	Qty	Cost/yr	O&M PV	
1 - No Action	There are no operations and maintenance costs associated with this alternative							
							Total O&M PV $	**-**
						Total Cost $	**-**	
						30% Below $	-	
						50% Above $	-	
2 - MNA	1) Semiannual Groundwater Monitoring (Years 1-5)							**$ 155,425**
	a) Fieldwork	2 hr/well, 2 field techs	$ 4,500	2	10	$ 9,000	$ 39,073	
	b) Equipment	Field equipment and vehicles	$ 1,000	2	10	$ 2,000	$ 8,683	
	c) Analytical	$550 ea.	$ 8,250	4	10	$ 16,500	$ 71,634	
	d) Reporting	40 hr mid level eng,10 hr sr. support	$ 4,150	2	10	$ 8,300	$ 36,034	
	2) Annual Groundwater Monitoring (Years 6-30)							**$ 200,619**
	a) Fieldwork	2 hr/well, 2 field techs	$ 4,500	2	25	$ 4,500	$ 50,435	
	b) Equipment	Field equipment and vehicles	$ 1,000	2	25	$ 1,000	$ 11,208	
	c) Analytical	$550 ea.	$ 8,250	4	25	$ 8,250	$ 92,464	
	d) Reporting	40 hr mid level eng,10 hr sr. support	$ 4,150	2	25	$ 4,150	$ 46,512	
	3) Land Use Controls							**$ 21,458**
	a) Site notif., sign maint., site insp.		$ 1,380	2	30	$ 1,380	$ 21,458	
							Subtotal O&M PV $	377,502
							Contingency @ 15% $	56,625
							Total O&M PV $	**434,127**
						Total Cost $	**484,331**	
						30% Below $	339,032	
						50% Above $	726,497	

APPENDIX C
Final Cost Estimates[1]
St. Juliens Creek Annex Site 21

Remedial Alternative	Design Criteria		
3 - ISCR for high-conc. areas	Saturated zone thickness	12	ft
followed by	Injection zone thickness (8-17 ft bgs)	9	ft
ERD for low-conc. areas	Effective treatment thickness factor [2]	0.25	
	Effective porosity	0.25	
Includes:	Saturated zone soil dry bulk density	1.5	ton/cy
Permitting	High-conc. zone target area	36,600	sf
ZVI inj. through DPT well points	Low-conc. zone target area	294,300	sf
EVO inj. through DPT well points	High-conc. zone target soil vol	12,200	cy
	Low-conc. zone target soil vol	98,100	cy
Land Use Controls	High-conc. zone target soil mass	18,300	ton
Quarterly GW Monitoring (yrs 1-5)	Low-conc. zone target soil mass	147,200	ton
Annual GW Monitoring (yrs 6-30)	High-conc. zone target pore vol	3,100	cy
	Low-conc. zone target pore vol	24,500	cy
	ZVI inj. radius	5.4	ft
	ZVI coverage factor [3]	1	
	Number of ZVI inj. points	400	
	ZVI mass dose	0.5%	
	Total ZVI requirement	183,000	lb
	ZVI inj. per well	458	lb
	EVO inj. radius	6.5	ft
	EVO coverage factor [3]	0.25	
	Number of EVO inj. points	554	
	EVO mass dose	0.125%	
	Total EVO requirement	122,625	lb
	EVO inj. per well	221	lb
	Monitor wells in sampling program	15	
	New monitor wells	5	
	O&M time frame	30	yr
	APR	4.9%	

Capital Costs

Description	Specifications	Rate	Source	Qty	Cost	
1) Preparation						**$ 22,000**
a) Pre-construction planning and preparation	Lump sum	$ 22,000	2	1	$ 22,000	
2) Install New Monitor Wells						**$ 33,325**
a) Monitoring plan	Lump sum	$ 12,000	2	1	$ 12,000	
b) Mobilize Equipment	Lump sum	$ 950	4	1	$ 950	
c) Well components	2", 20 ft deep PVC well	$ 2,000	1	5	$ 10,000	
d) Vaults, bollards, etc.	per well	$ 450	4	5	$ 2,250	
e) Well development	per well	$ 325	1	5	$ 1,625	
f) Disposal of generated wastes	per well	$ 1,000	2	5	$ 5,000	
g) Surveying	Lump sum	$ 1,500	1	1	$ 1,500	
3) Perform ZVI Injections in High-Concentration Target Zones						**$ 1,270,591**
a) Mob/demob equipment and personnel	Lump sum	$ 9,400	5	1	$ 9,400	
b) Planning by subcontractor	Lump sum	$ 25,000	5	1	$ 25,000	
c) ZVI materials (including shipping)	per pound	$ 0.85	7	183,000	$ 155,550	
d) DPT well point installation and injection	per well	$ 2,290	5	400	$ 914,912	
e) Royalties	15% Capital costs	$ 165,729	5	1	$ 165,729	
4) Perform EVO Injections in Low-Concentration Target Zone						**$ 979,671**
a) Mob/demob equipment and personnel	Lump sum	$ 50,200	8	1	$ 50,200	
b) Planning by subcontractor	Lump sum	$ 21,400	8	1	$ 21,400	
b) EVO materials (including shipping)	per pound	$ 1.80	6	122,625	$ 220,725	
c) DPT well point installation and injection	per well	$ 1,240	8	554	$ 687,346	
5) Completion						**$ 10,000**
a) Site cleanup and restoration	Lump sum	$ 10,000	3	1	$ 10,000	
6) Engineering Services						**$ 393,650**
a) Design	6% Capital costs	6%	2	$2,315,587	$ 138,935	
b) Construction Management	6% Capital costs	6%	2	$2,315,587	$ 138,935	
c) Project Management	5% Capital costs	5%	2	$2,315,587	$ 115,779	
					Subtotal Capital Cost	$ 2,709,237
					Contingency @ 15%	$ 406,385
					Total Capital Cost	**$ 3,115,622**

Operation and Maintenance Costs

Description	Specifications	Rate	Source	Qty	Cost/yr	O&M PV	
1) Quarterly Groundwater Monitoring (Years 1-5)							**$ 425,030**
a) Fieldwork	2 hr/well, 2 field techs	$ 4,500	2	20	$ 18,000	$ 78,146	
b) Equipment	Field equipment and vehicles	$ 1,000	2	20	$ 4,000	$ 17,366	
c) Analytical	$850 ea.	$12,750	4	20	$ 51,000	$ 221,415	
d) Reporting & effectiveness assess.	60 hr mid level eng + 15 sr. support	$ 6,225	2	20	$ 24,900	$ 108,103	
2) Annual Groundwater Monitoring (Years 6-30)							**$ 223,875**
a) Fieldwork	2 hr/well, 2 field techs	$ 4,500	2	25	$ 4,500	$ 50,435	
b) Equipment	Field equipment and vehicles	$ 1,000	2	25	$ 1,000	$ 11,208	
c) Analytical	$550 ea.	$ 8,250	4	25	$ 8,250	$ 92,464	
d) Reporting & effectiveness assess.	60 hr mid level eng + 15 sr. support	$ 6,225	2	25	$ 6,225	$ 69,768	
3) Land Use Controls							**$ 21,458**
a) Site notif., sign maint., site insp.	Lump sum	$ 1,380	2	30	$ 1,380	$ 21,458	
						Subtotal O&M PV	$ 670,363
						Contingency @ 15%	$ 100,554
						Total O&M PV	**$ 770,918**

Total Cost	**$ 3,886,540**
30% Below	$ 2,720,578
50% Above	$ 5,829,810

APPENDIX C

Final Cost Estimates[1]

St. Juliens Creek Annex Site 21

Remedial Alternative	Design Criteria		
4 - ISCO for high-conc. areas	Saturated zone thickness	12	ft
followed by	Injection zone thickness	12	ft
ERD for low-conc. areas	Effective treatment thickness factor [2]	0.25	
	Effective porosity	0.25	
Includes:	Saturated zone soil dry bulk density	1.5	ton/cy
Permitting	High-conc. zone target area	36,600	sf
$NaMnO_4$ inj. through DPT well point	Low-conc. zone target area	294,300	sf
EVO inj. through DPT well points	High-conc. zone target soil vol	16,300	cy
	Low-conc. zone target soil vol	130,800	cy
Land Use Controls	High-conc. zone target soil mass	24,500	ton
Quarterly GW Monitoring (yrs 1-5)	Low-conc. zone target soil mass	196,200	ton
Annual GW Monitoring (yrs 6-30)	High-conc. zone target pore vol	4,100	cy
	Low-conc. zone target pore vol	32,700	cy
	$NaMnO_4$ inj. radius	6.5	ft
	EVO coverage factor [3]	1	
	Number of $NaMnO_4$ inj. points	276	
	$NaMnO_4$ mass dose	2.7	g/kg
	Total $NaMnO_4$ req. (40% pure)	330,052	lb
	NaMnO4 inj. per well	1,197	lb
	Total inj. vol. req. (6% solution)	619,260	gal
	inj. vol. per well (6% solution)	2,246	gal
	EVO inj. radius	6.5	ft
	EVO coverage factor [3]	0.25	
	Number of EVO inj. points	554	
	EVO mass dose	0.125%	
	Total EVO requirement	122,625	lb
	EVO inj. per well	221	lb
	Monitor wells in sampling program	15	
	New monitor wells	5	
	O&M time frame	30	yr
	APR	4.9%	

Capital Costs

Description	*Specifications*	*Rate*	*Source*	*Qty*	*Cost*	
1) Preparation						**$ 22,000**
a) Pre-construction planning and preparation	Lump sum	$ 22,000	2	1	$ 22,000	
2) Install New Monitor Wells						**$ 33,325**
a) Monitoring plan	Lump sum	$ 12,000	2	1	$ 12,000	
b) Mobilize Equipment	Lump sum	$ 950	4	1	$ 950	
c) Well components	2", 20 ft deep PVC well	$ 2,000	1	5	$ 10,000	
d) Vaults, bollards, etc.	per well	$ 450	4	5	$ 2,250	
e) Well development	per well	$ 325	1	5	$ 1,625	
f) Disposal of generated wastes	per well	$ 1,000	2	5	$ 5,000	
g) Surveying	Lump sum	$ 1,500	1	1	$ 1,500	
3) Perform $NaMnO_4$ Injections in High-Concentration Target Zones						**$ 1,422,038**
a) Mob/demob equipment and personnel	Lump sum	$ 7,600	5	1	$ 7,600	
b) Planning by subcontractor	Lump sum	$ 17,000	5	1	$ 17,000	
c) $NaMnO_4$ materials (including shipping and blendin	per pound	$ 3.17	7	330,052	$1,046,266	
d) DPT well point installation and injection	per well	$ 1,274	5	276	$ 351,173	
4) Perform EVO Injections in Low-Concentration Target Zone (Round 1)						**$ 979,671**
a) Mob/demob equipment and personnel	Lump sum	$ 50,200	8	1	$ 50,200	
b) Planning by subcontractor	Lump sum	$ 21,400	8	1	$ 21,400	
c) EVO materials (including shipping)	per pound	$ 1.80	6	122,625	$ 220,725	
d) DPT well point installation and injection	per well	$ 1,240	8	554	$ 687,346	
5) Perform EVO Injections in Low-Concentration Target Zone (Round 2)						**$ 979,671**
a) Mob/demob equipment and personnel	Lump sum	$ 50,200	8	1	$ 50,200	
b) Planning by subcontractor	Lump sum	$ 21,400	8	1	$ 21,400	
c) EVO materials (including shipping)	per pound	$ 1.80	6	122,625	$ 220,725	
d) DPT well point installation and injection	per well	$ 1,240	8	554	$ 687,346	
6) Completion						**$ 10,000**
a) Site cleanup and restoration	Lump sum	$ 10,000	3	1	$ 10,000	
7) Engineering Services						**$ 585,940**
a) Design	5% Capital costs	6%	2	$3,446,705	$ 206,802	
b) Construction Management	10% Capital costs	6%	2	$3,446,705	$ 206,802	
c) Project Management	10% Capital costs	5%	2	$3,446,705	$ 172,335	
					Subtotal Capital Cost	$ 4,032,645
					Contingency @ 15%	$ 604,897
					Total Capital Cost	**$ 4,637,541**

Operation and Maintenance Costs

Description	*Specifications*	*Rate*	*Source*	*Qty*	*Cost/yr*	*O&M PV*	
1) Quarterly Groundwater Monitoring (Years 1-5)							**$ 359,908**
a) Fieldwork	2 hr/well, 2 field techs	$ 4,500	2	20	$ 18,000	$ 78,146	
b) Equipment	Field equipment and vehicles	$ 1,000	2	20	$ 4,000	$ 17,366	
c) Analytical	$600 ea.	$ 9,000	4	20	$ 36,000	$ 156,293	
d) Reporting & effectiveness assess.	60 hr mid level eng + 15 sr. support	$ 6,225	2	20	$ 24,900	$ 108,103	
2) Annual Groundwater Monitoring (Years 6-30)							**$ 232,281**
a) Fieldwork	2 hr/well, 2 field techs	$ 4,500	2	25	$ 4,500	$ 50,435	
b) Equipment	Field equipment and vehicles	$ 1,000	2	25	$ 1,000	$ 11,208	
c) Analytical	$600 ea.	$ 9,000	4	25	$ 9,000	$ 100,870	
d) Reporting & effectiveness assess.	60 hr mid level eng + 15 sr. support	$ 6,225	2	25	$ 6,225	$ 69,768	
3) Land Use Controls							**$ 21,458**
a) Site notif., sign maint., site insp.	Lump sum	$ 1,380	2	30	$ 1,380	$ 21,458	
						Subtotal O&M PV	$ 613,647
						Contingency @ 15%	$ 92,047
						Total O&M PV	**$ 705,694**

Total Cost	**$ 5,343,236**
30% Below	$ 3,740,265
50% Above	$ 8,014,853

Notes:

1. The cost estimates shown have been prepared for guidance in project evaluation and implementation from the information available at the time of the estimate. The actual costs of the project will depend on actual labor and material costs, competitive market conditions, final project scope, implementation schedule, and other variable factors. As a result, the actual project costs will vary from the estimates presented herein. Because of this, project feasibility and funding needs must be carefully reviewed prior to making specific financial decisions to help ensure proper project evaluation and adequate funding.
2. The treatment thickness factor is defined here as the fraction of the treatment zone depth that is impacted by the EVO injection.
3. The coverage factor is defined here as the fraction of the total area to be treated covered initially by the injected treatment product. Natural groundwater advection will disperse the treatment product into the open areas.