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FINAL FEASIBILITY STUDY REPORT FOR GROUNDWATER SITE 3 NWS YORKTOWN VA
01/1/2014
CH2M HILL

Final

Feasibility Study Report for Groundwater at Site 3

Naval Weapons Station Yorktown
Yorktown, Virginia

Contract Task Order WE35

January 2014

Prepared for

Department of the Navy
Naval Facilities Engineering Command
Mid-Atlantic

Under the

NAVFAC CLEAN 8012 Program
Contract N62470-11-D-8012

Prepared by

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Executive Summary

This report describes the Feasibility Study (FS) for groundwater completed for Site 3, the Group 16 Magazines Landfill, Naval Weapons Station Yorktown, in Yorktown, Virginia. Based on the results noted in the final Phase II Remedial Investigation (RI) report for Sites 1 and 3 (CH2M HILL, 2012), five site-related groundwater constituents of concern were identified to be addressed in the FS—trichloroethene (TCE), cis-1,2-dichloroethene (DCE), vinyl chloride (VC), manganese, and arsenic. This FS report describes the development of remedial action objectives (RAOs) to protect human health and the environment, identifies applicable or relevant and appropriate requirements (ARARs) and to-be-considered criteria, and describes the development and evaluation of remedial alternatives to address potential unacceptable risks from exposure to groundwater contaminants at Site 3. The remedial alternatives were developed by combining the process options retained following the initial screening process. To avoid evaluating an unmanageable number of alternatives, only the most logistically and technically sensible combinations for the given site conditions were carried forward. The following five groundwater remedial alternatives were retained for detailed evaluation and comparative analysis:

- Alternative 1 – No Action
- Alternative 2 – Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs)
- Alternative 3 – Enhanced *In Situ* Bioremediation (EISB), MNA, and LUCs
- Alternative 4 – *In Situ* Chemical Reduction (ISCR), MNA, and LUCs
- Alternative 5 – *In Situ* Chemical Oxidation (ISCO), MNA, and LUCs

In addition to the remedial alternatives, pre-design investigation and a contingency soil excavation were developed independently for addition to any of the alternatives, with the exception of No Action. The contingency measure is being included in this FS report to facilitate the Comprehensive Environmental Response, Compensation, and Liability Act process and avoid a future Record of Decision amendment. This report discusses the detailed analysis of each alternative and the contingency action against the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) criteria, followed by a description of the comparative analysis of the remedial alternatives against one another. Alternative 1, No Action, is only included as a baseline for comparison of alternatives. It does not meet the statutory requirements of the NCP and is not a viable remedial action for this site. The following table summarizes the results from the detailed analysis.

EISB (Alternative 3) would be synergistic with natural attenuation processes for TCE, cis-1,2-DCE, and VC and would likely enhance anaerobic biodegradation in the downgradient portion of the plume as the carbon substrate and microbial cultures migrate with groundwater. Given the slow groundwater flow rate (~4 feet per year) at the site, a soluble substrate is considered to have moderate persistence in the subsurface at the site. A second injection would facilitate mixing in the aquifer. ISCR (Alternative 4) is also compatible with existing anaerobic conditions. The combined zero-valent iron (ZVI) and carbon reagent used in this alternative would stay within the injected zone; it would create more deeply reduced conditions and provide a carbon source, which would also enhance anaerobic biodegradation. The micron-scale ZVI would also have up to several years of persistence. Although ISCO (Alternative 5) does not require or take advantage of the existing reducing conditions, TCE, cis-1,2-DCE, and VC in the treatment zone would be rapidly broken down by the oxidant, which may persist for up to a few years. Therefore, the EISB, ISCR, and ISCO alternatives can address potential desorption or back-diffusion of TCE, cis-1,2-DCE, and VC sorbed to the clay layer at the top of the Yorktown-Eastover Aquifer.

Evaluation Criterion	Alternative 1 (No Action)	Alternative 2 (MNA and LUCs)	Alternative 3 (EISB, MNA, and LUCs)	Alternative 4 (ISCR, MNA, and LUCs)	Alternative 5 (ISCO, MNA, and LUCs)	Contingency (Soil Excavation)	Comparative Analysis
Overall Protection of Human Health and the Environment	Not Protective	Protective	Protective	Protective	Protective	Protective	Except for No Action, all alternatives are protective. LUCs and groundwater monitoring would be implemented and maintained until RAOs are achieved.
Compliance with ARARs	Does not meet	Meets	Meets	Meets	Meets	Meets	Except for No Action, all alternatives meet ARARs.
Long-Term Effectiveness and Permanence	Ineffective	Effective and permanent	Effective and permanent	Effective and permanent	Effective and permanent	Effective and permanent	Alternatives 3, 4, and 5 may have slightly lower residual risk because they include active treatment. Monitoring, LUCs, and Five-year Reviews would be needed until RAOs are achieved.
Reduction of Toxicity, Mobility, and Volume Through Treatment	No treatment	Passive treatment	Active treatment	Active treatment	Active treatment	Active treatment	Alternatives 3, 4, and 5 achieve a reduction of toxicity, mobility, or volume through active treatment. Alternative 3 has the highest reduction of toxicity, mobility, or volume because EISB is more appropriate for treating a larger area and volume of the plume at Site 3.
Short-term Effectiveness	Moderate to high	Moderate to high	Moderate to high	Moderate	Moderate	Moderate	Alternative 2 has the highest short-term effectiveness because it includes no construction and minimal intrusive activities. Alternative 4 would have the highest air emissions of nitrogen oxide, sulfur oxide, and particulate matter less than 10 micrometers in aerodynamic diameter. Alternative 5 would result in the highest water consumption, greenhouse gas emissions, and total energy use. Alternatives 3, 4, and 5 would have shorter remediation timeframes compared to Alternative 2.
Implementability	Moderate to high	High	Moderate to high	Moderate to high	Moderate to high	Moderate to high	Alternative 2 has the highest implementability because it involves no construction and is less likely to have schedule delays. All technologies are readily available, able to be monitored for effectiveness, and can be followed by other remedial actions, if necessary. The required approvals from the necessary agencies are readily obtainable.
Total PV Costs: *PV Capital Costs:* *PV O&M Costs:*	$- $- $-	$1,117,000 $13,000 $1,104,000	$953,000 $169,000 $784,000	$1,313,000 $479,000 $834,000	$1,324,000 $496,000 $828,000	$624,000 $624,000 $0	

O&M = operations and maintenance

PV = present value

Because EISB (Alternative 3) would create more reducing conditions, dissolved manganese and dissolved arsenic concentrations may temporarily increase. The solid forms of iron (iron hydroxides) and manganese (manganese oxides), which are usually present in the natural soil matrix, can dissolve more readily under these reduction-oxidation conditions. If arsenic is sorbed to these hydroxides and oxides, it can also be released to groundwater. However, as the EISB substrate is exhausted and the organic contamination is degraded, the shallow groundwater system should return to more oxidized conditions and dissolved manganese and dissolved arsenic concentrations should decrease. ISCR (Alternative 4) would also create more reducing conditions in groundwater, potentially increasing dissolved manganese concentrations. However, ZVI can co-precipitate dissolved arsenic from groundwater, potentially decreasing dissolved arsenic concentrations. ISCO (Alternative 5) would create more oxidizing conditions in groundwater. This may facilitate the precipitation of dissolved iron and manganese into their solid forms, which would result in a decrease in dissolved manganese concentrations. Dissolved arsenic concentrations could also decrease as it more readily adsorbs onto the solid hydroxides and oxides. In addition, arsenic can be directly oxidized by the oxidant. However, arsenic concentrations in groundwater may temporarily increase immediately following the injection of permanganate due to heavy metal impurities in the oxidant.

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Acronyms and Abbreviations

µg/kg	microgram(s) per kilogram
µg/L	microgram(s) per liter
ARAR	applicable or relevant and appropriate requirement
Baker	Baker Environmental, Inc.
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
cells/ml	cells per milliliter
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHP	catalyzed hydrogen peroxide
CLEAN	Comprehensive Long-term Environmental Action—Navy
CO_2	carbon dioxide
COC	constituent of concern
CSM	conceptual site model
CTE	central tendency exposure
CVOC	chlorinated volatile organic compound
DAF	dilution attenuation factor
DCA	dichloroethane
DCE	dichloroethene
DHC	*Dehalococcoides*
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DPT	direct-push technology
EISB	Enhanced *In Situ* Bioremediation
EO	Executive Order
EPC	exposure point concentration
FS	Feasibility Study
ft^2	square foot/feet
GHG	greenhouse gas
GPS	global positioning system
HHRA	Human Health Risk Assessment
HI	hazard index
ISCO	*in situ* chemical oxidation
ISCR	*in situ* chemical reduction
$KMnO_4$	potassium permanganate
LUC	Land Use Control
mg/day	milligrams per day
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MCL	maximum contaminant level
MIP	membrane interface probe
MNA	Monitored Natural Attenuation

msl	mean sea level
mV	millivolt(s)
$NaMnO_4$	sodium permanganate
NAVFAC	Naval Facilities Engineering Command
Navy	Department of the Navy
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NOD	natural oxidant demand
NOx	nitrogen oxide
O&M	operations and maintenance
ORP	oxidation-reduction potential
pH	hydrogen (ion) concentration
PM_{10}	particulate matter less than 10 micrometers in aerodynamic diameter
PRG	preliminary remediation goal
psi	pounds per square inch
RAO	remedial action objective
RG	remediation goal
RI	Remedial Investigation
RME	reasonable maximum exposure
ROD	Record of Decision
ROI	radius of influence
SARA	Superfund Amendments and Reauthorization Act
SOx	sulfur oxide
SSL	soil screening level
SVOC	semivolatile organic compound
TBC	to-be-considered
TCE	trichloroethene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TTZ	target treatment zone
USEPA	United States Environmental Protection Agency
VC	vinyl chloride
VFA	volatile fatty acid
VOC	volatile organic compound
WPNSTA	Naval Weapons Station
ZVI	zero-valent iron

SECTION 1

Introduction and Background

This report presents the Feasibility Study (FS) conducted for groundwater at Site 3, Naval Weapons Station (WPNSTA) Yorktown, in Yorktown, Virginia. This report was prepared under the Department of the Navy(Navy), Naval Facilities Engineering Command (NAVFAC) Mid-Atlantic, Comprehensive Long-term Environmental Action—Navy (CLEAN) 8012 Program, Contract N62470-11-D-8012, Contract Task Order WE35, for submittal to NAVFAC, the United States Environmental Protection Agency (USEPA) Region 3, and the Virginia Department of Environmental Quality.

The FS was performed in accordance with the process outlined in the Navy's Environmental Restoration Program, which is consistent with the National Oil and Hazardous Substance Pollution 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 and Approach

Previous investigations have identified potential human health risks associated with contamination in groundwater at Site 3. No potential ecological risks were identified. The nature and extent of contamination, Human Health Risk Assessment (HHRA), and Ecological Risk Assessment are documented in the final Phase II Remedial Investigation (RI) report for Sites 1 and 3 (CH2M HILL, 2012). In response to these findings, this FS report presents the remedial action objectives (RAOs) developed to protect human health and the environment, identifies applicable or relevant and appropriate requirements (ARARs) and to-be-considered (TBC) criteria, and describes the development and evaluation of remedial alternatives to prevent unacceptable risk from exposure to site-related contaminants in groundwater at Site 3.

1.2 Report Organization

This report consists of seven sections, as follows:

- Section 1 introduces the FS and summarizes the location and history of WPNSTA Yorktown and Site 3, including a description of the physical setting of the site.
- Section 2 provides background information, comprising a summary of previous investigations, nature and extent of contamination, contaminant fate and transport, and human health and ecological risks, and presents an overall conceptual site model (CSM) for Site 3.
- Section 3 presents the ARARs, RAOs, and preliminary remediation goals (PRGs) intended to adequately protect human health and the environment.
- Section 4 presents general response actions that address remedial action goals and are used to identify the technology types and process options. This section discusses a preliminary screening of technologies and formulates the remedial action alternatives to be considered in the screening step.
- Section 5 presents a detailed evaluation of the remedial alternatives.
- Section 6 presents a summary of the FS and conclusions for Site 3.
- Section 7 contains references to the documents used during preparation of this FS.

1.3 Facility Description and History

WPNSTA Yorktown is a 10,624-acre installation on the Virginia Peninsula in York and James City counties, Virginia (**Figure 1-1**). It is bounded on the northwest by Cheatham Annex, on the northeast by the York River and the Colonial National Historic Parkway, on the southwest by Route 143 and Interstate 64, and on the southeast by Route 238 and the town of Lackey.

Originally named the United States Mine Depot, WPNSTA Yorktown was established in 1918 to support the laying of mines in the North Sea during World War I. For 20 years after World War I, the depot continued to receive, reclaim, store, and issue mines, depth charges, and related materials. During World War II, the facility was expanded to include three trinitrotoluene loading plants and new torpedo overhaul facilities. A research and development laboratory for experimentation with high explosives was established in 1944. In 1947, a quality evaluation laboratory was developed to monitor special tasks assigned to the facility, which included the design and development of depth charges and advanced underwater weapons. On August 7, 1959, the depot was renamed the United States WPNSTA. Today, the primary mission of WPNSTA Yorktown is to provide ordnance, technical support, and related services to sustain the war-fighting capability of the armed forces in support of national military strategy.

1.4 Site 3 Description and History

Site 3, the Group 16 Magazines Landfill, is a 2-acre wooded area behind the former Group 16 Magazines, located in the northern portion of WPNSTA Yorktown, west of Indian Field Creek (**Figure 1-2**). The area adjacent to Indian Field Creek is covered by woods that act as a riparian buffer for surface water runoff. North of Site 3 is an unnamed tributary that leads into Indian Field Creek. Site 3 lies inside an area encumbered by the Explosive Safety Quantity Distance and cannot be developed for real estate purposes.

Site 3 is named for its proximity to the Group 16 Magazines; however, the history of this landfill is unrelated to operations at the Magazines. The site was originally used for sand mining and consisted of one borrow pit to a depth of 10 feet below ground surface (bgs). Between 1940 and 1970, Site 3 was operated as a landfill. Waste was disposed of in the borrow pit and reportedly included solvents, sludge from boiler cleaning operations, grease trap wastes, Imhoff tank skimmings (containing oil and grease), and animal carcasses. Test pit investigations performed in 1997 confirmed the presence of scrap metal, 55-gallon metal drums, grease, wax, lumber, banding, concrete blocks, plastic sheeting, and surface debris. The Site 3 waste boundary was approximated during site investigations, which included a geophysical survey.

In 1999, a remedial action was completed and resulted in the removal of 284 tons of polycyclic aromatic hydrocarbon-contaminated soil and landfill waste, including approximately 50 drums of solidified resin and powdered aluminum, 127 tons of abandoned dry cell batteries, and 4,700 tons of galley waste (**Figure 1-2**). After removal of the wastes and contaminated soil, the area was re-graded and covered with 4 inches of topsoil (OHM Remediation Services Corporation [OHM], 2001).

Site 3 is generally grassy and surrounded by woods. The topography slopes to the northeast, with steeper slopes adjacent to Indian Field Creek and the unnamed tributary to Indian Field Creek. Ground surface elevations range from 0 to 50 feet above mean sea level (msl). Surface water runoff generally follows the topography and is conveyed to Indian Field Creek. Indian Field Creek is a tidally influenced tributary to the York River, and the surface water flow direction reverses diurnally due to tidal fluctuations.

The geology and hydrogeology at WPNSTA Yorktown are described in detail in the final Phase II RI report (CH2M HILL, 2012). In the higher topographical areas, sands and silty sands are present. Although groundwater is not observed in this layer, perched water tables may exist. This unit is underlain by the Yorktown Confining Unit, which consists of silt and clay. Beneath this confining unit lies the silty, fine- to coarse-grained sand and shell hash of the Yorktown-Eastover Aquifer. At Site 3, the silty sands begin at approximately 20 to 40 feet bgs or between 5 feet above msl to 5 feet below msl. Based on the United States Geological Survey study conducted at WPNSTA Yorktown (Brockman et al., 1997), the Yorktown-Eastover Aquifer may be up to 80 feet thick. The Yorktown-Eastover Aquifer is underlain by the approximately 100- to 200-foot-thick Eastover-Calvert Confining Unit. This confining unit was not encountered in the deepest boring at the site, which extended to a depth of approximately 80 feet bgs. Three geologic cross-sections were developed from Site 3 soil boring logs. **Figure 1-4** presents the cross-section locations, and **Figures 1-5**, **1-6**, and **1-7** present the geologic cross-sections.

Groundwater is first encountered at the site within the Yorktown-Eastover Aquifer. The aquifer is confined except in low-lying areas adjacent to the creek, where the Yorktown Confining Unit is missing. Because of the variable ground elevation at the site, the depth to groundwater ranged from 3 feet bgs to 39 feet bgs in 2009. This translates to groundwater elevations between 1 and 10 feet above msl. Groundwater generally flows eastward to northeastward towards Indian Field Creek (**Figure 1-3**). Two localized groundwater mounds occur within the eastern portion of the site, which is consistent with site topography. The average horizontal hydraulic conductivity within the Yorktown-Eastover Aquifer is 0.2 foot per day, based on the single well hydraulic conductivity ("slug") tests conducted at Site 3 monitoring wells (CH2M HILL, 2012). With an assumed effective porosity of 0.20 and an estimated hydraulic gradient of approximately 0.01 foot per foot, the estimated groundwater velocity at Site 3 is approximately 4 feet per year.

The source of all domestic potable water supplies for WPNSTA Yorktown and surrounding communities is from the waterworks of the City of Newport News, Virginia, which consists of a series of surface water reservoirs. No drinking water wells exist at WPNSTA Yorktown; four historical water supply wells have been abandoned.

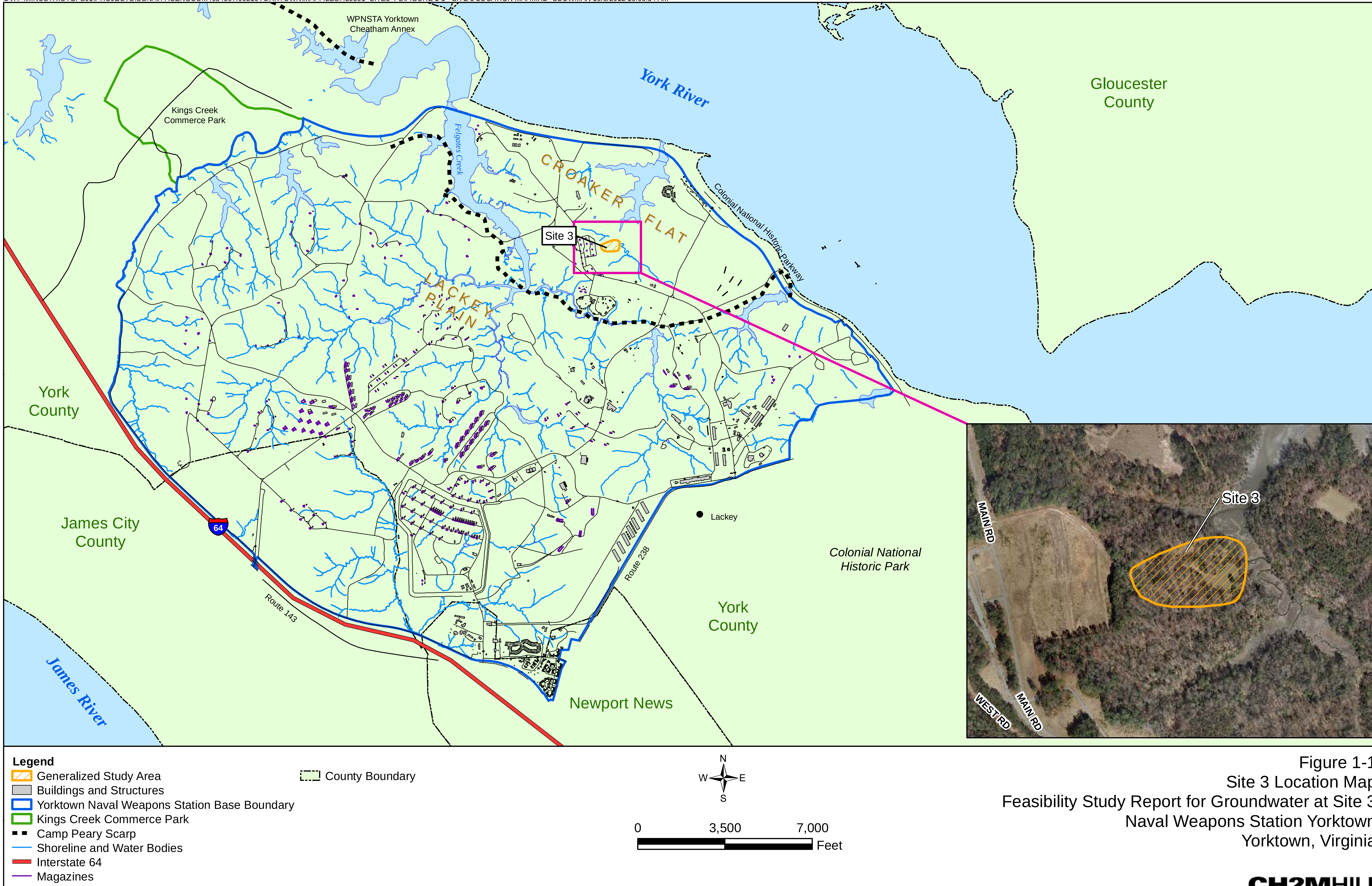

Figure 1-1
Site 3 Location Map
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

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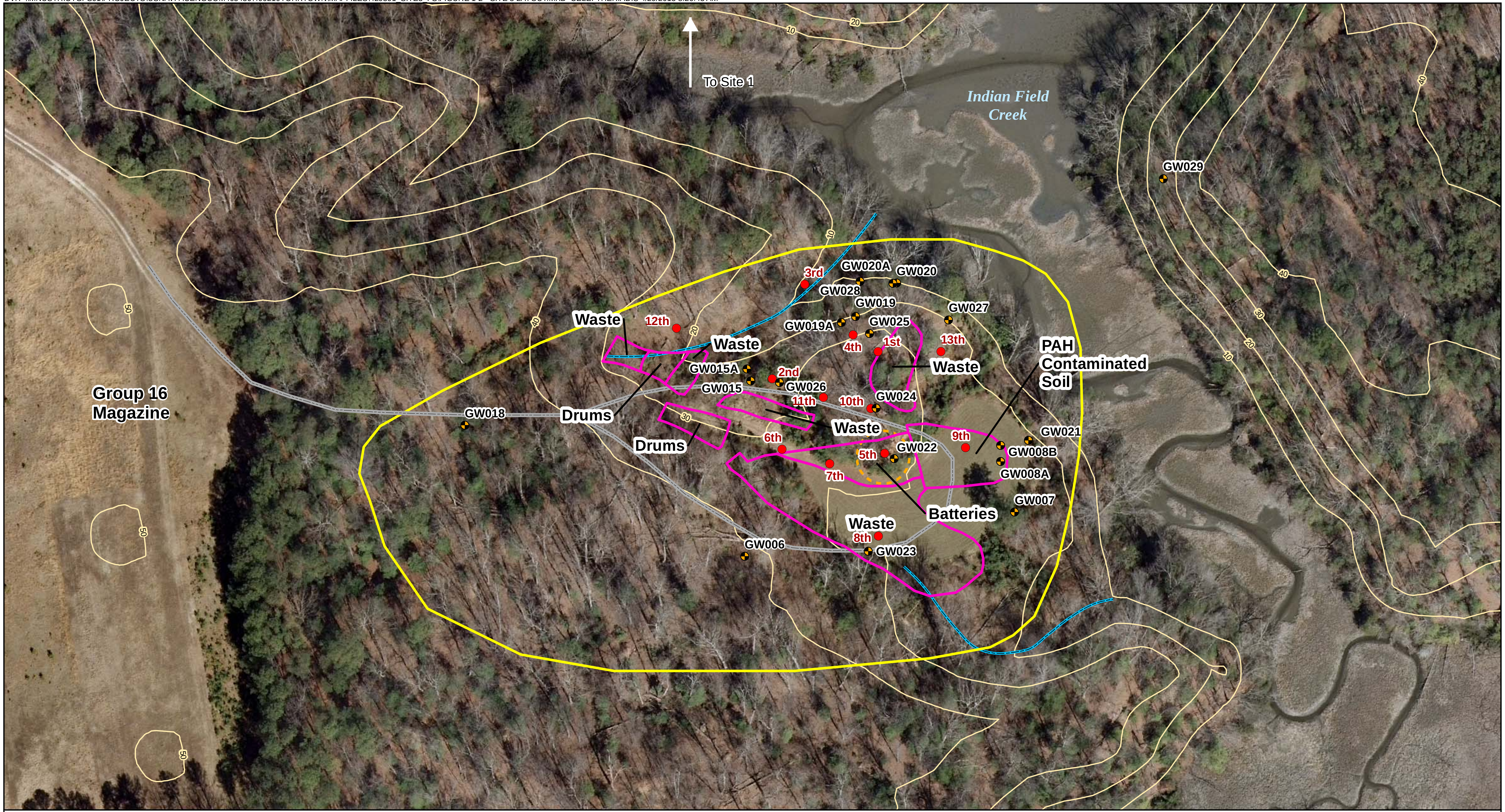

Legend

- Yorktown Monitoring Wells
- MIP Locations
- Site 3 Study Area Boundary
- Approximate Waste Limits (1999 Remedial Action)
- Approximate Unsaturated TPH Contamination
- Landfill Access Road
- Elevation Contour (10 ft interval)
- Estimated Drainage Channel

Notes:
1. The following waste was identified at the site: scrap metal, 55-gallon metal drums, grease, wax, lumber, banding, concrete blocks, plastic sheeting, and surface debris.
2. In 1999, 284 tons of polycyclic aromatic hydrocarbon-contaminated soil and landfill waste, including approximately 50 drums of solidified resin and powdered aluminum, 127 tons of abandoned dry cell batteries, and 4,700 tons of galley waste were removed.
3. The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

0 100 200 Feet

N W E S

Figure 1-2
Site 3 Layout
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

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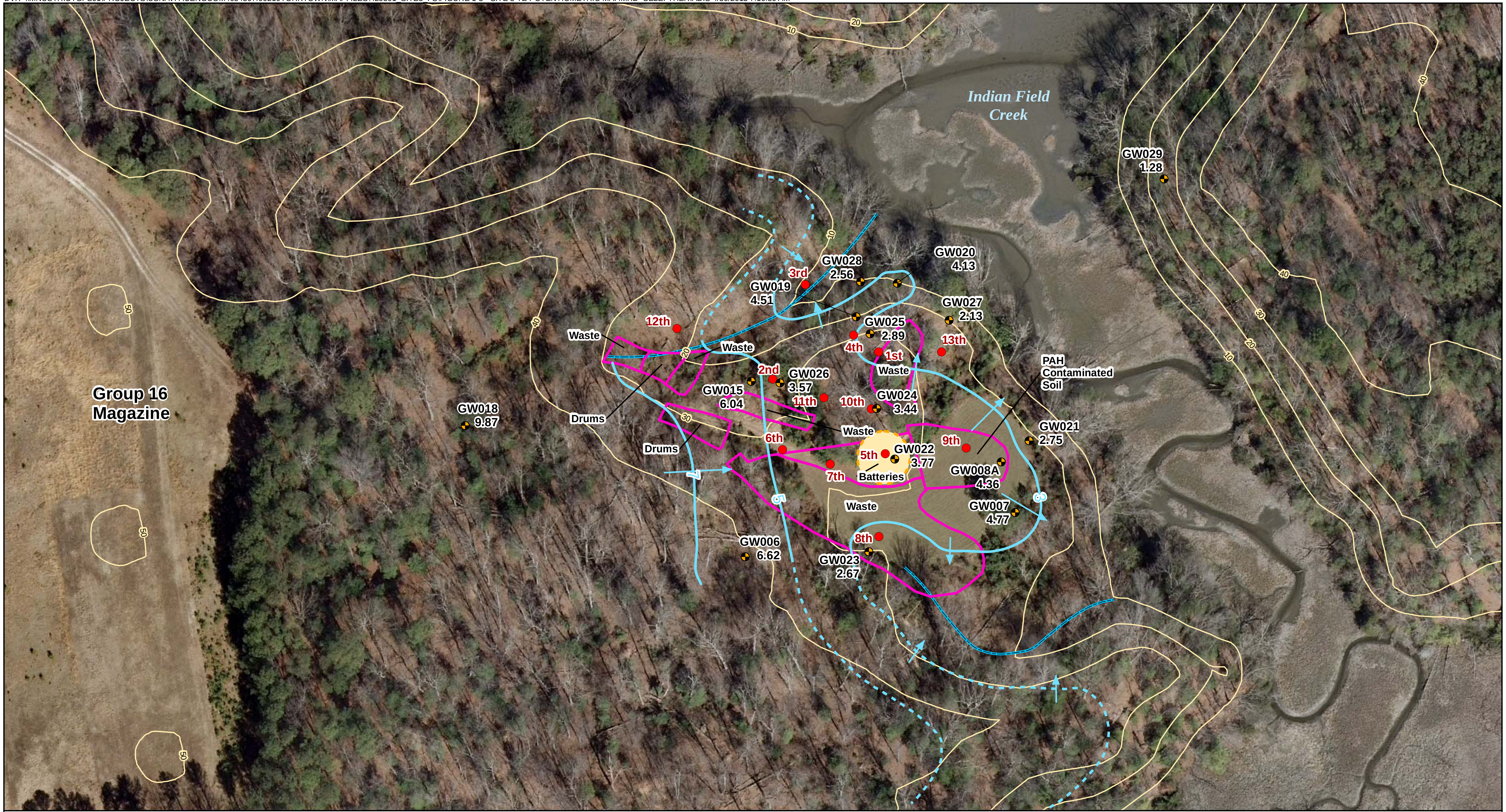

Legend

- Yorktown Monitoring Wells
- MIP Locations
- Groundwater Flow Direction
- Groundwater Elevation Contour
- Inferred Groundwater Elevation Contour
- Estimated Drainage Channel
- Approximate Unsaturated TPH Contamination
- Approximate Waste Limits (1999 Remedial Action)
- Elevation Contour (10 ft interval)

Notes:
1. The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

0 100 200 Feet

Figure 1-3
Site 3 Groundwater Elevation Contour Map Yorktown-Eastover Aquifer
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

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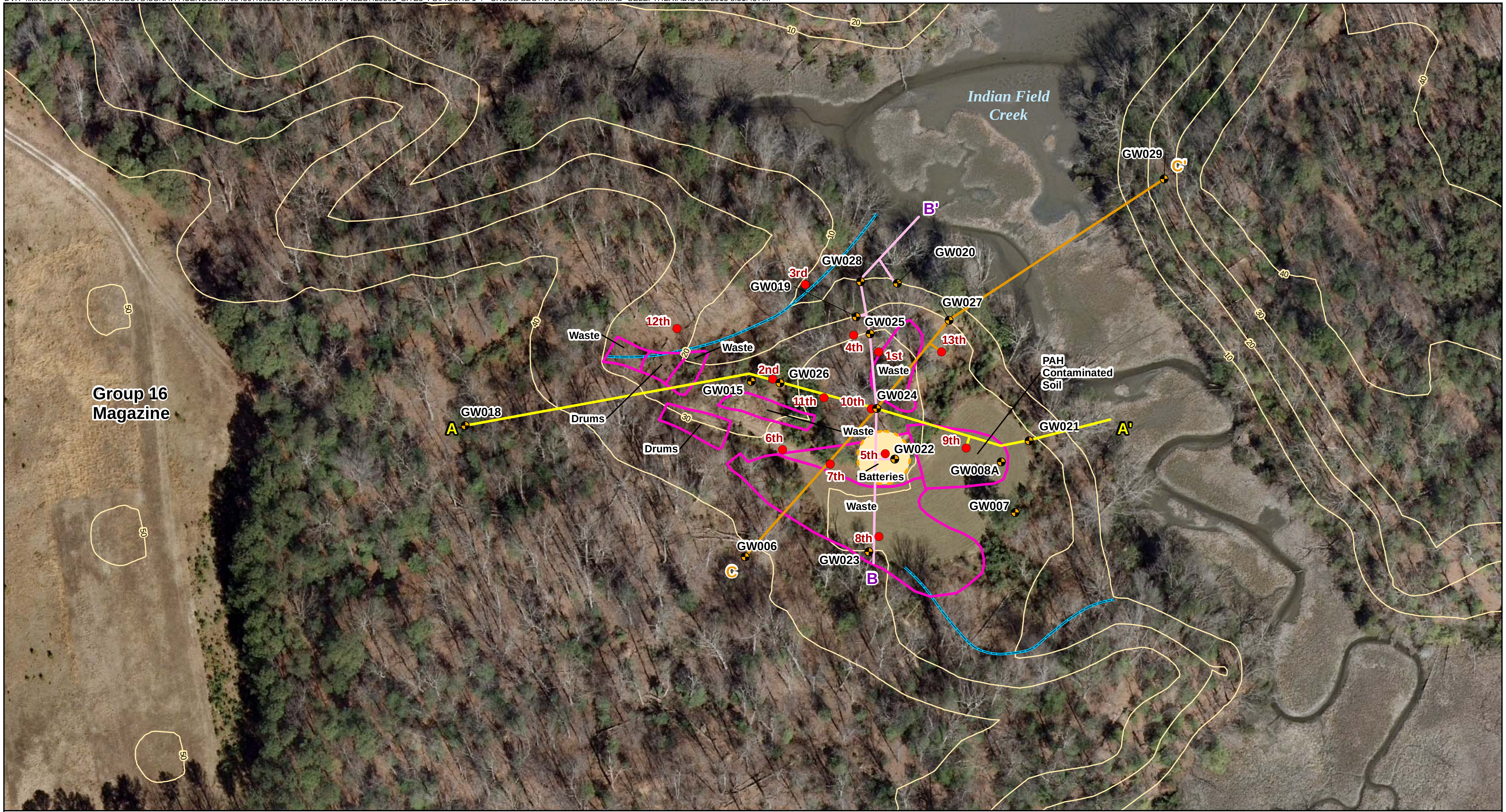
DVR \\MNUSTRICTGFS01\PROJECTS\USNAVFACENGCOM405450\400210YORKTOWN\MAPFILES\429391_SITE3_FS\FIGURE 1-4 - CROSS SECTION LOCATIONS.MXD CELEFTHERIADIS 5/3/2013 8:51:45 AM



Legend

- Yorktown Monitoring Wells
- MIP Locations
- Estimated Drainage Channel
- Approximate Unsaturated TPH Contamination
- Approximate Waste Limits (1999 Remedial Action)
- Elevation Contour (10 ft interval)
- Transect A-A'
- Transect B-B'
- Transect C-C'

N / W / E / S

0 100 200 Feet

Figure 1-4
Cross-Section Locations
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

CH2MHILL

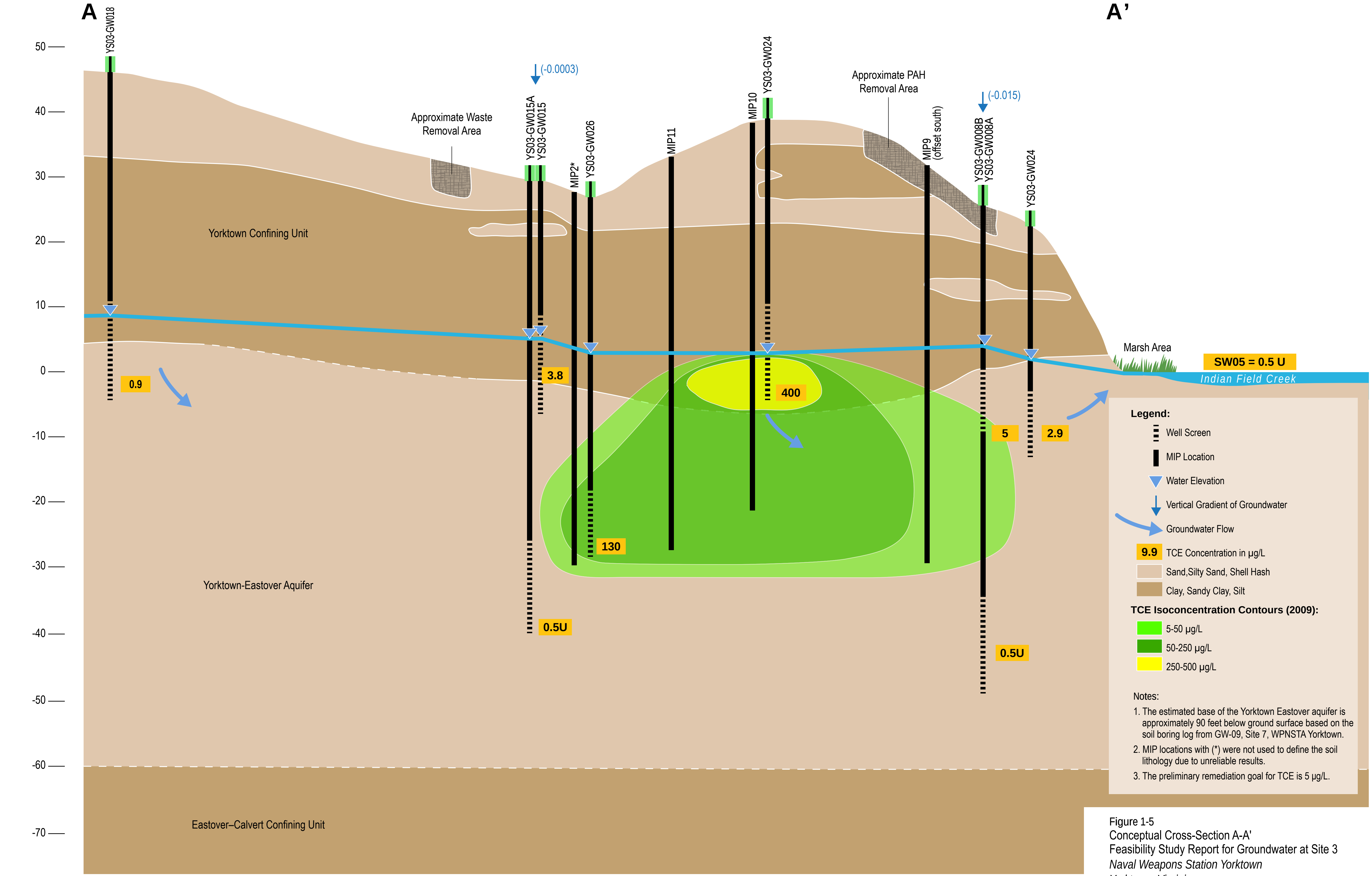
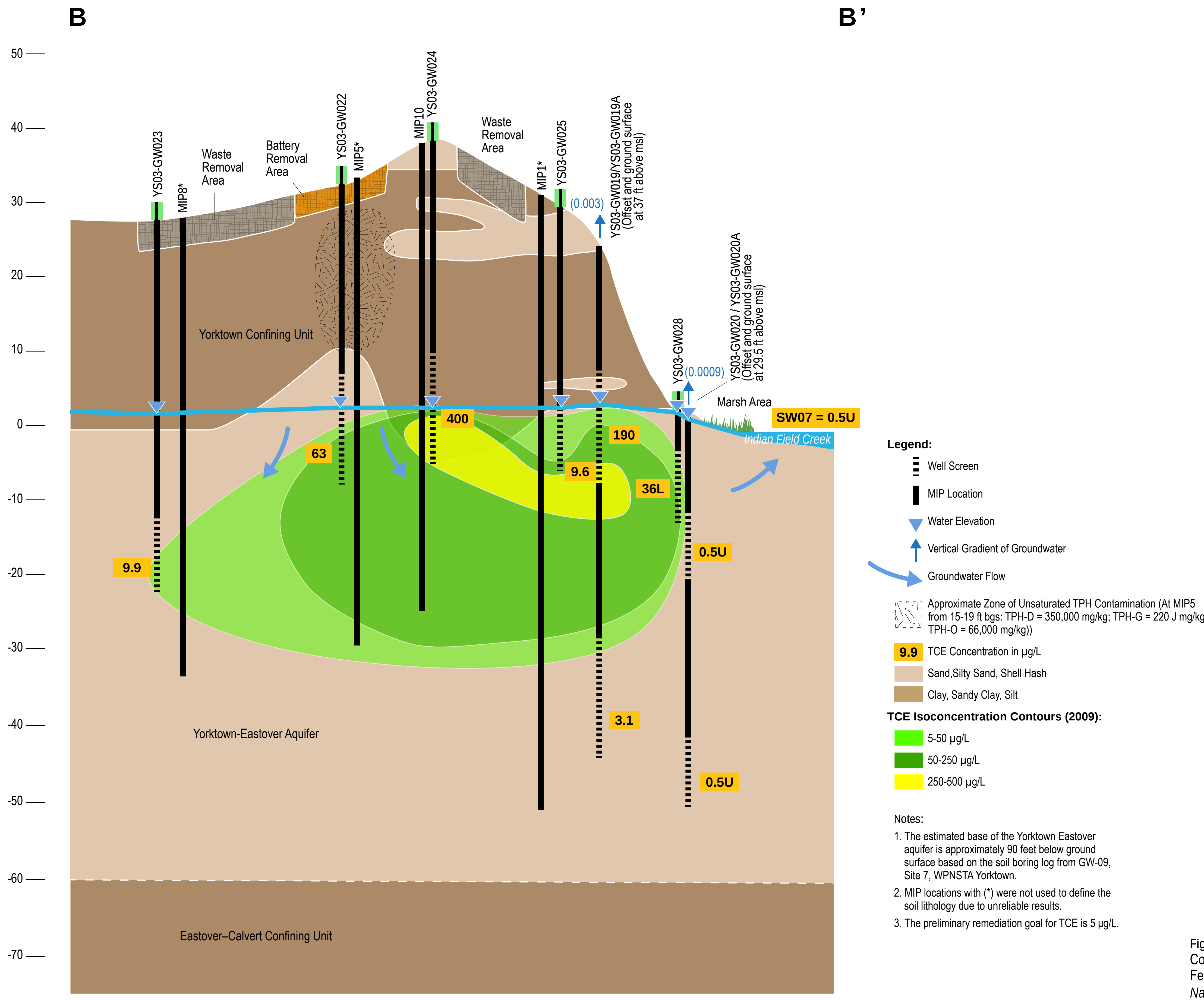


Figure 1-5
Conceptual Cross-Section A-A'
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia



Notes:

1. The estimated base of the Yorktown Eastover aquifer is approximately 90 feet below ground surface based on the soil boring log from GW-09, Site 7, WPNSTA Yorktown.
2. MIP locations with (*) were not used to define the soil lithology due to unreliable results.
3. The preliminary remediation goal for TCE is 5 µg/L.

Figure 1-6
Conceptual Cross-Section B-B'
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

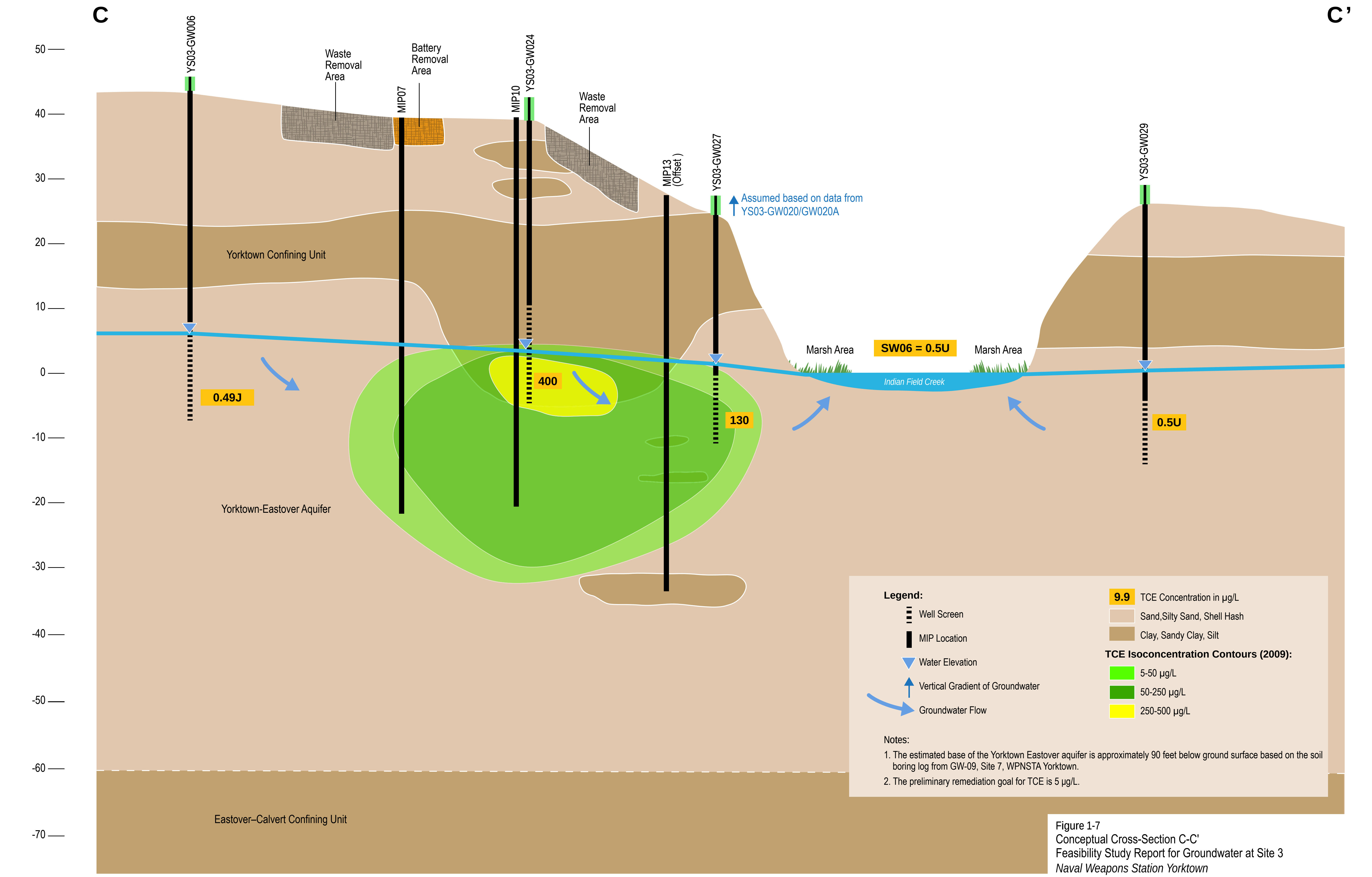


Figure 1-7
Conceptual Cross-Section C-C'
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

SECTION 2

Scope and Results of Environmental Investigation

2.1 Previous Investigations and Remedial Action

Several investigations and a remedial action have been conducted at Site 3. Results of this work are documented in the following reports:

- Initial *Assessment Study of Naval Supply Center (Norfolk) Cheatham Annex and Yorktown Fuels Division*. (Naval Energy and Environmental Support Activity, 1984)
- *Confirmation Study Step IA (Verification), Round One, Naval Weapons Station Yorktown, Yorktown, Virginia* (Dames & Moore, 1986)
- *Confirmation Study Step IA (Verification), Round Two, Naval Weapons Station Yorktown, Yorktown, Virginia* (Dames & Moore, 1988)
- *Final Remedial Investigation Interim Report, Fleet and Industrial Supply Center (Norfolk), Cheatham Annex* (Versar, 1991)
- *Final Round One Remedial Investigation Report for Sites 1-9, 11, 12, 16-19, and 21, Naval Weapons Station Yorktown, Yorktown, Virginia* (Baker Environmental, Inc. [Baker]and Weston, 1993)
- *Final Round Two Remedial Investigation Report for Sites 1 and 3, Naval Weapons Station Yorktown, Yorktown, Virginia* (Baker, 1997a)
- *Final Focused Feasibility Study for Sites 1 and 3, Naval Weapons Station Yorktown, Yorktown, Virginia* (Baker, 1997b)
- *Final Record of Decision for Sites 1 and 3, Naval Weapons Station Yorktown, Yorktown, Virginia* (Baker, 1999)
- *Final Report, Remedial Action, Sites 1 and 3, and SSA 22, Naval Weapons Station Yorktown, Virginia* (OHM, 2001)
- *Phase I Remedial Investigation Report for Groundwater at Sites 1, 3, 6, 7, 11, 17, 24, and 25, Naval Weapons Station Yorktown, Yorktown, Virginia* (CH2M HILL, 2007)
- *Final Technical Memorandum, Documentation of Post-Remedial Action Site Conditions Site 3 – Group 16 Magazines Landfill, Naval Weapons Station Yorktown, Yorktown, Virginia* (CH2M HILL, 2008a)
- *Explanation of Significant Differences for Site 3, Naval Weapons Station Yorktown, Yorktown, Virginia* (CH2M HILL, 2008b)
- *Final Phase II Remedial Investigation Report Sites 1 and 3, Naval Weapons Station Yorktown, Yorktown, Virginia* (CH2M HILL, 2012)

Based on the results of site investigations, a remedy for soil contamination at Site 3 was documented in the final Record of Decision (ROD) (Baker, 1999) and implemented between July 1999 and April 2000. The preferred alternative included excavation with offsite disposal and debris removal. Following the excavation, OHM worked with the United States Fish and Wildlife Service and WPNSTA Yorktown Natural Resource personnel to develop a grading and site restoration plan that met natural resource management needs to provide wildlife habitat (CH2M HILL, 2008a). All excavated areas were backfilled with clean fill and covered with 6 inches of topsoil and seeded. Backfill was obtained from on-base borrow material that was deemed acceptable based on analytical laboratory results. Toxicity characteristic leaching procedure organics and metals, total petroleum hydrocarbons (TPH), and benzene, toluene, ethylbenzene, and xylenes (BTEX) were either non-detect or below regulatory limits (OHM, 2001). Although the ROD only proposed removal of soil contamination above industrial criteria, ultimately all landfill wastes and soil with concentrations above residential criteria were removed. A Technical Memorandum documenting the rationale for no unacceptable post-remediation human health and ecological risks remaining from exposure to soil was completed in 2008 (CH2M HILL, 2008a). An Explanation of Significant Difference was signed in 2008 to document removal of all waste and associated soil contamination to levels acceptable for unlimited use and unrestricted exposure at Site 3 and removing the need for land use controls (LUCs) and Five-year Review of the site regarding soil (CH2M HILL, 2008b).

Because the 1999 ROD and subsequent remedial actions only addressed soil at Site 3, Phase I and II RIs were conducted to further assess the nature and extent of groundwater contamination. Phase I RI field activities were conducted in September and October 2004 and included groundwater sampling (CH2M HILL, 2007). Phase II RI activities were performed between January and September 2009 (CH2M HILL, 2012). Field activities consisted of membrane interface probe (MIP) logging, direct-push technology (DPT) sampling, monitoring well installation and sampling, and hydraulic conductivity testing. Additionally, surface water, sediment, and sediment pore water samples were collected within the channel of the South-Western Branch of Indian Field Creek and the tributary to the creek that flows to the north of Site 3. Using the Phase II RI results, an HHRA was conducted to evaluate potential risks from constituents in groundwater at Site 3 and surface water and sediment in the creek and the tributary. An Ecological Risk Assessment was conducted to assess potential risks to the environment from constituents in surface water, sediment, and pore water. The findings of the Phase II RI are summarized in the following section.

2.2 Summary of Findings

As recommended in the Phase II RI, this FS report only addresses constituents of concern (COCs) in groundwater at Site 3. Groundwater COCs identified as posing potential risks to human receptors and would warrant remediation were trichloroethene (TCE), cis-1,2- dichloroethene (DCE), vinyl chloride (VC), arsenic, and manganese. As described in Section 2.1, soil has been remediated to levels acceptable for unlimited use and unrestricted exposure. The Phase II RI report did not identify any COCs for surface water, sediment, or sediment pore water because the human health and ecological risks were within or below acceptable levels. Therefore, the following discussion provides an overview only of the groundwater nature and extent of contamination, contaminant fate and transport, and Phase II RI risk assessment (HHRA) findings. The groundwater CSM for Site 3 is depicted on **Figure 2-1**. The detailed results of the investigations and risk assessment for groundwater are presented in the final Phase II RI report for Sites 1 and 3 (CH2M HILL, 2012).

2.2.1 Nature and Extent of Contamination

Volatile Organic Compounds

During the MIP investigation, elevated electron capture detector readings suggested that chlorinated volatile organic compounds (CVOCs) may be present in a localized area within the vadose zone between MIP-5 and MIP-10 (**Figure 1-3**). As a result, two unsaturated soil samples were collected where the highest electron capture detector response was observed (MIP-5 at 12 to 16 feet bgs and 15 to 19 feet bgs). TCE and cis-1,2-DCE were detected at the 12- to 16-foot bgs sample. TCE was detected at 14 micrograms per kilogram (µg/kg), below its May 2012 adjusted residential regional screening level of 440 µg/kg, and cis-1,2-DCE was detected at 11 µg/kg, below its residential regional screening level of 16,000 µg/kg. TCE and cis-1,2-DCE concentrations were also reported below their maximum contaminant level (MCL)-based soil screening levels (SSLs) of 36 µg/kg and 420 µg/kg, respectively. These adjusted SSLs are based on a dilution attenuation factor (DAF) of 20, which is consistent with the Soil Screening Guidance recommendation for areas covering less than 0.5 acre (USEPA, 1996). They were derived by multiplying the May 2013 SSLs (which assume a conservative DAF of 1) by a DAF factor of 20. Concentrations of all other detected volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, and polychlorinated biphenyls also did not exceed residential risk-based screening criteria in soil at Site 3. TPH within the diesel range were observed in the soil between 15 and 19 feet bgs (350,000 µg/kg).

The CVOC plume generally occurs beneath the former landfill area and extends 250 to 300 feet toward Indian Field Creek. Based upon the MIP and groundwater analytical data, the plume is present within the uppermost portion of the Yorktown-Eastover Aquifer (top 35 feet). TCE is the most extensive CVOC in groundwater. Historically, the highest concentration detected at the site was 860 micrograms per liter (µg/L) at monitoring well YS03-GW19 in 1996. During the 2009 Phase II RI sampling event, the maximum concentration of TCE in groundwater was 400 µg/L at YS03-GW024. **Figure 2-2** presents the horizontal extent of the TCE plume, and **Figures 1-5-**, **1-6**, and **1-7** present the vertical extent of the TCE plume beneath Site 3. As shown on the cross-section figures, the clay of the Yorktown Confining Unit dips down at the location of monitoring well YS03-GW024. Therefore, the highest concentrations are observed in a clay matrix rather than in the silty sand where the majority of the dissolved plume occurs. Although cis-1,2-DCE and VC are less horizontally extensive in groundwater than TCE (see **Figures 2-3** and **2-4**), they are present at higher concentrations. The maximum concentrations of cis-1,2-DCE (1,400 J µg/L) and VC (1,200 µg/L) were both detected at monitoring well YS03-GW024.

The presence of dense non-aqueous phase liquid (DNAPL) was evaluated using Indigo Blue test dye kits. A positive detection for the presence of free-phase, light non-aqueous phase liquid and DNAPL was only observed at YS03-GW022. Because petroleum constituents were observed in the vadose zone and TCE, cis-1,2-DCE, and VC in groundwater were reported at concentrations well below their aqueous solubilities at this location, the detection by the dye kit is attributed to petroleum constituents rather than DNAPL.

Inorganic Compounds

Arsenic and manganese were the only dissolved inorganic constituents observed above screening criteria. Dissolved arsenic was detected above its MCL of 10 µg/L in only two downgradient wells (YS03-GW021 and -GW029). The highest concentration, 34.7 µg/L, was detected at YS03-GW021. As shown on **Figure 2-5**, both of these monitoring wells are adjacent to Indian Field Creek. One of the monitoring wells (YS03-GW29) is on the eastern side of Indian Field Creek, whereas Site 3 is on the western side of the creek. Because shallow groundwater discharges into the creek, the groundwater flow direction at YS03-GW29 is likely to the west towards the creek, and the elevated concentrations are due to reducing conditions near wetlands rather than activities at Site 3. Dissolved manganese was detected above its PRG of 320 milligrams per liter (mg/L) (see Section 3.3.1) in three downgradient monitoring wells (YS03-GW019A, -GW021, and -GW027); the highest concentration was detected in YS03-GW021 at 1,260 µg/L. As shown on **Figure 2-6**, two of these monitoring wells were also close to Indian Field Creek.

2.2.2 Contaminant Fate and Transport

The source of groundwater contamination at Site 3 is attributed to leaching of contaminants from the burial of wastes in the landfill. A remedial action was conducted between 1999 and 2000, which removed all waste and soil contaminated above residential risk-based criteria.

Migration Pathways

As depicted in the CSM (**Figure 2-1**), the primary migration pathways of constituents in groundwater at Site 3 are:

- Volatilization of groundwater contaminants into the vadose zone and subsequently into the atmosphere
- Dissolved contaminant migration downgradient with groundwater flow (advection)
- Groundwater discharge to Indian Field Creek

Volatilization is the tendency for chemicals in a dissolved or adsorbed phase to migrate into the vapor phase, such as in soil gas. At the water table interface, the gaseous contaminants can migrate from the saturated zone upwards to the vadose zone and, if not attenuated there, eventually to the atmosphere. The Henry's Law Constant values for TCE, cis-1,2-DCE, and VC are greater than 10^{-3} atmosphere-cubic meters per mole, suggesting that they are expected to volatilize readily from water to air.

Contaminants migrate with groundwater flow via advection to the north and east. As described in Section 1.4, the estimated groundwater velocity at Site 3 is approximately 4 feet per year. However, most contaminants in groundwater at Site 3 are not expected to migrate as rapidly as groundwater flow because of soil retardation. Assuming a bulk density of 1.6 grams per milliliter (silty sand), a fraction of organic carbon value of 0.0025, an effective porosity of 0.2, and applicable chemical soil-water partition coefficients, retardation coefficients for TCE, cis-1,2-DCE, and VC were estimated at 2.7, 2.0, and 1.0, respectively. The effect of retardation is estimated by dividing the groundwater flow velocity by the retardation coefficient, which provides a value of migration that is either equal to (in the case of no retardation) or less than the flow rate (in the presence of retardation). The calculated contaminant migration rates for TCE, cis-1,2-DCE, and VC were estimated at 1.5, 2.0, and 4.0 feet per year, respectively.

Based on upward vertical hydraulic gradients observed at Site 3, groundwater from the Yorktown-Eastover Aquifer discharges into Indian Field Creek. However, TCE, cis-1,2-DCE, and VC likely volatilize once discharged to the creek. These constituents were not detected in surface water, sediment, or sediment pore water. Although metals in groundwater may be discharging to the creek based on previous detections in surface water, they are not detected in surface water or sediment at levels posing potential unacceptable risk. Therefore, the discharge of groundwater contaminants from Site 3 into the creek is not considered a significant migration pathway.

Biodegradation and Transformation

TCE, cis-1,2-DCE, and VC in groundwater at Site 3 are subject to degradation via biological and abiotic mechanisms. Under anaerobic conditions, biodegradation of CVOCs typically occurs via reductive dechlorination, which is a naturally occurring, 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 the electron receptor. Therefore, an external electron donor source is required for the reaction to occur. Potential electron donor sources include biodegradable organic co-contaminants or native organic matter. Biotic reductive dechlorination occurs most favorably under strongly reducing conditions between sulfate-reducing and methanogenic conditions.

The reductive dechlorination pathway for TCE, cis-1,2-DCE, and VC is as follows:

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

The transformation rate for each step varies but tends to become slower with progress along the breakdown sequence and may result in accumulation of cis-1,2-DCE and VC. Complete reductive dechlorination with ethene as the end product is possible, depending on the site-specific biogeochemical conditions. The less-chlorinated ethenes, especially cis-1,2-DCE and VC, are subject to aerobic degradation in addition to anaerobic reductive dechlorination. Abiotic degradation of CVOCs by iron-bearing minerals (such as iron monosulfide) in the subsurface has also been widely reported in literature (He et al., 2010; Lee, et al., 2009).

Analytical data collected from Site 3 groundwater generally indicate favorable conditions for reductive dechlorination. Although there is limited geochemical data available, aquifer conditions are considered to be similar to Site 22 (the Burn Pad), for which a monitored natural attenuation (MNA) remedy for CVOCs in groundwater was selected (CH2M HILL, 2012). Nevertheless, the variable reduction-oxidation conditions in the aquifer at Site 3 add some uncertainty as to the degree at which biodegradation may be occurring. Favorable indicators are summarized below:

- The decrease in TCE concentrations since the Round Two RI and the presence of TCE reductive degradation products (cis-1,2-DCE, VC, and ethene) provide direct evidence.

- TCE concentrations decreased at the monitoring well (YS03-GW019) with the historically highest concentrations from 860 μg/L in February 1996 to 120 μg/L in October 2004; since then concentrations have been statistically stable.
- Because cis-1,2-DCE and VC are not considered parent compounds (or chemicals used during site activities), their presence in groundwater is attributed to reductive dechlorination of the parent compound TCE.
  - In YS03-GW019, cis-1,2-DCE was observed to decrease in concentration from the Round II RI through early 2005, at which point concentrations increased. This increase is attributed to the reductive degradation of TCE.
  - In YS03-GW019, VC has shown some fluctuation over time and increasing concentrations since 2005. This increase is attributed to the reductive degradation of cis-1,2-DCE. Fluctuations in concentration may be due to the combined effects from generation via reductive dechlorination, degradation via anaerobic and/or aerobic biodegradation, and advection of the plume.
  - Changes in cis-1,2-DCE and VC concentrations are not attributed to impacts from the creek because there is no indication from field parameters (such as salinity) that this well is tidally influenced. Monitoring well YS03-GW020, which is approximately 50 feet downgradient of YS03-GW019 and closer to the creek, has had no fluctuations in concentrations and no COC detections since February 2005.
- The final reductive degradation products ethene and ethane were detected in several affected wells (ethene and ethane were not detected in the upgradient well YS03-GW018). Ethane was detected at or above 15 μg/L in monitoring wells YS03-GW024 and –GW027. Ethane was detected at trace amounts in nine other monitoring wells and ethene was detected in trace amounts at six wells.

- Within the plume, groundwater appears to be primarily under moderately reducing conditions.
  - Except for monitoring wells YS03-GW024, -GW025, -GW027, and –GW028, groundwater from wells located in the combined TCE, cis-1,2-DCE, and VC plumes had dissolved oxygen (DO) values of less than 1 mg/L and oxidation-reduction potential (ORP) values between -50 millivolts (mV) and -269 mV, indicative of anaerobic conditions (see **Table 2-1**).
  - In monitoring wells YS03-GW024, -GW025, -GW027, and –GW028, DO values were greater than 2 mg/L and ORP values were 17 mV or higher, indicative of more oxidizing conditions. However, geochemical data in monitoring wells YS03-GW024 and -GW027 had the strongest indicators for anaerobic conditions, including the highest concentrations of ethane, ethene, and methane at the site; chloride concentrations over 4 times greater than in the upgradient well (YS03-GW018); and decreased sulfate concentrations compared to the upgradient well (see **Table 2-1**).
- Elevated alkalinity values within the combined TCE, cis-1,2-DCE, and VC plumes compared to the upgradient well are suggestive of biological activity.
- Concentrations of *Dehalococcoides* (DHC), which can facilitate dechlorination of TCE and daughter products to ethene and ethane, were detected at 6.2 and 26.2 cells per milliliter (cells/ml) at Site 3, which is indicative of a population that may sustain dechlorination.
- The average hydrogen (ion) concentration (pH) value of 8.2 in groundwater is slighter higher than the favorable range for biodegradation of 6 to 8.

Total organic carbon (TOC) concentrations in groundwater at Site 3 were very low, measuring between less than 1 mg/L to 6.8 mg/L within the combined TCE, cis-1,2-DCE, and VC plumes. This may limit the rate of reductive dechlorination. However, as the plume moves downgradient, the organic carbon content appears to increase adjacent to Indian Field Creek. TOC concentrations were measured as high as 17 mg/L at YS03-GW012, near Indian Field Creek. In sediment samples collected from the creek, TOC was detected as high as 22,000 milligrams per kilogram (mg/kg). The TPH present in unsaturated soils may leach slowly into the aquifer and also be a potential source of carbon for reductive dechlorination. However, the carbon available to microorganisms for biodegradation is an uncertainty.

Metals can occur in the environment as free ions or as complexed species composed of positively charged cations, negatively charged anions, or neutral molecules. The mobility of metals is particularly complex and depends on such factors as overall groundwater composition, pH, metal complex formation, valence state of the metal, and cation-ion exchange capacity. Transformation occurs when the valence state of metals is increased (oxidation) or decreased (reduction). It can be caused by changes in oxidation potential or pH, and by microbial or nonmicrobial (abiotic) processes. Transformation may have a significant effect on the mobility of a metal, either increasing or decreasing it.

The solid forms of iron (iron hydroxides) and manganese (manganese oxides) are usually present in the natural soil matrix. If sufficient amounts of oxygen and nitrate are not present in the subsurface, iron hydroxides and manganese oxides will be used as electron acceptors by metabolic activity and dissolved under reducing conditions into soluble forms. Sulfides present in groundwater can also result in the dissolution of iron hydroxides. Several inorganic constituents (such as arsenic) have a tendency to sorb to these iron hydroxides and manganese oxides. If these compounds are dissolved, the inorganic constituents that are bound to these hydroxides and oxides will also be released. At Site 3, groundwater appears to be under slightly reduced conditions due to the natural water quality and biodegradation of contamination. This may be causing the higher detected concentrations of dissolved manganese and arsenic found at the site. Another factor is the environment surrounding Indian Field Creek, which is likely under even more reduced conditions naturally. The highest concentrations of dissolved manganese, arsenic, and TOC were detected in wells adjacent to the creek.

2.2.3 Risk Assessment

The HHRA was conducted to evaluate the potential human health risks associated with groundwater at Site 3. This baseline risk assessment characterized potential current and future human health risks on the basis of potential and unlikely (but conservative) receptor populations and exposure scenarios if no remedial action is implemented. Under current land use, there are no complete exposure pathways for groundwater. Potential future exposure routes studied in the evaluation were: residents (adult and child), construction workers, and industrial workers. However, the future residential land use scenario evaluated in this assessment was very conservative because it assumed that land use will change in the future to allow residential development. Even if residential land use occurred, it is unlikely that the Yorktown-Eastover Aquifer groundwater would be used as a potable water supply.

Table 2-2 provides a summary of the HHRA results. The future construction worker reasonable maximum exposure (RME) non-carcinogenic hazard associated with exposure to groundwater exceeded the acceptable hazard index (HI) of 1.0; TCE (dermal contact) was the only individual constituent of potential concern with an HI exceeding 1.0. The central tendency exposure (CTE) non-carcinogenic hazard was also above the acceptable HI of 1.0; however, there were no target organ/ effects with HIs exceeding 1.0. The future construction worker RME carcinogenic risk (1.7×10^{-5}) is within the acceptable risk range of 10^{-6} to 10^{-4}. All estimated non-carcinogenic hazards and carcinogenic risks associated with future residential and industrial receptors exposed to groundwater at Site 3 exceeded the acceptable non-carcinogenic HI of 1.0 or the carcinogenic risk range of 10^{-6} to 10^{-4}.

The following groundwater COCs were identified: TCE, cis-1,2-DCE, VC, arsenic, and manganese. Chromium, iron, and 1,1-dichloroethane (DCA) were not included as COCs for the following reasons:

- Chromium in groundwater poses risk only under the construction worker scenario, due to concentrations in total metals samples. The total HI for the construction worker non-cancer hazard was 2.9 (RME) and 1.2 (CTE), which slightly exceeds USEPA's threshold for an acceptable hazard (1.0). The individual contribution to the hazard quotient (HQ) from chromium was 0.3 (RME) and 0.2 (CTE) and there were no individual target organ HIs greater than 1.0. Consequently, the Navy, in partnership with the USEPA and Virginia Department of Environmental Quality, recommended that no additional action be required to address chromium in groundwater at Site 3 in the Phase II RI.

- Iron was also identified as a human health constituent of potential concern based on the residential child who uses groundwater as a potable water supply. However, iron is an essential human nutrient, and the average daily intake of iron by a child as presented in the HHRA (0.12 mg/kg per day [from Appendix J, Table 7.2.RME from the RI] x body weight of 15 kilograms per day = 1.8 milligrams per day [mg/day]) is below the estimated average requirements for dietary reference intake. The average daily nutrient intake level estimated to meet the requirements of half of the healthy individuals in a group is 3.0 mg/day for children ages 1 to 3 years and 4.1 mg/day for children ages 4 to 8 years(Food and Nutrition Board, Institute of Medicine, National Academies, 2001),. In addition, the maximum detected concentration of iron (2,010 µg/L in filtered sample YS03-GW021) in groundwater at Site 3 was below the calculated human health based PRG (11,000 µg/L). Therefore, iron in groundwater is not expected to pose unacceptable risks and was not been carried forward as a COC.
- 1,1-DCA in groundwater only poses risk under the future resident child/adult scenario. However, 1,1 DCA only had a minor contribution ($2x10^{-6}$) to the total cancer risk of $2x10^{-4}$. On the contrary, all other carcinogenic COCs contributed individual cancer risks above 10^{-4}. Therefore, 1,1-DCA was not carried forward as a COC.

2.2.4 Phase II Remedial Investigation Conclusions

The Phase II RI report recommended the following:

- An FS to address concentrations of TCE, cis-1,2-DCE, VC, arsenic and manganese in groundwater
- A pre-design investigation following completion of the ROD:
  - Installation of a new shallow monitoring well northwest of monitoring well 3GW28 to refine the delineation of groundwater contamination
  - Analysis of SVOCs at shallow monitoring well YS03-GW022 to confirm that TPH in vadose zone soil adjacent to MIP-5 have not affected groundwater
  - Analysis of 1,4-dioxane at shallow monitoring wells YS03-GW020, -GW024, -GW027, and –GW028 to confirm that there is no human health concern in groundwater based on recently available toxicity data

2.2.5 Post-Phase II Remedial Investigation Discussion

The Site 3 pre-design investigation recommendations included in the Phase II RI report were discussed during the November 2012 Yorktown Partnering Meeting. The following is a summary of the considerations during the development of the pre-design investigation:

- Because GW028 is located south of the ravine, and the ravine is expected to create a diversion to groundwater flow (**Figure 1-3**), there is no need for an additional monitoring well to the northwest of GW028.
- Sampling of monitoring well YS03-GW022 for SVOCs at the MIP-5 location.
- Sampling of shallow monitoring wells YS03-GW020, -GW024, -GW027, and –GW028 for 1,4-dioxane for evaluation of recently available toxicity data.
- Installation of a new shallow monitoring well southeast of the site adjacent to Indian Field Creek that would serve as a site-specific background location to evaluate the impacts of possible reducing conditions caused by the wetlands on the mobility of the arsenic and manganese in groundwater.

- Installation of up to three additional new shallow monitoring wells along the center of the TCE plume to further refine the understanding of groundwater contamination.
- Installation of a new shallow monitoring well adjacent to YS03-GW007, which has been damaged and not sampled since 1996, to help monitor future plume dynamics.
- Installation of a new deep monitoring well adjacent to shallow monitoring well YS03-GW027 to resolve data gaps in the CSM, which include refining the site lithology, identifying the base of the Yorktown-Eastover Aquifer, evaluating the vertical hydraulic gradient next to Indian Field Creek, and confirming that contaminated groundwater is not migrating under Indian Field Creek.
- Collection of additional MNA data. This includes TCE and its reductive degradation daughter products (cis-1,2-DCE, VC, ethene, and ethane). Required analyses listed in Table 2-3 of the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (USEPA, 1998), TOC, and alkalinity will also be collected to assess if subsurface conditions are favorable for reductive dechlorination.

TABLE 2-1
Groundwater Detected Analytical Results
March and July 2009
Site 3 Feasibility Study
Naval Weapons Station Yorktown
Yorktown, Virginia

Station ID	YS03-GW006	YS03-GW008A	YS03-GW008B	YS03-GW015	YS03-GW015A	YS03-GW018	YS03-GW019	YS03-GW019A	YS03-GW020	YS03-GW020A	YS03-GW021	YS03-GW022	YS03-GW023	YS03-GW024	YS03-GW025	YS03-GW026	YS03-GW027	YS03-GW028	YS03-GW029	
Sample Date	03/19/09	03/18/09	03/18/09	03/17/09	03/17/09	03/17/09	03/19/09	04/06/09	03/20/09	03/20/09	03/18/09	03/19/09	03/18/09	03/30/09	03/20/09	03/17/09	03/20/09	03/19/09	03/30/09	07/13/09
Chemical Name																				
Volatile Organic Compounds (µg/l)																				
cis -1,2-Dichloroethene (*cis* -DCE)	0.15 J	0.5 U	0.12 J	3.7	0.18 J	0.5 U	330	6.5	0.5 U	0.5 U	2.5	110	5.9	1,400	52	330	890	120 L	0.29 J	0.5 U
Trichloroethene (TCE)	0.49 J	0.5 U	4.9	3.8	0.5 U	0.91	190	3.1	0.5 U	0.5 U	2.9	63	9.9	400	9.6	130	130	36 L	0.24 J	0.5 U
Vinyl chloride (VC)	0.5 U	0.5 U	0.5 U	2.3	0.5 U	0.5 U	58	0.26 J	0.5 U	0.5 U	0.5 U	9.8	0.19 J	1,200	4.3	10 U	1,100	5.2 L	0.24 J	0.5 U
Total Metals (µg/l)																				
Arsenic	2.2 U	2.2 U	2.2 U	2.2 U	2.2 U	2.2 U	2.2 U	60.7	2.2 U	2.2 U	45	2.2 U	2.7 J	32.3	3.6 J	2.2 U	17.2	2.2 U	18.5	NA
Manganese	41.7	77.5	39.2	219	47.6	0.42 B	33.3	1,320	25.6	80.2	1,260	102	147	523	147	79.1	500	30.5	42.7	NA
Dissolved Metals (µg/l)																				
Arsenic, Dissolved	4.9 J	4.7 J	3.5 J	3.1 J	2.2 U	2.2 U	4.8 J	5.6 J	2.8 J	2.9 J	34.7	6.5 J	6 J	6.4 J	7.9 J	3.1 J	5.7 J	3.2 J	25.8	NA
Manganese, Dissolved	28.5	77.3	32.8	226	25.5	0.37 U	32.8	448	13.5	59.2	1,260	121	152	225	148	76.5	482	28.2	40.7	NA
Wet Chemistry																				
Alkalinity (mg/l)	10 U	178	300	399	176	10 U	356	160	124	117	293	428	236	536 D	362	270	386	214	194	NA
Chloride (mg/l)	12 D	10 D	15 D	7.2 JD	8.9 JD	7.9 JD	14 D	10 D	11 D	12 D	17 D	19 D	12 D	56 D	10 D	16 D	33 D	12 D	10 JD	NA
Ethane (µg/l)	2 U	2 U	2 U	0.4 J	2 U	2 U	1 J	2 U	2 U	2 U	0.3 J	0.7 J	0.3 J	21	0.5 J	0.1 J	15	0.2 J	0.1 J	NA
Ethene (µg/l)	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	0.2 J	2 U	0.2 J	1 J	2 U	0.3 J	1 J	2 U	0.05 J	NA
Sulfate (mg/l)	62 D	47 D	29 D	18 JD	24 JD	26 D	24 JD	39 D	49 D	25 JD	18 JD	19 JD	95 D	11 JD	18 JD	43 D	20 JD	24 JD	21 JD	NA
Total organic carbon (TOC) (mg/l)	0.44 J	1.3 J	0.54 J	1.8 J	1.1 J	1.9 J	1.4 J	1.8 J	1.3 J	1.6 J	17	2.7 J	1.5 J	6.8	2.9 J	2 J	1 J	2.1 J	4 J	NA
Dechlorinating Bacteria (cells/ml)																				
Dehalococcoides	NA	NA	NA	NA	NA	NA	6.1	NA	NA	NA	NA	NA	NA	26.2	NA	NA	NA	NA	NA	NA
Field Parameter																				
Dissolved Oxygen (mg/L)	0.57	0.01	0.52	0.75	0.24	6.06	0.32	NR	2.5	2.53	0.45	0.67	0.4	3.71	2.12	ND	2.08	2.26	2.56	NA
Dissolved Oxygen by Chemets (mg/L)	5	1.5	1.5	2.5	1.5	7	2	4	2.5	1.5	2	1	1	1	1	3	1	5	1.5	NA
Oxidation Reduction Potential (mV)	-124	-180	-96	-169	-89	-79	-150	NR	-120	-137	-286	-54	-269	17	17	-184	73	18	-119	NA
pH	7.48	12.79	6.16	7.57	10.58	12.77	7.3	NR	7	7.01	6.56	9.45	6.71	6.2	6.73	12.46	6.65	8.34	6.69	NA
Salinity (pct)	0.02	0.03	0.02	0.03	0.02	0.01	0.03	NR	0.9	0.2	0.02	0.05	0.02	4	ND	0.04	ND	0.02	ND	NA
Specific Conductivity (mS/cm)	0.432	0.655	0.534	0.663	0.559	0.179	0.601	NR	15.9	3.7	0.465	0.999	0.578	NR	0.761	0.854	0.95	0.557	0.565	NA
Temperature (°C)	16.81	15.44	15.36	14.95	14.92	15.06	16.38	NR	15.04	14.95	16.29	17.02	15.9	16.8	14.9	14.9	15.6	13.8	16.3	NA
Turbidity (NTU)	9.1	ND	ND	NR	10	NR	ND	NR	60	41.4	NR	ND	7	580	120	26.4	165	ND	17.6	NA
Nitrite (mg/L)	0.004	ND	ND	0.015	0.063	ND	ND	ND	0.005	0.009	ND	0.018	ND	ND	ND	0.008	ND	0.015	ND	NA
Nitrate (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA
Sulfide (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA

Notes:

Shading indicates detections
NA - Not analyzed
ND - Not detected
B - Analyte not detected above the level reported in blanks
D - Compound identified in an analysis at a secondary dilution factor
J - Analyte present, value may or may not be accurate or precise
K - Analyte present, value may be biased high, actual value may be lower
L - Analyte present, value may be biased low, actual value may be higher
U - The material was analyzed for, but not detected
UJ - Analyte not detected, quantitation limit may be inaccurate
UL - Analyte not detected, quantitation limit is probably higher

Field duplicates are not shown.

ºC - degrees Celsius
cells/ml - Cells per milliliter
mg/l - Milligrams per liter
µg/l - Micrograms per liter
mS/cm - milliseimens per centimeter
mV - millivolts
NTU - nephelometric turbidity unit
pct - Percent

TABLE 2-2

Summary Cancer Risks and Hazard Indices for Groundwater

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Receptor	Exposure Route	Cancer Risk	Chemicals with Cancer Risks >10^{-6} and <10^{-4}	Chemicals with Cancer Risks >10^{-4}	Hazard Index	Chemicals with HI>0.1 and <1	Chemicals with HI>1
Reasonable Maximum Exposure							
Future Resident Adult	Ingestion	N/A			4.4E+01	Manganese-dissolved	cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride, Arsenic-dissolved
	Dermal Contact	N/A			4.3E+00	Vinyl chloride	cis-1,2-Dichloroethene, Trichloroethene
	Inhalation/Shower	N/A			7.7E-01	Vinyl chloride	
	Inhalation/Indoor Air	N/A			1.2E+01		Trichloroethene, Vinyl chloride
	Total	N/A			6.1E+01		cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride, Arsenic-dissolved
Future Resident Child	Ingestion	N/A			1.0E+02	Iron-Dissolved	cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride, Arsenic-dissolved, Manganese-dissolved
	Dermal Contact	N/A			9.9E+00	Manganese-dissolved	cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride
	Inhalation/Shower	N/A			1.4E+01		Trichloroethene, Vinyl chloride
	Inhalation/Indoor Air	N/A			5.6E+01		Trichloroethene, Vinyl chloride
	Total	N/A			1.8E+02		cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride, Arsenic-dissolved, Manganese-dissolved
Future Resident Adult/Child	Ingestion	1.8E-02		Trichloroethene, Vinyl chloride, Arsenic-dissolved	N/A		
	Dermal Contact	3.7E-03	Trichloroethene, Arsenic-dissolved	Vinyl chloride	N/A		
	Inhalation/Shower	3.9E-04	1,1-Dichloroethane, Trichloroethene	Vinyl chloride	N/A		
	Inhalation/Indoor Air	2.5E-03		Vinyl chloride, Trichloroethene	N/A		
	Total	2.4E-02		Trichloroethene, Vinyl chloride, Arsenic-dissolved	N/A		

TABLE 2-2

Summary Cancer Risks and Hazard Indices for Groundwater

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Receptor	Exposure Route	Cancer Risk	Chemicals with Cancer Risks >10^{-6} and <10^{-4}	Chemicals with Cancer Risks >10^{-4}	Hazard Index	Chemicals with HI>0.1 and <1	Chemicals with HI>1
Future Industrial Worker - Adult	Ingestion	3.0E-03	Trichloroethene	Vinyl chloride, Arsenic-dissolved	1.6E+01	Arsenic-dissolved, Manganese-dissolved	cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride
	Dermal Contact	N/A			N/A		
	Inhalation/Indoor Air	4.1E-04	Trichloroethene	Vinyl chloride	1.4E+01		Trichloroethene, Vinyl chloride
	Total	3.4E-03		Vinyl chloride	3.0E+01		cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride
Future Construction Worker - Adult	Ingestion	N/A			N/A		
	Dermal Contact	1.7E-05	Vinyl chloride, Chromium		2.4E+00	Vinyl chloride, Chromium, Manganese	Trichloroethene
	Inhalation/Excavation	5.5E-08			4.7E-01	Trichloroethene	
	Total	1.7E-05			2.9E+00		Trichloroethene
Central Tendency Exposure							
Future Resident Adult	Ingestion	N/A			2.1E+01	Manganese-Dissolved	cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride, Arsenic-dissolved
	Dermal Contact	N/A			1.9E+00	cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride	
	Inhalation/Shower	N/A			2.6E+00		Vinyl chloride
	Inhalation/Indoor Air	N/A			2.4E+01		Trichloroethene, Vinyl chloride
	Total	N/A			4.9E+01		cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride

TABLE 2-2

Summary Cancer Risks and Hazard Indices for Groundwater

Site 3 Feasibility Study

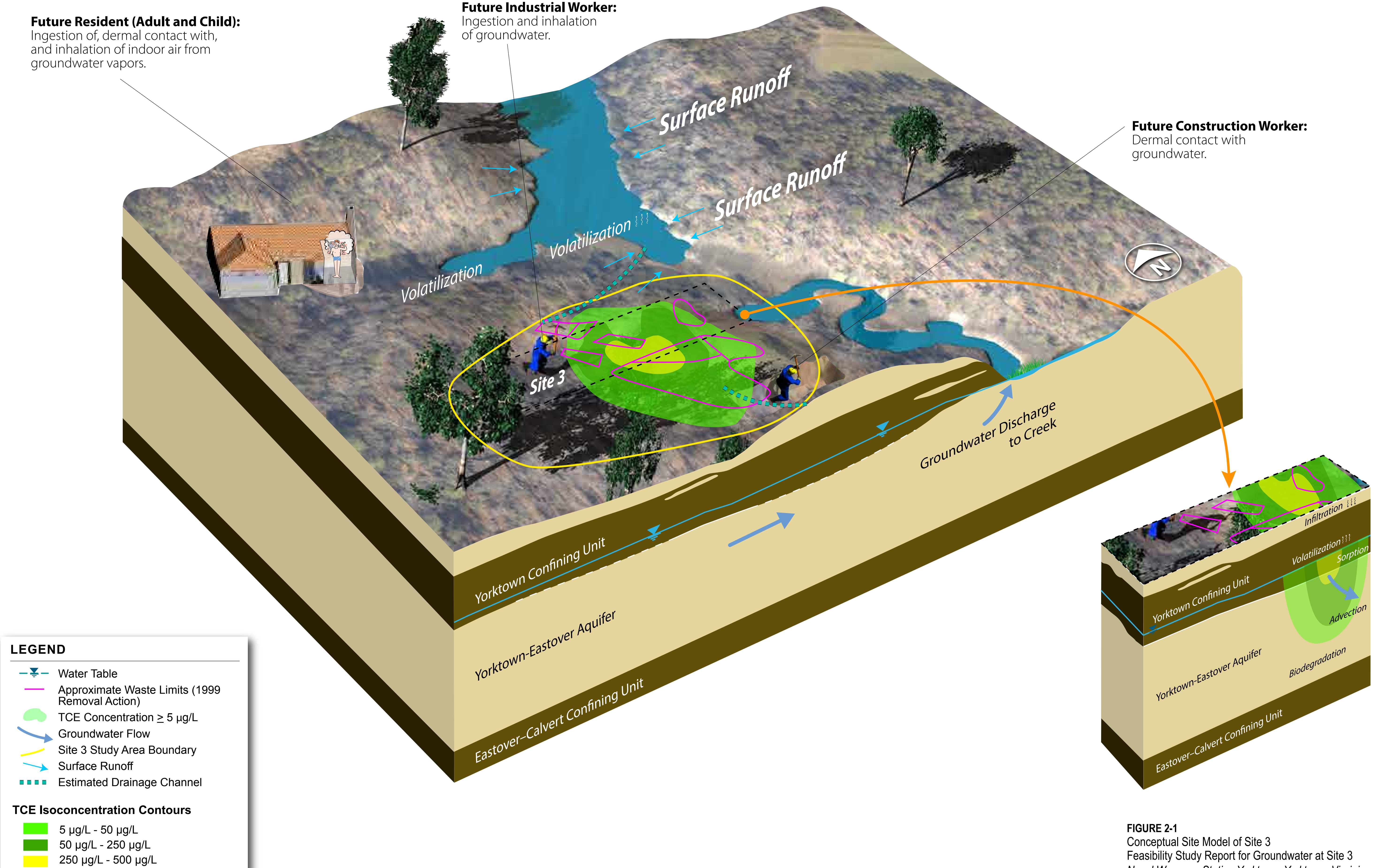
Naval Weapons Station Yorktown

Yorktown, Virginia

Receptor	Exposure Route	Cancer Risk	Chemicals with Cancer Risks $>10^{-6}$ and $<10^{-4}$	Chemicals with Cancer Risks $>10^{-4}$	Hazard Index	Chemicals with HI>0.1 and <1	Chemicals with HI>1
Future Resident Child	Ingestion	N/A			6.9E+01		cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride, Arsenic-dissolved, Manganese-dissolved
	Dermal Contact	N/A			5.5E+00	Vinyl chloride	cis-1,2-Dichloroethene, Trichloroethene
	Inhalation/Shower	N/A			1.4E+00	Vinyl chloride	Trichloroethene
	Inhalation/Indoor Air	N/A			2.4E+01		Trichloroethene, Vinyl chloride
	Total	N/A			9.9E+01		cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride, Arsenic-dissolved, Manganese-dissolved
Future Resident Adult/Child	Ingestion	8.0E-03		Trichloroethene, Vinyl chloride, Arsenic-dissolved	N/A		
	Dermal Contact	2.8E-04	Trichloroethene	Vinyl chloride	N/A		
	Inhalation/Shower	1.6E-04	1,1-Dichloroethane, Trichloroethene, Vinyl chloride		N/A		
	Inhalation/Indoor Air	9.9E-04		Trichloroethene, Vinyl chloride	N/A		
	Total	9.4E-03		Trichloroethene, Vinyl chloride, Arsenic-dissolved	N/A		
Future Industrial Worker - Adult	Ingestion	9.5E-04	Trichloroethene, Arsenic-dissolved	Vinyl chloride	1.4E+01	Arsenic-dissolved, Manganese-dissolved	cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride
	Dermal Contact	N/A			N/A		
	Inhalation/Indoor Air	3.9E-04	Trichloroethene	Vinyl chloride	8.4E+00		Trichloroethene, Vinyl chloride
	Total	1.3E-03		Vinyl chloride	2.2E+01		cis-1,2-Dichloroethene, Trichloroethene, Vinyl chloride
Future Construction Worker - Adult	Ingestion	N/A			N/A		
	Dermal Contact	8.8E-06	Vinyl chloride		1.2E+00	Trichloroethene, Vinyl chloride, Chromium, Manganese	
	Total	8.8E-06			1.2E+00		

Note

N/A - Not applicable, pathway incomplete.

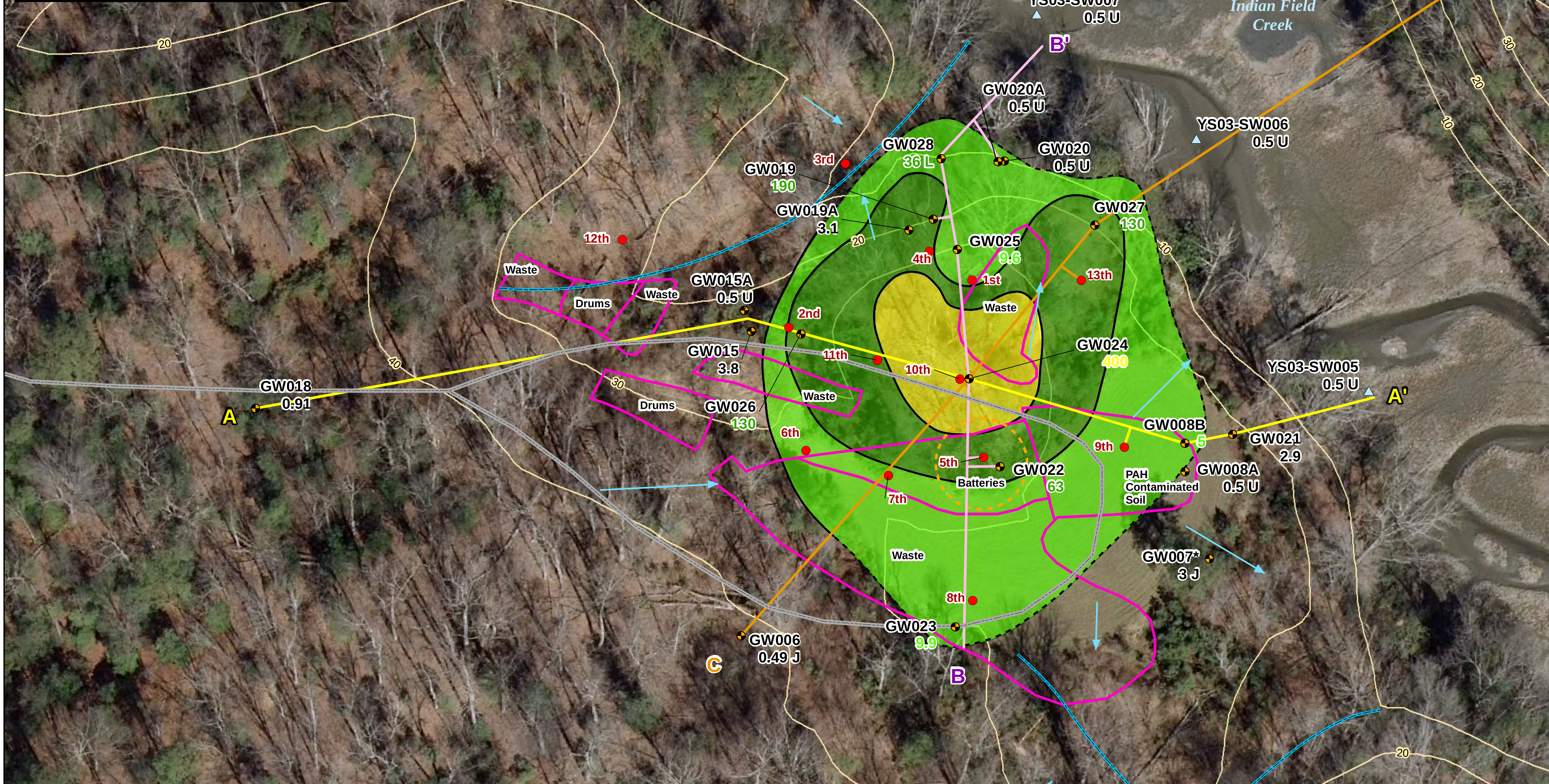


Note: While TCE is the only contaminant shown, the other COCs are co-located within the TCE contaminated area.

FIGURE 2-1
Conceptual Site Model of Site 3
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown, Yorktown, Virginia

DVR \\MNUSTRICTGFS01\PROJECTS\USNAVFACENGCOM405450\400210YORKTOWN\MAPFILES\429391_SITE3_FS\FIGURE 2-2 - SITE 3 TCE ISOCONCENTRATIONS.MXD CELEFTHERIADIS 4/29/2013 8:48:29 AM

COC	PRG (µg/L)
TCE	5



Legend

- Surface Water Sample Location
- Yorktown Monitoring Wells
- MIP Locations

TCE Isoconcentrations (Data collected in 2009)

- 5 µg/L - 50 µg/L
- 50 µg/L - 250 µg/L
- 250 µg/L - 500 µg/L
- Approximate Unsaturated TPH Contamination
- Approximate Waste Limits (1999 Remedial Action)
- Landfill Access Road
- Transect A-A'
- Transect B-B'
- Transect C-C'
- Elevation Contour (10 ft interval)
- Groundwater Flow Direction
- Estimated Drainage Channel

Note:
Concentrations are in µg/L
* Groundwater data for GW07 from 1996
"U" – The material was analyzed for, but not detected
"L" – Analyte present, value may be biased low, actual value may be higher
"J" – Analyte present, value may or may not be accurate or precise
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

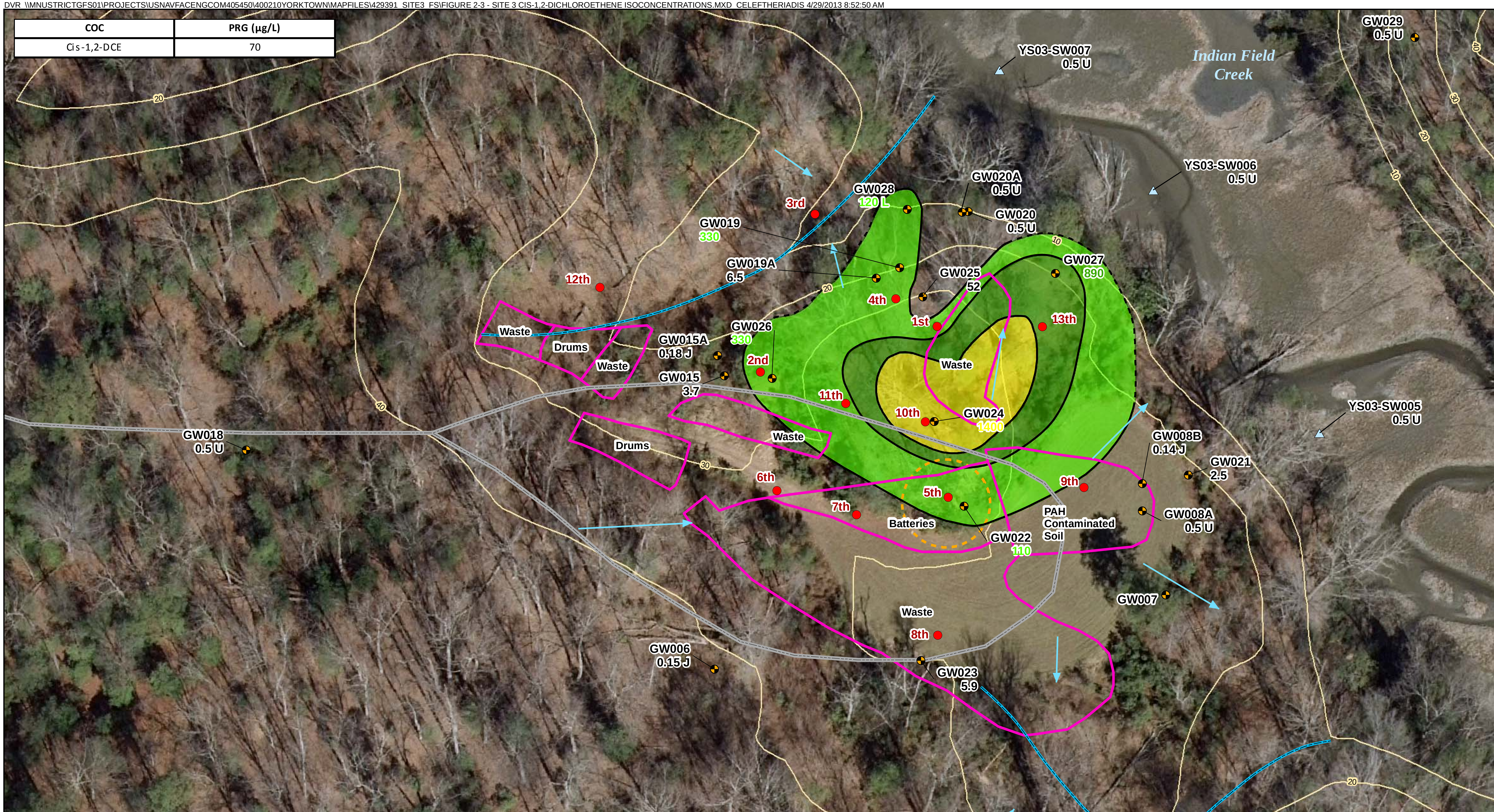
N W E S

0 60 120 Feet

Figure 2-2
Site 3 TCE Isoconcentrations
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

CH2MHILL

COC	PRG (µg/L)
Cis-1,2-DCE	70



Legend

- Surface Water Sample Location
- Yorktown Monitoring Wells
- MIP Locations

Cis-1,2-Dichloroethene Isoconcentrations (Data collected in 2009)

- 70 µg/L - 700 µg/L
- 700 µg/L - 1000 µg/L
- 1000 µg/L - 1500 µg/L
- Approximate Unsaturated TPH Contamination
- Approximate Waste Limits (1999 Remedial Action)
- Landfill Access Road
- Elevation Contour (10 ft interval)
- Groundwater Flow Direction
- Estimated Drainage Channel

Note:
Concentrations are in µg/L
"L" - Analyte present, value may be biased low, actual value may be higher
"J" - Analyte present, value may or may not be accurate or precise
"U" – The material was analyzed for, but not detected
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

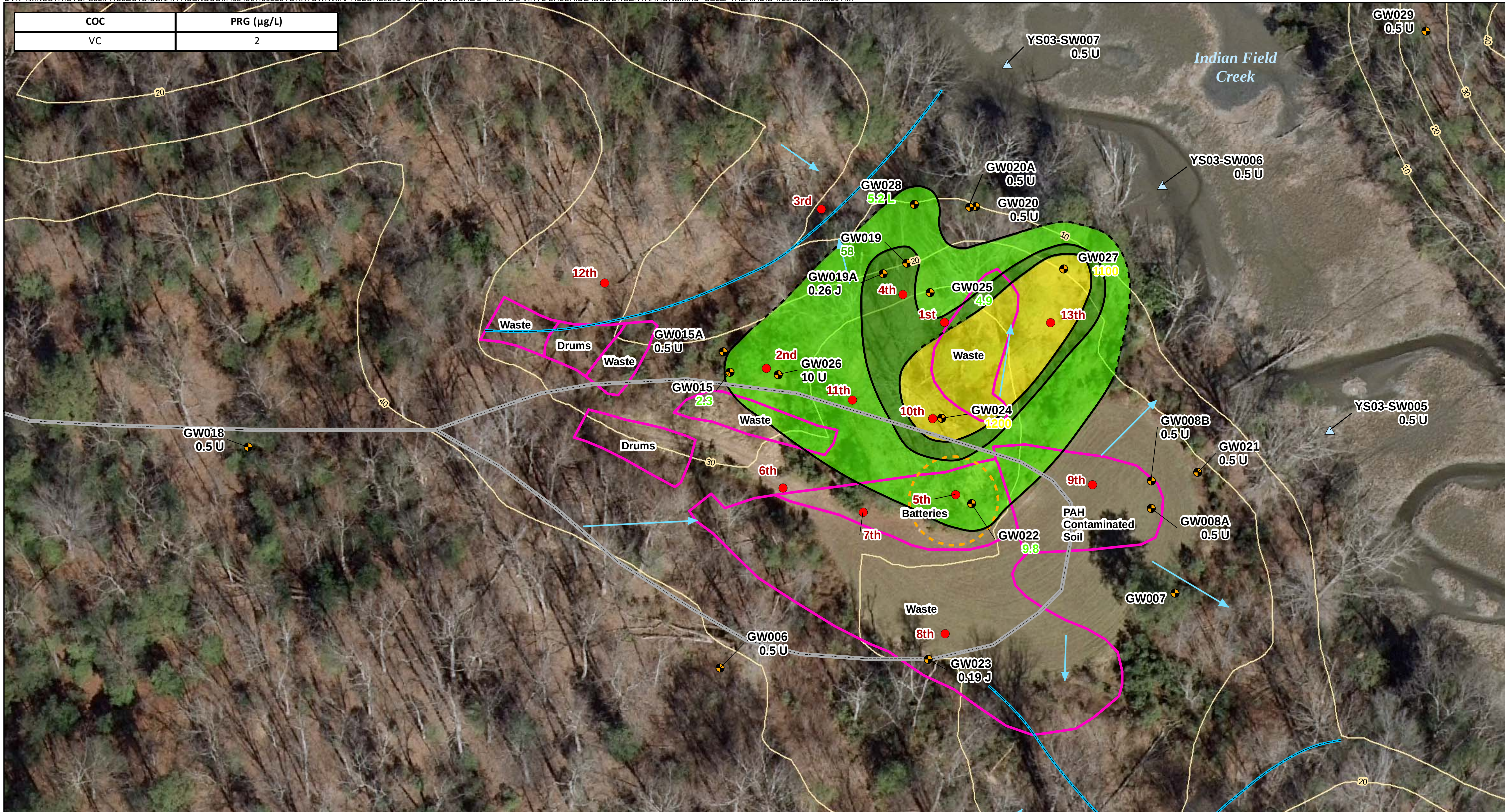
N W E S

0 60 120 Feet

Figure 2-3
Site 3 Cis-1,2-Dichloroethene Isoconcentrations
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

CH2MHILL

COC	PRG (µg/L)
VC	2



Legend

- Surface Water Sample Location
- Yorktown Monitoring Wells
- MIP Locations

VC Isoconcentrations (Data collected in 2009)

- 2 µg/L - 20 µg/L
- 20 µg/L - 100 µg/L
- 100 µg/L - 1500 µg/L

- Approximate Unsaturated TPH Contamination
- Approximate Waste Limits (1999 Remedial Action)
- Landfill Access Road
- Elevation Contour (10 ft interval)
- Groundwater Flow Direction
- Estimated Drainage Channel

Note:
Concentrations are in µg/L
"L" - Analyte present, value may be biased low, actual value may be higher
"J" - Analyte present, value may or may not be accurate or precise
"U" – The material was analyzed for, but not detected
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

N W E S

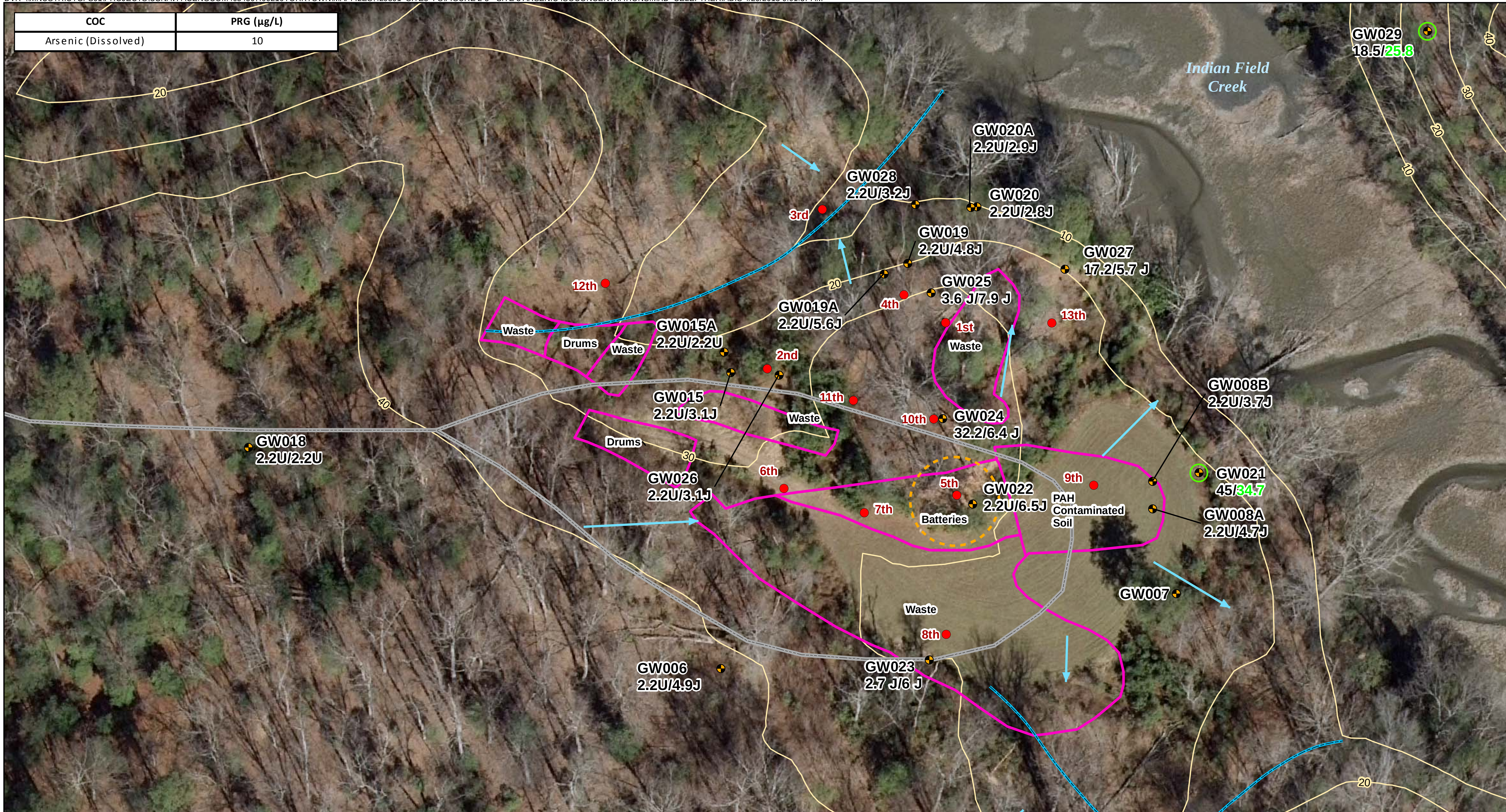
0 60 120 Feet

Figure 2-4
Site 3 Vinyl Chloride Isoconcentrations
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

CH2MHILL

DVR \\MNUSTRICTGFS01\PROJECTS\USNAVFACENGCOM405450\400210YORKTOWN\MAPFILES\429391_SITE3_FS\FIGURE 2-5 - SITE 3 ARSENIC ISOCONCENTRATIONS.MXD CELEFTHERIADIS 4/29/2013 9:01:37 AM

COC	PRG (µg/L)
Arsenic (Dissolved)	10



Legend

- Yorktown Monitoring Wells
- MIP Locations
- Landfill Access Road
- Elevation Contour (10 ft interval)
- Estimated Drainage Channel
- Groundwater Flow Direction
- Approximate Waste Limits (1999 Remedial Action)
- Approximate Unsaturated TPH Contamination
- Exceeds Dissolved Arsenic Preliminary Remediation Goal

Note:
Concentrations shown are total arsenic/dissolved arsenic in units of µg/L.
"U" - Material analyzed for, but not detected
"J" - Analyte present, value may or may not be accurate or precise
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.
Values highlighted in green indicate an exceedance of Arsenic Preliminary Remediation Goal.
Data collected in 2009.

N W E S

0 60 120 Feet

Figure 2-5
Site 3 Arsenic Isoconcentrations
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

CH2MHILL

DVR \\MNUSTRICTGFS01\PROJECTS\USNAVFACENGCOM405450\400210YORKTOWN\MAPFILES\429391_SITE3_FS\FIGURE 2-6 - SITE 3 MANGANESE ISOCONCENTRATIONS.MXD CELEFTHERIADIS 4/29/2013 9:17:09 AM

COC	PRG (µg/L)
Manganese (Dissolved)	320

Legend

- Yorktown Monitoring Wells
- MIP Locations
- Landfill Access Road
- Elevation Contour (10 ft interval)
- Estimated Drainage Channel
- Groundwater Flow Direction
- Approximate Waste Limits (1999 Remedial Action)
- Approximate Unsaturated TPH Contamination
- Exceeds Dissolved Manganese Preliminary Remediation Goal

Note:
Concentrations shown are total manganese/dissolved manganese in units of ug/L.
"U" - Material analyzed for, but not detected
"B" - Analyte not detected above the level reported in blanks
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.
Values highlighted in green indicate an exceedance of Manganese Preliminary Remediation Goal.
Data collected in 2009.

N W E S

0 60 120 Feet

Figure 2-6
Site 3 Manganese Isoconcentrations
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

CH2MHILL

SECTION 3

Remedial Action Objectives and Applicable or Relevant and Appropriate Requirements

This section discusses the NCP and CERCLA objectives and identifies the Site 3 RAOs and ARARs for the remedial action alternatives considered in the FS.

Because the site characterization and remediation process at WPNSTA Yorktown is being conducted in accordance with the guidelines established under CERCLA, the general RAOs are defined by the NCP and CERCLA, as amended by SARA. CERCLA defines the statutory requirements for developing remedies. Site-specific RAOs relate to specific contaminated media and the potential exposure routes.

Site-specific RAOs, which require an understanding of the contaminants and the physical properties in their respective media, are based on an evaluation of the risks to public health and to the environment and evaluation of the ARARs.

Section 121(d) of SARA mandates that site remediation under CERCLA must achieve a level or standard of control for hazardous substances that at least attains the levels specified in the ARARs. Only promulgated federal and state laws and regulations can be considered ARARs.

3.1 NCP and CERCLA Objectives

The NCP requires that the selected remedy meet the following objectives:

- Each remedial action selected will 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 identified at the time of the ROD signature (40 CFR 300.430 [f][ii][B]).
- Each remedial action selected will be cost-effective, provided that it first satisfies the threshold criteria set forth in §300.430(f)(1)(ii)(A) and (B). A remedy will be deemed cost-effective if its costs are proportional to its overall effectiveness.
- Each remedial action will 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” (Section 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 over remedial actions not involving such treatment” (Section 121[b][1]). If the treatment or recovery technologies selected is not a permanent solution, an explanation must be published (Section 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 (Section 121[b][1]).
- The selected remedy must comply with or attain the level of any standard, requirement, criterion, or limitation under federal environmental law or any promulgated standard, requirement, criterion, or

limitation under a state environmental or facility siting law that is more stringent than any federal standard, requirement, criterion, or limitation (Section 121[d][2][A]).

3.2 Remedial Action Objectives

Both the level of contamination and the potential exposure routes are considered when developing medium-specific and site-specific RAOs for protecting public health and the environment.

Additional action is necessary to address site-related COCs within the groundwater at Site 3. The RAOs for the protection of human health and the environment from Site 3 groundwater are:

- Reduce TCE, cis-1,2-DCE, VC, arsenic, and manganese concentrations in groundwater to risk-based cleanup levels
- Prevent future human receptors (resident and industrial worker) exposure to groundwater until risk-based cleanup levels are met
- Prevent unacceptable risk to ecological receptors from exposure to COCs in groundwater that discharges to Indian Field Creek

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 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. Once included in a ROD, 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 the 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 deal directly with actions or with conditions in the environment. Administrative requirements implement the substantive requirements by prescribing procedures, such as fees, permitting, and inspection, which 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 as follows. The remedial action alternatives developed during the FS were analyzed for compliance with the potential federal and state ARARs presented in **Appendix A**.

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 COCs 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 A**.

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. The wetland areas adjacent to Site 3 will remain undisturbed during the remedial actions identified in this report. Federal and Commonwealth of Virginia location-specific regulations that have been reviewed are summarized in **Appendix A**.

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 A**.

3.4 Development of Risk-Based Preliminary Remediation Goals

3.4.1 Human Health Remediation Goals

PRGs have been developed for site-related groundwater COCs that contribute to a potential unacceptable risk to human health under future residential scenarios. Chemicals were identified as human health COCs during the RI if they contributed a cancer risk greater than 10^{-6} to cumulative risk greater than 10^{-4}, or a non-cancer hazard greater than 0.1 to cumulative non-cancer hazard greater than 1.

The selected PRGs for site-related COCs are presented in **Table 3-1**. The MCL was established as the PRG when available (for TCE, cis-1,2-DCE, VC, and arsenic). MCLs are the highest level of a contaminant allowed in drinking water. They are set close to the concentration at which there is no known or suspected risk to health given the best available treatment technology and cost considerations. Because no MCL has been established for manganese, a risk-based PRG was calculated. The Yorktown background values for dissolved arsenic and manganese in groundwater were also taken into consideration when selecting the PRGs, and are also listed in **Table 3-1**. As more data are collected, site-specific background data will also be documented.

The risk-based PRG for manganese was calculated using the exposure point concentration (EPC) and non-carcinogenic hazards or carcinogenic risks calculated in the baseline HHRA (CH2M HILL, 2012). The ratio between the target carcinogenic risk and the calculated carcinogenic risk (or target non-carcinogenic hazard and calculated non-carcinogenic hazard) from a specific COC in groundwater was used to calculate the PRG, as follows:

$$\text{PRG (chemical i)} = \frac{\text{EPC (chemical i)} \times \text{ Target Risk or Hazard (chemical i)}}{\text{Calculated Risk (chemical i)}}$$

where,

PRG (chemical i) = PRG for chemical i, µg/L

EPC (chemical i) = EPC for chemical i, µg/L

Target Risk or Hazard = 10^{-5} for carcinogens, and 1 for non-carcinogens

Calculated Risk (chemical i) = calculated (cancer risk for carcinogens or calculated non-cancer hazard for non-carcinogens) for chemical i

The information from the HHRA used to calculate the PRG for manganese is provided in **Appendix B** (**Tables B-1** and **B-2**). The PRG calculations are presented in **Appendix B** (**Table B-3**). The target risk level of 10^{-5} was selected so that cumulative risk does not exceed 10^{-4}, and the target hazard level of 1 was selected so that the cumulative hazard to each target organ does not exceed 1 (none of the COCs affect the same target organ).

3.4.2 Extent of Site-Related COCs Exceeding Preliminary Remediation Goals

The estimated extents of organic and inorganic constituent contamination in groundwater that will be addressed by the remedial action alternatives discussed in this report are presented on **Figure 3-1**. The horizontal footprint of the combined TCE, cis-1,2-DCE, and VC plumes is 60,250 square feet (ft^2). The combined TCE, cis-1,2-DCE, and VC plumes extend from the waste area at monitoring wells GW015/GW015A, approximately 250 feet to the east towards Indian Field Creek. Because of the distribution of historical waste at the site and the northeastern groundwater flow component, the combined plumes are approximately 300 feet wide from the north to the south. Exceedances of arsenic and manganese PRGs generally occur only in the most downgradient wells and do not correlate with the highest TCE, cis-1,2-DCE, and VC concentrations observed at the site. Groundwater data collected during the RI indicate that the bulk of contamination is located in the uppermost portion of the Yorktown-Eastover Aquifer. The vertical extent of contamination is estimated to be from the groundwater table (approximately 2 to 5 feet above msl within the area of contamination) to an elevation of 32 feet below msl.

To evaluate a range of less- to more-aggressive remedial alternatives for the organic constituent contamination, two target treatment zones (TTZs) were identified. TTZ-1 is defined as the 11,200-ft^2 area where CVOC concentrations are 50 percent higher than their PRG—that is, where TCE is greater than 250 μg/L, cis-1,2-DCE is greater than 3,200 μg/L, and VC is greater than 100 μg/L. Within TTZ-1, the top of the CVOC plume extends into the silty clay of the Yorktown Confining Unit in the vicinity of monitoring well YS03-GW024 (See **Figures 1-4-**, **1-5**, and **1-6**). This appears to be the only location at the site where the clay unit dips down. Because the highest CVOC concentrations are observed in this well, the proposed vertical treatment interval within a 30-foot radius of YS03-GW024 (that is, an area of 2,826 ft^2) is 5 feet above msl to 30 feet below msl (thickness of 35 feet). Specialized injection technologies will have to be considered for the clay zone. Outside of this 30-foot radius area, the proposed vertical treatment interval is 5 feet below msl to 30 feet below msl (thickness of 25 feet) to avoid the fine-grained lithology that is not favorable for many remedial technologies.

TTZ-2 surrounds TTZ-1 and is defined as the 15,700-ft^2 area where CVOC concentrations are 10 percent higher than their PRG—that is, where TCE is greater than 50 μg/L, cis-1,2-DCE is greater than 700 μg/L, and VC is greater than 20 μg/L. The proposed vertical treatment interval in TTZ-2 is 5 feet below msl to 30 feet below msl (thickness of 25 feet). The extents of the combined TCE, cis-1,2-DCE, and VC plumes and TTZs are considered to be sufficiently defined for FS-level conceptual designs and evaluation; however, additional monitoring wells will be installed and sampled during the pre-design investigation to refine the plume delineations for the design of the selected remedial alternative.

Dissolved arsenic and/or manganese contamination only occurs in four isolated monitoring wells (**Figure 3-1**). One well is located within TTZ-1; one is located within TTZ-2; and two wells are located outside the extent of CVOC contamination. A site-specific background monitoring well will be installed and sampled during the pre-design investigation to evaluate the impacts of possible reducing conditions caused by the wetlands. These data will be used to refine the given extent of inorganic contamination in groundwater.

TABLE 3-1
Preliminary Remediation Goals
Site 3 Feasibility Study Report
Naval Weapons Station Yorktown
Yorktown, Virginia

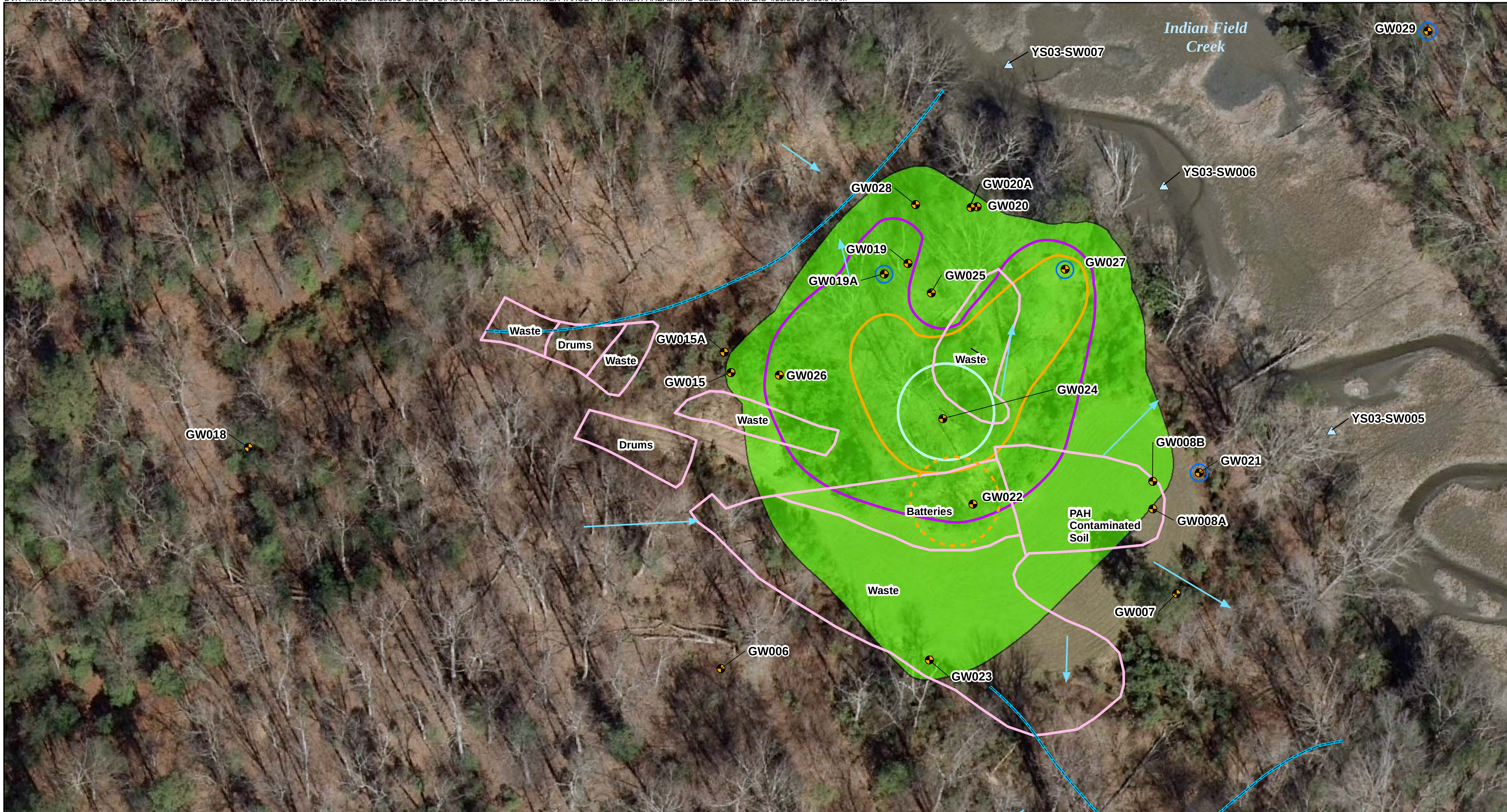
Chemical	MCL	Calculated RGO	RGO Basis	Yorktown Background Criteria - Yorktown-Eastover Aquifer (November 2010)	Selected PRG
Groundwater					
VOCs (µg/L)					
cis -1,2-Dichloroethene	70	---	---	--	70
Trichloroethene	5	---	---	--	5
Vinyl chloride	2	---	---	--	2
Metals					
Arsenic, dissolved	10	---	---	1.37	10
Manganese, dissolved	--	320	Residential Child, HI = 1	49.5	320

Notes:

1. Target Cancer Risk of 10^{-5} selected so that cumulative risk does not exceed 10^{-4}.
2. Target hazard index of 1 selected so that cumulative hazard to target organ does not exceed 1.
3. When an MCL is available for a chemical, it is selected as the PRG.

CR = cancer risk
HI = noncarcinogenic hazard index
MCL - maximum contaminant level
µg/L - micrograms per liter
PRG - preliminary remediation goal
RGO - remediation goal option
VOCs - volatile organic compounds

DVR \\MNUSTRICTGFS01\PROJECTS\USNAVFACENGCOM405450\400210YORKTOWN\MAPFILES\429391_SITE3_FS\FIGURE 3-1 - GROUNDWATER TARGET TREATMENT AREAS.MXD CELEFTHERIADIS 4/29/2013 9:31:54 AM



Legend

- Surface Water Sample Location
- Yorktown Monitoring Wells
- Groundwater Flow Direction
- Estimated Drainage Channel
- Approximate Unsaturated TPH Contamination
- Approximate Waste Limits (1999 Remedial Action)
- Target Treatment Zone 1 - Clay
- Target Treatment Zone 1 - Silty Sand
- Target Treatment Zone 2
- Maximum Extent of the TCE, cisDCE, and VC plumes
- Exceeds Dissolved Arsenic and/or Manganese Preliminary Remediation Goal

Notes:
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

N W E S

0 60 120 Feet

Figure 3-1
Groundwater Target Treatment Zones
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

CH2MHILL

SECTION 4

Screening of Remedial Technologies and Development of Remedial Alternatives

To identify which technologies are best suited for use at Site 3 for remedial alternative development, all applicable technologies and process options were evaluated. Initially, technologies were screened with respect to the site contaminants and site-specific conditions. The technologies retained following the screening process were used to develop a reasonable number of remedial alternatives. A remedial alternative may include a combination of technologies or process options.

4.1 Screening of Remedial Technologies

Before developing potential remedial alternatives to address groundwater contamination at Site 3, potentially applicable groundwater remediation technologies were screened. The screening process incorporated the Navy's preference to select a remedy that would minimize impacts to current land use, meet proposed RAOs, and minimize the timeframes during which the treatment technology would have to be operated and maintained. The recent initiative by USEPA for consideration of sustainable environmental practices in remediation, which favors remedies with lower carbon footprints, was also incorporated. **Table 4-1** summarizes the screening process and is color-coded for which technologies were retained following screening.

Technologies were placed through a two-phased screening process. The first phase assessed whether the technology is applicable for the contaminants and has the potential to work at the site. During the initial screening process, general response actions were identified for the remediation of Site 3. General response actions are broad responses, remedies, or technologies developed to meet site-specific RAOs and address COCs, migration pathways, and exposure routes. A variety of general response actions are typically combined to create remedies that are protective of human health and the environment. The general response actions selected were:

- No action
- *In situ* treatment
- Institutional controls
- Monitoring
- Removal

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

In situ treatment response actions are *in situ* remedies to reduce the toxicity, mobility, volume, or mass of contaminants in groundwater. Treatment technologies consist of biological, chemical, or physical processes.

Institutional Controls consist of a number of alternatives that can be used alone or as part of another response action. Administrative LUCs include activities such as restricting groundwater use through land-use, deed, or access restrictions. A system of approvals may be set up to require a permit for various activities (such as excavation or installation of wells). Engineering controls physically limit access or land use on a property or exposure to contaminated media through engineered structures.

The *monitoring* response action includes a groundwater sampling and analysis program to assess the behavior of contaminants, natural attenuation processes, or performance of an active remediation over time.

The *removal* response action would reduce or remove the volume of contaminants in soil or shallow groundwater. This response action can be applied to select areas.

If a technology passed the primary screening, it was then evaluated for effectiveness, implementability, and relative cost. These evaluations are summarized in **Table 4-1**. Following the secondary screening, technologies retained for further consideration included those that have the potential to significantly reduce contaminant concentrations or complement the naturally occurring biodegradation of site-related COCs. Such technologies are cost-effective given the area exceeding PRGs and the levels of contamination. The No Action response was retained as a baseline for the comparison of alternatives. The following technologies were retained for remedial alternative development:

- MNA – Retained based on its potential effectiveness from naturally occurring processes and corresponding low capital and operations and maintenance (O&M) costs.
- LUCs – Retained based on relatively low cost and effectiveness in preventing direct contact between contaminants and potential receptors, provided controls are properly maintained.
- Enhanced *In Situ* Bioremediation (EISB) – Retained based on its effectiveness at degrading the site-related COCs and low safety hazards during implementation. Because the presence of degradation products suggests that reductive dechlorination of TCE is already occurring, this technology is consistent with existing site conditions. Addition of electron donor and/or microbial cultures will enhance biodegradation of TCE, cis-1,2-DCE, and VC and potentially achieve remediation goals (RGs) in a significantly shorter timeframe than MNA.
- *In Situ* Chemical Reduction (ISCR) – Retained based on its high effectiveness at degrading the site-related COCs. ISCR accelerates abiotic reduction of COCs and is consistent with the generally anaerobic conditions at the site. The addition of reducing agents helps stabilize the dissolved downgradient plume and shortens the timeframe to achieve RGs. Additionally, zero-valent iron (ZVI) can be used to lower dissolved arsenic concentrations in groundwater.
- *In Situ* Chemical Oxidation (ISCO) – Retained based on its effectiveness at degrading the site-related COCs. Technology would quickly create oxidizing conditions, thereby stabilizing the dissolved plume. This technology also has the potential to achieve RGs in a significantly shorter timeframe than MNA. Additionally, the oxidizing conditions would facilitate the precipitation of manganese and arsenic dissolved in groundwater.
- Removal and Offsite Disposal – Retained for the unsaturated TPH soil contamination as a contingency measure based on its effectiveness in removing a source of organic carbon, which may be facilitating manganese and arsenic dissolution, in a short timeframe.

4.2 Development of Remedial Alternatives

Remedial alternatives were developed by combining the retained technologies following the screening process presented in **Table 4-1**. To avoid evaluating an unmanageable number of alternatives, only the most logistically and technically sensible combinations for the given site conditions were carried forward. Five remedial alternative combinations were developed, providing a range of less- to more-aggressive technologies. All alternatives, with the exception of No Action, meet Site 3 RAOs. The alternatives are as follows:

- Alternative 1 – No Action
- Alternative 2 – MNA and LUCs
- Alternative 3 – EISB, MNA, and LUCs
- Alternative 4 – ISCR, MNA, and LUCs
- Alternative 5 – ISCO, MNA, and LUCs

Elevated concentrations of dissolved arsenic and manganese in groundwater are likely the result of several factors, which may include the naturally occurring reducing conditions near Indian Field Creek, the reducing conditions resulting from TCE, cis-1,2-DCE, and VC contamination in groundwater, and potentially TPH contamination that remains in localized, unsaturated soils (see Section 2.2.1). As described in this report, a pre-design investigation would be conducted to investigate the influence of the wetlands on inorganic COCs. If it is found that the wetlands and existing groundwater contamination are not the primary causes of elevated concentrations of dissolved arsenic and manganese in groundwater, then the TPH present in unsaturated soils may have to be addressed. To facilitate the CERCLA process and avoid a future ROD amendment, a contingency action was developed to potentially address the TPH contamination that remains in localized, unsaturated soils and is discussed in this report.

The remedial alternatives discussed in the following subsections are intended to be conceptual. Assumptions are provided for each of the alternatives for the purpose of evaluation. However, additional details would be developed during the remedial design phase and may vary.

4.2.1 Pre-Design Investigation

A pre-design investigation would be conducted after completion of the ROD and before implementation of the selected remedy. In accordance with the recommendations made in the Phase II RI report (Section 2.2.4) and in subsequent Yorktown Partnering meetings (Section 2.2.5), this investigation would include installation of five new shallow monitoring wells and one new deep monitoring well (described in Section 2.2.5) and one round of groundwater sampling. The proposed well locations are presented on **Figure 4-1**.

Because the slow groundwater flow rate affects the proposed layout of many of the FS conceptual designs, slug testing would be conducted for additional confirmation of the hydraulic conductivity within the aquifer. Falling head (slug in) and rising head (slug out) tests would be conducted at three of the newly installed monitoring wells. The data would be analyzed using appropriate and accepted evaluation methods, such as those of Bouwer and Rice (1976) and Bouwer (1989).

A baseline monitoring event would be conducted to confirm the magnitude and extent of contamination at the time of the remedial action and address data gaps identified in the Phase II RI report. The monitoring plan used for FS purposes is summarized as follows:

Monitoring Well	New or Existing Well	Well Location	Analysis
YS03-GW006	Existing	Upgradient Well	COCs only
YS03-GW008A	Existing	Downgradient/ Cross-gradient Well	
YS03-GW008B	Existing	Deep Cross-gradient Well	
YS03-GW015	Existing	Cross-gradient Plume Well	
YS03-GW015A	Existing	Deep Cross-gradient Well	
YS03-GW019A	Existing	Deep Plume Well	
YS03-GW020A	Existing	Deep Downgradient Well	
YS03-GW021	Existing	Downgradient Well	
YS03-GW025	Existing	Interior Plume Well	
YS03-GW029	Existing	Downgradient Well	
YS03-GW034	New	Downgradient/ Cross-gradient Well	
YS03-GW018	Existing	Upgradient Well	COCs and indicator parameters
YS03-GW019	Existing	Interior Plume Well	
YS03-GW023	Existing	Cross-gradient Plume Well	
YS03-GW026	Existing	Interior Plume Well	
YS03-GW035	New	Deep Downgradient Well	
YS03-GW020	Existing	Downgradient Plume Well	COCs and 1,4-dioxane
YS03-GW024	Existing	Interior Plume Well	COCs, 1,4-dioxane, and indicator parameters
YS03-GW027	Existing	Downgradient Plume Well	
YS03-GW028	Existing	Interior Plume Well	
YS03-GW031	New	Interior Plume Well	
YS03-GW032	New	Interior Plume Well	
YS03-GW033	New	Downgradient Plume Well	
YS03-GW022	Existing	Interior Plume Well, adjacent to MIP-5	COCs, SVOCs, and indicator parameters
YS03-GW030	New	Background Well, adjacent to Indian Field Creek	Dissolved arsenic and manganese and indicator parameters

Notes:

1. Groundwater COCs are TCE, cis-1,2-DCE, VC, arsenic, and manganese.
2. Indicator parameters are alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron, chloride, methane, ethane, and ethene.
3. Water quality parameters (DO, ORP, pH, specific conductivity, temperature, and turbidity) would be measured in the field at all wells.

The proposed analytical parameters are summarized in the table above. However, a pre-design investigation work plan will be submitted to the Yorktown Partnering Team for review before the investigation. Indicator parameters include reductive degradation products (ethene and ethane) along with geochemical parameters, which can be used as further evidence that conditions are favorable for reductive dechlorination of CVOCs (see Section 2.2.2). Because no activities have been conducted at the site to enhance biodegradation of CVOCs, hydrogen and volatile fatty acids (VFAs) are not included; these parameters are not considered critical indicators (USEPA, 1998). Based on previous site data, BTEX is not considered a potential carbon source for biodegradation and therefore will not be included in the evaluation.

Based on the analytical groundwater results, the selected remedial action may be modified. For example, if SVOCs and 1,4-dioxane are not detected at concentrations above their screening criteria, they would not be included in the long-term monitoring plan for the site. In addition, if arsenic and manganese concentrations are similar to or below the concentrations in new well YS03-GW030, the elevated concentrations observed in downgradient monitoring wells would be attributed to the naturally occurring reducing conditions near Indian Field Creek rather than to site-related contamination. Therefore, these constituents would no longer be considered COCs and would not be included in the long-term monitoring plan for the site. For FS purposes, it was assumed that SVOCs and 1,4-dioxane will not be included in future site monitoring. However, it was assumed that arsenic and manganese will be included in future site monitoring.

4.2.2 Alternative 1 – No Action

Alternative 1 is the No Action alternative. Under this scenario, no remedial action would be undertaken at Site 3, and contaminants in groundwater would remain in place. Alternative 1 is required as a baseline for comparison of alternatives.

4.2.3 Alternative 2 – Monitored Natural Attenuation and Land Use Controls

Alternative 2 consists of the following remedial actions:

- Conduct semiannual and annual monitoring
  - Optimize sample locations, analysis, and/or frequency over the life of the remedy
  - Evaluate need for contingency action
- Enforce LUCs and conduct Five-year Reviews until RGs are met
- Not including the contingency action, the estimated duration of the alternative is 19 years (for FS cost-estimating purposes)

Details of the remedial actions, including derivation of the remedial timeframe, are provided in the following subsections.

Alternative 2 includes MNA of TCE, cis-1,2-DCE, VC, arsenic, and manganese in groundwater. Natural attenuation processes encompass a variety of physical, chemical, or biological processes that under favorable conditions act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in groundwater. These processes consist of biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biological stabilization, transformation, or destruction of contaminants. The effectiveness of these natural attenuation processes would be monitored periodically.

Degradation and transformation of groundwater COCs at Site 3 was described in Section 2.2.2. As summarized in **Table 2-2**, water quality and geochemical data generally indicate favorable conditions for reductive dechlorination. The most favorable indicators were observed at the source well GW024, where sulfate reduction may be occurring. The ratio of CVOC parent to daughter product concentrations in Site 3 groundwater indicates historical occurrence of reductive dechlorination. TCE was detected in groundwater at a maximum concentration of 400 µg/L, and cis-1,2-DCE and VC were detected at concentrations of more than 1,000 µg/L. Additionally, trace levels of ethene and/or ethane were detected at a few locations within the plume. DHC bacteria are present in groundwater at populations capable of sustaining biodegradation.

The average pH value of 8.2 in groundwater is slightly above the favorable range for biodegradation. Although TOC concentrations in groundwater are relatively low, they appear to increase with proximity to the creek, which is attributed to the depositional environment near the creek. Additionally, the TPH in unsaturated soils may migrate slowly to the aquifer and may be providing a carbon source for reductive dechlorination.

At Site 3, the reductive dissolution of iron hydroxides and manganese oxides is likely the source of elevated concentrations of dissolved manganese and arsenic (which is frequently bound to these hydroxides and oxides) in groundwater. As organic contamination is removed, the aquifer conditions may become less reducing. This would facilitate precipitation of these inorganic constituents back into a solid state. However, if reducing conditions are naturally present in the aquifer, elevated concentrations may persist.

Physical natural attenuation processes are also likely occurring within the Site 3 plumes. Based on the volatility of TCE, cis-1,2-DCE, and VC, contaminants can enter the soil gas phase at the water table interface. Because the contaminant plume thicknesses (~30 feet) are small compared to the aquifer thickness (greater than 80 feet), dilution and dispersion are also probably active attenuation mechanisms.

Monitoring

The actual groundwater monitoring plan, including the number of monitoring wells, sample parameters, and sample frequency, would be developed during the remedial design phase. This plan would take into consideration the results of the pre-design baseline monitoring event. Only monitoring wells located within the contaminant plumes, upgradient or background wells, and necessary downgradient compliance wells will be included. **Figure 4-1** presents the monitoring well locations in reference to the current plumes. During the remedy implementation, the monitoring plan would be reviewed periodically and optimized as needed to reflect any changes in site conditions and the fate and transport of the COCs at this site.

As part of the MNA program, groundwater monitoring would also provide warning if the future plume was to begin discharging into Indian Field Creek at unacceptable levels. Based on surface water, sediment, and sediment pore water concentrations, contaminant discharge to surface water via groundwater was not found to pose unacceptable ecological or human health risks at Site 3. Because groundwater is also not considered a significant continuing source of contaminants to the aquatic habitats adjacent to the site, the RI report recommended no further action for surface water and sediment. However, in order to ensure that the future downgradient migration of contaminants is not occurring at unacceptable levels and in an effort to continuously refine the nature and extent of the plume, groundwater data would be collected and undergo evaluation. Concentrations across the plume would be monitored to assess plume stability. Concentrations in downgradient monitoring wells would be evaluated against the levels present during the RI. The evaluation process would potentially consider the effects of attenuation (that is, primarily dilution) on groundwater concentrations before and during discharge into the creek.

For FS cost-estimating purposes only, it was assumed that 20 monitoring wells would be included in the MNA well network. To evaluate attenuation and stability of the TCE, cis-1,2-DCE, and VC plumes, groundwater from 19 wells would be analyzed for TCE, cis-1,2-DCE, and VC. Degradation products (ethene and ethane) and geochemical parameters (chloride, methane, alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, and ferrous iron) would be analyzed at 10 monitoring wells. To evaluate attenuation and stability of the inorganic plumes, groundwater from eight monitoring wells would be analyzed for dissolved arsenic and manganese. Groundwater samples for TCE, cis-1,2-DCE, VC, dissolved arsenic, and manganese would be collected on a semiannual basis for the first 5 years of monitoring to document MNA effectiveness before the first Five-year Review and then transition to an annual sampling frequency. However, this sample frequency would be re-evaluated annually. Degradation products and geochemical parameters would only be collected on an annual basis. These monitoring data would also be used to help determine whether the contingency soil removal is necessary (Section 4.2.7). The monitoring assumptions, including frequency, duration, and analytical parameters, are included in the cost estimates (**Appendix C**).

For cost-estimating purposes, an estimate for the remediation timeframe, or project duration, was derived using simple, first-order decay calculations (**Appendix D**). This is consistent with recent USEPA guidance, *An Approach for Evaluating the Progress of Natural Attenuation in Groundwater* (USEPA, 2011). Because limited temporal groundwater data were available at Site 3, attenuation rates could not be estimated at the wells with the highest TCE, cis-1,2-DCE, and VC concentrations (that is, YS03-GW024 and –GW027). Reductive dechlorination decay rates were obtained for TCE (1.1 per year), cis-1,2-DCE (1.5 per year), and VC (0.37 per year) from Suarez and Rifai (1999). Based on these decay rates and the highest detected groundwater concentrations at the site during the 2009 Phase II RI groundwater event, the monitoring duration for organic COCs under Alternative 2 was assumed to be 17 years. Because the concentration of inorganic constituents in groundwater depends on so many factors, it can be more difficult to predict. It was assumed that after the organic contamination is attenuated, groundwater conditions would become less reducing, thereby precipitating dissolved arsenic and manganese from groundwater. For FS purposes, an additional 2 years of annual monitoring were assumed to be conducted for dissolved arsenic and manganese during this process. Therefore, the final estimated duration for Alternative 2 is 19 years, although the actual remediation timeframe may vary. The remediation timeframe would be re-evaluated as more data become available over time, potentially using more-robust evaluation methods that incorporate contaminant desorption and flux through the aquifer.

Land Use Controls

Under Alternative 2, the site would be designated as a “restricted use” area in the WPNSTA Yorktown geographic information system. This designation would place controls on intrusive activities, such as excavation, residential development, and groundwater use. A LUC remedial design would be developed for the site. Records of the groundwater contamination would be kept or tracked in the Naval Installation Restoration Information Solution database as well as the Base master plan. The restricted use designation would remain in place until groundwater monitoring indicates that RGs have been met. An annual inspection of administrative controls and the site conditions (if physical controls were required) would be conducted. An annual inspection checklist and brief report would be completed.

Because contaminants would remain in place under this alternative, Five-year Reviews would be needed to evaluate the implementation and performance of the remedy and whether it continues to be protective of human health and the environment. The Five-year Review process may include the following tasks: notifying potentially interested parties, developing a review schedule, establishing a review team, involving the community, and submitting a Five-year Review report.

Contingency Soil Excavation

A contingency measure was included in the FS to facilitate the CERCLA process and avoid a future ROD amendment. As previously stated, dissolved arsenic and manganese concentrations in groundwater are above their PRGs, likely because of the reducing conditions present in the subsurface. Under these conditions, manganese (and iron) can be reductively dissolved, thereby releasing other metals that may be bound to them (such as arsenic). A background well will be installed at the site (see Section 2.2.5) to evaluate whether the wetlands adjacent to Indian Field Creek are creating the reducing conditions that are elevating arsenic and manganese concentrations in groundwater. Groundwater monitoring throughout the site would be conducted to evaluate whether dissolved arsenic and manganese concentrations decrease following the degradation of TCE, cis-1,2-DCE,and VC contamination, which may also be creating more reducing conditions. After these evaluations have been completed, if the Yorktown Tier I Partnering Team concludes additional action is needed to address unacceptable risks from dissolved arsenic and manganese concentrations in groundwater, a contingency action may be conducted for TPH in unsaturated soil (**Figure 4-1**). Although VOCs and SVOCs in soil are present below screening levels, TPH may still be providing a carbon source for anaerobic biological processes and facilitating more reducing conditions. Therefore, removal of this TPH contamination in soil may result in the precipitation of manganese and arsenic to their solid forms. The contingency would subsequently reduce the time required for inorganic constituent concentrations to decrease to RGs or background levels.

The proposed contingency action for Site 3 is soil excavation. *In situ* treatment technologies are not preferred because of the limited extent of TPH in unsaturated soil and the potential impacts that treatment could have on the saturated zone. *Ex situ* treatment would likely not be cost-effective based on the anticipated treatment volume and the type of contamination. As part of the contingency, excavation and offsite disposal of subsurface soil would be conducted within a 50-foot by 50-foot area (2,500 ft^2) around MIP-5, which exhibited elevated TPH concentrations in soil during previous investigations (**Figure 4-1**). Before soil removal begins, monitoring well YS03-GW022 would need to be abandoned by a registered driller. The excavation would be conducted up to a depth of 20 feet bgs. Because the water table is estimated to be at 30 feet bgs in this location, no dewatering would be conducted. Sloping would be used to achieve a safe excavation, but if this is not possible, a structural support system (shoring) would be required. No confirmation samples would be required because the excavation would be performed only in support of the groundwater remedy. Erosion and sediment and stormwater controls would be implemented to prevent contamination migration in accordance with the *Virginia Erosion and Sediment Control Handbook,* Third Edition (Virginia Department of Conservation and Recreation, 1992).

The 50,000 cubic feet of excavated soil excavated would be loaded into haul trucks and transported to an appropriate offsite disposal facility. For cost-estimating purposes, it was assumed the excavated soil would be classified as nonhazardous. The site would be restored upon completion of the soil removal. Clean fill would be used to backfill the excavation. The area would be re-vegetated to prevent future soil erosion. Following the excavation, groundwater monitoring would be conducted until RGs are achieved. For FS purposes, it was assumed that groundwater from eight monitoring wells would be analyzed for dissolved arsenic and manganese on an annual basis. Because this is only a contingency action and not needed for comparison of alternatives, monitoring costs were not included in the cost estimates due to the uncertainty in the length of the monitoring period.

4.2.4 Alternative 3 – Enhanced *In Situ* Bioremediation, Monitored Natural Attenuation, and Land Use Controls

Alternative 3 consists of the following remedial actions:

- Conduct first injection of biostimulation substrates and bioaugmentation culture through DPT points in TTZ-1 and TTZ-2 (see Section 3.4.2 for TTZ details)
- Collect post-injection groundwater samples for TOC
- Conduct 3 quarters of quarterly monitoring
- Conduct second injection of biostimulation substrates through DPT points in TTZ-1 only
- Conduct 1 quarter of quarterly monitoring
- Conduct semiannual and annual monitoring
  - Optimize sample locations, analysis, and/or frequency over the life of the remedy
  - Evaluate need for contingency action
- Enforce LUCs and conduct Five-year Reviews until RGs are met
- Not including the contingency action, the estimated duration of alternative is 9 years (for FS cost-estimating purposes)

Details of the remedial actions, including derivation of the remedial timeframe, are provided in the following subsections.

Alternative 3 includes EISB of TCE, cis-1,2-DCE, and VC in groundwater within both TTZ-1 and TTZ-2, MNA of TCE, cis-1,2-DCE, and VC within the remainder of the dissolved plume, and MNA of arsenic and manganese. As discussed in Section 2.2.2, TCE, cis-1,2-DCE, and VC can be biodegraded via anaerobic reductive dechlorination. The presence and abundance of specific microorganisms, together with other favorable geochemical conditions, are essential for complete dechlorination. EISB of TCE, cis-1,2-DCE, and VC can be implemented via biostimulation with or without bioaugmentation. Biostimulation involves adding a suitable carbon substrate (soluble or insoluble, also known as slow-releasing) to the subsurface. The introduced substrate serves multiple purposes, such as depletion of competing electron acceptors to create strongly reducing conditions and providing an electron donor source for reductive dechlorination. The substrate may also include nutrients, such as phosphorus, nitrogen, yeast extract, and vitamin B_{12}, which are desirable for the growth of the dechlorinating bacteria. Because reductive dechlorination is most effective at neutral or near neutral pH, a buffering agent may be introduced if the aquifer's natural buffering capacity is low.

Bioaugmentation is conducted using a microbial culture, usually containing DHC, to "jump start" the biodegradation process and prevent reductive dechlorination from stalling at DCE or VC. Bioaugmentation is recommended at Site 3 because biostimulation would increase the rate of reductive dechlorination, creating a greater risk of accumulating daughter products (DCE and VC). Only a moderate population of DHC in the Yorktown-Eastover Aquifer was measured during the Phase II RI (6.1 to 26.2 cells/ml). The lack of specific microorganisms and functional genes (that is, reductive dehalogenase) in an EISB system will result in incomplete dechlorination, with the reaction stalling at cis-1,2-DCE and VC.

Evaluation of Enhanced *In Situ* Bioremediation Substrates

Implementation of EISB at Site 3 would be achieved via biostimulation (addition of a readily fermentable organic substrate) and bioaugmentation. Both soluble (for example, lactate) and slow-releasing (for example, emulsified vegetable oil) substrates can be used in EISB. Commonly used soluble substrates are lactate, molasses, and corn syrup. Soluble substrates are readily available to microorganisms and easily transported with groundwater flow. Because these substrates degrade rapidly and may be flushed out of the TTZ if groundwater flow is fast, more-frequent injections are required than for insoluble substrates. Commonly used slow-release substrates include emulsified vegetable oil (multiple brand names in market), 3-D Microemulsion, and LactOil (50:50 mixture of soluble and slow releasing substrates). Because slow-release substrates last longer, they typically reduce the frequency of injections, thereby minimizing O&M. They may also maintain lower hydrogen levels under which reductive dechlorinating bacteria (chlororespirators) can compete better with other microorganisms (such as methanogens). However, if groundwater flow is slow, the substrate may not be carried sufficiently away from the location of injection and the radius of influence (ROI) may be limited. A drawback of oil-based, insoluble substrates, in particular, is that they may sequester TCE, cis-1,2-DCE, and VC, which are then released later when the oil is consumed and may interfere with the bioremediation process. Additionally, the availability of bacteria to help break down the oil to a fermentable material (thus, the slow release of available carbon) may be more limited in slow groundwater systems, where less natural mixing occurs.

For the FS evaluation, the use of a soluble substrate, such as WilClear Plus (a commercial lactate substrate with nutrient package) was selected. However, another substrate may later be selected in the remedial design phase. WilClear Plus contains three active components: the primary lactate component provides carbon for rapid establishment of anaerobic conditions, VFAs promote growth of an assortment of dechlorinating microbial populations, and the nutrient blend provides growth factors to increase dechlorination efficiency. Because of the slow groundwater flow rate, a soluble substrate may be more easily broken down and available for reductive dechlorinating bacteria than a slow-release substrate at Site 3. The commonly assumed degradation pathway for lactate is degradation to propionate, with release of a single hydrogen molecule, followed by further degradation to acetate, with another H_2 molecule released. Therefore, a single molecule of lactate provides at least 2 molecules of hydrogen. The very slow groundwater flow rate at this site will help the soluble substrate persist in the TTZ. The longevity of the substrate, with sufficient initial dosage, may minimize the need for reinjection to meet the RGs considering the relatively low concentration of TCE, cis-1,2-DCE, and VC. However, additional injections may also benefit the process by causing some "mixing" within the treatment zone, which may be limited because of the slow flow rate.

Bioaugmentation would be implemented at Site 3 in TTZ-1. A number of commercial bioaugmentation cultures can be considered for this site to enhance degradation of chloroethenes, including KB-1 and SDC-9. For the FS evaluation, the use of SDC-9 was assumed.

Full-scale Substrate Injection

Given the relatively low levels of contamination observed in groundwater and the slow groundwater flow rate, only two EISB injections of a soluble substrate were assumed. No laboratory treatability studies or field pilot studies would be conducted before full-scale implementation.

Soluble substrate delivery would be completed through DPT rods in TTZ-1 and TTZ-2 (see Section 3.4.2 for TTZ details)**.** Within the soft clay surrounding YS03-GW024 in TTZ-1, WilClear Plus would be injected using high injection pressures and would have an assumed ROI of approximately 5 feet. In the silty sands of the Yorktown-Eastover Aquifer in TTZ-1 and TTZ-2, WilClear Plus would be injected under standard injection pressures (not to exceed 20 pounds per square inch [psi]) and would have an assumed ROI of 8 feet. To reduce the maximum concentrations observed within the combined TCE, cis-1,2-DCE, and VC plumes, the injection points in TTZ-1 would be placed in a grid layout with offset rows aligned relatively perpendicular to groundwater flow (**Figure 4-2**). A grid layout was selected because the slow groundwater flow rate would limit the transport of lactate downgradient with groundwater. To facilitate biodegradation within the remainder of the plume, the injection points in TTZ-2 would be placed along three transects: along the western side of the TTZ-2, within the center of the TTZ, and along the eastern edge of the TTZ (**Figure 4-2**). Based on these relatively small ROIs of 5 and 8 feet and the slow groundwater flow rate at the site, impacts to Indian Field Creek are not anticipated.

Based on the estimated ROIs, treatment areas, and vertical injection intervals, the number of injection points and substrate volume for each TTZ are listed as follows:

- TTZ-1 Yorktown-Eastover aquifer silty sands (11,200-ft^2 area and 25-foot injection interval)
  - 46 injection points set at 16-foot centers
  - 10,200 pounds of WilClear Plus
- TTZ-1 clay (2,826 ft^2 area and 10-foot injection interval)
  - 28 injection points set at 9- to 11-foot centers; 13 injections would be co-located with the injection borings conducted in the sandy aquifer, while 15 injections would be conducted in separate borings
  - 8,400 pounds of WilClear Plus
- TTZ-2 Yorktown-Eastover aquifer silty sands (three transects and 25-foot injection interval)
  - 21 injection points set at 16-foot centers, except no points would be located where the transects intersect TTZ-1
  - 1,800 pounds of WilClear Plus

In total, 12,000 pounds (20 drums) of WilClear Plus would be injected into the subsurface at a total of 82 DPT injection borings. As recommended by the vendor, the substrate would be diluted to 10 percent solution (by volume)—that is, one part of product in nine parts of water (1:9). Therefore, the total injection volume would be 11,000 gallons, representing a small percentage (3 percent) of the total pore volume of the TTZs. However, because WilClear Plus is a soluble substrate, it would be fully distributed within the TTZs by diffusion and dispersion.

To avoid daylighting of the substrate, the average injection rate was assumed to be approximately 3 gallons per minute at each injection point. It was assumed that injection would occur in four locations simultaneously. A top-to-bottom injection approach would be used to prevent substrate migration into the sand during high-pressure injections. Injection pressure and injection rates would be measured frequently during injection. Standard DPT injection pressures would not exceed 20 psi. In the clay zone, DPT injections would be conducted at higher pressures, which can cause fracturing and facilitate substrate distribution. These higher injection pressures would require a specialized slurry pump. For injection points co-located in the aquifer sands and the clay in TTZ-1, the same equipment would be used but the injection pressures would be increased in the clay zone. Measurement of water level, DO, conductivity, and ORP, and visual observation would be conducted periodically in surrounding monitoring wells. Water associated with injection solution would be obtained from a fire hydrant on the Base. Following injection, the horizontal positions of the injection points would be recorded using a global positioning system (GPS).

Because groundwater at the site is already under predominantly reducing conditions, the bioaugmentation injection would be integrated into the first biostimulation injection event. Approximately 1 liter of SDC-9 culture (with cell density greater than or equal to 10^{11} cells/ml) would be injected into each of 46 DPT points in the sandy portion of TTZ-1 (total of 46 liters) with nitrogen gas. No bioaugmentation injections would occur in the clay zone in TTZ-1 or in TTZ-2. The 9,350-gallon solution in the first injection for the lower TTZ-1 sandy aquifer needs to be anaerobic (less than 0.2 mg/L DO and less than 50 mV ORP) because it also functions as chase water to distribute the anaerobic bioaugmentation culture throughout the TTZ. Approximately 1.5 pounds of sodium sulfite per 500 gallons of solution would be needed to remove the DO.

For FS cost-estimating purposes, a second injection would be conducted approximately 9 months after the initial injection. A second injection was conservatively included because WilClear Plus is a soluble substrate and not as persistent as slow-release substrates. Another injection would also facilitate mixing in the aquifer, which may be beneficial given the slow groundwater flow rate at the site. However, performance monitoring data would be used to confirm the need for additional injections. The second injection would only be conducted in TTZ-1.

Monitoring, Land Use Controls, and Contingency

The actual groundwater monitoring plan, including the number of monitoring wells, sample parameters, and sample frequency, would be developed during the remedial design phase. This plan would take into consideration the results of the pre-design baseline monitoring event. During the remedy implementation, the monitoring plan would be reviewed periodically and optimized as needed to reflect any changes in site conditions and the fate and transport of the COCs at this site.

Performance monitoring of the EISB injections would be conducted to evaluate the effectiveness of the treatment technology. Groundwater monitoring would also provide warning if the future plume was to begin discharging into Indian Field Creek at unacceptable levels, as described in Section 4.2.3. Immediately following the injection, selected monitoring wells would be sampled for TOC to evaluate the ROI. For FS cost-estimating purposes, it was assumed that quarterly groundwater sampling would be conducted for a year following the first injection. Groundwater from 19 wells would be analyzed for TCE, cis-1,2-DCE, VC, and degradation products (ethene and ethane), and seven wells would be analyzed for geochemical parameters, as described in Alternative 2 (Section 4.2.3). Additionally, during the first year of monitoring, semiannual analysis of VFAs and DHC from four selected monitoring wells would be conducted. VFAs would be analyzed to evaluate substrate utilization and fermentation. To evaluate attenuation and stability of the inorganic plumes, groundwater from eight monitoring wells would be analyzed for dissolved arsenic and manganese.

Following active EISB treatment, MNA would be conducted until RGs are achieved. For the FS evaluation, EISB would be expected to decrease the remediation timeframe for the entire plume by 60 percent. Large mass reduction would be expected in TTZ-1 (where the highest concentrations are present) and to a lesser degree in TTZ-2. However, outside of the target treatment areas, degradation would still be subject to the rates of natural decay. Therefore, the project duration of organic COCs was estimated at 7 years (or a 60 percent reduction of the MNA remediation timeframe). Similar to Alternative 2, monitoring of arsenic and manganese would continue for an additional 2 years, resulting in a total projected duration of 9 years.

For FS cost-estimating purposes only, it was assumed that sampling would be conducted at 20 monitoring wells to evaluate the effectiveness of MNA and the need for the contingency soil removal (Section 4.2.7). Nineteen wells would be sampled for organic COCs; 10 wells would be sampled for geochemical parameters, ethene, and ethane; and 8 wells would be sampled for arsenic and manganese. Monitoring well YS03-GW030 would only be used to evaluate background arsenic and manganese levels, and therefore, no organic data would be collected. Analytical data collected during MNA would be the same as described in Alternative 2 (Section 4.2.3). For FS purposes, groundwater samples would be collected on a semiannual basis for 4 years and then transition to an annual sampling frequency. However, this sample frequency would be re-evaluated annually. The monitoring assumptions, including frequency, duration, and analytical parameters, are also included in the cost estimates (**Appendix C**).

For Alternative 3, LUCs would be maintained similar to Alternative 2 (described in Section 4.2.3) until RGs are achieved, with Five-year statutory Reviews to ensure protection of human health and the environment. If needed, the contingency soil excavation would also be conducted as described in Alternative 2 (Section 4.2.3).

4.2.5 Alternative 4 – *In Situ* Chemical Reduction, Monitored Natural Attenuation, and Land Use Controls

Alternative 4 consists of the following remedial actions:

- Conduct injection of an ISCR reagent through DPT points in TTZ-1 (only one injection event proposed; see Section 3.4.2 for TTZ details)
- Conduct 4 quarters of quarterly monitoring
  - Conduct semiannual and annual monitoring
  - Optimize sample locations, analysis, and/or frequency over the life of the remedy
  - Evaluate need for contingency action
- Enforce LUCs and conduct Five-year Reviews until RGs are met
- Not including the contingency action, the estimated duration of alternative is 11 years (for FS cost-estimating purposes)

Details of the remedial actions, including derivation of the remedial timeframe, are provided in the following subsections.

Alternative 4 includes ISCR of TCE, cis-1,2-DCE, and VC in groundwater within TTZ-1, MNA of TCE, cis-1,2-DCE, and VC within the remainder of the dissolved plume, and MNA of arsenic and manganese. ISCR refers to the delivery of chemical reagents to contaminated media in order to chemically (abiotically) and sometimes biologically reduce the contaminants to acceptable end products. The ISCR amendments can be introduced as an injected slurry using DPT rods; this requires pumps that can inject at low-flow rates but high pressures (upward of 100 psi). A smaller ROI is typically achieved for injection of the ISCR reagent slurry compared to a carbon substrate (EISB) or permanganate (ISCO) solution.

During chemical reduction, electrons are transferred from the reductant to the contaminant. A number of chemical amendments can be used to reduce site contaminants. These include EHC, ABC+ (both containing micro-scale ZVI), or micro-scale ZVI alone. When ZVI (Fe^0[s]) oxidizes to Fe^{+2}, electrons are released and hydrogen gas is produced:

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

$$Fe^0(s) + 2H_2O \rightarrow Fe^{+2}(aq) + 2OH^- + H_2(g)$$

Under properly catalyzed conditions, the reduction of TCE, cis-1,2-DCE, and VC can be coupled with ZVI oxidation to Fe^{+2}.

Although MNA of dissolved arsenic and dissolved manganese is proposed under Alternative 4, the use of ZVI can have a beneficial impact on arsenic concentrations in groundwater. ZVI reduces arsenic from As(V) to

As(III), thereby co-precipitating dissolved arsenic from groundwater. The enhanced reducing conditions may temporarily increase dissolved manganese concentrations in groundwater.

A variety of ZVI types can be used for ISCR treatment. These include granular particles (greater than 300 microns, which are typically used in trench-based permeable reactive barriers), micron-scale particles (10 to 100 microns, which are commonly used with pneumatic fracturing and injected in boreholes under pressure as a water-based slurry), and nano-scale particles (less than 1 micron), which are typically distributed into the formation similar to micron particles. The reactivity of the iron is closely related to particle size and surface area (that is, smaller particles have higher surface areas that yield faster reaction rates). Conversely, the longevity of the ZVI materials tend to be shorter for the smaller particles (granular iron lasts more than 10 years; micron-scale iron lasts up to several years; and nano-scale iron lasts only days to months).

For the FS evaluation, EHC was selected as the ISCR reagent. However, another reagent may later be selected in the remedial design phase. The EHC technology is a controlled-release, integrated carbon and micron-scale ZVI reagent that yields redox potentials as low as -500 mV. EHC provides a combination of abiotic chemical reduction and anaerobic biological reduction, which will treat both TCE and daughter products.

Full-scale *In Situ* Chemical Reduction Implementation

ISCR would be implemented in TTZ-1 to reduce the maximum concentrations observed within the combined TCE, cis-1,2-DCE, and VC plumes (see Section 3.4.2 for TTZ details). This reduction in contaminant mass should facilitate natural attenuation. Based on the concentrations observed in TTZ-1 and the expected persistence of the micron-scale ZVI treatment in the subsurface, it was assumed that only one ZVI application would be required to reduce CVOC concentrations to levels amenable to MNA. Given the relatively low concentrations of TCE (between 36 and 190 µg/L), ISCR was not considered favorable within TTZ-2.

ISCR would be implemented within TTZ-1 using hydraulic fracturing via DPT (**Figure 4-3**). No laboratory treatability studies or field pilot studies were assumed before beginning full-scale implementation. A conservative 5-foot ROI was assumed to ensure even distribution of the ISCR reagent slurry. The injection points in TTZ-1 would be placed in a grid layout with offset rows aligned relatively perpendicular to groundwater flow. A grid layout was selected to treat the entire TTZ because the micron-scale ZVI in the EHC reagent is not expected to migrate significantly from the location where it is injected. In addition, migration of the carbon component would also be limited at this site due to the slow groundwater velocity. Impacts to Indian Field Creek are also not anticipated due to the relatively small ROI of 5 feet and the slow groundwater flow rate at the site.

Based on the estimated ROI, treatment areas, and vertical injection intervals, the number of injection points and reagent volume for each TTZ would be as follows:

- TTZ-1 Yorktown-Eastover Aquifer silty sands (11,200-ft^2 area and 25-foot injection interval)
  - 105 injection points set at 10-foot centers
  - 37,800 pounds of EHC
- TTZ-1 clay (2,826 ft^2-area and 10-foot injection interval)
  - 28 co-located injection points set at 10-foot centers
  - 3,850 pounds of EHC

Because all of the injections in the clay zone would be co-located with injection borings within the aquifer sands, a total of 105 DPT injection borings would be implemented at Site 3. The injections would be conducted using high injection pressures (100 psi or greater) and a bottom–to-top sequence in 1- to 4-foot intervals. One of the benefits of hydraulically fracturing the formation with injection pressures of 100 psi or more is the potential ability to treat contamination in low-permeability zones. Based on input from the technology vendor, the reagent would be diluted to a 30 percent (by weight) slurry before injection. As a result, 13,600 gallons would be injected in the aquifer sands of TTZ-1 and 1,385 gallons would be injected in the clay zone of TTZ-1. For the FS, it was assumed that it would take 21 days to finish the slurry injection. Following injection, the horizontal positions of the injection points would be recorded using a GPS.

Monitoring, Land Use Controls, and Contingency

The actual groundwater monitoring plan, including the number of monitoring wells, sample parameters, and sample frequency, would be developed during the remedial design phase. This plan would take into consideration the results of the pre-design baseline monitoring event. During the remedy implementation, the monitoring plan would be reviewed periodically and optimized as needed to reflect any changes in site conditions and the fate and transport of the COCs at this site.

Performance monitoring of the ISCR injections would be conducted to evaluate the effectiveness of the treatment technology. Groundwater monitoring would also provide warning if the future plume was to begin discharging into Indian Field Creek at unacceptable levels, as described in Section 4.2.3. For cost-estimating purposes, quarterly groundwater sampling would be conducted for a year following the injection. Groundwater from 19 wells would be analyzed for TCE, cis-1,2-DCE, VC, and degradation products (ethene and ethane), and seven wells would be analyzed for geochemical parameters, as described in Alternative 2 (Section 4.2.3). To evaluate attenuation and stability of the inorganic plumes, groundwater from eight monitoring wells would be analyzed for dissolved arsenic and manganese.

Following ISCR treatment, MNA would be conducted until RGs are achieved. For the FS evaluation, ISCR in the TTZ would be expected to decrease the remediation timeframe of the entire plume by 45 percent. Large mass reduction would be expected in TTZ-1 (where the highest concentrations are present), likely at a faster rate than with EISB. However, no active treatment would be conducted outside of this area and degradation would still be subject to the rates of natural decay. Therefore, the project duration for organic COCs is estimated at 9 years (or a 45 percent reduction of the MNA remediation timeframe). Similar to Alternative 2, monitoring of arsenic and manganese would continue for an additional 2 years, for a final project duration of 11 years.

For cost-estimating purposes only, it was assumed that sampling would be conducted at 20 monitoring wells to evaluate the effectiveness of MNA and the need for the contingency soil removal (4.2.7). Nineteen wells would be sampled for organic COCs; 10 wells would be sampled for geochemical parameters, ethene, and ethane; and 8 wells would be sampled for arsenic and manganese. Analytical data collected during MNA would be the same as described in Alternative 2 (Section 4.2.3). For FS purposes, groundwater samples would be collected on a semiannual basis for the first 4 years and then transition to an annual sampling frequency. However, this sample frequency would be re-evaluated annually. The monitoring assumptions, including frequency, duration, and analytical parameters, are also included in the cost estimates (**Appendix C**).

For Alternative 4, LUCs would be maintained similar to Alternative 2 (described in Section 4.2.3) until RGs are achieved, with Five-year statutory Reviews to ensure protection of human health and the environment. If needed, the contingency soil excavation would also be conducted as described in Alternative 2 (Section 4.2.3).

4.2.6 Alternative 5 – *In Situ* Chemical Oxidation, Monitored Natural Attenuation, and Land Use Controls

Alternative 5 includes the following remedial actions:

- Collect pre-injection soil samples for natural oxidant demand (NOD)
- Conduct injection of oxidant solution through DPT points in TTZ-1 (only one injection event proposed; see Section 3.4.2 for TTZ details)
- Conduct 4 quarters of quarterly monitoring

- Conduct semiannual and annual monitoring
  - Optimize sample locations, analysis, and/or frequency over the life of the remedy
  - Evaluate need for contingency action
- Enforce LUCs and conduct Five-year Reviews until RGs are met
- Not including the contingency action, the estimated duration of alternative is 11 years (for FS cost-estimating purposes)

Details of the remedial actions, including derivation of the remedial timeframe, are provided in the following subsections.

Alternative 5 includes ISCO of TCE, cis-1,2-DCE, and VC in groundwater within TTZ-1; MNA of TCE, cis-1,2-DCE, and VC within the remainder of the dissolved plume; and MNA of arsenic and manganese. ISCO is an aggressive technology used for the rapid treatment of a variety of organic contaminants in groundwater. It is based on the delivery of a chemical oxidant to contaminated media in order to oxidize TCE, cis-1,2-DCE, and VC to innocuous compounds (carbon dioxide [CO_2], chloride ions, and hydrogen ions).

Although MNA of dissolved arsenic and dissolved manganese is proposed under Alternative 5, the use of an oxidant can decrease the concentrations of dissolved arsenic and dissolved manganese concentrations in groundwater. The increase of subsurface oxidizing conditions may facilitate the precipitation of dissolved iron and manganese into their solid forms, which would result in a decrease in dissolved manganese concentrations. Dissolved arsenic concentrations could also decrease as the oxidant adsorbs onto the solid hydroxides and oxides. In addition, arsenic can be directly oxidized by the oxidant. However, arsenic concentrations in groundwater may temporarily increase immediately following the injection of permanganate because of heavy metal impurities in the oxidant.

Evaluation of Oxidants

ISCO involves injecting chemical reagents into the groundwater to oxidize contaminants upon direct contact with the oxidant, destroying them in a series of chemical reactions. The most commonly used oxidants are catalyzed hydrogen peroxide (CHP) propagations (also known as modified Fenton's reagent), permanganate, persulfate, and ozone. The first three of these are typically delivered as liquid-phase reagents using permanent injection wells, temporary well points, or DPT methods. Ozone is typically delivered to the subsurface as a gas via sparging methods. A description of the various oxidants is summarized as follows:

- The CHP process is based on the catalyzed decomposition of hydrogen peroxide by chelated iron to generate the strong oxidant hydroxyl radical (OH•), as well as other reactive oxygen species. If iron chelates are used, the reactions can be conducted under neutral pH conditions. Hydroxyl radicals react rapidly with chloroethenes. A shortcoming of CHP ISCO is its fast rate of hydrogen peroxide decomposition, resulting in a short half-life ranging from a few minutes to a few hours (Watts and Teel, 2006). Using stabilizers such as citrate or phytate increase the half-life by up to 10 days. Because of this short longevity or persistence, only contamination that comes into immediate contact with the oxidant gets treated. Therefore, the injection spacing tends to be lower (tighter grid) and the oxidant solution is unlikely to drift very far downgradient for additional treatment.
- Permanganate is commonly used for groundwater contaminated with chloroethenes. It is a stable oxidant and can persist in the subsurface for months (SERDP-ESTCP, 2010) to a few years.
- Activated persulfate (potential activators include iron ethylenediaminetetraacetic acid, hydrogen peroxide, heat, or sodium hydroxide) generates both hydroxyl radicals and sulfate radicals ($SO_4^{\bullet -}$). The sulfate free radical is almost as reactive as the hydroxyl radical. Depending on the amount of soil organic matter and abundance of reduced iron and manganese, persulfate can persist for weeks to months. It can effectively oxidize a variety of COCs, including both chlorinated ethenes and alkanes, in the subsurface. Concerns with persulfate are its potential to lower the pH, which may slow down the natural

biodegradation rate immediately after ISCO treatment and residual sulfate concentrations in groundwater. However, field experience has shown effective natural attenuation to be restored within months of persulfate applications.

- Ozone is a strong oxidant, but its oxidation strength is less than that of the hydroxyl and sulfate radicals. Ozone is usually produced onsite using an ozone generator and therefore requires more-complex infrastructure (power) for its application than other oxidants. Ozone is also short-lived, with a half-life of approximately 30 minutes in groundwater under normal conditions (Interstate Technology and Regulatory Council, 2005), limiting the extent of radial treatment around an injection point. In addition, ozone's oxidation potential is limited by the mass transfer of ozone into groundwater (Watts and Teel, 2006).

Oxidants can cause select metals to change into more-soluble states, making them more mobile. However, with a groundwater velocity of 4 feet per year, mobility is not a great concern. Additionally, if an oxidant (such as permanganate) contains trace amounts of metals and a large amount of oxidant is injected, then inorganic constituent concentrations may temporarily exceed applicable MCLs. Research and field data have shown that once the oxidant is consumed and oxidative conditions in groundwater return to ambient conditions, metals also return to background concentrations. Monitoring the trends of select metals post-ISCO application is recommended.

Permanganate was selected as the oxidant for the Alternative 5 evaluation because of its demonstrated effectiveness on chloroethenes and its stability. However, another oxidant may later be selected in the remedial design phase.

Pre-injection Investigation

A sufficient quantity of permanganate is required to overcome the NOD of the soil and effectively react with COCs. Because permanganate is a non-selective oxidant, it reacts with many soil and subsurface constituents, including natural organic matter and reduced metals, carbonates, hydrogen sulfide, and bacteria. NOD tests have been conducted for the Yorktown-Eastover Aquifer at WPNSTA Yorktown Sites 12 and 22 (CH2M HILL, 2008c; CH2M HILL, 2009). The results ranged from greater than 0.6 to 9.3 grams of permanganate per kilogram soil. Based on the results from this testing, the NOD of the sandy aquifer at Site 3 was conservatively estimated to be 3.0 grams permanganate per kilogram of soil for this FS.

Before actual injection, site-specific NOD data would be required for the Site 3 remedial design. The cost estimate assumed that two soil samples would be collected during the pre-design investigation. While the new monitoring wells are being installed, one soil sample would be collected in the soft clay at 5 to 10 feet above msl while the second soil sample would be collected from the silty sand between 10 to 30 feet below msl.

Full-scale Permanganate Injection

ISCO would be implemented in TTZ-1 to reduce the maximum concentrations observed within the combined TCE, cis-1,2-DCE, and VC plumes (see Section 3.4.2 for TTZ details). This reduction in contaminant mass should facilitate natural attenuation. Based on the concentrations observed in TTZ-1 and the expected persistence of the permanganate in the subsurface, it was assumed that only one ISCO application would be required to reduce TCE, cis-1,2-DCE, and VC concentrations to levels amenable to MNA. Given the relatively low concentrations of TCE (between 36 and 190 µg/L), ISCO was not considered favorable within TTZ-2.

Permanganate would be injected within TTZ-1 using DPT methods. Similar to Alternative 3, permanganate would be injected into the clay zone of TTZ-1 using high injection pressures and have an assumed ROI of approximately 5 feet. In the aquifer sands, permanganate would be injected in TTZ-1 at much lower pressures and have an assumed ROI of 8 feet. The ROI of 8 feet was calculated based on an NOD of 3.0 grams of permanganate per kilogram of soil using the ISCO tool (SERDP-ESTCP, 2010). The injection points would be placed in a grid layout with offset rows aligned relatively perpendicular to groundwater flow (**Figure 4-4**). A grid layout was selected because of the slow groundwater flow rate. Impacts to Indian Field

Creek are also not anticipated due to the relatively small ROI of 5 feet and the slow groundwater flow rate at the site.

Based on the estimated ROI, treatment areas, and vertical injection intervals, the number of injection points and reagent volume for each TTZ are as follows:

- TTZ-1 Yorktown-Eastover Aquifer silty sands (11,200-ft^2 area and 25-foot injection interval)
  - 51 injection points set at 15-foot centers (10 percent overlap)
  - 41,530 pounds of permanganate
- TTZ-1 clay (2,826 ft^2-area and 10-foot injection interval)
  - 28 injection points set at 9- to 11-foot centers; 14 injections would be co-located with the injection borings conducted in the sandy aquifer, and 14 injections would be conducted in separate borings
  - 4,190 pounds of permanganate

In total, 65 DPT injection borings would be implemented at Site 3. Assuming an effective porosity of 0.20, an NOD of 3.0 grams of permanganate per kilogram of soil, and an average VOC concentration of 1 mg/L, the amount of permanganate required to treat both the sand and clay zones of TTZ-1 would be approximately 4,000 gallons of 40 percent by weight sodium permanganate ($NaMnO_4$) solution. The liquid $NaMnO_4$ would be delivered to the site in totes and drums. The 40 percent by weight $NaMnO_4$ solution would be diluted with water to a 2 percent by weight $NaMnO_4$ solution (107,600 gallons) before being injected. This injection volume is equal to approximately 23 percent of the pore volume of the targeted treatment zone. Water to form the injection solution would be obtained from a fire hydrant on the Base. Potassium permanganate ($KMnO_4$) and $NaMnO_4$ are equally effective as an oxidant, but liquid $NaMnO_4$ is easier to handle onsite than mixing the powder form of $KMnO_4$. $NaMnO_4$ was used for cost-estimating purposes; however, the cost may be slightly lower if $KMnO_4$ is selected and if it can be delivered to the site pre-mixed or be mixed onsite.

At each of the injection points, permanganate would be delivered at approximately five sequential 5-foot intervals in the same boring to treat the entire vertical interval. A top-to-bottom injection sequence would be used to prevent oxidant migration into the sand during high-pressure injections. Injection would occur through specially designed injection screens with variable 1- to 5-foot intervals. In the aquifer sands, low pressures (less than 20 psi) would be used. To inject into the clay zone, hydraulic fracturing with higher pressures would be used initially to facilitate oxidant distribution. However, once the fractures were initiated, lower pressures could be used to deliver the targeted volume of $NaMnO_4$ at each injection boring. An average injection rate of 3 gallons per minute was assumed, based on ranges of injection rates at similar sites in Virginia. It was also assumed that injection would occur in four locations simultaneously and that it would take 19 days to complete the injection. During the ISCO application, oxidant injection pressure, flow rates, and injection solution concentration would be measured. Water levels, color, oxidant concentration, DO, conductivity, and ORP would be measured periodically in surrounding monitoring wells. Following the ISCO injection, each point would be surveyed by a handheld GPS.

Monitoring, Land Use Controls, and Contingency

The actual groundwater monitoring plan, including the number of monitoring wells, sample parameters, and sample frequency, would be developed during the remedial design phase. This plan would take into consideration the results of the pre-design baseline monitoring event. During the remedy implementation, the monitoring plan would be reviewed periodically and optimized as needed to reflect any changes in site conditions and the fate and transport of the COCs at this site.

Performance monitoring of the ISCO injections would be conducted to evaluate the effectiveness of the treatment technology. Groundwater monitoring would also provide warning if the future plume was to begin discharging into Indian Field Creek at unacceptable levels, as described in Section 4.2.3. For cost-estimating purposes, quarterly groundwater sampling would be conducted for a year following the injection.

Groundwater from 19 wells would be analyzed for organic COCs (TCE, cis-1,2-DCE, and VC) and selected dissolved metals (such as copper, iron, manganese, arsenic, barium, cadmium, chromium, lead, and selenium). Additionally, permanganate (through colorimeter and spectrophotometer field kit) would be measured. Based on the permanganate injection volume and the target treatment volume, concentrations of metals (such as arsenic and chromium) may temporarily increase above their MCLs.

Following ISCO treatment, MNA would be conducted until RGs are achieved. For the FS evaluation, permanganate injection would be expected to decrease the remediation timeframe of the entire plume by 45 percent. However, no active treatment would be conducted outside of this area and degradation would still be subject to the rates of natural decay. The project duration for organic COCs for Alternative 5 was estimated to be 9 years (or a 45 percent reduction of the MNA remediation timeframe). Similar to Alternative 2, monitoring of arsenic and manganese would continue for an additional 2 years, for final project duration of 11 years.

For cost-estimating purposes only, it was assumed that sampling would be conducted at 20 monitoring wells to evaluate the effectiveness of MNA and the need for the contingency soil removal. Nineteen wells would be sampled for organic COCs; 10 wells would be sampled for geochemical parameters; and 8 wells would be sampled for arsenic and manganese. Analytical data collected during MNA would be the same as described in Alternative 2 (Section 4.2.3). For FS purposes, groundwater samples would be collected on a semiannual basis for 4 years and then transition to an annual sampling frequency. However, this sample frequency would be re-evaluated annually. The monitoring assumptions, including frequency, duration, and analytical parameters, are also included in the cost estimates (**Appendix C**).

For Alternative 5, LUCs would be maintained similar to Alternative 2 (described in Section 4.2.3) until RGs are achieved, with Five-year statutory Reviews to ensure protection of human health and the environment. If needed, the contingency soil excavation would also be conducted as described in Alternative 2 (Section 4.2.3).

TABLE 4-1

Screening of Remedial Technologies
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

General Response Action	Remedial Technology	Process Options	Description	Primary Screening			Secondary Screening					
				Retain	Reject	Primary Screening Comments	Effectiveness	Implementability	Relative Cost	Retain	Reject	Secondary Screening Comments
No Action	None	None	No further actions to address contaminated groundwater.	X		Retained for baseline comparison.	Low. Some attenuation of constituents expected over time. However, the remedial timeframe may be extensive and no monitoring would be conducted to evaluate short-term risks to human health and environment from exposure to contaminants of concern (COCs).	High. No work required.	No cost.	X		Retained for baseline comparison
Institutional Controls	Administrative Restrictions or Engineering Controls	Land Use Controls (LUCs)	Land Use Controls are required for property within potentially contaminated areas to restrict property use, well installation, and other intrusive activties.	X		Although there are currently no groundwater uses onsite, LUCs will be required until the RGs are achieved to prevent human exposure.	Moderate. Can be effective at protecting human health receptors given proper enforcement.	High. Requires working with the regulators and the base to establish well prohibition within and adjacent to the plume. Legal aspects can require extended timeframe.	Low.	X		Retained for use site-wide. Required to be a component of any remedial alternative until RAOs are met.
Groundwater Containment	Physical Barriers	Slurry wall, sheet piling, vibrating barrier wall, etc.	Physical and/or chemical wall that prevents contaminated groundwater from flowing either horizontally or vertically.		X	Rejected because no treatment would be conducted and the barrier wall may actually limit natural attenuation processes because of its impact on groundwater flow.						
	Bio-Chemical Treatment	Funnel + Gate	Low permeability walls (funnels) are constructed on the outside of the source or plume to contain and direct contaminated groundwater through a permeable *in situ* treatment system (gate). Treatment can be chemical (e.g., ZVI barrier) or biological (e.g., mulch bio-barrier). Walls are usually constructed of bentonite slurry or sheet piling.		X	Rejected because technically impracticable to install wall deep enough to contain groundwater plume and not effective in groundwater plume treatment. Will not meet the RAOs.						
	Hydraulic Barriers	Pump and Treat (P&T)	Groundwater is extracted and treated in an *ex-situ* treatment system. Various biological, physical or chemical *ex situ* treatment technologies may be applied. System can be designed to alter the natural hydraulic gradient to prevent contaminated groundwater flow either horizontally or vertically, and can also be used to treat mobile NAPL.		X	Rejected because P&T is not a plume treatment remedy but a containment technology. Low cost-effectiveness of this technology for low concentration plumes; would take much longer time than the other active remedies to reach RAOs.						
Removal	Multi-Phase extraction	Collection Trenches	Perforated pipe in trenches backfilled with porous medium to collect water and mobile NAPL.		X	Rejected because mobile NAPL is not considered a concern at this site.						
		Skimmer Wells and Pumps	Mobile LNAPLs floating on top of the water table are extracted via pump. Mobile DNAPLs are extracted by pumps at the bottom of the well. Dual-pump systems may allow extraction of water and NAPLs.		X	Rejected because mobile NAPL is not considered a concern at this site.						
		Dual Phase Extraction	A groundwater collection system is used to lower the water table to expose contaminated soil. Soil vapor extraction is then used to removed absorbed or trapped contaminants. Used for NAPL source zones.		X	Rejected because mobile NAPL is not considered a concern at this site.						
Groundwater Treatment (*In Situ*)	Chemical	*In Situ* Chemical Oxidation (ISCO)	Injection of oxidant such as hydrogen peroxide or permanganate to chemically oxidize the organic contaminants to non-toxic end products. ISCO may temporarily mobilize some inorganics.	X		Retained because the technology is applicable to the site contaminants and widely demonstrated.	Moderate to high. Quickly creates oxidizing conditions in subsurface. Demonstrated effectiveness on CVOCs. Dissolved metals (Mn and As) will be oxidized and precipitated. Requires good contact between contaminants and reagent. Homogeneous silty sand aquifer in TTZ-1 facilitates uniform distribution of oxidant. Natural oxygen demand of the sandy aquifer is estimated to be 3 g/kg, but needs to be tested prior to field application.	Moderate to high. Most suitable for source area treatment. The permeable aquifer facilitates injection and good distribution of oxidant in the subsurface. Short-term risks to field workers and the environment from the chemicals on-site. Not compatible with existing anaerobic natural attenuation. The reductive environment in Site 3 groundwater may exert a high oxidant demand.	Moderate. Cost-effective for source treatment. One injection is assumed because of the relatively low concentrations of the plume.	X		Retained due to its demonstrated effectiveness on site COCs and moderate cost.

TABLE 4-1

Screening of Remedial Technologies
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

General Response Action	Remedial Technology	Process Options	Description	Primary Screening			Secondary Screening					
				Retain	Reject	Primary Screening Comments	Effectiveness	Implementability	Relative Cost	Retain	Reject	Secondary Screening Comments
Groundwater Treatment (In Situ) (continued)		Flushing	Chemical injection (e.g. surfactant, hot water or steam) facilitates removal of residual NAPL or contaminants from the subsurface. Chemicals are extracted or re-circulated.		X	Rejected due to the low contaminant concentrations at this site, and the potential to mobilize contaminants.						
	Chemical Treatment	*In Situ* Chemical Reduction (ISCR)	Reducing agents (e.g., ZVI) are added into the subsurface via hydraulic/pneumatic fracturing to promote abiotic *in situ* reduction. Carbon substrates/nutrients may be blended into the amendments to enhance anaerobic bioremediation as well as a supplementary treatment mechanism.	X		Retained because the technology is applicable to the site contaminants and widely demonstrated.	Moderate to high. A long-lived technology, demonstrated effectiveness on CVOCs. Abiotic reactions occur quickly. Enhanced reductive environment would cause dissolved metals (Mn and As) to stay dissolved in groundwater. However, arsenic would react directly with ZVI, co-precipitating it out of groundwater. Requires good contact between contaminants and reagent.	Moderate to high. Most suitable for source area treatment. Injection (likely through hydraulic fracturing) needs specialized vendor. Compatible with existing anaerobic natural attenuation.	Moderate. Multiple choices of amendments, including micron-scale ZVI, mixed ZVI and carbon substrates/nutrients in market. Injection technique is only available from specialized vendor.	X		Retained because this technology is highly effective at degrading the COCs at this site, suitable for source area treatment, and compatible with natural anaerobic biodegradation.
		In Situ Chemical Reduction (ISCR) (continued)	ZVI is injected or mixed into the soil in an emulsified form (EZVI) to promote abiotic *in situ* reduction. Since the reagent is in an emulsified form, pneumatic fracturing to distribute the EZVI is not necessary. The oil in the emulsification also provides a carbon source for reductive dechlorination.	X		Retained because the technology is applicable to the site contaminants and has been demonstrated.	Moderate to high. High reactivity but short longevity (weeks to months). Enhanced reductive environment would cause dissolved metals (Mn and As) to stay dissolved in groundwaterand therefore require monitoring. Requires good contact between contaminants and reagent.	Moderate. High viscosity of EZVI reduces the achievable radius of influence (ROI). Technology would need to be obtained from specialized vendor. May require regulatory approval for use of surfactant in the EZVI.	High. Nano-scale ZVI is more costly than other types of ZVI. Requires more injection points due to shorter ROI.		X	Rejected because this technology is not cost-effective for low concentration plumes. Injection may not achieve good distribution of the reagent in the subsurface, which limits the effectiveness.
		Permeable Reactive Barrier (PRB)	Treats groundwater plume as it passes through a permeable reactive zone. Reactive zone may be a combination of physical, chemical, and biological processes. May also include measures such as low-permeability barriers to channel groundwater towards treatment zone. PRB can be constructed by trenching or injection.		X	Rejected because the groundwater flow at this site is extremely slow, therefore areal/grid treatment is considered a more effective strategy.						
	Physical Treatment	Air Sparging/Soil Vapor Extraction (AS/SVE)	Air injected into groundwater through a system of wells or horizontal perforated pipes to volatize target contaminants. May be combined with SVE to collect CVOCs in the vadose zone.		X	Rejected because the low permeable clay layer on top of the sandy aquifer could divert the airflow laterally, resulting in inconsistent air distribution, and cause AS/SVE system to be ineffective.						
		Heating	The subsurface is heated using hot water/steam injection or six phase/radio frequency (Electrical Resistive Heating) to enhance volatilization of contaminants. The volatilized contaminants rise to the unsaturated zone and are removed by vacuum extraction and treated.		X	Rejected because the technology is cost prohibitive and technically challenging due to the stratified aquifers. SVE would not be feasible because of presence of clay in the vadose zone.						

TABLE 4-1

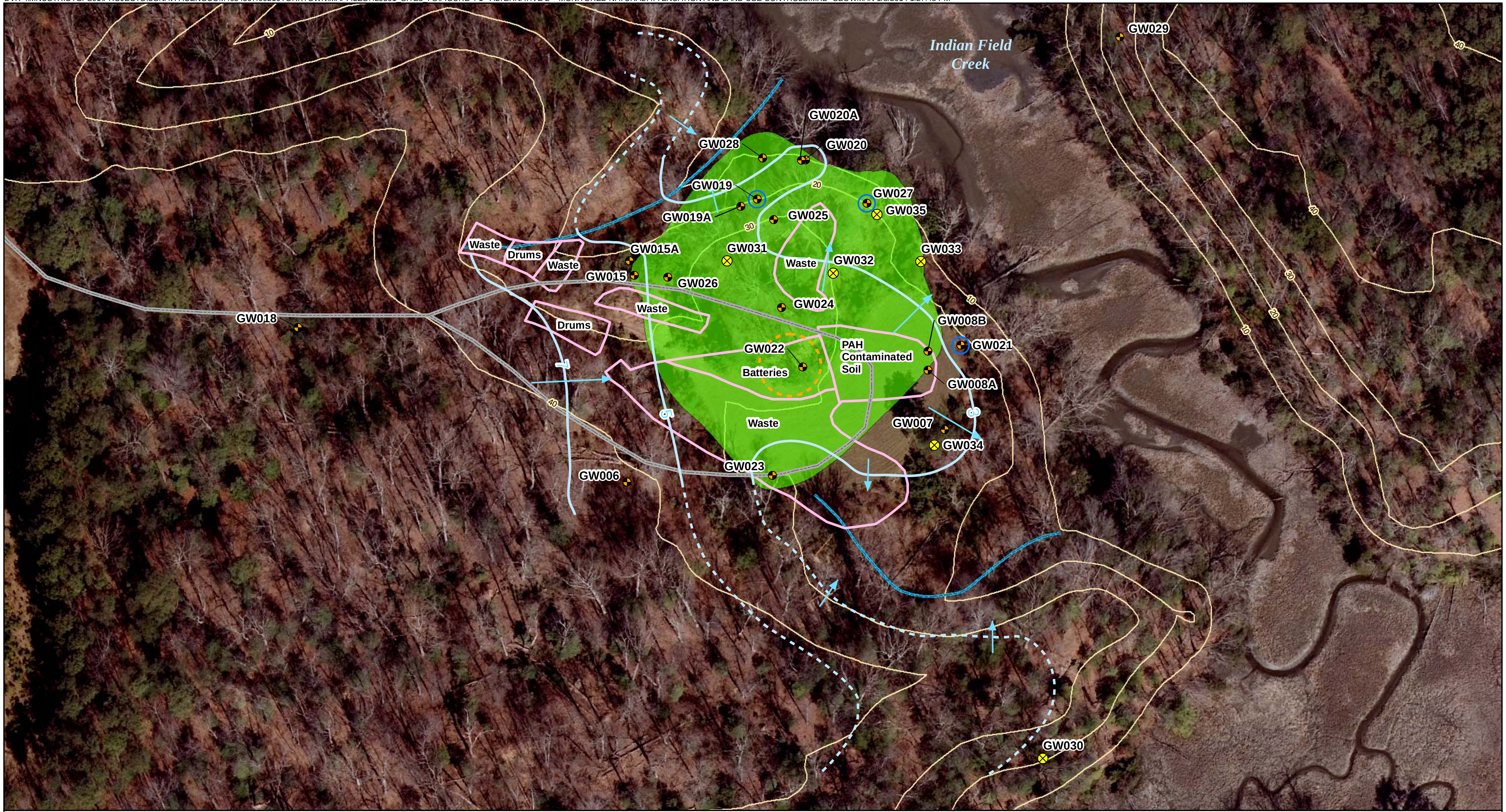
Screening of Remedial Technologies
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

General Response Action	Remedial Technology	Process Options	Description	Primary Screening			Secondary Screening					
				Retain	Reject	Primary Screening Comments	Effectiveness	Implementability	Relative Cost	Retain	Reject	Secondary Screening Comments
Groundwater Treatment (In-situ) (continued)	Biological Treatment	Enhanced Aerobic Bioremediation	Stimulation of indigenous microorganisms to aerobically degrade the contamination by injecting nutrients, oxygen, substrates, or engineered microorganisms. Degradation may be metabolic and/or cometabolic processes.		X	Rejected because aerobic biodegradation (mainly a cometabolic process) of TCE/*cis*-DCE/VC is less sustainable/robust, and much more difficult to engineer and document its effectiveness in the field than anaerobic bioremediation. Also not compatible with the existing anaerobic natural attenuation under reducing conditions.						
	Biological Treatment	Enhanced Anaerobic Bioremediation	Use of an electron donor (Hydrogen Releasing Compound, vegetable oil, or molasses) to promote anaerobic biodegradation of organic compounds (biostimulation). Also may involve the use of nutrients and engineered bacterial cultures to promote biodegradation (bioaugmentation).	X		Retained because the technology is applicable to the site contaminants and widely demonstrated.	Moderate to high. Proven to be effective for the CVOCs at this site. Injection of soluble substrates may achieve greater ROI. Homogeneous silty sand aquifer in TTZ-1 facilitates uniform distribution of substrate. Enhanced reductive environment would cause dissolved metals (Mn and As) to stay dissolved in groundwater and therefore require monitoring.	Moderate to high. The permeable aquifer facilitates injection and good distribution of amendments in the subsurface. Compatible with existing anaerobic natural attenuation.	Moderate. Typically considered a cost-effective alternative. One injection is assumed because of the relatively low concentrations of the plume. Bioaugmentation culture would be used to avoid accumulation of daughter products.	X		Retained due to its demonstrated effectiveness on site COCs and its relatively low cost.
		Phytoremediation	Use of plants to remove, stabilize, or destroy contaminants in shallow soil or groundwater.		X	Rejected because depth to water (~ 30 ft bgs) and the depth interval of the plume (~35-70 ft bgs) are too deep for phytoremediation to be effective.						
Monitoring	Monitoring	Monitored Natural Attenuation (MNA)/ Performance Monitoring	Regular monitoring and data evaluation to assess effectiveness of natural and/or active treatment processes. Monitoring is necessary to demonstrate that contaminant concentrations and/or mass continue to decrease and verify that potentially toxic transformation products are not created at levels that are a threat to human health or the environment.	X		Retained because natural attenuation of COCs is likely occurring in groundwater and might be sufficient to meet site RAOs.	Low to moderate. Effective at reducing COC concentrations at this site, but remedial timeframe may be long.	High. No construction activities would be conducted. Therefore, there would be limited disruption ot the site.	Low to moderate. Costs include monitoring and are dependent on frequency and number of sampling points.	X		Retained. May be used as a remedial alternative for the entire site or in combination with active treatment of targeted zones. Monitoring required to evaluate active treatment performance.

Notes:
Technologies in darker areas are rejected in primary or secondary screening.

AS - Air sparging
COC - Contaminant of concern
CVOCs - Chlorinated VOCs
DNAPL - Dense NAPL
EZVI - Emulsified ZVI
ISCO - *In situ* chemical oxidation
ISCR - *In situ* chemical reduction
LNAPL - Light NAPL
LUCs - Land Use Controls
MNA - Monitored natural attenuation
NAPL - Non-aqueous Phase Liquid
NOD - Natural oxidant demand
O&M - Operation and maintenance
PRB - Permeable reactive barrier
RAOs - Remedial action objectives
SVE - Soil vapor extraction
VOC - Volatile organic compound
ZVI - Zero valent iron

DVR \\MNUSTRICTGFS01\PROJECTS\USNAVFACENGCOM405450\400210YORKTOWN\MAPFILES\429391_SITE3_FS\FIGURE 4-1 - ALTERNATIVE 2 - MONITORED NATURAL ATTENUATION AND LAND USE CONTROLS.MXD CBOWMAN 1/8/2014 1:27:48 PM



Legend

- Proposed Monitoring Well
- Yorktown Monitoring Wells
- Groundwater Flow Direction
- Groundwater Elevation Contour
- Inferred Groundwater Elevation Contour
- Landfill Access Road
- Estimated Drainage Channel
- Elevation Contour (10 ft interval)
- Approximate Unsaturated TPH Contamination
- Approximate Waste Limits (1999 Remedial Action)
- Maximun Extent of the TCE, cisDCE, and VC plumes
- Exceeds Dissolved Arsenic and Manganese Preliminary Remediation Goal

Notes:
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

N
W E
S

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Feet

Figure 4-1
Alternative 2 - Monitored Natural Attenuation and Land Use Controls
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

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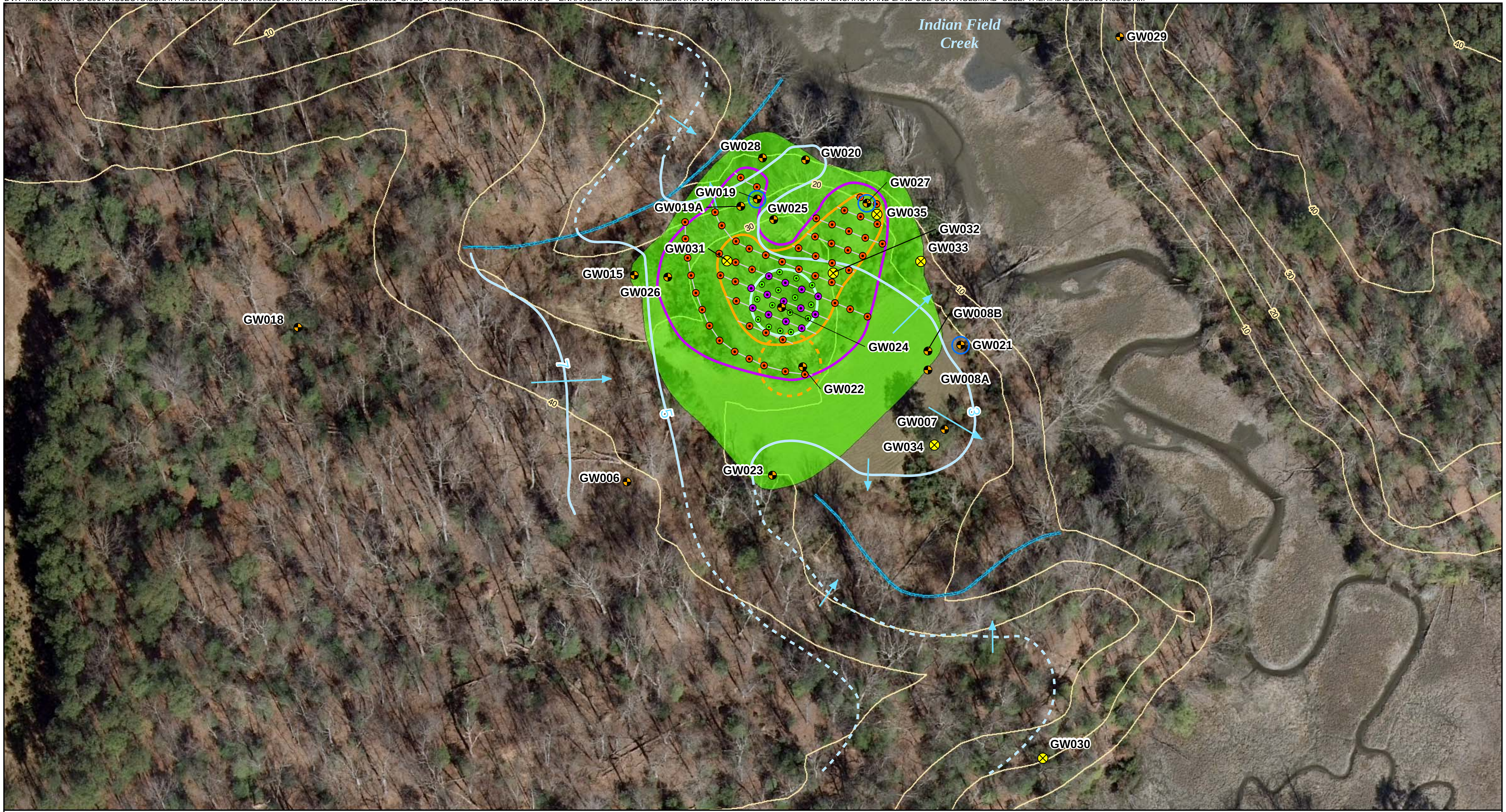
DVR \\MNUSTRICTGFS01\PROJECTS\USNAVFACENGCOM405450\400210YORKTOWN\MAPFILES\429391_SITE3_FS\FIGURE 4-2 - ALTERNATIVE 3 - ENHANCED IN SITU BIOREMEDIATION WITH MONITORED NATURAL ATTENUATION AND LAND USE CONTROLS.MXD CELEFTHERIADIS 5/2/2013 7:55:05 AM



Legend

- Proposed Injection - Clay
- Proposed Injection - Silty Sand
- Proposed Injection - Silty Sand and Clay
- Proposed Monitoring Well
- Yorktown Monitoring Wells
- Groundwater Flow Direction
- Groundwater Elevation Contour
- Inferred Groundwater Elevation Contour
- Estimated Drainage Channel
- Approximate Unsaturated TPH Contamination
- Target Treatment Zone 1 - Silty Sand
- Target Treatment Zone 2
- Elevation Contour (10 ft interval)
- Maximun Extent of the TCE, cisDCE, and VC plumes
- Exceeds Dissolved Arsenic and Manganese Preliminary Remediation Goal
- Target Treatment Zone 1 - Clay

Notes:
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

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Figure 4-2
Alternative 3 - Enhanced In Situ Bioremediation with Monitored Natural Attenuation and Land Use Controls
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

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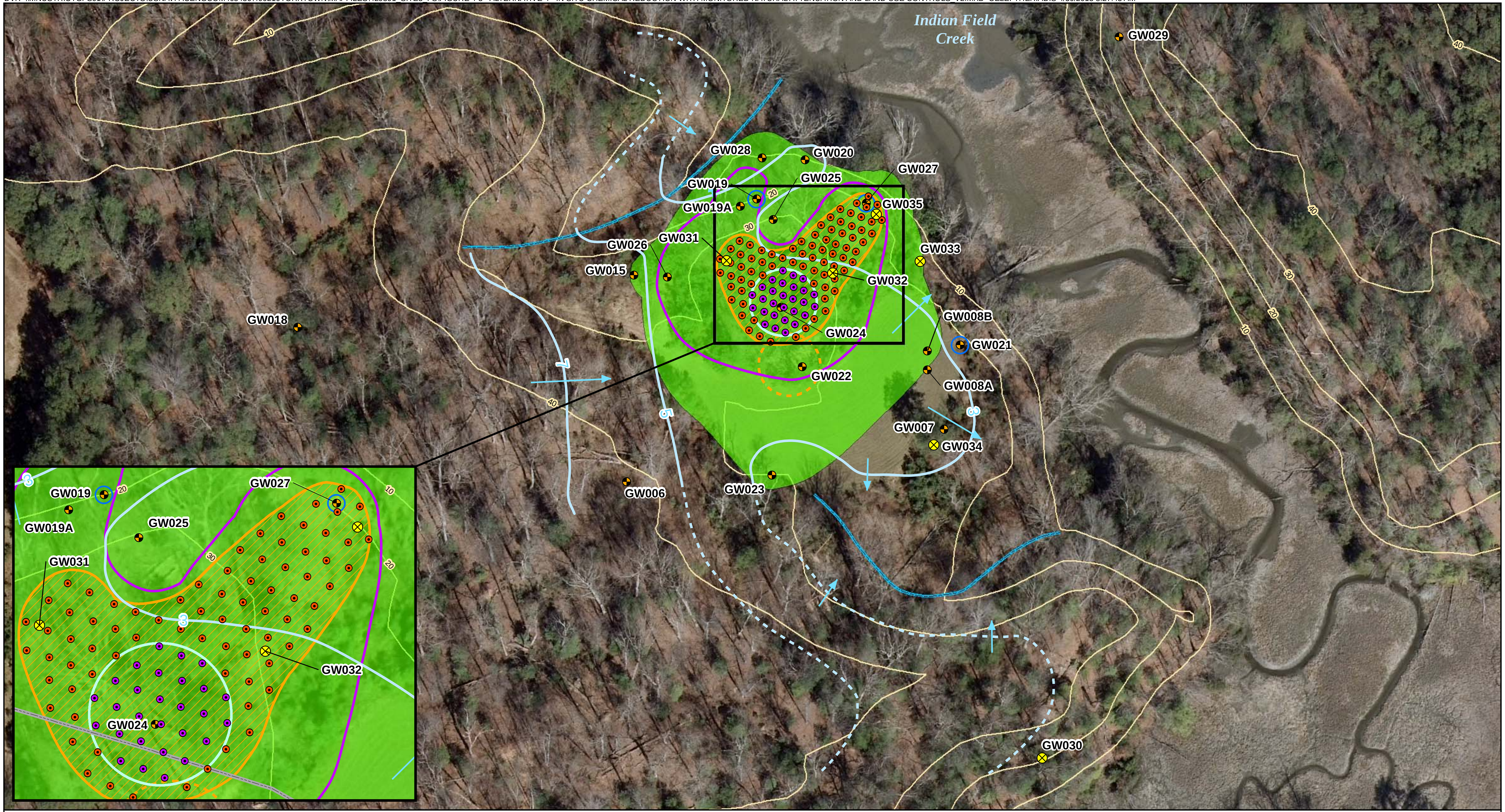

Legend

- Proposed Injection - Silty Sand
- Proposed Injection - Silty Sand and Clay
- Proposed Monitoring Well
- Yorktown Monitoring Wells
- Groundwater Flow Direction
- Groundwater Elevation Contour
- Inferred Groundwater Elevation Contour
- Elevation Contour (10 ft interval)
- Estimated Drainage Channel
- Approximate Unsaturated TPH Contamination
- Target Treatment Zone 1
- Target Treatment Zone 1 - Clay
- Target Treatment Zone 2
- Maximun Extent of the TCE, cisDCE, and VC plumes
- Exceeds Dissolved Arsenic and Manganese Preliminary Remediation Goal

Notes:
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

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Figure 4-3
Alternative 4 - In Situ Chemical Reduction with Monitored Natural Attenuation and Land Use Controls
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

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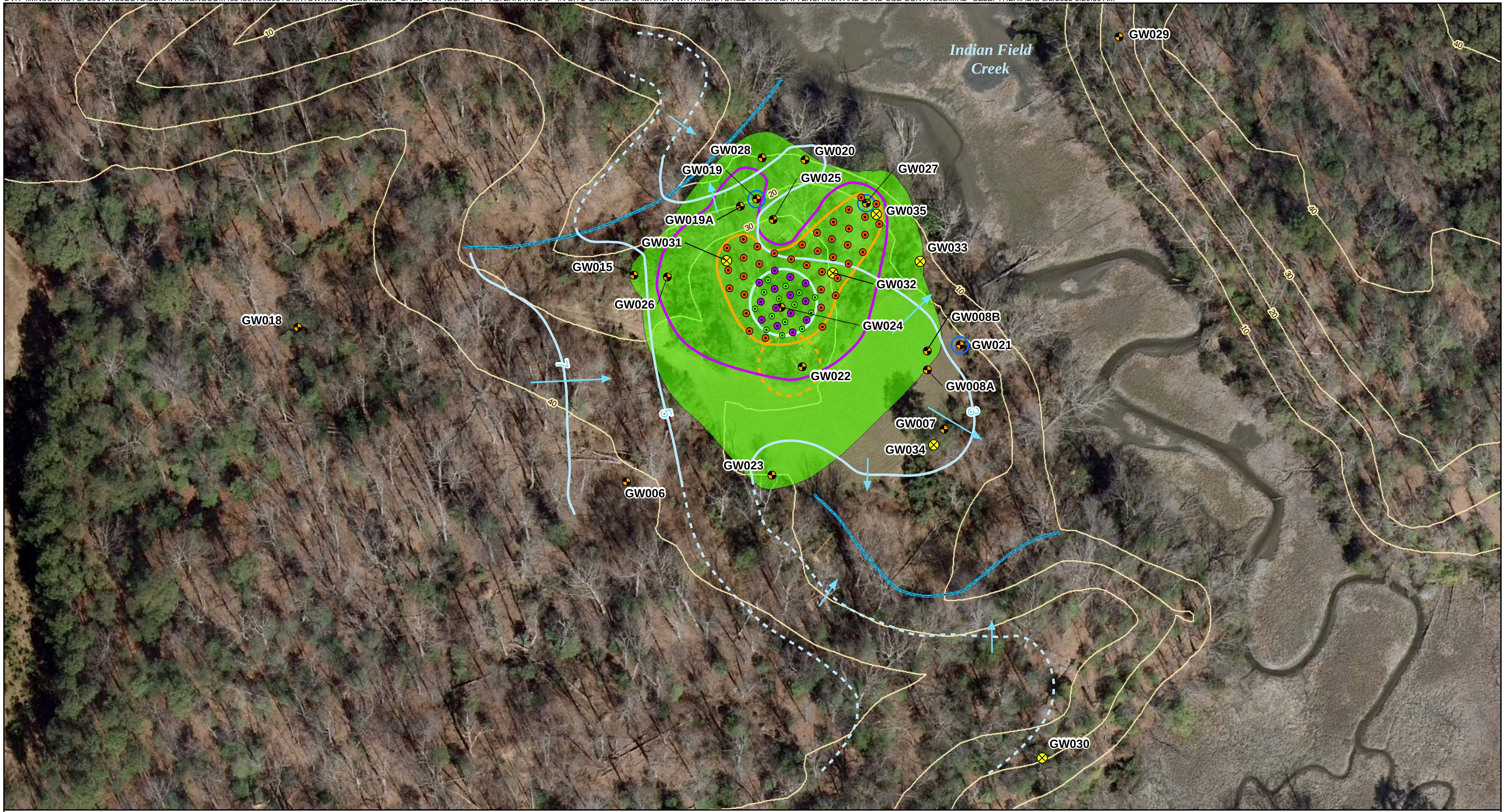

Legend

- Proposed Injection - Clay
- Proposed Injection - Silty Sand
- Proposed Injection - Silty Sand and Clay
- Proposed Monitoring Well
- Yorktown Monitoring Wells
- Groundwater Flow Direction
- Groundwater Elevation Contour
- Inferred Groundwater Elevation Contour
- Elevation Contour (10 ft interval)
- Estimated Drainage Channel
- Approximate Unsaturated TPH Contamination
- Target Treatment Zone 1 Silty Sand
- Target Treatment Zone 1 - Clay
- Target Treatment Zone 2
- Maximun Extent of the TCE, cisDCE, and VC plumes
- Exceeds Dissolved Arsenic and Manganese Preliminary Remediation Goal

Notes:
The prefix "YS03-" for the monitoring well identifications are not shown on the figure due to space limitations.

N W E S

0 85 170 Feet

Figure 4-4
Alternative 5 - In Situ Chemical Oxidation with Monitored Natural Attenuation and Land Use Controls
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

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SECTION 5

Detailed Evaluation of Alternatives

This section discusses the evaluation of alternatives developed in the previous section to provide a basis for selecting a remedy. Section 5.1 discusses the NCP criteria used to evaluate the alternatives. Section 5.2 discusses the sustainability guidance and metrics that were incorporated into each NCP criterion. Section 5.3 presents a comparative analysis of the remedial alternatives.

5.1 Evaluation Criteria for Remedial Alternatives

The remedial alternatives were evaluated against a common set of criteria. Each alternative was developed to address risk to human health and/or the environment posed by COCs in groundwater at Site 3. The NCP requires evaluation of remedial alternatives against the following nine criteria:

- 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, which 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 described in this section. The last two criteria, state and community acceptance, are modifying criteria and would be addressed in the Proposed Plan and ROD for Site 3.

The detailed alternatives 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 as follows.

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, performance, and short-term effectiveness. This evaluation focuses on whether each alternative achieves adequate protection and describes how site risks are eliminated, reduced, or controlled. Also, the criterion allows for consideration of whether an alternative poses any unacceptable short-term or cross-media impacts.

5.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

This criterion is used to evaluate whether each alternative would meet all of the federal and state ARARs identified; the ARARs were discussed in Section 3.3. The following factors were considered as each alternative was evaluated for this criterion on state and federal levels:

- Compliance with chemical-specific ARARs: Health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, establish the amount or concentration of a chemical that may remain in or be discharged to the environment.

- Compliance with location-specific ARARs: These restrict the concentrations of hazardous substances or the conduct of activities solely because they are in specific locations, such as floodplains, wetlands, historical areas, or sensitive ecosystems or habitats.

- Compliance with action-specific ARARs: Technology- or activity-based requirements that set controls or restrictions on design performance of remedial actions or management of hazardous constituents.

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 were considered as each alternative was evaluated for this criterion:

- Magnitude of estimated residual risk: An assessment of the risk remaining from untreated waste or treatment residuals after the response objectives have been met.
- Adequacy and reliability of controls: An evaluation of the controls that can be used to manage treatment residuals or untreated wastes that remain at the facility, including the sufficiency of institutional controls to ensure that any exposures to human and ecological receptors are within protective levels.

5.1.4 Reduction in 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 were considered as each alternative was 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 were considered as each alternative was evaluated for this criterion:

- Protection of community during remedial actions: Risk that results from implementation of the proposed remedial action, such as dust, increased traffic, odor, or air-quality impacts.
- Protection of workers during remedial actions: Threats that may be posed to workers by heavy equipment, machinery, and transportation and the effectiveness and reliability of protective measures that could be taken.
- Environmental impacts: Potential adverse environmental (ecological, water, or resource) impacts that may result from the implementation of an alternative such as greenhouse gas (GHG) emissions, criteria pollutant emissions, destruction of habitats, and consumption of resources.
- Time until remedial response objectives are achieved: Estimate of the time required to achieve protection for either the entire site or individual elements associated with specific site areas or threats.

5.1.6 Implementability

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

- Technical feasibility
  - Ability to construct and operate the technology
  - Reliability of the technology (likelihood that technical problems would lead to schedule delays)
  - Ease of undertaking additional remedial action, if necessary
  - Ability to monitor effectiveness of the remedy
- Administrative feasibility
  - Ability to coordinate with and obtain approvals from other agencies
  - Availability of offsite treatment, storage, and disposal services and capacity
  - Availability of necessary equipment and specialists
  - Availability of prospective technologies

5.1.7 Cost

This criterion evaluates alternatives based on the associated capital cost and O&M cost to achieve the RAOs. The estimated cost of each remedial option is expressed as a present value based on an assumed discount rate of 3.8 percent up to a 30-year operation period. The discount rate is based on the 2012 Discount Rates for the federal Office of Management and Budget Circular No. A-94 (2013). The O&M period was estimated for evaluation purposes only; the actual O&M period could be much longer in some cases, but would have minimal impact to the cost estimate based on the discount rate. Total costs are estimated to an accuracy of plus 50 to minus 30 percent.

5.1.8 State Acceptance

This criterion evaluates concerns the state may have regarding each of the alternatives. This criterion is not discussed in this report but would be addressed in the Proposed Plan and ROD.

5.1.9 Community Acceptance

Typically, community comment and acceptance is evaluated in the ROD and is a result of the community review of the Proposed Plan.

5.2 Sustainability Metrics and Evaluation Criteria

Consideration of sustainable practices is becoming increasingly important throughout the remediation community, and this emphasis is now being reflected in policy and guidance.

Executive Order (EO) 13423, released on January 26, 2007, mandated all federal agencies to conduct their environmental, transportation, and energy activities in an environmentally, economically, and fiscally sound, integrated, continuously improving, efficient, and sustainable manner. In April 2008, USEPA issued *Green Remediation: Incorporating Sustainable Environmental Practices into the Remediation of Contaminated Sites* (USEPA, 2008), which is dedicated to developing and promoting innovative cleanup strategies that restore contaminated sites to productive use and reduce associated costs while promoting environmental stewardship.

The Navy's environmental strategy lays out a vision for "Sustaining our Environment, Protecting our Freedom," which links accomplishing the Navy's defense mission with its responsibility to safeguard the natural systems upon which the nation's quality of life depends (NAVFAC, 2009). The Department of Defense issued a Green and Sustainable Remediation Policy on August 10, 2009, encouraging the services to use strategies that consider all environmental effects of a remedy implementation and operation and incorporate options to maximize the overall benefit of cleanup actions. EO 13514, released on October 5, 2009, sets sustainability goals for federal agencies and focuses on making improvements in their environmental, energy, and economic performance. The EO requires federal agencies to set a 2020 GHG emissions reduction target within 90 days, increase energy efficiency, reduce fleet petroleum consumption, conserve water, reduce waste, support sustainable communities, and leverage federal purchasing power to promote environmentally responsible products and technologies. NAVFAC (2009) prepared a *Sustainable Environmental Remediation Fact Sheet*, which outlines the Navy's guidance on incorporating sustainable remediation into the environmental remediation process. Furthermore, regulatory agencies are beginning to request that sustainability be considered during remedy implementation.

Using the approach described in the NAVFAC fact sheet (2009), sustainable environmental remediation was evaluated under each of the NCP Criteria for Site 3. The eight sustainability metrics discussed in the NAVFAC fact sheet are:

- Energy consumption
- GHG emissions
- Criteria pollutant emissions
- Water impacts
- Ecological impacts
- Resource consumption
- Worker safety
- Community impacts

Although there is no accepted protocol for implementing green and sustainable remediation technologies, SiteWise Version 2.0 (SiteWise), developed jointly by the Navy, United States Army Corps of Engineers, and Battelle (Battelle, 2011), was used to quantify values for the sustainability metrics. SiteWise uses various emission factors from governmental or non-governmental research sources to delineate the environmental footprint of each activity. SiteWise uses a "cradle to grave" approach to quantify footprints. As a result, some activities, such as material production, create environmental burdens that do not directly occur onsite, but contribute to the overall footprints of the remedial alternative. This is particularly true in the case of GHGs, which contribute on a global, long-term scale. The quantitative metrics calculated by the tool include:

1. GHGs reported as CO_2 equivalents, consisting of CO_2, methane, and nitrous oxide
2. Energy usage (expressed as British thermal units)
3. Water usage (gallons of water)
4. Air emissions of criteria pollutants consisting of nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter less than 10 micrometers in aerodynamic diameter (PM_{10})
5. Accident risk (risk of injury and risk of fatality)

Table 5-1 summarizes how each of NAVFAC's sustainability metrics can be addressed under the existing NCP criteria. Based on the evaluation completed, the sustainability metrics were most effectively addressed in the two NCP criteria of (1) long-term effectiveness and permanence and (2) short-term effectiveness. The input parameters and results from SiteWise were associated with the assumptions linked with the alternative descriptions discussed in Section 4, **Appendix C** (Preliminary Cost Estimates), and **Appendix E** (Sustainability Evaluation). The SiteWise results are summarized in **Table 5-2** and were incorporated into the balancing criteria discussion in Sections 5.3 and 5.4, where individual and detailed comparative analyses of remedial alternatives are presented.

5.3 Individual Analysis of Alternatives

During the individual evaluation, each alternative was assessed against the first seven NCP criteria described in Section 5.1. The contingency soil excavation was evaluated against the NCP criteria on its own because it can be added to any of the proposed alternatives. The individual evaluation for each alternative is presented in the following narrative and is summarized in **Table 5-3**.

5.3.1 Alternative 1 – No Action

As noted earlier, the No Action alternative is required by CERCLA to be considered as the baseline remedial action. This alternative allows natural attenuation to reduce the contaminant plumes, but does not provide measures to prevent exposure to site-related COCs. Therefore, it was not considered protective of either human health or the environment. Currently, concentrations of COCs in groundwater exceed PRGs and this alternative provides no means to monitor future risks; therefore, this alternative does not meet ARARs. Likewise, long-term effectiveness is unacceptable because the plume would not be monitored and there would be no mechanism for limiting future exposure to contaminated groundwater. There is high uncertainty as to whether RAOs would be achieved in the short term. This alternative does not include active treatment. Natural biodegradation may occur, but at unmonitored rates and at unknown locations. Therefore, it was assumed that no contaminants would be treated or destroyed with this alternative. Short-term effectiveness was considered moderate to high. Although there would be no remedial construction and no immediate environmental impacts of this remedy, no response action would be conducted to provide protection of the site. This alternative is easy to implement and the cost is essentially zero.

5.3.2 Alternative 2 – Monitored Natural Attenuation

Alternative 2 allows natural attenuation to decrease TCE, cis-1,2-DCE, VC, arsenic, and manganese in groundwater. This alternative was considered protective of human health and the environment because site-related COCs would decrease over time from natural processes (biodegradation, dilution, and volatilization). LUCs and groundwater monitoring would be maintained until RAOs are achieved. Monitoring during implementation would provide warning if the plume was to migrate. LUCs would prevent groundwater use and intrusive activities before RAOs are achieved. This remedy would comply with ARARs and is considered effective and permanent.

This alternative does not employ an active treatment process for the plume. It relies on natural biodegradation and other attenuation processes to remediate the plume. Therefore, reduction of toxicity, mobility, or volume of the plumes would be acceptable, but was assumed to be slow compared to active treatment. The short-term effectiveness was considered moderate to high because there would be relatively low impact to the environment; however, the remediation timeframe may be extensive. Handling of investigation-derived waste and transportation of personnel and equipment to and from the site would account for the majority of GHG, total energy, and of NO_X, SO_X, and PM_{10} footprints for this alternative. There would be minimal risk to workers and the community during implementation. Because active treatment is not engaged, the timeframe to achieve RAOs was estimated at 19 years.

MNA is a reliable technology that is technically feasible for this site and could be easily implemented with available labor, materials, and equipment. The costs of this alternative would be split between capital costs ($13,000) and O&M costs ($1,104,000). These costs could increase if RAOs are not achieved within the assumed 19-year monitoring period or if monitoring and Five-year Reviews indicate that additional remedial action is necessary.

5.3.3 Alternative 3 – Enhanced *In Situ* Bioremediation

Alternative 3 would enhance the biodegradation of TCE, cis-1,2-DCE, and VC in both TTZ-1 and, to a lesser degree, TTZ-2. The enhanced reducing conditions may temporarily increase dissolved arsenic and manganese concentrations. Natural attenuation would also act to decrease contaminant concentrations of TCE, cis-1,2-DCE, and VC, and ultimately arsenic and manganese, after the EISB substrate and organic contamination were degraded. This alternative was considered protective of human health and the environment because site-related COCs would degrade over time from active EISB treatment and natural processes. LUCs and groundwater monitoring would be maintained until RAOs are achieved. Monitoring during implementation would provide warning if the plume was to migrate. LUCs would prevent groundwater use and intrusive activities before RAOs are achieved. This remedy would comply with ARARs and was considered effective and permanent.

EISB treatment and natural attenuation would significantly reduce human health and environmental risks. The grid configuration in TTZ-1 would treat the highest concentrations observed at the site, while the three-transect configuration in TTZ-2 may enhance biodegradation throughout the plume as carbon substrates and functional bacteria are transported to a limited extent downgradient with the slow groundwater advection. The active EISB treatment in the plume would be synergistic with the existing anaerobic conditions observed in the plume. Therefore, the reduction of toxicity, mobility, or volume of the plume would be acceptable. Because of the relative small ROI of the injections and the slow groundwater flow rate at the site, there are no anticipated impacts to Indian Field Creek. In addition, no utilities or features would serve as preferential pathways. If the EISB substrate were to eventually drift towards the creek, it would likely be diluted and degraded to a concentration that would not pose a risk to associated receptors. Monitoring would be conducted to evaluate if temporary plume migration were to occur following the injection.

The short-term effectiveness was considered moderate to high. This alternative has a moderate environmental footprint and remediation timeframe. Substrate manufacturing would account for most of the GHG emissions and total energy use for this alternative. Drilling and injection activities would account for most of the criteria pollutant footprints (NO_x, SO_x, and PM_{10}) and water consumption. Although accident risks were quantified as high in SiteWise compared to MNA, risks to workers, the community, and the environment from the handling and transportation of carbon substrates and potential spills or daylighting of substrates during the injection work were considered minimal because of the benign nature of the food-grade substrate. The timeframe to achieve RAOs would be shortened due to the active treatment in TTZ-1 and TTZ-2.

EISB is a reliable and demonstrated technology that is technically feasible for the site and could be easily implemented with available labor, materials, and equipment. However, injection would likely be distributed less effectively into the clay zone than in the aquifer sands, causing the potential for schedule delays. Additionally, there is more uncertainty as to whether the microbial community would flourish in the clay environment. The costs of this alternative would be split between capital costs ($169,000) and O&M costs ($784,000). These costs could increase if monitoring indicates that additional EISB injections are needed or if RAOs are not achieved within the assumed 9-year monitoring period.

5.3.4 Alternative 4 – *In Situ* Chemical Reduction

Alternative 4 enhances reduction of TCE, cis-1,2-DCE, and VC and biological degradation via a combined micron-scale ZVI and carbon reagent injection at TTZ-1, thereby quickly reducing the highest concentrations at the site. ZVI can also co-precipitate dissolved arsenic from groundwater. However, dissolved manganese concentrations may temporarily increase due to the enhanced reducing conditions. ISCR treatment in TTZ-1 would in turn decrease contaminant mass flux into the downgradient plume. Natural attenuation would also act to decrease TCE, cis-1,2-DCE, VC, arsenic, and manganese concentrations in the downgradient plume. This alternative was considered protective of human health and the environment because site-related COCs would degrade over time from targeted ISCR and natural processes. LUCs and groundwater monitoring would be maintained until RAOs are achieved. Monitoring during implementation would provide warning if the plume was to migrate. LUCs would prevent groundwater use and intrusive activities before RAOs are achieved. This remedy would comply with ARARs and was considered effective and permanent.

ISCR treatment and natural attenuation would significantly reduce risks. The combined ZVI and carbon treatment in the TTZ is compatible with natural anaerobic biodegradation by creating more strongly reduced conditions. Therefore, reduction of toxicity, mobility, or volume of the plume would be acceptable. Because of the relative small ROI of the injection, the slow groundwater flow rate at the site, and the very limited mobility of the ISCR reagent, there are no anticipated impacts to Indian Field Creek. Monitoring would be conducted to evaluate if temporary plume migration were to occur following the injection.

The short-term effectiveness was considered moderate. Even though this alternative has a relatively high overall environmental footprint, risks to human health and the environment were considered to be minimal, and the remedial timeframe would be moderate. Production of ZVI and reagent transportation to the site would account for most of the GHG emissions and energy use for this alternative. Drilling and injection activities would account for most of the criteria pollutant footprints (NO_x, SO_x, and PM_{10}) and water consumption. Risks to workers, the community, and the environment from the handling and transportation of a combined carbon and ZVI reagent and potential spills or daylighting of substrates during the injection work were considered minimal. The timeframe to achieve RAOs would be shortened by active treatment in the TTZ.

ISCR is a reliable and demonstrated technology that is technically feasible for the site and could be readily implemented with available labor, materials, and equipment. However, injection into the clay and the number of injection points would increase the potential for schedule delays. The costs of this alternative would be split between capital costs ($479,000) and O&M costs ($834,000). These costs could increase if monitoring indicates that more ISCR injections are needed or if RAOs are not achieved within the assumed 11-year monitoring period.

5.3.5 Alternative 5 – *In Situ* Chemical Oxidation

Alternative 5 chemically oxidizes TCE, cis-1,2-DCE, and VC in TTZ-1, thereby quickly reducing the highest concentrations at the site. ISCO would also create more oxidizing conditions in the subsurface, which may result in the precipitation of dissolved manganese and the adsorption of arsenic to manganese or iron hydroxides. This in turn would decrease contaminant mass flux into the downgradient plume. Natural attenuation would also decrease TCE, cis-1,2-DCE, VC, arsenic, and manganese concentrations in the downgradient plume. This alternative was considered protective of human health and the environment because site-related COCs would degrade over time from targeted ISCO and natural processes. LUCs and groundwater monitoring would be maintained until RAOs are achieved. Monitoring during implementation would provide warning if the plume was to migrate. LUCs would prevent groundwater use and intrusive activities before RAOs are achieved. This remedy would comply with ARARs and was considered effective and permanent.

ISCO treatment and natural attenuation would significantly reduce risks. Reduction of toxicity, mobility, or volume of the plume would be acceptable. Because of the relative small ROI of the injections, the slow groundwater flow rate at the site and the reactivity of the oxidant, there are no anticipated impacts to Indian Field Creek. In addition, no utilities or features would serve as preferential pathways. If the oxidant were to eventually drift towards the creek, it would likely be diluted to a concentration that would not pose a risk to associated receptors. Monitoring would be conducted to evaluate if temporary plume migration were to occur following the injection.

The short-term effectiveness was considered moderate. Even though this alternative has a high overall environmental footprint, risks to human health and the environment and the remediation timeframe were considered to be moderate. Permanganate manufacturing and transportation would contribute the majority of GHG emissions and energy use footprints. Drilling and injection activities would account for most of the criteria pollutant footprints (NO_x, SO_x, and PM_{10}) and water consumption. Risks to workers, the community, and the environment from the handling and transportation of permanganate and potential spills or daylighting of substrates during the injection work were considered moderate. Because of the large dose of permanganate to be injected, the trace metals in the permanganate product may result in temporary exceedances of MCLs for metals in the groundwater. The timeframe to achieve RAOs would be shortened due to the active treatment.

ISCO is a reliable and demonstrated technology that is technically feasible for the site and could be easily implemented with available labor, materials, and equipment. However, injection into the clay would increase the potential for schedule delays. The costs of this alternative would be split between capital costs ($496,000) and O&M costs ($828,000). These costs could increase if monitoring indicates that more-extensive injections are needed or if RAOs are not achieved within the assumed 11-year monitoring period.

5.3.6 Contingency Soil Excavation

The contingency action would remove TPH contamination that remains in localized, unsaturated soils in order to decrease arsenic and manganese in groundwater. This contingency was considered protective of human health and the environment because it would facilitate attenuation (in particular, transformation to solid precipitates) of arsenic and manganese in groundwater by removing a potential source of reducing conditions in groundwater. LUCs and groundwater monitoring would be maintained under the selected remedy until RAOs are achieved. This remedy would comply with ARARs and was considered effective and permanent. The decrease in groundwater concentrations resulting from the soil excavation would significantly reduce risks. Therefore, reduction of toxicity, mobility, or volume of the plume would be acceptable.

The short-term effectiveness was considered to be moderate. Even though this alternative would have a high overall environmental footprint, risks to human health and the environment and the remediation timeframe were considered to be moderate. The contingency would require the use of heavy equipment and transportation and disposal of contaminated soil to an approved landfill, which would account for the most the criteria pollutant footprints (NO_x, SO_x, and PM_{10}) and GHG emissions. However, the proposed area of soil removal would be relatively small (~2,500 ft^2) and the soil would be assumed to be nonhazardous. Therefore, risks to workers, the community, and the environment from the handling and transportation of contaminated soil were considered to be moderate. The timeframe to achieve RAOs would be shortened by active soil removal. The actual time to implement the contingency would be short.

Soil excavation is a reliable and demonstrated technology that is technically feasible for the site and could be easily implemented with available labor, materials, and equipment. The costs of this alternative were only capital costs ($624,000). There would be no O&M costs.

5.4 Comparative Analysis of Remedial Alternatives

The analysis of the alternatives against the NCP criteria was used to compare the alternatives and identify the key tradeoffs among them. The contingency soil excavation was not included in this evaluation because it only addresses a contingency component of the remedy for achieving RAOs and is therefore not comparable with the five primary remedial alternatives. A quantitative comparative analysis for each sub-criterion was employed using a ranking system of 1 to 10, with 1 being the lowest valued metric and 10 being the highest. A score of 1 indicated the alternative did not meet any of the attributes of the criterion. A score of 10 indicated the alternative met all attributes of the criterion. The scores between 1 and 10 reflect the degree to which an alternative met all attributes of the criterion. **Table 5-4** provides a detailed breakdown, including the scoring of the individual sub-criteria, and the results of the ranking for each alternative. This approach provided 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.

5.4.1 Overall Protection of Human Health and the Environment

All alternatives, except for Alternative 1, are protective of human health and the environment. Performance monitoring would be conducted, and LUCs would be maintained to provide adequate protection of human health and the environment by controlling exposure to contaminated site media until the RAOs are met.

5.4.2 Compliance with Applicable or Relevant and Appropriate Requirements

All alternatives, except for Alternative 1, are expected to comply with ARARs. Alternatives 2 through 5 would all require performance monitoring and LUCs. Alternatives 3 through 5 would also comply with ARARs related to underground injections of reagents and erosion and sediment controls of larger construction areas. The ARARs are presented in **Appendix A**.

5.4.3 Long-term Effectiveness and Permanence

Magnitude of Residual Risk

Once response actions (such as *in situ* treatment) are conducted, all alternatives, except Alternative 1, are expected to have residual risks of the same magnitude. Some residual risk would be apparent because Alternatives 2 through 5 rely on natural attenuation and LUCs. Alternatives 3, 4, and 5 were scored higher because their active treatment element may result in more-complete degradation of the COCs in the plume. Both ISCR and EISB treatment substrates were considered to persist in the subsurface and may address potential desorption or back-diffusion of TCE, cis-1,2-DCE, and VC sorbed to the clay layer over time. Permanganate may also potentially persist in the subsurface between months and years. Alternative 1 scored the lowest because it would not achieve the RAOs.

Adequacy and Reliability of Controls

With proper engineering, planning, and implementation, controls can be put in place to effectively monitor all of the alternatives and verify continued compliance with RAOs. A monitoring plan needs to be implemented to provide for an adequate frequency of monitoring to detect any indications of contaminant rebound or migration that could threaten human or ecological receptors, or threaten compliance with ARARs. LUCs need to be continually enforced until the RAOs are achieved and while COCs exceed their RGs.

Alternatives 2 through 5 received the same scores because their controls would all be reliable. Alternative 1 scored the lowest because no controls would be in place to monitor conditions.

5.4.4 Reduction of Toxicity, Mobility, and Volume through Treatment

Treatment Process Used and Materials Treated

Alternative 3 received the highest score because it would employ active treatment in both TTZ-1 and TTZ-2. Additionally, EISB may treat COCs outside of the injection ROI as the injection substrates migrate with groundwater. However, this will likely be limited by the slow groundwater flow rate. Alternatives 4 and 5 received the next-highest score because they would include treatment in TTZ-1. Alternatives 1 and 2 received low scores because active treatment would not be a component of these alternatives.

Amount of Hazardous Materials Destroyed or Treated

The relative differences in scores and the rationale for the scores for this sub-criterion mirror those for the Treatment Process Used and Materials Treated sub-criterion. Alternatives with an active treatment component would treat and destroy a larger amount of hazardous materials than those with passive treatment or no treatment. Alternative 3 received the highest score because it would include treatment of both TTZ-1 and TTZ-2. However, the active treatment component of Alternative 3 may temporarily increase arsenic and manganese concentrations as more reducing conditions are established in groundwater. Alternatives 4 and 5 received the next-highest score for their treatment of TTZ-1. ISCR may only generate minimal VC whereas ISCO would not generate any VC. Additionally, the active treatment component of Alternative 4 may beneficially decrease arsenic concentrations and the active treatment component of Alternative 5 may beneficially decrease dissolved arsenic and manganese concentrations. Alternatives 1 and 2 received low scores because active treatment would not be a component of these alternatives.

Degree of Expected Reductions in Toxicity, Mobility, or Volume

The relative differences in scores and the rationale for the scores for this sub-criterion mirror those for the Amount of Hazardous Materials Destroyed or Treated sub-criterion. Alternative 3 received the highest score, followed by Alternatives 4 and 5. Alternatives 1 and 2 received low scores because treatment would not be a component of these alternatives.

Degree to Which Treatment Is Irreversible

The relative differences in scores and the rationale for the scores for this sub-criterion mirror those for the Treatment Process Used and Materials Treated sub-criterion. The more extensive the active treatment area, the higher the degree to which treatment is irreversible. Alternative 3 received the highest score, and

Alternatives 4 and 5 received the next highest scores because they were considered equally effective in degrading the COCs at this site. Alternatives 1 and 2 received low scores because active treatment would not be a component of these alternatives.

Type and Quantity of Residual Remaining after Treatment

The relative differences in scores and the rationale for the scores for this sub-criterion mirror those for the Degree to Which Treatment Is Irreversible sub-criterion. The more extensive the active treatment area, the lower the type and quantity of residual remaining after treatment and the higher the score. Alternative 3 received the highest score, and Alternatives 4 and 5 received the next highest scores because they were considered equally effective at degrading the COCs at this site. Alternatives 1 and 2 received low scores because active treatment would not be a component of these alternatives.

5.4.5 Short-term Effectiveness

Protection of Community during Remedial Actions

Alternative 1 received the highest score because it would not involve any activities that would affect the community. Alternative 2 received the next-highest score based on generating minimal impacts to the community during implementation. Alternatives 3, 4, and 5 scored lower because they would include reagent injections and a higher volume of heavy machinery traffic.

Protection of Workers during Remedial Actions

All workers can be protected during remedial actions through implementation of health and safety programs. However, the more intensive the construction project, the greater the probability of injury.

Alternative 1 scored the highest because it would not include any activities involving workers. Alternative 2 would pose slightly higher risk to workers during collection of contaminated groundwater samples and driving to and from the site. Alternatives 3, 4, and 5 would have higher accident risks, primarily because of the transportation of materials, equipment, and workers to the site (automobile or truck accidents). Operation of the DPT rig also would contribute to the accident risk for these alternatives. SiteWise does not take into consideration short-term risks to workers from contact with site contaminants or treatment reagents or the incremental risk from high-pressure injection. In that regards, lactate (Alternative 3) was considered to pose less risk to workers than ZVI or permanganate.

Environmental Impacts

Except for Alternative 1, all alternatives would have some level of negative impact to the environment. Long-term monitoring requires years of trips to the site and the creation of purge water and emission of GHGs from transportation. Natural resources and energy consumption would occur with the use of fuel. GHG and criteria pollutant emissions could occur through use of fossil fuels. Potential impacts to wildlife include noise, construction activities, materials brought onsite, and habitat disturbed during remedial construction.

Alternative 1 had the fewest environmental impacts and was therefore scored the highest. Alternative 2 scored the next highest because it would present the fewest intrusive activities and minimal environmental impacts. Alternative 3 scored lower because it would likely result in high GHG emissions and energy from DPT injections, material production, and the associated transportation and heavy machinery use. Alternatives 4 and 5 scored the lowest because of their even more intensive intrusive work on the site and reagent production. Alternative 5 would have the highest water consumption and Alternative 4 would have the highest NO_x, SO_x, and PM_{10} air emissions, primarily from DPT injection. Alternatives 3 through 5 would have similar accident risks. Similar to the Protection of Workers during Remedial Actions sub-criterion, SiteWise does not incorporate impacts of lactate, ZVI, or permanganate on the environment.

Time until Remedial Response Objectives are Achieved

Alternative 1 would not protect the site because no response action would be taken. For Alternatives 2 through 5, protection would be achieved once LUCs and monitoring were implemented. The *in situ* treatment response action would be achieved once the performance monitoring of EISB, ISCR, or ISCO was completed.

The timeframe associated with achieving the RAOs associated with each remedial technology is uncertain. Estimated timeframes for Alternative 2 through 5 to meet the RAOs are presented in **Table 5-3**. Alternative 2 would have the longest timeframe because it is a passive treatment process. Alternative 3, which actively treats the largest area, scored the highest, followed by Alternatives 4 and 5.

5.4.6 Implementability

Ability to Construct and Operate the Technology

Alternative 1 received the highest score because it requires no action. Alternative 2 was scored the next-highest because it does not require construction and only involves groundwater sampling. Alternatives 3, 4, and 5 scored lower because they would implement EISB, ISCR, and ISCO, increasing the construction and operation component of the remedy. Alternative 4 scored slightly lower than Alternatives 3 and 5 because it would involve a larger number of injection points. Alternative 4 would include 105 DPT injection borings, whereas Alternatives 3 and 5 would only include 82 and 65 DPT injection borings, respectively.

Reliability of the Technology

All alternatives can be implemented reliably onsite due to the maturity of the technologies involved. Alternative 1 scored the highest because it would require no implementation and therefore has no potential to create any delays in the project schedule. Alternative 2 scored the next highest because it would include only groundwater monitoring and its implementation would be less likely to cause schedule delays. Alternatives 3, 4, and 5 scored lower because implementation of EISB, ISCR, or ISCO would be less reliable and more likely to cause schedule delays. Because Alternative 4 would include the most injection points and is estimated to take the most days for injection, it is the most likely to have schedule delays.

Ease of Undertaking Additional Remedial Actions, If Necessary

Additional remedial actions can be undertaken with all of the alternatives, if necessary. Alternative 1 received the highest score because it would require no action. Alternative 3 received a slightly lower score than Alternatives 2, 4, and 5 because implementation of EISB via high-pressure injection into clay is less documented than ISCR or ISCO.

Ability to Monitor Effectiveness of Remedy

Alternative 1 would not entail monitoring. Alternatives 2 through 5 are designed with effective monitoring programs; therefore, they all received relatively high scores.

Ability to Coordinate and Obtain Approvals from Other Agencies

Alternatives 2 through 5 would likely be able to obtain the required approvals from the necessary agencies; therefore, they all received high scores. Alternative 1 received the lowest score because it is not expected to receive approval from the necessary agencies.

Availability of Offsite Treatment, Storage, and Disposal Services and Capacity

Adequate treatment, storage capacity, and disposal services are available for all alternatives.

Availability of Necessary Equipment and Specialists

Adequate equipment and specialists to implement all alternatives are available. Alternative 1 scored the highest because it would require no implementation. Alternative 2 scored the next highest because groundwater monitoring equipment is readily available from multiple vendors. Alternatives 3, 4, and 5 scored lower because they would require treatment reagents to be purchased from specialized vendors and high-pressure injections would require more-specialized equipment.

Availability of Prospective Technologies

The prospective technologies for all alternatives are available.

5.4.7 Cost

An order-of-magnitude cost for each alternative was estimated based on a variety of key assumptions, as specified in the cost estimates (**Appendix C**). The timeframes required to achieve the RGs vary among alternatives. Significant uncertainty is associated with the timeframes. The order-of-magnitude cost estimates were prepared in accordance with USEPA (2000) guidance and represent a minus-30 to plus-50 percent range of accuracy.

Appendix C contains a summary table that shows the estimated capital, O&M, and total present-value costs of each alternative. Other than the No Action Alternative (Alternative 1), the least-expensive alternative is Alternative 3, with an estimated total present value cost of $953,000. Alternative 2 has a slightly higher estimated present value cost of $1,117,000. Alternatives 4 and 5 have comparable estimated present-value costs of $1,313,000 and $1,324,000, respectively. Alternative 2 has the lowest total capital cost, estimated at $13,000. Alternatives 3, 4, and 5 have estimated capital costs of $169,000, $479,000, and $496,000, respectively.

TABLE 5-1
Sustainability Metrics and NCP Criteria
Site 3 Feasibility Study Report
Naval Weapons Station Yorktown
Yorktown, Virginia

NCP Criteria	Sub-criteria	Sustainability Metrics							
		Energy Consumption	GHG Emissions	Criteria Pollutant Emissions	Water Impacts	Ecological Impacts	Resources Consumption	Worker Safety	Community Impacts
Protection of Human Health and the Environment	Protection of Human Health and Environment								
Compliance with ARARs	Compliance with Chemical-Specific ARARs								
	Compliance with Action-Specific ARARs								
	Compliance with Location-Specific ARARs								
	Compliance with other criteria, advisories, and guidance								
Long-Term Effectiveness and Permanence	Magnitude of Residual Risk		E	E					
	Adequacy and Reliability of Controls								
Reduction in Toxicity, Mobility, and Volume	Treatment Process Used and Materials Treated								
	Amount of Hazardous materials destroyed or treated								
	Degree of Expected Reductions in Toxicity, Mobility, and Volume								
	Degree of which treatment is irreversible								
	Type and Quantity of Residual Remaining After Remedial Action								
Short-Term Effectiveness	Protection of Community During Remedial Action								A
	Protection of Workers During Remedial Actions							B	
	Environmental Impacts	F	E	D			C		
	Time until Remedial Action Objectives are achieved								
Implementability	Ability to Construct and Operate the Technology								
	Reliability of the Technology								
	Ease of Undertaking Additional Remedial Actions, if necessary								
	Ability to Monitor Effectiveness of Remedy								
	Ability to Obtain Approvals from Other Agencies								
	Coordination with Other Agencies								
	Availability of Offsite Treatment, Storage, and Disposal Services and Capacity								
	Availability of Necessary Equipment and Specialists								
	Availability of Prospective Technologies								
Cost	Capital Costs								
	Operating and Maintenance Costs								
	Present-Worth Costs								
State Acceptance	State Acceptance								
Community Acceptance	Community Acceptance								

Legend:
ARARs - applicable or relevant and appropriate requirements
A - Complements NCP criteria but also addresses risks to community in terms of potential for injury or fatality associated with traffic
B - Complements NCP criteria but also addresses potential for injury or fatality associated with total hours worked
C - Use of non-renewable energy (coal for power requirements [fuel])
D - Impacts associated with release of volatile organic compounds to the atmosphere
E - Some emissions persist only in the short term, others last for decades and may persist after RAO's have been achieved
F - Environmental impacts associated with energy extraction from earth resources
Note: F, E, D, and C could potentially be mapped to NCP Criteria "Protection of Human Health and The Environment" - but this would be a more difficult fit because the main focus of those criteria is risk-based exposure.

TABLE 5-2
Summary of Overall Sustainability Results
Site 3 Feasibility Study Report
Naval Weapons Station Yorktown
Yorktown, Virginia

Remedial Alternatives	GHG Emissions	Total energy Used	Water Consumption	NO_x emissions	SO_x Emissions	PM_{10} Emissions	Accident Risk Fatality	Accident Risk Injury
	metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Alternative 1 - No Action	0	0	0	0	0	0	0	0
Alternative 2 - MNA and LUCs	4.8	54.6	0	1.34E-03	3.10E-05	1.48E-04	1.99E-04	4.15E-02
Alternative 3 - EISB, MNA, and LUCs	17.1	228.2	20,350	9.77E-03	7.35E-04	9.17E-04	2.57E-04	4.58E-02
Alternative 4 - ISCR, MNA, and LUCs	21.9	216.2	11,644	1.85E-02	1.98E-03	1.74E-03	3.10E-04	6.41E-02
Alternative 5 - ISCO, MNA, and LUCs	22.3	317.5	103,600	1.67E-02	1.79E-03	1.58E-03	2.97E-04	6.16E-02

Comparative (Relative) Impact								
Remedial Alternatives	**GHG Emissions**	**Total energy Used**	**Water Consumption**	**NO_x emissions**	**SO_x Emissions**	**PM_{10} Emissions**	**Accident Risk Fatality**	**Accident Risk Injury**
	metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Alternative 1 - No Action	Low	Low	Low	Low	Low	Low	Low	Low
Alternative 2 - MNA and LUCs	Low	Low	Low	Low	Low	Low	Medium	Medium
Alternative 3 - EISB, MNA, and LUCs	High	High	Low	Medium	Medium	Medium	High	High
Alternative 4 - ISCR, MNA, and LUCs	High	High	Medium	High	High	High	High	High
Alternative 5 - ISCO, MNA, and LUCs	High	High	High	High	High	High	High	High

The comparative impact is a qualitative assessment of the relative footprint of each alternative, a rating of High for an alternative is assigned if it is 70% of the maximum footprint, a rating of Medium is assigned if it is between 30 and 70% of the maximum footprint, and a rating of Low is assigned if it is less than 30% of the maximum footprint.

Notes:
EISB - enhanced in situ bioremediation
GHG - greenhouse gas
ISCO - in situ chemical oxidation
ISCR - in situ chemical reduction
LUCs - land use controls
MMBTU - million British Thermal Unit
MNA - monitored natural attenuation
NOx - nitrogen oxides
SOx - sulfur oxides
PM10 - particulate matter less than 10 microns in aerodynamic diameter

TABLE 5-3
Detailed Evaluation of Remedial Alternatives
Site 3 Feasibility Study Report
Naval Weapons Station Yorktown
Yorktown, Virginia

Evaluation Criteria	Alternative 1 No Action	Alternative 2 Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs)	Alternative 3 Enhanced *In Situ* Bioremediation (EISB), MNA, and LUCs	Alternative 4 *In Situ* Chemical Reduction (ISCR), MNA, and LUCs	Alternative 5 *In Situ* Chemical Oxidation (ISCO), MNA, and LUCs	Contingency Soil Excavation
Overall Protection of Human Health and the Environment	**Not Protective.** • Does not prevent exposure to site-related constituents of concern (COCs) or provide measures to reduce site-related COC concentrations to achieve remedial action objectives (RAOs).	**Protective**. • Site-related COCs will decrease over time via natural attenuation processes; • LUCs and groundwater monitoring implemented and maintained until RAOs are achieved.	**Protective**. • Enhanced anaerobic biodegradation of site-related CVOCs in both target treatment zone (TTZ)-1 and TTZ-2, which covers the majority of the CVOC plume; • COCs outside of the TTZs will decrease over time via natural attenuation processes; • LUCs and groundwater monitoring implemented and maintained until RAOs are achieved.	**Protective**. • Reduction of site-related CVOCs via chemical reduction using micron-scale zero valent iron (ZVI) treatment in TTZ-1 (may use commercial products blended with carbon substrates to also enhance biodegradation); • COCs outside of TTZ-1 will decrease over time via natural attenuation processes; • LUCs and groundwater monitoring implemented and maintained until RAOs are achieved.	**Protective**. • Enhanced degradation of site-related CVOCs in TTZ-1 and downgradient plume by chemical oxidation using permanganate; • COCs in the plume outside of TTZ-1 will decrease over time via natural attenuation processes; • LUCs and groundwater monitoring implemented and maintained until RAOs are achieved.	**Protective**. • Enhanced transformation of arsenic and manganese by removing TPH in unsaturated soil, which may be creating more reduced conditions in groundwater; • COCs will decrease over time via natural attenuation processes; • LUCs and groundwater monitoring implemented under the selected remedial alternative and maintained until RAOs are achieved.
Compliance with Applicable or Relevant and Appropriate Requirements	**Does not meet.** • Not in compliance; • Groundwater concentrations currently exceed preliminary remedial goals (PRGs); • Risks to contaminated groundwater above remedial goals (RGs) remain.	**Meets**. • Extended timeframe to meet RGs by natural attenuation; • Land use controls would prevent groundwater use and intrusive activities.	**Meets**. • Treatment system designed to meet RGs; • Underground injection control (UIC) permit would be required prior to remedy implementation; • Moderate timeframe; • Land use controls would prevent groundwater use and intrusive activities.	**Meets**. • Treatment system designed to meet RGs; • UIC permit would be required prior to remedy implementation; • Moderate timeframe; • Land use controls would prevent groundwater use and intrusive activities.	**Meets**. • Treatment system designed to meet RGs; • UIC permit would be required prior to remedy implementation; • Moderate timeframe; • Land use controls would prevent groundwater use and intrusive activities.	**Meets**. • Soil Excavation designed to meet RGs; • Controls required to prevent fugitive dust and erosion to soil.
Long-Term Effectiveness and Permanence	**Ineffective**. • No treatment or monitoring or LUCs, uncertain if RAOs would be achieved, no protection of human and ecological receptors.	**Effective and Permanent**. • Risks gradually reduce through natural attenuation processes; • Low level of residual risk due to reliance on LUCs; • Monitoring, LUCs, and 5-year reviews needed until levels allow for unrestricted use.	**Effective and Permanent**. • Low residual risks as a result of the enhanced irreversible biodegradation of site-related CVOCs to non-toxic end products (i.e., ethene, ethane) • Low level of residual risk due to reliance on LUCs; • Monitoring, LUCs, and 5-year reviews needed until levels allow for unrestricted use.	**Effective and Permanent**. • Risks in TTZ -1 are expected to reduce significantly due to the aggressive ISCR (combined with ERD) remediation, which results in more complete degradation of COCs; • Low level of residual risk due to reliance on LUCs; • Monitoring, LUCs, and 5-year reviews needed until levels allow for unrestricted use.	**Effective and Permanent**. • Risks in TTZ -1 are expected to reduce significantly due to the aggressive ISCO remediation; • Low level of residual risk due to reliance on LUCs; • Monitoring, LUCs, and 5-year reviews needed until levels allow for unrestricted use.	**Effective and Permanent**. • Risks are expected to reduce significantly due to permanent removal of TPH in unsaturated soil, which may be creating more reduced conditions in groundwater; • Monitoring, LUCs, and 5-year reviews implemented under the selected remedial alternative.
Reduction of Toxicity, Mobility, and Volume Through Treatment	**No Treatment**. • Reduction of toxicity, mobility, and volume (TMV) would only gradually occur as a result of natural processes; • Reduction and mobility of site-related COCs would remain unknown and undocumented; • Not acceptable as a principal remedial element.	**Passive Treatment**. • Reduction in TMV would gradually occur as a result of natural attenuation processes; • Monitoring to assess TMV of site-related COCs in groundwater would be performed.	**Active Treatment**. • EISB will significantly reduce TMV in both TTZ-1 and TTZ-2 and destroy CVOCs permanently; bioaugmentation will help ensure complete dechlorination; • Additional reduction in TMV would gradually occur as a result of natural processes and beneficial influence of the EISB treatment; • Monitoring to assess TMV of site-related COCs in groundwater would be performed.	**Active Treatment**. • ISCR will significantly reduce TMV in TTZ-1 and destroy CVOCs permanently; • Additional reduction in TMV would gradually occur as a result of natural processes and beneficial influence of the ISCR treatment; • ZVI may co-precipitate dissolved arsenic from groundwater; • Monitoring to assess TMV of site-related COCs in groundwater would be performed.	**Active Treatment**. • ISCO will significantly reduce TMV in TTZ-1 and destroy CVOCs permanently; • Additional reduction in TMV would gradually occur as a result of natural processes; • Oxidizing environment may transform dissolved manganese to solid hydroxides • Monitoring to assess TMV of site-related COCs in groundwater would be performed.	**Active Treatment**. • Soil excavation will reduce TMV of arsenic and manganese in groundwater; • Removal of TPH in unsaturated soils should result in a more oxidizing environment; thereby transforming dissolved manganese to solid hydroxides; • Monitoring to assess TMV of site-related COCs in groundwater would be performed under the selected remedial alternative.
Short-Term Effectiveness	**Moderate to High**. • High protection and environmental short-term effectiveness; • Construction and implementation phases do not present risk to the community, workers, or environment; • No response action would be conducted, and protection of the site is not expected.	**Moderate to High**. • Minimal risks of lost time and accidents to workers and community from transportation and well abandonment; • High environmental short-term effectiveness (Low impacts): - Low greenhouse gas (GHG) and total energy footprint from transportation of investigation-derived waste (IDW) and personnel - Low sulfur oxides(SO_x), nitrogen oxides (NO_x), and particulate matter less than 10 microns in aerodynamic diameter (PM_{10}) emissions • Timeframe to achieve RAOs is low to moderate (estimated at 19 years) as no active treatment is used.	**Moderate to High**. • Moderate risks of lost time and accidents to workers and community from handling and transportation of bioremediation substrates and drilling; • Moderate environmental short-term effectiveness (Moderate impacts): - High GHG and total energy footprint from transportation of equipment, substrates, IDW, and personnel - Moderate SO_x, NO_x, and PM_{10} emissions - Moderate water consumption from DPT injection • Timeframe to achieve RAOs is short (estimated at 9 years) due to active treatment in both TTZs.	**Moderate**. • Greater risks of lost time and accidents to workers and community from handling and transportation of combined ZVI and carbon reagent and drilling; • Low environmental short-term effectiveness (High impacts): - High GHG and total energy footprint from transportation of equipment, ZVI and carbon reagent, IDW, and personnel - Highest SO_x, NO_x, and PM_{10} emissions - Moderate water consumption from DPT injection • Timeframe to achieve RAOs is short (estimated at 11 years) due to active treatment in TTZ-1.	**Moderate**. • Greater risks of lost time and accidents to workers and community from handling and transportation of oxidant and drilling; • Low environmental short-term effectiveness (High impacts): - Highest GHG and total energy footprint from transportation of equipment, permanganate, IDW, and personnel - High SO_x, NO_x, and PM_{10} emissions - Highest water consumption from DPT injection • Timeframe to achieve RAOs is short (estimated at 11 years) due to active treatment in TTZ-1.	**Moderate**. • Moderate risks of lost time and accidents to workers and community from handling and transportation of contaminated soil; • Low environmental short-term effectiveness (High impacts): - High GHG and SO_x, NO_x, and PM_{10} emissions from transportation and disposal of soil - Some impacts also due to use of heavy equipment • Time to implement contingency would be short.

TABLE 5-3
Detailed Evaluation of Remedial Alternatives
Site 3 Feasibility Study Report
Naval Weapons Station Yorktown
Yorktown, Virginia

Evaluation Criteria	Alternative 1 No Action	Alternative 2 Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs)	Alternative 3 Enhanced *In Situ* Bioremediation (EISB), MNA, and LUCs	Alternative 4 *In Situ* Chemical Reduction (ISCR), MNA, and LUCs	Alternative 5 *In Situ* Chemical Oxidation (ISCO), MNA, and LUCs	Contingency Soil Excavation
Implementability	**Moderate to High**. • No action is easy to operate; • Highly reliable technology (no schedule delays); • No way to monitor its effectiveness; • Unlikely to coordinate and obtain approval from agencies.	**High**. • Easy to operate and construct; • Highly reliable technology (unlikely for schedule delays); • Able to monitor effectiveness.	**Moderate to High**. • Able to operate and construct; no routine maintenance; • Injection into the upper clay zone in TTZ-1 may entail fracturing technology, which is more challenging and most likely less effective than regular DPT injection into sandy zones for EISB, potential for schedule delays; • Fracturing injection service only available from specialized vendors; • Significant water demand; water availability is a potential issue; • Materials are available from multiple venders; competition could reduce costs and help with schedule; • Able to monitor effectiveness.	**Moderate to High**. • Able to operate and construct; no routine maintenance; • Slurry Injection requires fracturing technology, which is more challenging than regular DPT injection • Fracturing injection service only available from specialized vendors; • Significant water demand, water availability is a potential issue; • Over 100 potential injection points and less reliable injection technology may result in more potential logistics issues and higher potential for schedule delays; • Able to monitor effectiveness.	**Moderate to High**. • Able to operate and construct; no routine maintenance; • Injection into the upper clay zone in TTZ-1 may entail fracturing technology, which is more challenging than regular DPT injection, potential for schedule delays; • Fracturing injection service only available from specialized vendors; • Significant water demand, water availability is a potential issue; • Able to monitor effectiveness.	**Moderate to High**. • Able to operate and construct; no routine maintenance; • Soil excavation has the potential for schedule delays; • Equipment and services available from multiple venders; • Able to monitor effectiveness under the selected remedial alternative.
Cost	**No Cost**	Total Present Value: $1,117,000 Present Value – Capital Costs: $13,000 Present Value – O&M Costs: $1,104,000	Total Present Value: $953,000 Present Value – Capital Costs: $169,000 Present Value – O&M Costs: $784,000	Total Present Value: $1,313,000 Present Value – Capital Costs: $479,000 Present Value – O&M Costs: $834,000	Total Present Value: $1,324,000 Present Value – Capital Costs: $496,000 Present Value – O&M Costs: $828,000	Total Present Value: $624,000 Present Value – Capital Costs: $624,000 Present Value – O&M Costs: $0

TABLE 5-4

Detailed Comparative Analysis of Remedial Alternatives

Site 3 Feasibility Study Report

Naval Weapons Station Yorktown

Yorktown, Virginia

Evaluation Criteria	Alternative 1 - No Action	Alternative 2 - Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs)	Alternative 3 - Enhanced *In Situ* Bioremediation (EISB), MNA, and LUCs	Alternative 4 - *In Situ* Chemical Reduction (ISCR), MNA, and LUCs	Alternative 5 - *In Situ* Chemical Oxidation (ISCO), MNA, and LUCs
Overall Protection of Human Health and the Environment	**1**	**10**	**10**	**10**	**10**
Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)	**1**	**10**	**10**	**10**	**10**
Compliance with Chemical-Specific ARARs	1	10	10	10	10
Compliance with Action-Specific ARARs	1	10	10	10	10
Compliance with Location-Specific ARARs	1	10	10	10	10
Compliance with Other Criteria, Advisories, and Guidance	1	10	10	10	10
Long-Term Effectiveness and Permanence	**1.0**	**8.5**	**9.0**	**9.0**	**9.0**
Magnitude of Residual Risk	1	8	9	9	9
Adequacy and Reliability of Controls	1	9	9	9	9
Reduction of Toxicity, Mobility, and Volume Through Treatment	**1.0**	**1.0**	**9.0**	**8.0**	**8.0**
Treatment Process Used and Materials Treated	1	1	9	8	8
Amount of Hazardous Materials Destroyed or Treated	1	1	9	8	8
Degree of Expected Reductions in Toxicity, Mobility, and Volume	1	1	9	8	8
Degree to Which Treatment is Irreversible	1	1	9	8	8
Type and Quantity of Residual Remaining After Treatment	1	1	9	8	8
Short-Term Effectiveness	**7.8**	**7.5**	**7.3**	**6.0**	**5.5**
Protection of Community During Remedial Actions	10	9	8	8	7
Protection of Workers During Remedial Actions	10	8	6	4	4
Environmental Impacts	10	8	6	4	3
Time Until Remedial Action Objectives are Achieved	1	5	9	8	8
Implementability	**7.8**	**9.4**	**8.4**	**8.3**	**8.5**
Ability to Construct and Operate the Technology	10	9	6	5	6
Reliability of the Technology (Likelihood of Schedule Delays)	10	9	7	6	7
Ease of Undertaking Additional Remedial Actions, if Necessary	10	9	8	9	9
Ability to Monitor Effectiveness of Remedy	1	9	9	9	9
Ability to Coordinate and Obtain Approvals From Other Agencies	1	10	10	10	10
Availability of Offsite Treatment, Storage, and Disposal Services and Capacity	10	10	10	10	10
Availability of Necessary Equipment and Specialists	10	9	7	7	7
Availability of Prospective Technologies	10	10	10	10	10
Total Benefit	**19.5**	**46.4**	**53.6**	**51.3**	**51.0**
Total Present Value Cost	**$0**	**$1,117,000**	**$953,000**	**$1,313,000**	**$1,324,000**
Cost ($1,000/benefit unit) -30% to +50% range	**-**	**16.9 - 36.1**	**12.5 - 26.7**	**18 - 38.4**	**18.2 - 38.9**

Note: Qualitative comparative analysis of alternatives using a rating scale of 1 through 10 (1 = lowest score, 10 = highest score)

SECTION 6
Summary and Conclusions

Based on the comparison of alternatives using the NCP criteria, all alternatives except Alternative 1 and the contingency action would be protective of human health and the environment and are expected to comply with ARARs. Alternatives 2 through 5 would rely to some degree on MNA to reduce the concentrations of site-related COCs, plus LUCs to maintain protectiveness of human health and the environment while COC concentrations are being reduced to achieve RGs. Alternative 2 would rely solely on natural attenuation to meet RAOs, whereas Alternatives 3, 4, and 5 would implement active treatment technologies (EISB, ISCR, or ISCO) in the highest concentration area (TTZ-1) to accelerate the remediation timeframe. Alternative 3 also would include some active treatment of the downgradient plume (TTZ-2). All the treatment technologies (EISB, ISCR, and ISCO) are effective at degrading TCE, cis-1,2-DCE, and VC in groundwater. If needed, the contingency action would engage active soil excavation to remove TPH in unsaturated soils, which may be creating more reducing conditions in groundwater. This contingency should facilitate transformation of arsenic and manganese in groundwater, thereby reducing concentrations in groundwater. Arsenic and manganese would continue to be monitored until RGs are met.

Because Alternatives 3, 4, and 5 and the contingency action would include active treatment as a component of the remedy, they were considered to have greater long-term effectiveness and permanence, along with reduction of toxicity, mobility, or volume through treatment. Because of the slow groundwater flow rate (~4 feet per year), lactate may have moderate persistence in the subsurface at the site; however, a second injection would likely be required. The combined micron-scale ZVI and carbon reagent injected into the TTZ would have up to several years of persistence, while permanganate may persist in the subsurface from a few months to a few years. Therefore, all of these technologies can address potential desorption or back-diffusion of COCs sorbed to the clay layer over time. EISB would be synergistic with natural attenuation processes for TCE, cis-1,2-DCE, and VC and may enhance natural anaerobic biodegradation in the downgradient portion of the plume as the carbon substrate and microbial cultures migrate with groundwater. However, the increase in reducing conditions may temporarily increase dissolved manganese and dissolved arsenic concentrations in groundwater. ISCR is also compatible with existing anaerobic conditions. The ZVI would stay within the injected zone; however, it may create more strongly reduced conditions, which is favorable for natural biodegradation. Although these reducing concentrations may temporarily increase dissolved manganese concentrations, ZVI can co-precipitate dissolved arsenic from groundwater. Although ISCO does not take advantage of the existing reducing conditions, TCE, cis-1,2-DCE, and VC in the treatment zone would be rapidly broken down by the oxidant. The oxidizing conditions would also facilitate the precipitation of dissolved manganese and subsequent adsorption of dissolved arsenic. However, dissolved arsenic concentrations could temporarily increase immediately following the injection of permanganate because of heavy metal impurities in the oxidant.

Alternative 3 would have the lowest costs, followed by Alternatives 2 and 5. Alternative 4 would have the highest associated costs. Although Alternatives 3, 4, and 5 would result in shorter remediation timeframes compared to Alternative 2, the environmental impacts of the treatment activities would result in an overall lower short-term effectiveness for Alternative 2. Based on the SiteWise sustainability analysis, GHG emissions, total energy use, and risk to workers from construction activities and travel would be high for Alternatives 3, 4 and 5. Alternatives 4 and 5 would likely have the highest water consumption and NO_x, SO_x, and PM_{10} air emissions. Although not quantified in SiteWise, permanganate and ZVI may pose more short-term risks to workers than lactate. All alternatives and the contingency action can be implemented reliably onsite because of the maturity of the technologies involved. However, high-pressure injection of EISB is less proven than ISCR and ISCO. The active treatment components of Alternatives 3 through 5 and the contingency action would have higher likelihoods of schedule delays.

SECTION 7
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Appendix A
ARARs and TBCs

APPENDIX A

Applicable or Relevant and Appropriate Requirements
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

Classification	Media/ Location/ Action	Requirement	Prerequisite	Citation	Alternative	ARAR/TBC Determination	Comment
Federal-Chemical Specific	***Remedial Goals***						
	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.	Groundwater contamination exceeds MCLs. Cleanup to MCLs for the contaminants presenting human health risk is being considered in order to meet the state's expectations for beneficial use.	40 CFR 141.61 (a) (1), (5), and (9); 40 CFR 141.62(b)(16)	2, 3, 4, 5	Relevant and Appropriate	Relevant and appropriate because the aquifer is neither currently, nor reasonably anticipated in the future to be used as a potable water supply. The RGs set using MCLs are: Trichloroethene (CAS# 79-01-6): 5 micrograms per liter (µg/L) cis-1,2-Dichloroethene(CAS# 156-59-2): 70 µg/L Vinyl chloride(CAS# 75-01-4): 2 µg/L Arsenic(CAS# 7440-38-2): 10 µg/L
	Groundwater	Chemical concentrations corresponding to fixed levels of human health risk (i.e., a hazard quotient of 1, or lifetime cancer risk of 10^{-6}, whichever occurs at a lower concentration).	Assessment of potential human health risks.	USEPA Region III RSL Tables only as they apply to Manganese (CAS# 7439-96-5)	2, 3, 4, 5	To Be Considered	The following remediation goal at Site 3 was developed using regional screening levels: Manganese (CAS# 7439-96-5): 320 µg/L
Virginia - Chemical Specific	Groundwater	If the concentration of any constituent in ground water exceeds the limit in the standard for that constituent, no addition of that constituent to the naturally occurring concentration shall be made.	Groundwater contamination exceeds a given standard	9 VAC 25-280-30	2, 3, 4, 5	Applicable	The antidegradation policy is applicable with respect to identified COCs and other groundwater constituents identified in ongoing remedy-specific monitoring plans developed during remedy implementation.
Federal-Location Specific	***Migratory Flyway***						
	Migratory bird area	Protects almost all species of native birds in the United States from unregulated taking.	Presence of migratory birds.	16 USC 703	2, 3, 4, 5	Applicable	Site 3 is located in the Atlantic Migratory Flyway. If migratory birds listed in the Act, or their nests or eggs, are identified at Site 3, operations will not destroy the birds, nests or eggs.
	Coastal Zone						
	Coastal zone or area that will affect the coastal zone	Federal activities must be consistent with, to the maximum extent practicable, State coastal zone management programs. Federal agencies must comply with the consistency requirements of 15 CFR § 930.	Actions that may affect identified coastal zone resources or uses.	15 CFR 930.33(a)(1), (c); .36(a); .39(b), (c)	2, 3, 4, 5	Applicable	Activities at Site 3 that will affect Virginia’s coastal zone will be consistent to the maximum extent practicable with Virginia’s enforceable policies. Activities performed onsite and in compliance with CERCLA are not subject to administrative review; however, the substantive requirements of making a consistency determination will be met.

Applicable or Relevant and Appropriate Requirements
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

Classification	Media/ Location/ Action	Requirement	Prerequisite	Citation	Alternative	ARAR/TBC Determination	Comment
Federal-Action Specific	***Storage of Oils***						
	Storage of fuels and oils (petroleum and non-petroleum) onsite	If storage capacity limits are exceeded a Spill, Prevention, Control, and Countermeasures Plan must be prepared and implemented with procedures, methods, equipment, and other requirements to prevent the discharge of oil into or upon the navigable waters of the United States. All oils, including vegetable oils, are regulated under these rules, Empty containers count toward the total capacity unless they are rendered permanently unusable. Containers include oil and all fuel reservoirs in equipment.	Total onsite storage capacity exceeding 1,320 gallons in containers that are 55 gallons or larger in size. The capacity of the containers (regardless of empty or full) triggers this requirement. Example: 24 or more, 55-gallon drums of vegetable oil present, empty or full, onsite at any time.	40 CFR 112.3(a)(1); 112.5; 112.6(a)(3), (b)(3); 112.7(a)-(c), (e)-(g), (i),(k); and 112.8(b),(c)(1), (c)(2), (c)(3), (c)(6), (c)(8)(iii), (c) (10), (d)(3), (d)(4), and (d)(5)	3	Applicable	Although the biodegradation compounds are not specified, many times an oil is used as the electron donor. Projects commonly require 24 or more 55-gallon drums of oil. This ARAR is applicable for Alternative 3 if 1,320 gallons of storage capacity for all oils in containers of 55-gallons or greater is present onsite at any time. If this occurs, a Spill Prevention, Control, and Countermeasure Plan, or equivalent, will be prepared and implemented.
	Subsurface injections						
	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 its largest surface dimension, where the principal function of the hole is in subsurface placement of fluids.	40 CFR 144.12(a), 144.82(a)(1) and (b), 146.8(a) through (c), and 146.10(c)	3, 4, 5	Applicable	These alternatives will include reagent injections. Permits and administrative reviews are not applicable to on-site CERCLA injection wells; however, these alternatives will comply with the substantive requirements of the regulation.
Virginia-Action Specific	***Dust Control***						
	Generation of fugitive dust	Regulations regarding reasonable precautions to prevent particulate matter from becoming airborne.	Conducting any activity which may cause particulate matter to become airborne.	9 VAC 5-50-90	Contingency Action	Applicable	Dust control measures will be implemented during activities at the site.
	Erosion and Sediment Control						
	Erosion and deposits of soil/sediment caused by land disturbing activities	Regulations for the effective control of soil erosion, sediment deposition and nonagricultural runoff which must be met in any control program to prevent the unreasonable degradation of properties, stream channels, waters and other natural resources.	Construction activities that will disturb more than 10,000 square feet of land.	4 VAC 50-30-40(1); (2); (3); (4); (17); (18); (19)(h), (i)	Contingency Action	Relevant and Appropriate	The regulations are not applicable because less than 10,000 square feet of land will be disturbed during remediation activities. However, they are relevant and appropriate to address the possible migration of contaminants during hot spot excavation activities, if performed. Erosion control measures will be implemented as needed to prevent migration during excavation work.
	Waste Management						
	Accumulation of hazardous waste in containers onsite for less than 90 days	Hazardous waste may be accumulated on site in containers for up to 90 days so long as the containers are in good condition, compatible with the waste being stored, and labeled with the words “Hazardous Waste” and the date that accumulation began. The containers must also be kept closed unless adding or removing waste and inspected weekly.	Accumulation of hazardous waste in containers onsite.	9 VAC 20-60-262 only as it incorporates 40 CFR 262.34 (a) (1)(i), (2), (3)	2, 3, 4, 5	Applicable	This requirement is only applicable if hazardous waste is generated. Containers will be managed in accordance with these requirements.

Applicable or Relevant and Appropriate Requirements
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

Classification	Media/ Location/ Action	Requirement	Prerequisite	Citation	Alternative	ARAR/TBC Determination	Comment
Virginia-Action Specific (continued)	Management of non-hazardous waste in containers	Establishes standards and procedures pertaining to the management of non-hazardous solid wastes in containers. Nonputrescible wastes must be stored in appropriate containers and not staged for more than 90 days.	Generation of non-hazardous solid waste that is managed onsite in containers.	9 VAC 20-81-95(D)(10)(b)	2, 3, 4, 5	Applicable	It is anticipated that some wastes (such as decontamination fluids) may be generated and managed onsite in containers. Based on the analytical results from previous investigations, it is expected that these wastes will be non-hazardous solid waste. Wastes will be characterized prior to offsite disposal.
	Monitoring Well Installation and Abandonment						
	Monitoring Well Installation and Abandonment	Establishes requirements for the installation and abandonment of observation and monitoring wells, governed jointly by the State Board of Health and Department of Environmental Quality.	Observation and monitoring wells must be properly installed and abandoned in accordance with Virginia regulations to prevent contamination from reaching groundwater resources via the well.	12 VAC 5-630-420(B) and (C); and 450(C)(1),(2),(4),(5),(7), (8), and (9)	2, 3, 4, 5	Applicable	Monitoring wells will be installed and abandoned in accordance with the Virginia regulations.
	Material Staging and Storage						
	Staging of chemicals onsite where stormwater conveyances are present.	Discharge of pollutants to state waters is prohibited.	Activities that could result in the discharge of pollutants into surface waters, or otherwise altering the physical, chemical or biological properties of surface waters.	9 VAC 25-210-50(A)	3, 4, 5	Applicable	It is possible that chemicals staged onsite during remedial actions could affect waters of the state if spilled or if "daylighting" should occur. Stormwater inlets and other pathways to surface water will be protected to prevent accidental discharges of treatment chemicals to surface water.

APPENDIX A

Applicable or Relevant and Appropriate Requirements
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

Classification	Media/ Location/ Action	Requirement	Prerequisite	Citation	Alternative	ARAR/TBC Determination	Comment

Notes:

Alt 1 - No Action (Note: none of the ARARs or TBC criteria apply to Alternative 1)
Alt 2 - Monitored Natural Attenuation (MNA)
Alt 3 - Enhanced *In Situ* Bioremediation (EISB)
Alt 4 - *In situ* Chemical Reduction (ISCR)
Alt 5 - *In situ* Chemical Oxidation (ISCO)
Contingency - Soil Excavation and Offsite Removal

Acronyms and Abbreviations

ARAR	Applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
HHRA	Human Health Risk Assessment
MCL	Maximum Contaminant Level
PRG	Preliminary Remediation Goal
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
USC	United States Code
VA	Virginia
VAC	Virginia Administrative Code

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

Appendix B
Calculation of Groundwater Remediation Goal Options

TABLE B-1

Values Used for Daily Intake Calculations for COCs: Reasonable Maximum Exposure (RME)

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Scenario Timeframe: Future
Medium: Groundwater
Exposure Medium: Groundwater

Exposure Route	Receptor Population	Receptor Age	Exposure Point	Parameter Code	Parameter Definition	Value	Units	Rationale/ Reference	Intake Equation/ Model Name
Ingestion	Resident	Adult	Yorktown-Eastover Aquifer - Tap Water	CW	Chemical Concentration in Water	See Table 3.1	µg/l	See Table 3.1	Chronic Daily Intake (CDI) (mg/kg-day) =
				IR-W	Ingestion Rate of Water	2	liters/day	EPA, 1997	CW x IR-W x EF x ED x CF2 x 1/BW x 1/AT
				EF	Exposure Frequency	350	days/year	EPA, 1991	
				ED	Exposure Duration	24	years	EPA, 1991	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				BW	Body Weight	70	kg	EPA, 1991	
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	
				AT-N	Averaging Time (Non-Cancer)	8,760	days	EPA, 1989	
		Child	Yorktown-Eastover Aquifer - Tap Water	CW	Chemical Concentration in Water	See Table 3.1	µg/l	See Table 3.1	CDI (mg/kg-day) =
				IR-W	Ingestion Rate of Water	1	liters/day	EPA, 1997	CW x IR-W x EF x ED x CF2 x 1/BW x 1/AT
				EF	Exposure Frequency	350	days/year	EPA, 1991	
				ED	Exposure Duration	6	years	EPA, 1991	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				BW	Body Weight	15	kg	EPA, 1991	
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	
				AT-N	Averaging Time (Non-Cancer)	2,190	days	EPA, 1989	
		Child/Adult	Yorktown-Eastover Aquifer - Tap Water	CW	Chemical Concentration in Water	See Table 3.1	µg/l	See Table 3.1	CDI (mg/kg-day) =
				IR-W-A	Ingestion Rate of Water, Adult	2	liters/day	EPA, 1997	CW x IR-W-Adj x EF x CF2 x 1/AT
				IR-W-C	Ingestion Rate of Water, Child	1	liters/day	EPA, 1997	
				IR-W-Adj	Ingestion Rate of Water, Age-adjusted	1.09	liter-year/kg-day	calculated	IR-W-Adj (liter-year/kd-day) =
				EF	Exposure Frequency	350	days/year	EPA, 1991	(ED-C x IR-W-C / BW-C) +
				ED-A	Exposure Duration, Adult	24	years	EPA, 1991	(ED-A x IR-W-A / BW-A)
				ED-C	Exposure Duration, Child	6	years	EPA, 1991	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				BW-A	Body Weight , Adult	70	kg	EPA, 1991	
				BW-C	Body Weight, Child	15	kg	EPA, 1991	
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	
	Industrial Worker	Adult	Yorktown-Eastover Aquifer - Tap Water	CW	Chemical Concentration in Water	See Table 3.1	µg/l	See Table 3.1	CDI (mg/kg-day) =
				IR-W	Ingestion Rate of Water	1	liters/day	EPA, 1991	CW x IR-W x EF x ED x CF2 x 1/BW x 1/AT
				EF	Exposure Frequency	250	days/year	EPA, 1991	
				ED	Exposure Duration	25	years	EPA, 1991	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				BW	Body Weight	70	kg	EPA, 1991	
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	
				AT-N	Averaging Time (Non-Cancer)	9,125	days	EPA, 1989	

TABLE B-1

Values Used for Daily Intake Calculations for COCs: Reasonable Maximum Exposure (RME)

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Scenario Timeframe: Future
Medium: Groundwater
Exposure Medium: Groundwater

Exposure Route	Receptor Population	Receptor Age	Exposure Point	Parameter Code	Parameter Definition	Value	Units	Rationale/ Reference	Intake Equation/ Model Name
Dermal	Resident	Adult	Yorktown-Eastover Aquifer - Tap Water	CW	Chemical Concentration in Water	See Table 3.1	µg/l	See Table 3.1	CDI (mg/kg-day) =
				DAevent	Dermally Absorbed Dose per Event	calculated	mg/cm^2-event	calculated	DAevent x SA x EV x EF x ED x 1/BW x 1/AT
				FA	Fraction absorbed water	chemical specific	dimensionless	EPA, 2004	
				K_p	Permeability Coefficient	chemical specific	cm/hr	EPA, 2004	Inorganics: DAevent (mg/cm^2-event) =
				t	Lag Time	chemical specific	hr/event	EPA, 2004	Kp x CW x t_{event} x CF2 x CF3
				t*	Time to Reach Steady-state	chemical specific	hours	EPA, 2004	
				B	Ratio of Permeability of Stratum Corneum to Epidermis	chemical specific	dimensionless	EPA, 2004	Organics :
				t_{event}	Event Time	0.58	hr/event	EPA, 2004	t_{event}<t*: DAevent (mg/cm^2-event) =
				SA	Skin Surface Area Available for Contact	18,000	cm^2	EPA, 2004	2 x FA x Kp x CW x (sqrt((6 x t x t_{event})/p))
				EV	Event Frequency	1	events/day	EPA, 2004	x CF2 x CF3
				EF	Exposure Frequency	350	days/year	EPA, 2004	
				ED	Exposure Duration	24	years	EPA, 2004	t_{event}>t*: DAevent (mg/cm^2-event) =
				BW	Body Weight	70	kg	EPA, 1991	FA x Kp x CW x (t_{event}/(1+B) + 2 x t x
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	((1 + 3B + 3B^2)/(1+B)^2)) x CF2 x CF3
				AT-N	Averaging Time (Non-Cancer)	8,760	days	EPA, 1989	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				CF3	Conversion Factor 3	0.001	l/cm^3	- -	
	Resident	Child	Yorktown-Eastover Aquifer - Tap Water	CW	Chemical Concentration in Water	See Table 3.1	µg/l	See Table 3.1	CDI (mg/kg-day) =
				DAevent	Dermally Absorbed Dose per Event	calculated	mg/cm^2-event	calculated	DAevent x SA x EV x EF x ED x 1/BW x 1/AT
				FA	Fraction absorbed water	chemical specific	dimensionless	EPA, 2004	
				K_p	Permeability Coefficient	chemical specific	cm/hr	EPA, 2004	Inorganics: DAevent (mg/cm^2-event) =
				t	Lag Time	chemical specific	hr/event	EPA, 2004	Kp x CW x t_{event} x CF2 x CF3
				t*	Time to Reach Steady-state	chemical specific	hours	EPA, 2004	
				B	Ratio of Permeability of Stratum Corneum to Epidermis	chemical specific	dimensionless	EPA, 2004	Organics :
				t_{event}	Event Time	1.0	hr/event	EPA, 2004	t_{event}<t*: DAevent (mg/cm^2-event) =
				SA	Skin Surface Area Available for Contact	6,600	cm^2	EPA, 2004	2 x FA x Kp x CW x (sqrt((6 x t x t_{event})/p))
				EV	Event Frequency	1	events/day	EPA, 2004	x CF2 x CF3
				EF	Exposure Frequency	350	days/year	EPA, 2004	
				ED	Exposure Duration	6	years	EPA, 2004	t_{event}>t*: DAevent (mg/cm^2-event) =
				BW	Body Weight	15	kg	EPA, 1991	FA x Kp x CW x (t_{event}/(1+B) + 2 x t x
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	((1 + 3B + 3B^2)/(1+B)^2)) x CF2 x CF3
				AT-N	Averaging Time (Non-Cancer)	2,190	days	EPA, 1989	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				CF3	Conversion Factor 3	0.001	l/cm^3	- -	

TABLE B-1

Values Used for Daily Intake Calculations for COCs: Reasonable Maximum Exposure (RME)

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Scenario Timeframe: Future
Medium: Groundwater
Exposure Medium: Groundwater

Exposure Route	Receptor Population	Receptor Age	Exposure Point	Parameter Code	Parameter Definition	Value	Units	Rationale/ Reference	Intake Equation/ Model Name
Dermal		Child/Adult	Yorktown-Eastover Aquifer - Tap Water	CW	Chemical Concentration in Water	See Table 3.1	µg/l	See Table 3.1	CDI (mg/kg-day) = DA-Adj x EF x 1/AT
				DAevent-A	Dermally Absorbed Dose per Event, Adult	calculated	mg/cm^2-event	calculated	
				DAevent-C	Dermally Absorbed Dose per Event, Child	calculated	mg/cm^2-event	calculated	DA-Adj = (Daevent-A x SA-A x ED-A x 1/BW-A)
				DA-Adj	Dermally Absorbed Dose, Age-adjusted	calculated	mg-year/event-kg	calculated	+ (Daevent-C x SA-C x ED-C x 1/BW-C)
				FA	Fraction absorbed water	chemical specific	dimensionless	EPA, 2004	
				K_p	Permeability Coefficient	chemical specific	cm/hr	EPA, 2004	Inorganics: DAevent (mg/cm^2-event) =
				t	Lag Time	chemical specific	hr/event	EPA, 2004	Kp x CW x t_{event} x CF2 x CF3
				t*	Time to Reach Steady-state	chemical specific	hours	EPA, 2004	
				B	Ratio of Permeability of Stratum Corneum to Epidermis	chemical specific	dimensionless	EPA, 2004	Organics :
				t_{event}-A	Event Time, Adult	0.58	hr/event	EPA, 2004	t_{event}<t*: DAevent (mg/cm^2-event) =
				t_{event}-C	Event Time, Child	1.0	hr/event	EPA, 2004	2 x FA x Kp x CW x (sqrt((6 x t x t_{event})/p))
				SA-A	Skin Surface Area, Adult	18,000	cm^2	EPA, 2004	x CF2 x CF3
				SA-C	Skin Surface Area, Child	6,600	cm^2	EPA, 2004	
				EV	Event Frequency	1	events/day	EPA, 2004	t_{event}>t*: DAevent (mg/cm^2-event) =
				EF	Exposure Frequency	350	days/year	EPA, 2004	FA x Kp x CW x (t_{event}/(1+B) + 2 x t x
				ED-A	Exposure Duration, Adult	24	years	EPA, 2004	((1 + 3B + 3B^2)/(1+B)^2)) x CF2 x CF3
				ED-C	Exposure Duration, Child	6	years	EPA, 2004	
				BW-A	Body Weight, Adult	70	kg	EPA, 1991	
				BW-C	Body Weight, Child	15	kg	EPA, 1991	
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				CF3	Conversion Factor 3	0.001	l/cm^3	- -	
	Construction Worker	Adult	Yorktown-Eastover Aquifer - Excavation Pit	CW	Chemical Concentration in Water	See Table 3.3.RME	µg/l	See Table 3.3.RME	CDI (mg/kg-day) =
				DAevent	Dermally Absorbed Dose per Event	calculated	mg/cm^2-event	calculated	DAevent x SA x EV x EF x ED x 1/BW x 1/AT
				FA	Fraction absorbed water	chemical specific	dimensionless	EPA, 2004	
				K_p	Permeability Coefficient	chemical specific	cm/hr	EPA, 2004	Inorganics: DAevent (mg/cm^2-event) =
				t	Lag Time	chemical specific	hr/event	EPA, 2004	Kp x CW x t_{event} x CF2 x CF3
				t*	Time to Reach Steady-state	chemical specific	hours	EPA, 2004	
				B	Ratio of Permeability of Stratum Corneum to Epidermis	chemical specific	dimensionless	EPA, 2004	Organics :
				t_{event}	Event Time	8	hr/day	(1)	t_{event}<t*: DAevent (mg/cm^2-event) =
				SA	Skin Surface Area Available for Contact	5,700	cm^2	EPA, 2004, (3)	2 x FA x Kp x CW x (sqrt((6 x t x t_{event})/p))
				EV	Event Frequency	1	events/day	EPA, 2004	x CF2 x CF3
				EF	Exposure Frequency	125	days/year	(2)	
				ED	Exposure Duration	1	years	EPA, 1991	t_{event}>t*: DAevent (mg/cm^2-event) =
				BW	Body Weight	70	kg	EPA, 1991	FA x Kp x CW x (t_{event}/(1+B) + 2 x t x
				AT-C	Averaging Time (Cancer)	25,550	days	EPA, 1989	((1 + 3B + 3B^2)/(1+B)^2)) x CF2 x CF3
				AT-N	Averaging Time (Non-Cancer)	365	days	EPA, 1989	
				CF2	Conversion Factor 2	0.001	mg/µg	- -	
				CF3	Conversion Factor 3	0.001	l/cm^3	- -	

(1) Professional judgment based on construction activities that would occur 8 hrs per day for the RME.

(2) Assumed contact with groundwater during construction project would be 125 days/year.

(3) Skin surface area in contact with groundwater assumed to be hands, forearms, lower legs, and feet.

Sources:

EPA, 1989: Risk Assessment Guidance for Superfund. Vol.1: Human Health Evaluation Manual, Part A. OERR. EPA/540/1-89/002.

EPA, 1991: Risk Assessment Guidance for Superfund. Vol.1: Human Health Evaluation Manual - Supplemental Guidance, Standard Default Exposure Factors. Interim Final. OSWER Directive 9285.6-03.

EPA, 1997: Exposure Factors Handbook. EPA/600/P-95/002Fa.

EPA, 2004 . Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment (Final). EPA/540/R/99/005. July 2004.

TABLE B-2

Calculation of Chemical Cancer Risks and Noncancer Hazards for COCs: Reasonable Maximum Exposure

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Receptor	Exposure Medium	Exposure Point	Exposure Route	Chemical of Concern	Exposure Point Concentration	Units	Noncancer Hazard Calculations				
							Intake/Exposure Concentration	Units	RfD/RfC	Units	Hazard Quotient
Residential Adult	Groundwater	Yorktown Aquifer-Tap Water	Ingestion	Manganese, Dissolved	8.7E+02	µg/L	2.4E-02	mg/kg/day	2.4E-02	mg/kg/day	9.9E-01
			Dermal Absorption	Manganese, Dissolved	8.7E+02	µg/L	1.2E-04	mg/kg/day	9.6E-04	mg/kg/day	1.3E-01
Residential Child	Groundwater	Yorktown Aquifer-Tap Water	Ingestion	Manganese, Dissolved	8.7E+02	µg/L	5.5E-02	mg/kg/day	2.4E-02	mg/kg/day	2.3E+00
			Dermal Absorption	Manganese, Dissolved	8.7E+02	µg/L	3.7E-04	mg/kg/day	9.6E-04	mg/kg/day	3.8E-01
Industrial Worker	Groundwater	Yorktown Aquifer-Tap Water	Ingestion	Manganese, Dissolved	8.7E+02	µg/L	8.5E-03	mg/kg/day	2.4E-02	mg/kg/day	3.5E-01
Construction Worker	Groundwater	Water in Excavation Pit	Dermal Absorption	Manganese	1.3E+03	µg/L	2.9E-04	mg/kg/day	9.6E-04	mg/kg/day	3.1E-01

TABLE B-2

Calculation of Chemical Cancer Risks and Noncancer Hazards for COCs: Reasonable Maximum Exposure

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Receptor	Exposure Medium	Exposure Point	Exposure Route	Chemical of Concern	Exposure Point Concentration	Units	Cancer Risk Calculations				
							Intake/Exposure Concentration	Units	CSF/Unit Risk	Units	Cancer Risk
Residential Child/Adult	Groundwater	Yorktown Aquifer-Tap Water	Ingestion	Manganese, Dissolved	8.7E+02	µg/L	1.3E-02	mg/kg/day	N/A		N/A
			Dermal Absorption	Manganese, Dissolved	8.7E+02	µg/L	7.4E-05	mg/kg/day	N/A		N/A
Industrial Worker	Groundwater	Yorktown Aquifer-Tap Water	Ingestion	Manganese, Dissolved	8.7E+02	µg/L	3.0E-03	mg/kg/day	N/A		N/A
Construction Worker	Groundwater	Water in Excavation Pit	Dermal Absorption	Manganese	1.3E+03	µg/L	4.2E-06	mg/kg/day	N/A		N/A

Notes:

1. The medium-specific and exposure scenario–specific intake equations used in this assessment are provided in the RAGS Part D Table 4 (USEPA, 2001a).
2. Risk values obtained from Final Phase II Remedial Investigation (RI) Report Sites 1 and 3 (CH2M HILL, 2012).

N/A - not applicable

TABLE B-3

Calculation of Groundwater Remedial Goal Options for COCs

Site 3 Feasibility Study

Naval Weapons Station Yorktown

Yorktown, Virginia

Resident Child

Chemical	Exposure Point Concentration (µg/L)	Noncarcinogenic Hazard				RGO - 0.1 (µg/L)	RGO - 1 (µg/L)	Target Organ	Target HI	Target RGO (µg/L)
		Inh	Ing	Der	Total					
Manganese, Dissolved	8.7E+02	--	2.3E+00	3.8E-01	2.7E+00	3.2E+01	3.2E+02	CNS	1.0E+00	3.2E+02

Notes:

1. For noncarcinogens: RGO = (Exposure Point Concentration x Target Hazard Level)/ Total Hazard Quotient
2. Hazard quotient and exposure point concentration values presented in Table B-2.

Der - dermal absorption

Ing - ingestion

Inh - inhalation

µg/L - micrograms per liter

RGO - Remediation Goal Option

Appendix C
Preliminary Cost Estimates

APPENDIX C
Preliminary Cost Estimates
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

Remedial Action Cost Estimate Summary

Site: Naval Weapons Stations Yorktown
Location: Site 3 - Yorktown, Virginia
Phase: Pre-Draft FS
Base Year: 2013

	Pre-Design Investigation	Alternative 2: MNA and LUCs	Alternative 3: Enhanced In Situ Bioremediation	Alternative 4: In Situ Chemical Reduction	Alternative 5: In Situ Chemical Oxidation	Contingency Soil Excavation
Total Project Duration (Years)	Not applicable	19	8	11	12	Not applicable
Present Value - Capital Costs	$124,000	$12,664	$168,915	$479,126	$496,048	$623,677
Present Value - O&M Costs	$0	$1,103,561	$784,015	$833,579	$827,550	$0
Total Present Value Cost	**$124,000**	**$1,117,000**	**$953,000**	**$1,313,000**	**$1,324,000**	**$624,000**
Total Present Value Cost (+50%)		$1,676,000	$1,430,000	$1,970,000	$1,986,000	
Total Present Value Cost (-30%)		$782,000	$668,000	$920,000	$927,000	

Disclaimer:

1. The information in this cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. Changes in the cost elements are likely to occur as a result of new information and data collected.

2. This cost estimate has been prepared in accordance with EPA 540-R-00-002 and represents a -30 to +50 percent range of accuracy. This estimate is limited to the conditions existing at its issuance and is not a guaranty of actual price or cost. Uncertain market conditions such as, but not limited to: local labor or contractor availability, wages, other work, material market fluctuations, price escalations, force majeure events, and developing bidding conditions, may affect the accuracy of this estimate. CH2M HILL is not responsible for any variance from this estimate or actual prices and conditions obtained.

3. Estimates are presented in current dollars without escalation.

Pre-Design Investigation

Site: Naval Weapons Stations Yorktown
Location: Site 3 - Yorktown, Virginia
Phase: Pre-Draft FS
Base Year: 2013

KEY ASSUMPTIONS

1. 6 new permanent groundwater monitoring wells would be installed, with screens set at 22-32, 35-45, 27-37, 12-22, 30-40, and 80-90 ft bgs.
2. New permanent monitoring well construction would be consistent with existing monitoring wells. Continuous soil samples will be collected for lithology. The soil boring at the deep monitoring well location will extend to 100 ft bgs to reach the Eastover-Calvert confining unit.
3. Monitoring well installation would take 6 (10-hr) days.
4. Utility clearance and surveyor would take 1 (10-hr) day each.
5. Slug testing of 3 new monitoring wells would take 1 (10-hr) day.
6. 6 new and 19 existing shallow groundwater monitoring wells would be monitored during the baseline sampling event.
7. Sampling event preparation will take 10 hours (Geologist) for laboratory and data validation procurement, equipment ordering, and planning.
8. Baseline sampling event would include 2 Field Staff and would take 7 (10-hr) days.
9. Analysis: CVOCs at 24 wells; As and Mn at 25 wells; SVOCs at 1 well; 1,4-dioxane at 7 wells; and geochemical parameters (alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron, chloride, methane, ethane, and ethene) at 13 wells; Field water quality parameters at all wells.

Pre-Design Investigation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CAPITAL COSTS					
Utility Locator					
Private Utility Locator	1	LS	$2,580	$2,580	Vendor's bid 2010
Geologist	10	HR	$80	$800	Navy CLEAN Rate
Geologist (Per Diem)	1	DY	$147	$147	2012 DOD Per Diem
SUBTOTAL				**$3,527**	
Permanent Monitoring Well Installation					
Mobilization/demobilization of Driller	1	LS	$5,000	$5,000	Option Yr 4 Navy CLEAN BOA Rates
Driller Per diem (3 people)	6	DAY	$441	$2,646	2012 DOD Per Diem
Drilling (4.25-in HSA)	281	LF	$16.73	$4,701	Option Yr 4 Navy CLEAN BOA Rates Shallow wells - total depths plus extra foot Deep well - 100 feet
Split Spoon Samples (5-ft long barrel)	56	EA	$20.04	$1,126	Option Yr 4 Navy CLEAN BOA Rates
Well Materials-Riser	206	LF	$3.44	$709	Riser and screen, 2-inch sched 40 PVC (Option Yr 4 Navy CLEAN BOA Rates)
Well Materials-Screen	6	EA	$79.65	$478	Riser and screen, 2-inch sched 40 PVC (Option Yr 4 Navy CLEAN BOA Rates)
Annular Materials	281	LF	$12.56	$3,529	sand/bentonite/concrete (6.25"auger) (Option Yr 4 Navy CLEAN BOA Rates)
Well Completion	6	EA	$625	$3,750	Installation of Protective Casing with bollards Option Yr 4 Navy CLEAN BOA Rates
Well Development	12	HR	$105	$1,260	Option Yr 4 Navy CLEAN BOA Rates, assuming 2 hr per Well
Disposal of Generated Wastes	1	LS	$1,140	$1,140	2010 Navy CLEAN BOA Rates (1 drum soil per boring and 1 drum water per well)
Surveyor	1	LS	$1,500	$1,500	2-surveyors 1 day on site (Oct. 2009 BOA Rates)
Geologist	60	HR	$80	$4,800	Engineer's estimate
Geologist (per diem)	6	DY	$147	$882	2012 DOD Per Diem
Vehicle rental and fuel	6	DY	$125	$750	Engineer's estimate
Consumable supplies	6	DY	$50	$300	Engineer's estimate
SUBTOTAL				**$32,571**	
Baseline Monitoring Event and Slug Testing					See Notes 10 and 11
Procurement, equipment ordering, and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (6 days - 7 Geologists - 10 hrs/day)	140	HR	$80	$11,200	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	7	DY	$294	$2,058	2012 DOD Per Diem
Vehicle rental and fuel	7	DY	$125	$875	Engineer's estimate
Consumable supplies	7	DY	$50	$350	Engineer's estimate
Analytical	1	LS	$8,889	$8,889	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$1,793	$1,793	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation and Tech Memo	200	HR	$100	$20,000	Engineer's Estimate
SUBTOTAL				**$47,465**	
COMBINED SUBTOTAL				**$83,563**	
Undefined Scope and Market Allowance	25%	of	$83,563	$20,891	Based on Projects similar in nature
SUBTOTAL				**$104,454**	
Project Management	8%	of	$104,454	$8,356	Based on Projects similar in nature
Construction Management	10%	of	$104,454	$10,445	Based on Projects similar in nature
TOTAL CAPITAL COSTS				**$123,255**	

TOTAL PRESENT VALUE OF Pre-design Investigation	**$124,000**
TOTAL PRESENT VALUE OF Pre-design Investigation (+50%)	**$186,000**
TOTAL PRESENT VALUE OF Pre-design Investigation (-30%)	**$87,000**

Alternative 2: Monitored Natural Attenuation

Site: Naval Weapons Stations Yorktown
Location: Site 3 - Yorktown, Virginia
Phase: Pre-Draft FS
Base Year: 2013

KEY ASSUMPTIONS

1. Estimated duration of alternative is 19 years. Enforce LUCs and conduct 5-year reviews until RGs are met.

2. Conduct natural attenuation monitoring.
- Semiannual groundwater sampling for 5 years (organic and inorganic COCs); during this period degradation products and geochemical parameters would only be collected on an annual basis
- Annual groundwater sampling for 12 years (organic COCs)
- Annual groundwater sampling for 14 years (inorganic COCs)
3. Up to 20 monitoring wells would be included in the MNA well network.
4. Sampling event preparation would take 10 hours (Geologist) for laboratory and data validation procurement, equipment ordering, and planning.
5. Except for the last two years of monitoring (inorganics only), each sampling event would include 2 Field Staff and would take 4 (10-hr) days. The last two years of monitoring would take 2 Field Staff 2 (10-hr) days.
6. MNA analysis (Organics and Inorganics): CVOCs at 19 wells; As and Mn at 8 wells; geochemical parameters (alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron) and MEE (methane, ethene, ethane) from 10 wells
7. MNA analysis (Inorganics only): As and Mn at 8 wells
8. Design details are conceptual in nature and presented in this FS to develop costs for alternative comparison.

Alternative 2: Monitored Natural Attenuation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CAPITAL COSTS					
Land Use Controls					
Signs	4	EACH	$291	$1,164	R.S. Means #10-14-19.10 (2200)
Deed Notifications	1	LS	$11,500	$11,500	Engineer's Estimate
SUBTOTAL				**$12,664**	
TOTAL CAPITAL COSTS				**$12,664**	
OPERATION AND MAINTENANCE COSTS					
Cost per Land Use Controls Inspection (Years 1-19)					1 Event/year
Annual Inspection (Engineer)	16	HR	$100	$1,600	Navy CLEAN Rate
SUBTOTAL				**$1,600**	
Undefined Scope and Market Allowance	25%	of	$1,600	$400	Based on Projects similar in nature
SUBTOTAL				**$2,000**	
Project Management	8%	of	$2,000	$160	Based on Projects similar in nature
Operation and Maintenance Cost				**$2,160**	
Cost per Monitoring (Year 1-5)					2 Events/year; See Note 2
Procurement, equipment ordering, and planning	20	HR	$80	$1,600	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	160	HR	$80	$12,800	Navy CLEAN Rate
Field Equipment	2	LS	$1,500	$3,000	Engineer's Estimate
Geologists (per diem, 2-person crew)	8	DY	$294	$2,352	2012 DOD Per Diem
Vehicle rental and fuel	8	DY	$125	$1,000	Engineer's estimate
Consumable supplies	8	DY	$50	$400	Engineer's estimate
Analytical (VOCs, metals, and Geochem)	1	LS	$7,478	$7,478	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$1,602	$1,602	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$62,632**	
Undefined Scope and Market Allowance	25%	of	$62,632	$15,658	
SUBTOTAL				**$78,290**	
Project Management	8%	of	$78,290	$6,263	
Operation and Maintenance Cost				**$84,553**	
Cost per Monitoring (Years 6-17)					1 Event/year; See Note 2
Procurement, equipment ordering, and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	80	HR	$80	$6,400	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	4	DY	$294	$1,176	2012 DOD Per Diem
Vehicle rental and fuel	4	DY	$125	$500	Engineer's estimate
Consumable supplies	4	DY	$50	$200	Engineer's estimate
Analytical (VOCs, metals, and Geochem)	1	LS	$5,114	$5,114	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$1,051	$1,051	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$49,141**	
Undefined Scope and Market Allowance	25%	of	$49,141	$12,285	
SUBTOTAL				**$61,426**	
Project Management	8%	of	$61,426	$4,914	
Operation and Maintenance Cost				**$66,340**	
Cost per Monitoring (Years 18-19)					1 Event/year; See Note 2
Procurement, equipment ordering, and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (2 days - 2 Geologists - 10 hrs/day)	40	HR	$80	$3,200	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	2	DY	$294	$588	2012 DOD Per Diem
Vehicle rental and fuel	2	DY	$125	$250	Engineer's estimate
Consumable supplies	2	DY	$50	$100	Engineer's estimate
Analytical (metals)	1	LS	$274	$274	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$152	$152	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	10	HR	$120	$1,200	Engineer's Estimate
Annual Report	1	LS	$20,000	$20,000	Engineer's Estimate
SUBTOTAL				**$28,064**	
Undefined Scope and Market Allowance	25%	of	$28,064	$7,016	
SUBTOTAL				**$35,080**	
Project Management	8%	of	$35,080	$2,806	
Operation and Maintenance Cost				**$37,887**	
Cost per Periodic Review (Years 5, 10, 15)					
5 Year Review	1	LS	$5,000	$5,000	Historical Experience
SUBTOTAL				**$5,000**	
Undefined Scope and Market Allowance	25%	of	$5,000	$1,250	Historical Experience
SUBTOTAL				**$6,250**	
Project Management	8%	of	$6,250	$500	Historical Experience
Operation and Maintenance Cost				**$6,750**	

Alternative 2: Monitored Natural Attenuation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Cost per Well Abandonment (Year 19)					Monitoring Wells
Mobilization/demobilization of Driller	1	LS	$5,000	$5,000	Option Yr 4 Navy CLEAN BOA Rates
Driller Per diem (2 people)	15	DY	$294	$4,410	2012 DOD Per Diem
Well Abandonment (< 50 ft deep Wells)	800	LF	$8.55	$6,840	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Well Abandonment (50-100 ft deep Wells)	450	LF	$10.69	$4,810	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Geologist	150	HR	$80	$12,000	Engineer's estimate
Geologist (per diem)	15	DY	$147	$2,205	2012 DOD Per Diem
Vehicle rental and fuel	15	DY	$125	$1,875	Engineer's estimate
Consumable supplies	15	DY	$50	$750	Engineer's estimate
SUBTOTAL				**$37,890**	
Undefined Scope and Market Allowance	25%	of	$37,890	$9,472	
SUBTOTAL				**$47,362**	
Project Management	8%	of	$47,362	$3,789	
Operation and Maintenance Cost				**$51,151**	

PRESENT VALUE ANALYSIS Discount Rate : 2.7% — 2013 Discount Rates (20-Year) Federal Office of Management and Budget

END YEAR	DESCRIPTION	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE
0	Total Capital Costs	$12,664	$12,664	1	$12,664
1	Total Annual O&M Costs	$86,713	$86,713	0.974	$84,434
2	Total Annual O&M Costs	$86,713	$86,713	0.948	$82,214
3	Total Annual O&M Costs	$86,713	$86,713	0.923	$80,053
4	Total Annual O&M Costs	$86,713	$86,713	0.899	$77,948
5	Total Annual O&M Costs and 5-year review	$93,463	$93,463	0.875	$81,807
6	Total Annual O&M Costs	$68,500	$68,500	0.852	$58,381
7	Total Annual O&M Costs	$68,500	$68,500	0.830	$56,846
8	Total Annual O&M Costs	$68,500	$68,500	0.808	$55,352
9	Total Annual O&M Costs	$68,500	$68,500	0.787	$53,896
10	Total Annual O&M Costs and 5-year review	$75,250	$75,250	0.766	$57,651
11	Total Annual O&M Costs	$68,500	$68,500	0.746	$51,100
12	Total Annual O&M Costs	$68,500	$68,500	0.726	$49,756
13	Total Annual O&M Costs	$68,500	$68,500	0.707	$48,448
14	Total Annual O&M Costs	$68,500	$68,500	0.689	$47,174
15	Total Annual O&M Costs and 5-year review	$75,250	$75,250	0.671	$50,461
16	Total Annual O&M Costs	$68,500	$68,500	0.653	$44,727
17	Total Annual O&M Costs	$68,500	$68,500	0.636	$43,551
18	Total Annual O&M Costs	$40,047	$40,047	0.619	$24,791
19	Total Annual O&M Costs and well abandonment	$91,198	$91,198	0.603	$54,973
	SUBTOTAL				**$1,116,225**

TOTAL PRESENT VALUE OF ALTERNATIVE 2	**$1,117,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 2 (+50%)	**$1,676,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 2 (-30%)	**$782,000**

This cost estimate has been prepared in accordance with EPA 540-R-00-002 and represents a -30 to +50 percent range of accuracy. This estimate is limited to the conditions existing at its issuance and is not a guaranty of actual price or cost. Uncertain market conditions such as, but not limited to: local labor or contractor availability, wages, other work, material market fluctuations, price escalations, force majeure events, and developing bidding conditions, may affect the accuracy of this estimate. CH2M HILL is not responsible for any variance from this estimate or actual prices and conditions obtained.

Alternative 3: Enhanced In Situ Bioremediation

Site: Naval Weapons Stations Yorktown
Location: Site 3 - Yorktown, Virginia
Phase: Pre-Draft FS
Base Year: 2013

KEY ASSUMPTIONS

1. Estimated duration of alternative is 9 years. Enforce LUCs and conduct 5-year reviews until RGs are met.
2. Utility clearance would take 1 (10-hr) day each.
3. Two injections will be conducted in TTZ-1 sands while only one injection will be conducted in the TTZ-1 clay and TTZ-2. Soluble substrate would be injected using DPT. Injection in the clay will require specialized high pressure equipment. TTZ-1 includes 46 injection points in the Yorktown-Eastover aquifer sands and 28 injection points in the clay zone. 13 of the 28 points will be co-located with the injections in the sand while 15 injection points will be in separate borings. TTZ-2 includes 21 injection points.
4. An estimated 8,400, 10,200, and 1,800 lbs of WilClear Plus® would be injected into TTZ-1 clay zone, TTZ-1 sandy aquifer, and TTZ-2, respectively.
5. The substrate would be diluted to a 10 percent solution for a total of 20,350 gallons over the 2 injection events. Water associated with injection solution would be obtained from a fire hydrant on base.
6. 46 Liters of SDC-9 would be injected into the 46 DPT points in the TTZ-1 sandy aquifer (1 L per point) during the first injection.
7. The 9,350-gallon solution in the first injection at TTZ-1 needs be "O2-free" to protect the anaerobic bioaugmentation culture. Approximately 1.5 lbs sodium sulfite per 500 gallons of solution would be needed to remove the O2. This process would somewhat slow down the injection process.
8.The injection would be conducted using 1 DPT rig at an average injection rate of 3 gallons per minute and simultaneous substrate injection into 4 locations. Injection activities would take 4 (10-hr) days, with 8 of the 10 hours for injection. Field staff would GPS injection locations.
9. Conduct performance and natural attenuation monitoring
- Quarterly groundwater sampling for 1 year (organic and inorganic COCs)
- Semiannual groundwater sampling for 4 years (organic and inorganic COCs)
- Annual groundwater sampling for 2 years (organic COCs)
- Annual groundwater sampling for 4 years (inorganic COCs)
10. Up to 20 monitoring wells would be included in the monitoring network.
11. Sampling event preparation would take 10 hours (Geologist) for laboratory and data validation procurement, equipment ordering and planning.
12. Except for the last two years of monitoring (inorganics only), each sampling event would include 2 Field Staff and would take 4 (10-hr) days. The last two years of monitoring would take 2 Field Staff 2 (10-hr) days.
13. Quarterly performance monitoring analysis: CVOC, ethene, and ethane at 19 wells; As and Mn at 8 wells; geochemical parameters (chloride, methane, alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron) at 7 wells; VFAs and DHC analyses at 4 wells.
14. MNA analysis (Organics and Inorganics): CVOCs at 19 wells; As and Mn at 8 wells; geochemical parameters (alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron) and MEE (methane, ethene, ethane) at 10 wells.
15. MNA analysis (Inorganics only): As and Mn at 8 wells
16. Design details are conceptual in nature and presented in this FS to develop costs for alternative comparison.

Alternative 3: Enhanced In Situ Bioremediation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CAPITAL COSTS					
Land Use Controls					
Signs	4	EACH	$291	$1,164	R.S. Means #10-14-19.10 (2200)
Deed Notifications	1	LS	$11,500	$11,500	Engineer's Estimate
SUBTOTAL				**$12,664**	
Utility Locator					
Private Utility Locator	1	LS	$2,580	$2,580	Vendor's bid 2010
Geologist	10	HR	$80	$800	Navy CLEAN Rate
Geologist (Per Diem)	1	DY	$147	$147	2012 DOD Per Diem
SUBTOTAL				**$3,527**	
EISB DPT Injection					
Mobilization/demobilization of Driller	1	EACH	$2,500	$2,500	Redox Tech. LLC quote (Jan. 2013)
DPT Injection (2-driller crew)	4	Days	$3,400	$13,600	Redox Tech. LLC quote (Jan. 2013)
WilClear® substrate	12,000	LBS	$1.36	$16,320	JRW Bioremediation LLC quote (Jan. 2013)
Substrate (freight)	1	EACH	$1,726.00	$1,726	JRW Bioremediation LLC quote (Jan. 2013)
Bioaugmentation culture (including shipping)	46	L	$170.00	$7,820	Terra Systems verbal quote (Jan. 2013)
Sodium Sulfite (1 bag of 50 lbs)	1	EACH	$50.00	$50	Engineer's Estimate
Engineer/Hydrogeologist (per diem, 2-person crew)	4	DY	$284	$1,136	DOD Travel Per Diem Allowance, FY2011
Engineer/Hydrogeologist (including prep and field time)	100	HR	$100	$10,000	Navy CLEAN Rate - 2 people, 10-hr days
Vehicle rental and fuel	4	DY	$125	$500	Engineer's estimate
Consumable supplies	4	DY	$50	$200	Engineer's estimate
Senior Technologist	12	HR	$130	$1,560	Navy CLEAN Rate - 3 hr per inj. day
SUBTOTAL				**$55,412**	
Reporting					
Construction Completion Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$30,000**	
COMBINED SUBTOTAL				**$101,603**	
Undefined Scope and Market Allowance	25%	of	$101,603	$25,401	
SUBTOTAL				**$127,004**	
Project Management	8%	of	$127,004	$10,160	
Remedial Design	15%	of	$127,004	$19,051	
Construction Management	10%	of	$127,004	$12,700	
TOTAL CAPITAL COSTS				**$168,915**	

Alternative 3: Enhanced In Situ Bioremediation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
OPERATION AND MAINTENANCE COSTS					
Cost per Land Use Controls Inspection (Years 1-9)					1 Event/year
Annual Inspection (Engineer)	16	HR	$100	$1,600	Navy CLEAN Rate
SUBTOTAL				**$1,600**	
Undefined Scope and Market Allowance	25%	of	$1,600	$400	
SUBTOTAL				**$2,000**	
Project Management	8%	of	$2,000	$160	
Operation and Maintenance Cost				**$2,160**	
EISB DPT Re-injection (9 months later)					1 Event
Mobilization/demobilization of Driller	1	EACH	$2,500	$2,500	Redox Tech. LLC quote (Jan. 2013)
DPT Injection (2-driller crew)	3	Days	$3,400	$10,200	Redox Tech. LLC quote (Jan. 2013)
WilClear® substrate	10,200	LBS	$1.36	$13,872	JRW Bioremediation LLC quote (Jan. 2013)
Substrate (freight)	1	EACH	$1,726.00	$1,726	JRW Bioremediation LLC quote (Jan. 2013)
Engineer/Hydrogeologist (per diem, 2-person crew)	3	DY	$284	$852	DOD Travel Per Diem Allowance, FY2011
Engineer/Hydrogeologist	60	HR	$100	$6,000	Navy CLEAN Rate - 2 people, 10-hr days
Vehicle rental and fuel	3	DY	$125	$375	Engineer's estimate
Consumable supplies	3	DY	$50	$150	Engineer's estimate
Project Manager	9	HR	$130	$1,170	Navy CLEAN Rate - 3 hr per inj. day
SUBTOTAL				**$36,845**	
Undefined Scope and Market Allowance	25%	of	$36,845	$9,211	
SUBTOTAL				**$46,056**	
Project Management	8%	of	$46,056	$3,685	
Remedial Design	15%	of	$46,056	$6,908	
Construction Management	10%	of	$46,056	$4,606	
Operation and Maintenance Cost				**$61,255**	
Cost per Monitoring (Year 1)					4 Events/year; See Note 9
Quarterly groundwater monitoring					
Procurement, equipment ordering, and planning	40	HR	$80	$3,200	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	320	HR	$80	$25,600	Navy CLEAN Rate
Field Equipment	4	LS	$1,500	$6,000	Engineer's Estimate
Geologists (per diem, 2-person crew)	16	DY	$294	$4,704	2012 DOD Per Diem
Vehicle rental and fuel	16	DY	$125	$2,000	Engineer's estimate
Consumable supplies	16	DY	$50	$800	Engineer's estimate
Analytical	4	LS	$7,033	$28,132	2009 Navy CLEAN BOA Rates
Data Validation	4	LS	$1,022	$4,088	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	40	HR	$120	$4,800	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$109,324**	
Undefined Scope and Market Allowance	25%	of	$109,324	$27,331	
SUBTOTAL				**$136,655**	
Project Management	8%	of	$136,655	$10,932	
Operation and Maintenance Cost				**$147,588**	
Cost per Monitoring (Years 2-5)					2 Events/year; See Note 9
Semi-annual groundwater monitoring					
Procurement, equipment ordering, and planning	20	HR	$80	$1,600	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	160	HR	$80	$12,800	Navy CLEAN Rate
Field Equipment	2	LS	$1,500	$3,000	Engineer's Estimate
Geologists (per diem, 2-person crew)	8	DY	$294	$2,352	2012 DOD Per Diem
Vehicle rental and fuel	8	DY	$125	$1,000	Engineer's estimate
Consumable supplies	8	DY	$50	$400	Engineer's estimate
Analytical	2	LS	$5,114	$10,228	2009 Navy CLEAN BOA Rates
Data Validation	2	LS	$1,051	$2,102	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$65,882**	
Undefined Scope and Market Allowance	25%	of	$65,882	$16,471	
SUBTOTAL				**$82,353**	
Project Management	8%	of	$82,353	$6,588	
Operation and Maintenance Cost				**$88,941**	
Cost per Monitoring (Year 6-7)					1 Event/year; See Note 9
Annual groundwater monitoring					
Procurement, equipment ordering, and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	80	HR	$80	$6,400	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	4	DY	$294	$1,176	2012 DOD Per Diem
Vehicle rental and fuel	4	DY	$125	$500	Engineer's estimate
Consumable supplies	4	DY	$50	$200	Engineer's estimate
Analytical	1	LS	$5,114	$5,114	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$1,051	$1,051	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$49,141**	
Undefined Scope and Market Allowance	25%	of	$49,141	$12,285	
SUBTOTAL				**$61,426**	
Project Management	8%	of	$61,426	$4,914	
Operation and Maintenance Cost				**$66,340**	
Cost per Monitoring (Year 8-9)					1 Event/year; See Note 9
Annual groundwater monitoring					
Procurement, equipment ordering and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (2 days - 2 Geologists - 10 hrs/day)	40	HR	$80	$3,200	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	2	DY	$294	$588	2012 DOD Per Diem
Vehicle rental and fuel	2	DY	$125	$250	Engineer's estimate
Consumable supplies	2	DY	$50	$100	Engineer's estimate
Analytical	1	LS	$274	$274	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$152	$152	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	10	HR	$120	$1,200	Engineer's Estimate
Annual Report	1	LS	$20,000	$20,000	Engineer's Estimate
SUBTOTAL				**$28,064**	
Undefined Scope and Market Allowance	25%	of	$28,064	$7,016	
SUBTOTAL				**$35,080**	
Project Management	8%	of	$35,080	$2,806	
Operation and Maintenance Cost				**$37,887**	

Alternative 3: Enhanced In Situ Bioremediation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Cost per Periodic Review (Year 5)					
5 Year Review	1	LS	$5,000	$5,000	Historical Experience
SUBTOTAL				**$5,000**	
Undefined Scope and Market Allowance	25%	of	$5,000	$1,250	Historical Experience
SUBTOTAL				**$6,250**	
Project Management	8%	of	$6,250	$500	Historical Experience
Operation and Maintenance Cost				**$6,750**	
Cost per Well Abandonment (Year 9)					Monitoring Wells
Mobilization/demobilization of Driller	1	LS	$5,000	$5,000	Option Yr 4 Navy CLEAN BOA Rates
Driller Per diem (2 people)	15	DY	$294	$4,410	2012 DOD Per Diem
Well Abandonment (< 50 ft deep Wells)	800	LF	$8.55	$6,840	Option Yr 4 Navy CLEAN BOA Rates,
Well Abandonment (50-100 ft deep Wells)	450	LF	$10.69	$4,810	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Geologist	150	HR	$80	$12,000	Engineer's estimate
Geologist (per diem)	15	DY	$147	$2,205	2012 DOD Per Diem
Vehicle rental and fuel	15	DY	$125	$1,875	Engineer's estimate
Consumable supplies	15	DY	$50	$750	Engineer's estimate
SUBTOTAL				**$37,890**	
Undefined Scope and Market Allowance	25%	of	$37,890	$9,472	
SUBTOTAL				**$47,362**	
Project Management	8%	of	$47,362	$3,789	
Operation and Maintenance Cost				**$51,151**	

PRESENT VALUE ANALYSIS Discount Rate : 2.0% — 2013 Discount Rates (10-Year) Federal Office of Management and Budget

END YEAR	DESCRIPTION	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE
0	Total Capital Costs	$168,915	$168,915	1	$168,915
1	Total Annual O&M Costs	$211,003	$211,003	0.980	$206,865
2	Total Annual O&M Costs	$91,101	$91,101	0.961	$87,563
3	Total Annual O&M Costs	$91,101	$91,101	0.942	$85,846
4	Total Annual O&M Costs	$91,101	$91,101	0.924	$84,163
5	Total Annual O&M Costs and 5-year review	$97,851	$97,851	0.906	$88,627
6	Total Annual O&M Costs	$68,500	$68,500	0.888	$60,826
7	Total Annual O&M Costs	$68,500	$68,500	0.871	$59,634
8	Total Annual O&M Costs	$40,047	$40,047	0.853	$34,179
9	Total Annual O&M Costs and well abandonment	$91,198	$91,198	0.837	$76,310
	SUBTOTAL				**$952,930**

TOTAL PRESENT VALUE OF ALTERNATIVE 3	**$953,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 3 (+50%)	**$1,430,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 3 (-30%)	**$668,000**

This cost estimate has been prepared in accordance with EPA 540-R-00-002 and represents a -30 to +50 percent range of accuracy. This estimate is limited to the conditions existing at its issuance and is not a guaranty of actual price or cost. Uncertain market conditions such as, but not limited to: local labor or contractor availability, wages, other work, material market fluctuations, price escalations, force majeure events, and developing bidding conditions, may affect the accuracy of this estimate. CH2M HILL is not responsible for any variance from this estimate or actual prices and conditions obtained.

Alternative 4: In Situ Chemical Reduction

Site: Naval Weapons Stations Yorktown
Location: Site 3 - Yorktown, Virginia
Phase: Pre-Draft FS
Base Year: 2013

KEY ASSUMPTIONS

1. Estimated duration of alternative is 11 years. Enforce LUCs and conduct 5-year reviews until RGs are met.
2. Utility clearance would take 1 (10-hr) day each.
3. DPT injection of ISCR reagent using hydraulic fracturing. TTZ-1 includes 105 injection points in the Yorktown-Eastover aquifer sands and 36 injection points in the clay zone. Only one injection will be conducted.
4. An estimated 41,615 lbs of EHC would be injected into TTZ-1.
5. The reagent would be diluted to a 30 percent (by weight) slurry prior to injection for a total of approximately 13,600 gallons. Water associated with injection solution would be obtained from a fire hydrant on base.
6. The injection would be conducted using 1 DPT rig. Injection activities would take 21 (10-hr) days. Field staff would GPS injection locations.
7. Conduct performance and natural attenuation monitoring
- Quarterly groundwater sampling for 1 year (organic and inorganic COCs)
- Semiannual groundwater sampling for 4 years (organic and inorganic COCs)
- Annual groundwater sampling for 4 year (organic COCs)
- Annual groundwater sampling for 6 years (inorganic COCs)
8. Up to 20 monitoring wells would be included in the monitoring network.
9. Sampling event preparation will take 10 hours (Geologist) for laboratory and data validation procurement, equipment ordering, and planning.
10. Except for the last two years of monitoring (inorganics only), each sampling event would include 2 Field Staff and would take 4 (10-hr) days. The last two years of monitoring would take 2 Field Staff 2 (10-hr) days.
11. Quarterly performance monitoring analysis: CVOC, ethene, and ethane at 19 wells; As and Mn at 8 wells; geochemical parameters (chloride, methane, alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron) at 7 wells.
12. MNA analysis (Organics and Inorganics): CVOCs at 19 wells; As and Mn at 8 wells; geochemical parameters (alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron) and and MEE (methane, ethene, ethane) at 10 wells.
13. MNA analysis (Inorganics only): As and Mn at 8 wells
14. Design details are conceptual in nature and presented in this FS to develop costs for alternative comparison.

Alternative 4: In Situ Chemical Reduction

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CAPITAL COSTS					
Land Use Controls					
Signs	4	EACH	$291	$1,164	R.S. Means #10-14-19.10 (2200)
Deed Notifications	1	LS	$11,500	$11,500	Engineer's Estimate
SUBTOTAL				**$12,664**	
Utility Locator					
Private Utility Locator	1	LS	$2,580	$2,580	Vendor's bid 2010
Geologist	10	HR	$80	$800	Navy CLEAN Rate
Geologist (Per Diem)	1	DY	$147	$147	2012 DOD Per Diem
SUBTOTAL				**$3,527**	
ISCR DPT Hydraulic Fracturing Injection					
Mobilization/demobilization of Driller	1	EACH	$2,500	$2,500	Redox Tech. LLC quote (Jan. 2013)
DPT Injection (2-driller crew)	21	Days	$3,400	$71,400	Redox Tech. LLC quote (Jan. 2013)
EHC Reagent	41,615	LBS	$2.40	$99,876	FMC quote (Jan. 2013; May 2013)
Reagent (freight)	1	EACH	$8,400.00	$8,400	FMC quote (Jan. 2013; May 2013)
Engineer/Hydrogeologist (per diem, 2-person crew)	21	DY	$284	$5,964	DOD Travel Per Diem Allowance, FY2011
Engineer/Hydrogeologist	420	HR	$100	$42,000	Navy CLEAN Rate - 2 people, 10-hr days
Vehicle rental and fuel	21	DY	$125	$2,625	Engineer's estimate
Consumable supplies	21	DY	$50	$1,050	Engineer's estimate
Senior Technologist	63	HR	$130	$8,190	Navy CLEAN Rate - 3 hr per inj. day
SUBTOTAL				**$242,005**	
Reporting					
Construction Completion Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$30,000**	
COMBINED SUBTOTAL				**$288,196**	
Undefined Scope and Market Allowance	25%	of	$288,196	$72,049	
SUBTOTAL				**$360,245**	
Project Management	8%	of	$360,245	$28,820	
Remedial Design	15%	of	$360,245	$54,037	
Construction Management	10%	of	$360,245	$36,025	
TOTAL CAPITAL COSTS				**$479,126**	
OPERATION AND MAINTENANCE COSTS					
Cost per Land Use Controls Inspection (Years 1-11)					
Annual Inspection (Engineer)	16	HR	$100	$1,600	Navy CLEAN Rate
SUBTOTAL				**$1,600**	
Undefined Scope and Market Allowance	25%	of	$1,600	$400	
SUBTOTAL				**$2,000**	
Project Management	8%	of	$2,000	$160	
Operation and Maintenance Cost				**$2,160**	
Cost per Monitoring (Year 1)					4 Events/year; See Note 7
Quarterly groundwater monitoring					
Procurement, equipment ordering and planning	40	HR	$80	$3,200	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	320	HR	$80	$25,600	Navy CLEAN Rate
Field Equipment	4	LS	$1,500	$6,000	Engineer's Estimate
Geologists (per diem, 2-person crew)	16	DY	$294	$4,704	2012 DOD Per Diem
Vehicle rental and fuel	16	DY	$125	$2,000	Engineer's estimate
Consumable supplies	16	DY	$50	$800	Engineer's estimate
Analytical	4	LS	$5,633	$22,532	2009 Navy CLEAN BOA Rates
Data Validation	4	LS	$1,022	$4,088	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	40	HR	$120	$4,800	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$103,724**	
Undefined Scope and Market Allowance	25%	of	$103,724	$25,931	
SUBTOTAL				**$129,655**	
Project Management	8%	of	$129,655	$10,372	
Operation and Maintenance Cost				**$140,028**	

Alternative 4: In Situ Chemical Reduction

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Cost per Monitoring (Years 2-5)					2 Events/year; See Note 7
Semi-annual groundwater monitoring					
Procurement, equipment ordering and planning	20	HR	$80	$1,600	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	160	HR	$80	$12,800	Navy CLEAN Rate
Field Equipment	2	LS	$1,500	$3,000	Engineer's Estimate
Geologists (per diem, 2-person crew)	8	DY	$294	$2,352	2012 DOD Per Diem
Vehicle rental and fuel	8	DY	$125	$1,000	Engineer's estimate
Consumable supplies	8	DY	$50	$400	Engineer's estimate
Analytical	2	LS	$5,114	$10,228	2009 Navy CLEAN BOA Rates
Data Validation	2	LS	$1,051	$2,102	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$65,882**	
Undefined Scope and Market Allowance	25%	of	$65,882	$16,471	
SUBTOTAL				**$82,353**	
Project Management	8%	of	$82,353	$6,588	
Operation and Maintenance Cost				**$88,941**	
Cost per Monitoring (Year 6-9)					1 Event/year; See Note 7
Annual groundwater monitoring					
Procurement, equipment ordering and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	80	HR	$80	$6,400	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	4	DY	$294	$1,176	2012 DOD Per Diem
Vehicle rental and fuel	4	DY	$125	$500	Engineer's estimate
Consumable supplies	4	DY	$50	$200	Engineer's estimate
Analytical	1	LS	$5,114	$5,114	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$1,051	$1,051	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$49,141**	
Undefined Scope and Market Allowance	25%	of	$49,141	$12,285	
SUBTOTAL				**$61,426**	
Project Management	8%	of	$61,426	$4,914	
Operation and Maintenance Cost				**$66,340**	
Cost per Monitoring (Year 10-11)					1 Event/year; See Note 7
Annual groundwater monitoring					
Procurement, equipment ordering and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (2 days - 2 Geologists - 10 hrs/day)	40	HR	$80	$3,200	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	2	DY	$294	$588	2012 DOD Per Diem
Vehicle rental and fuel	2	DY	$125	$250	Engineer's estimate
Consumable supplies	2	DY	$50	$100	Engineer's estimate
Analytical	1	LS	$274	$274	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$152	$152	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	10	HR	$120	$1,200	Engineer's Estimate
Annual Report	1	LS	$20,000	$20,000	Engineer's Estimate
SUBTOTAL				**$28,064**	
Undefined Scope and Market Allowance	25%	of	$28,064	$7,016	
SUBTOTAL				**$35,080**	
Project Management	8%	of	$35,080	$2,806	
Operation and Maintenance Cost				**$37,887**	
Cost per Periodic Review (Year 5)					
5 Year Review	1	LS	$5,000	$5,000	Historical Experience
SUBTOTAL				**$5,000**	
Undefined Scope and Market Allowance	25%	of	$5,000	$1,250	Historical Experience
SUBTOTAL				**$6,250**	
Project Management	8%	of	$6,250	$500	Historical Experience
Operation and Maintenance Cost				**$6,750**	
Cost per Well Abandonment (Year 11)					Monitoring Wells
Mobilization/demobilization of Driller	1	LS	$5,000	$5,000	Option Yr 4 Navy CLEAN BOA Rates
Driller Per diem (2 people)	15	DY	$294	$4,410	2012 DOD Per Diem
Well Abandonment (< 50 ft deep Wells)	800	LF	$8.55	$6,840	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Well Abandonment (50-100 ft deep Wells)	450	LF	$10.69	$4,810	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Geologist	150	HR	$80	$12,000	Engineer's estimate
Geologist (per diem)	15	DY	$147	$2,205	2012 DOD Per Diem
Vehicle rental and fuel	15	DY	$125	$1,875	Engineer's estimate
Consumable supplies	15	DY	$50	$750	Engineer's estimate
SUBTOTAL				**$37,890**	
Undefined Scope and Market Allowance	25%	of	$37,890	$9,472	
SUBTOTAL				**$47,362**	
Project Management	8%	of	$47,362	$3,789	
Operation and Maintenance Cost				**$51,151**	

PRESENT VALUE ANALYSIS Discount Rate : 2.0% — 2013 Discount Rates (10-Year) Federal Office of Management and Budget

END YEAR	DESCRIPTION	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE
0	Total Capital Costs	$479,126	$479,126	1	$479,126
1	Total Annual O&M Costs	$142,188	$142,188	0.980	$139,400
2	Total Annual O&M Costs	$91,101	$91,101	0.961	$87,563
3	Total Annual O&M Costs	$91,101	$91,101	0.942	$85,846
4	Total Annual O&M Costs	$91,101	$91,101	0.924	$84,163
5	Total Annual O&M Costs and 5-year review	$97,851	$97,851	0.906	$88,627
6	Total Annual O&M Costs	$68,500	$68,500	0.888	$60,826
7	Total Annual O&M Costs	$68,500	$68,500	0.871	$59,634
8	Total Annual O&M Costs	$68,500	$68,500	0.853	$58,464
9	Total Annual O&M Costs	$68,500	$68,500	0.837	$57,318
10	Total Annual O&M Costs and 5-year review	$46,797	$46,797	0.820	$38,389
11	Total Annual O&M Costs and well abandonment	$91,198	$91,198	0.804	$73,347
	SUBTOTAL				**$1,312,705**

TOTAL PRESENT VALUE OF ALTERNATIVE 4	**$1,313,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 4 (+50%)	**$1,970,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 4 (-30%)	**$920,000**

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Alternative 5: In Situ Chemical Oxidation

Site: Naval Weapons Stations Yorktown
Location: Site 3 - Yorktown, Virginia
Phase: Pre-Draft FS
Base Year: 2013

KEY ASSUMPTIONS

1. Estimated duration of alternative is 11 years. Enforce LUCs and conduct 5-year reviews until RGs are met.
2. Utility clearance would take 1 (10-hr) day each.

3. Oxidant would be injected using DPT. Injection in the clay will require specialized high pressure equipment. TTZ-1 includes 51 injection points in the Yorktown-Eastover aquifer sands and 28 injection points in the clay zone. 14 of the 28 points will be co-located with the injections in the sand while 14 injection points will be in seprate borings. Only one injection will be conducted.
4. An estimated 45,720 lbs lbs or approximately 4,000 gallons of 40 percent by weight sodium permanganate (NaMnO4) solution would be injected in TTZ-1.
5. The solution would be diluted to a 2 percent by weight solution for a total of 107,600 gallons. Water associated with injection solution would be obtained from a fire hydrant on base.
6. The injection would be conducted using 1 DPT rig at an average injection rate of 3 gallons per minute and simultaneous substrate injection into 4 locations. Injection activities would take 19 (10-hr) days, with 8 of the 10 hours for injection. Field staff would GPS injection locations.
7. Conduct performance and natural attenuation monitoring
- Quarterly groundwater sampling for 1 year (organic and inorganic COCs)
- Semiannual groundwater sampling for 4 years (organic and inorganic COCs)
- Annual groundwater sampling for 4 year (organic COCs)
- Annual groundwater sampling for 6 years (inorganic COCs)
8. Up to 20 monitoring wells would be included in the monitoring network.
9. Sampling event preparation will take 10 hours (Geologist) for laboratory and data validation procurement, equipment ordering, and planning.
10. Except for the last two years of monitoring (inorganics only), each sampling event would include 2 Field Staff and would take 4 (10-hr) days. The last two years of monitoring would take 2 Field Staff 2 (10-hr) days.
11. Quarterly performance monitoring analysis: CVOCs and metals (copper, iron, manganese, arsenic, barium, cadmium, chromium, lead, and selenium) at 19 wells; Mn at 8 wells, As at 1 additional well; geochemical parameters (chloride, methane, alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron) at 7 wells.
12. MNA analysis (Organics and Inorganics): CVOCs at 19 wells; As and Mn at 8 wells; geochemical parameters (alkalinity, TOC, nitrate, nitrite, sulfate, sulfide, ferrous iron) and and MEE (methane, ethene, ethane) at 10 wells.
13. MNA analysis (Inorganics only): As and Mn at 8 wells
14. Design details are conceptual in nature and presented in this FS to develop costs for alternative comparison.

Alternative 5: In Situ Chemical Oxidation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
CAPITAL COSTS					
Land Use Controls					
Signs	4	EACH	$291	$1,164	R.S. Means #10-14-19.10 (2200)
Deed Notifications	1	LS	$11,500	$11,500	Engineer's Estimate
SUBTOTAL				**$12,664**	
Utility Locator					
Private Utility Locator	1	LS	$2,580	$2,580	Vendor's bid 2010
Geologist	10	HR	$80	$800	Navy CLEAN Rate
Geologist (Per Diem)	1	DY	$147	$147	2012 DOD Per Diem
SUBTOTAL				**$3,527**	
ISCO DPT Injection					
Mobilization/demobilization of Driller	1	EACH	$2,500	$2,500	Redox Tech. LLC quote (Jan. 2013)
DPT Injection (2-driller crew)	19	Days	$3,400	$64,600	Redox Tech. LLC quote (Jan. 2013)
Sodium Permanganate	45,720	LBS	$2.28	$104,242	Carus (Jan. 2013)
Shipping - Sodium Permanganate	1	LS	$4,072	$4,072	Carus (Jan. 2013)
ISCO Trail -Mounted Injection System	1	LS	$36,000	$36,000	Similar Project Cost Estimate - Kelly AFB (2010)
Equipment Setup (assumes self-performing)	40	HR	$100	$4,000	Engineer's estimate
Engineer/Hydrogeologist (per diem, 2-person crew)	19	DY	$284	$5,396	DOD Travel Per Diem Allowance, FY2011
Engineer/Hydrogeologist	380	HR	$100	$38,000	Navy CLEAN Rate - 2 people, 10-hr days
Vehicle rental and fuel	19	DY	$125	$2,375	Engineer's estimate
Consumable supplies	19	DY	$50	$950	Engineer's estimate
Senior Technologist	48	HR	$130	$6,240	Navy CLEAN Rate - 3 hr per inj. day
SUBTOTAL				**$268,375**	
Reporting					
Construction Completion Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$30,000**	
COMBINED SUBTOTAL				**$298,375**	
Undefined Scope and Market Allowance	25%	of	$298,375	$74,594	
SUBTOTAL				**$372,968**	
Project Management	8%	of	$372,968	$29,837	
Remedial Design	15%	of	$372,968	$55,945	
Construction Management	10%	of	$372,968	$37,297	
TOTAL CAPITAL COSTS				**$496,048**	
OPERATION AND MAINTENANCE COSTS					
Cost per Land Use Controls Inspection (Years 1-11)					
Annual Inspection (Engineer)	16	HR	$100	$1,600	Navy CLEAN Rate
SUBTOTAL				**$1,600**	
Undefined Scope and Market Allowance	25%	of	$1,600	$400	
SUBTOTAL				**$2,000**	
Project Management	8%	of	$2,000	$160	
Operation and Maintenance Cost				**$2,160**	
Cost per Monitoring (Year 1)					4 Events/year; See Note 7
Quarterly groundwater monitoring					
Procurement, equipment ordering and planning	40	HR	$80	$3,200	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	320	HR	$80	$25,600	Navy CLEAN Rate
Field Equipment	4	LS	$1,500	$6,000	Engineer's Estimate
Geologists (per diem, 2-person crew)	16	DY	$294	$4,704	2012 DOD Per Diem
Vehicle rental and fuel	16	DY	$125	$2,000	Engineer's estimate
Consumable supplies	16	DY	$50	$800	Engineer's estimate
Analytical	4	LS	$5,785	$23,140	2009 Navy CLEAN BOA Rates
Data Validation	4	LS	$779	$3,116	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	40	HR	$120	$4,800	Engineer's Estimate
Annual Report	1	LS	$25,000	$25,000	Engineer's Estimate
SUBTOTAL				**$98,360**	
Undefined Scope and Market Allowance	25%	of	$98,360	$24,590	
SUBTOTAL				**$122,950**	
Project Management	8%	of	$122,950	$9,836	
Operation and Maintenance Cost				**$132,786**	

Alternative 5: In Situ Chemical Oxidation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Cost per Monitoring (Years 2-5)					2 Events/year; See Note 7
Semi-annual groundwater monitoring					
Procurement, equipment ordering and planning	20	HR	$80	$1,600	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	160	HR	$80	$12,800	Navy CLEAN Rate
Field Equipment	2	LS	$1,500	$3,000	Engineer's Estimate
Geologists (per diem, 2-person crew)	8	DY	$294	$2,352	2012 DOD Per Diem
Vehicle rental and fuel	8	DY	$125	$1,000	Engineer's estimate
Consumable supplies	8	DY	$50	$400	Engineer's estimate
Analytical	2	LS	$5,114	$10,228	2009 Navy CLEAN BOA Rates
Data Validation	2	LS	$1,051	$2,102	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$65,882**	
Undefined Scope and Market Allowance	25%	of	$65,882	$16,471	
SUBTOTAL				**$82,353**	
Project Management	8%	of	$82,353	$6,588	
Operation and Maintenance Cost				**$88,941**	
Cost per Monitoring (Year 6-9)					1 Event/year; See Note 7
Annual groundwater monitoring					
Procurement, equipment ordering and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (4 days - 2 Geologists - 10 hrs/day)	80	HR	$80	$6,400	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	4	DY	$294	$1,176	2012 DOD Per Diem
Vehicle rental and fuel	4	DY	$125	$500	Engineer's estimate
Consumable supplies	4	DY	$50	$200	Engineer's estimate
Analytical	1	LS	$5,114	$5,114	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$1,051	$1,051	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	20	HR	$120	$2,400	Engineer's Estimate
Annual Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$49,141**	
Undefined Scope and Market Allowance	25%	of	$49,141	$12,285	
SUBTOTAL				**$61,426**	
Project Management	8%	of	$61,426	$4,914	
Operation and Maintenance Cost				**$66,340**	
Cost per Monitoring (Year 10-11)					1 Event/year; See Note 7
Annual groundwater monitoring					
Procurement, equipment ordering and planning	10	HR	$80	$800	Navy CLEAN Rate
Field Work (2 days - 2 Geologists - 10 hrs/day)	40	HR	$80	$3,200	Navy CLEAN Rate
Field Equipment	1	LS	$1,500	$1,500	Engineer's Estimate
Geologists (per diem, 2-person crew)	2	DY	$294	$588	2012 DOD Per Diem
Geologists (per diem, 2-person crew)	2	DY	$294	$588	2012 DOD Per Diem
Vehicle rental and fuel	2	DY	$125	$250	Engineer's estimate
Analytical	1	LS	$274	$274	2009 Navy CLEAN BOA Rates
Data Validation	1	LS	$152	$152	2010 Navy CLEAN BOA Rates
Data Analysis/Interpretation	10	HR	$120	$1,200	Engineer's Estimate
Annual Report	1	LS	$20,000	$20,000	Engineer's Estimate
SUBTOTAL				**$28,552**	
Undefined Scope and Market Allowance	25%	of	$28,552	$7,138	
SUBTOTAL				**$35,690**	
Project Management	8%	of	$35,690	$2,855	
Operation and Maintenance Cost				**$38,545**	
Cost per Periodic Review (Year 5)					
5 Year Review	1	LS	$5,000	$5,000	Historical Experience
SUBTOTAL				**$5,000**	
Undefined Scope and Market Allowance	25%	of	$5,000	$1,250	Historical Experience
SUBTOTAL				**$6,250**	
Project Management	8%	of	$6,250	$500	Historical Experience
Operation and Maintenance Cost				**$6,750**	
Cost per Well Abandonment (Year 11)					Monitoring Wells
Mobilization/demobilization of Driller	1	LS	$5,000	$5,000	Option Yr 4 Navy CLEAN BOA Rates
Driller Per diem (2 people)	15	DY	$294	$4,410	2012 DOD Per Diem
Well Abandonment (< 50 ft deep Wells)	800	LF	$8.55	$6,840	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Well Abandonment (50-100 ft deep Wells)	450	LF	$10.69	$4,810	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Geologist	150	HR	$80	$12,000	Engineer's estimate
Geologist (per diem)	15	DY	$147	$2,205	2012 DOD Per Diem
Vehicle rental and fuel	15	DY	$125	$1,875	Engineer's estimate
Consumable supplies	15	DY	$50	$750	Engineer's estimate
SUBTOTAL				**$37,890**	
Undefined Scope and Market Allowance	25%	of	$37,890	$9,472	
SUBTOTAL				**$47,362**	
Project Management	8%	of	$47,362	$3,789	
Operation and Maintenance Cost				**$51,151**	

PRESENT VALUE ANALYSIS — Discount Rate : 2.0% — 2013 Discount Rates (10-Year) Federal Office of Management and Budget

END YEAR	DESCRIPTION	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR	PRESENT VALUE
0	Total Capital Costs	$496,048	$496,048	1	$496,048
1	Total Annual O&M Costs	$134,946	$134,946	0.980	$132,300
2	Total Annual O&M Costs	$91,101	$91,101	0.961	$87,563
3	Total Annual O&M Costs	$91,101	$91,101	0.942	$85,846
4	Total Annual O&M Costs	$91,101	$91,101	0.924	$84,163
5	Total Annual O&M Costs and 5-year review	$97,851	$97,851	0.906	$88,627
6	Total Annual O&M Costs	$68,500	$68,500	0.888	$60,826
7	Total Annual O&M Costs	$68,500	$68,500	0.871	$59,634
8	Total Annual O&M Costs	$68,500	$68,500	0.853	$58,464
9	Total Annual O&M Costs	$68,500	$68,500	0.837	$57,318
10	Total Annual O&M Costs and 5-year review	$47,455	$47,455	0.820	$38,930
11	Total Annual O&M Costs and well abandonment	$91,857	$91,857	0.804	$73,877
	SUBTOTAL				**$1,323,597**

TOTAL PRESENT VALUE OF ALTERNATIVE 5	**$1,324,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 5 (+50%)	**$1,986,000**
TOTAL PRESENT VALUE OF ALTERNATIVE 5 (-30%)	**$927,000**

This cost estimate has been prepared in accordance with EPA 540-R-00-002 and represents a -30 to +50 percent range of accuracy. This estimate is limited to the conditions existing at its issuance and is not a guaranty of actual price or cost. Uncertain market conditions such as, but not limited to: local labor or contractor availability, wages, other work, material market fluctuations, price escalations, force majeure events, and developing bidding conditions, may affect the accuracy of this estimate. CH2M HILL is not responsible for any variance from this estimate or actual prices and conditions obtained.

Contingency Soil Excavation

Site: Naval Weapons Stations Yorktown
Location: Site 3 - Yorktown, Virginia
Phase: Pre-Draft FS
Base Year: 2013

KEY ASSUMPTIONS

1. Excavation and offsite disposal of subsurface soil would be conducted within a 50-foot by 50-foot area (2,500 ft2) around MIP-5 to a depth of 20 ft bgs
2. No dewatering would be conducted. Sloping would be used to achieve a safe excavation.
3. The 50,000 ft3 of soil excavated from the 15 to 20-feet bgs interval would be disposed off site as non-hazardous waste.
4. Assume vegetation clearing require (1 ac), clearing waste/debris remains on-site (no-chipping, burning, etc)
5. No access road to excavation area is needed; the area is adjacent to a dirt road.
9. Monitoring well YS03-GW022 would need to be abandoned prior to excavation.

Contingency Soil Excavation

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Well Abandonment					Monitoring Wells
Mobilization/demobilization of Driller	1	LS	$5,000	$5,000	Option Yr 4 Navy CLEAN BOA Rates
Driller Per diem (2 people)	1	DY	$294	$294	2012 DOD Per Diem
Well Abandonment (< 50 ft deep Wells)	40	LF	$8.55	$342	Option Yr 4 Navy CLEAN BOA Rates, assuming casing remains in place
Geologist	10	HR	$80	$800	Engineer's estimate
Geologist (per diem)	1	DY	$147	$147	2012 DOD Per Diem
Vehicle rental and fuel	1	DY	$125	$125	Engineer's estimate
Consumable supplies	1	DY	$50	$50	Engineer's estimate
SUBTOTAL				**$6,758**	
Soil Removal Contractor Services					
Submittals (Work Plan, HASP, QCP) (Subcontractor)	1	LS	$ 5,000.00	$ 5,000	Historical Experience
Utility Locating Services	1	LS	$2,580	$2,580	Vendor's bid 2010
Mobilization and Site Setup (includes decon/laydown area)	1	EA	$ 9,370.00	$ 9,370	RSMeans Crew #B-1, Crew #B-10T, and Crew #B-12B
Pre-Survey of project site	1	Day	$ 1,850.00	$ 1,850	RSMeans #01-71-23.13 (1200)
Site Preparation - Install Erosion Control measures	400	LF	$ 4.25	$ 1,700	Quote from Sub on project similar in nature on site)
Site Preparation - Clear Vegetation	1	Acre	$ 4,550.00	$ 4,550	
Soil Excavation (assume excavation of soil - 2,500 sf x 20 ft. depth / 27 = 1,852 cy) (Assumes no structures in area = no shoring required)	1,852	CY	$ 20.18	$ 37,370	RSMeans Crew #B-1, Crew #B-10T, and Crew #B-12B (Note: Excavation assumes 75% of material will be stockpiled as "clean" for reuse)
Additional Soil Excavation for benching down to reach 20 foot depth contaminated soil. (Assumes no structures in area = no shoring required).	1,481	CY	$ 20.18	$ 29,896	RSMeans Crew #B-1, Crew #B-10T, and Crew #B-12B (Note: Assumes Add'l Excavation for benching to 10 ft. depth for material removal)
Backfill of Excavation Areas - Using existing stockpile material (from excavation of soil from "benching down"	1,481	CY	$ 6.32	$ 9,370	RSMeans Crew #B-1, Crew #B-10T, and Crew #B-12B
Backfill of Excavation Areas - Imported Fill material	2,410	LCY	$ 24.72	$ 59,575	Crew #B-12B (est. 1,852 cy x 100% = 1,852 cy x 1.3 for compaction); assumes 1 week
Transportation and Disposal of Soil to an off-site landfill (assumes 100% Non-hazardous soil disposal) (Assumes 1.5 tons per cubic yard)	2,778	Ton	$ 75.00	$ 208,350	Recent Quote from Disposal facility (est. 1852 cy x 100% = 1,852 cy x 1.5 tons/cy)
Site Restoration - Hydroseeding	1.15	Acre	$ 2,831.40	$ 3,256	RSMeans #32-92-19.14 (2700)
Post-Survey of project site	1	Day	$ 1,850.00	$ 1,850	RSMeans #01-71-23.13 (1200)
Site Cleanup & Demobilization	1	LS	$ 9,370.00	$ 9,370	RSMeans Crew #B-1, Crew #B-10T, and Crew #B-12B
SUBTOTAL CONTRACTOR SERVICES				**$ 384,088**	
Analytical Services					
Disposal Characterization (Full suite TCLP and RCI)	3	Each	$ 662.00	$ 1,986	CLEAN average BOA rates; assume 1 sample/1000 tons
SUBTOTAL ANALYTICAL SERVICES				**$ 1,986**	
Reporting					
Construction Completion Report	1	LS	$30,000	$30,000	Engineer's Estimate
SUBTOTAL				**$30,000**	
COMBINED SUBTOTAL				**$422,832**	
Undefined Scope and Market Allowance	25%	of	$422,832	$105,708	
SUBTOTAL				**$528,540**	
Project Management	8%	of	$528,540	$42,283	
Construction Management	10%	of	$528,540	$52,854	
TOTAL CAPITAL COSTS				**$623,677**	

TOTAL PRESENT VALUE OF Pre-design Investigation	**$624,000**
TOTAL PRESENT VALUE OF Pre-design Investigation (+50%)	**$936,000**
TOTAL PRESENT VALUE OF Pre-design Investigation (-30%)	**$437,000**

Appendix D
Remediation Timeframe Calculations

Remediation Timeframe Calculations
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

1. Obtain TCE, cis-1,2-DCE, and vinyl chloride decay rates from literature

a. Source is:
Suarez, M.P. and Rifai, H.S. 1999 "Biodegradation Rates for Fuel Hydrocarbons and Chlorinated Solvents in Groundwater". Bioremediation Journal 3(4), 337-362.

b.

k(TCE) =	1.1	/year	0.003013699
k(cis-1,2DCE) =	1.5	/year	0.004109589
k(vinyl chloride) =	0.37	/year	0.001013699

2. Estimate time to reach PRGs under MNA

t = LN(C/Co)/(k)
where C = PRG
Co = Maximum Concentration

COC	PRG	Maximum Concentration	Sample Location	Timeframe (years)
TCE	5	400 =	YS03-GW024	4.0
cis-1,2-DCE	70	1400 =	YS03-GW024	2.0
vinyl chloride	2	1200 =	YS03-GW024	17

3. Estimate time to reach PRGs for the entire plume with EISB in TTZ-1 and TTZ-2 and MNA in remainder of dissolved plume

a. Assume 60 percent reduction in MNA-only remediation timeframe.
b. 17 years * 0.4 = 7 years

4. Estimate time to reach PRGs for the entire plume with ISCR in TTZ-1 and MNA in TTZ-2 and remainder of dissolved plume

a. Assume 45 percent reduction in MNA-only remediation timeframe.
b. 17 years * 0.55 = 9 years

5. Estimate time to reach PRGs for the entire plume with ISCO in TTZ-1 and MNA in TTZ-2 and remainder of dissolved plume

a. Assume 50 percent reduction in MNA-only remediation timeframe. (ISCO reactions considered faster than ISCR reactions)
b. 17 years * 0.55 = 9 years

Note: These remediation timeframes are estimates in support of the FS detailed cost analysis. Actual timeframes will vary and may be longer if the assumed decay rates are not achieved or reagents do not perform as designed with the contaminants and groundwater geochemistry.

Appendix E
Sustainability Evaluation

APPENDIX E

Sustainability Evaluation

Introduction

This appendix presents the approach taken and results obtained from a sustainability analysis that CH2M HILL performed for groundwater remedial alternatives at Site 3, Naval Weapons Station Yorktown, in Yorktown, Virginia. Five alternatives are provided for the treatment of groundwater at Site 3. A detailed summary of the remedial alternatives is provided in Section 4 of the Site 3 Feasibility Study (FS).

A sustainability analysis was performed by CH2M HILL using SiteWise Version 2.0 (Battelle, 2011) for the following remedial alternatives:

<u>Groundwater Alternatives</u>

1. No Action
2. Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs)
3. Enhanced *In Situ* Bioremediation (EISB) and Performance Monitoring with MNA and LUCs
4. *In Situ* Chemical Reduction (ISCR) and Performance Monitoring with MNA and LUCs
5. *In Situ* Chemical Oxidation (ISCO) and Performance Monitoring with MNA and LUCs

Method and Assumptions

The SiteWise tool consists of a series of Excel-based spreadsheets used to conduct a baseline assessment of sustainability metrics. The assessment is carried out using a spreadsheet-based building block approach, where every remedial alternative is first broken down into modules that mirror the phases of remedial action work, specifically: Remedial Investigation (RI), Remedial Action Construction (RAC), Remedial Action Operation (RAO), and Long-term Monitoring (LTM).

SiteWise uses various emission factors from governmental or non-governmental research sources to determine the environmental impact of each activity. The quantitative metrics calculated by the tool include:

1) Greenhouse gases (GHGs) reported as metric tons of carbon dioxide equivalents (CO_2e), consisting of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
2) Energy usage (expressed as million British Thermal Units [MMBTU])
3) Water usage (gallons of water)
4) Air emissions of criteria pollutants consisting of metric tons of nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter less than 10 micrometers in aerodynamic diameter (PM_{10})
5) Accident risk (risk of injury and risk of fatality)

For the purpose of this discussion the term “footprint” represents the compilation of the metrics estimated by SiteWise. To estimate the sustainability footprint for each remedial alternative, only those elements of the RI, RAC, RAO, and LTM possessing important sustainability elements were included in the assessment. The footprint of each remedial phase is combined into overall footprints for each remedial action.

A lower environmental footprint indicates lower potential deleterious impacts to environmental and social metrics, which collectively make up the SiteWise sustainability metrics. Conversely, a higher environmental footprint indicates higher potential deleterious impacts associated with the SiteWise metrics. It is important to note that a lower footprint does not necessarily indicate a more preferable alternative. The results of the sustainability analysis have to be considered in the context of the end-points of the alternative evaluated. For example, an active treatment alternative may have a higher sustainability footprint but it may also provide more protection of human health and the environment. The result of this sustainability assessment is only one decision criterion among the many that are typical considered in alternative analysis evaluation and selection.

The major conclusions of this sustainability analysis are incorporated into the short-term effectiveness criteria evaluation of the FS report.

Detailed assumptions for the groundwater alternatives are provided in **Table E-1** through **E-4**. The following is a description of the major activities for each alternative covered under the respective remedial action phase.

- RI: No actions for any alternative
- RAC: Transportation of personnel and labor hours
  - All alternatives involve surveying for LUCs.

    Note, since all the active remedial options involve injection using a direct-push drill rig, there is no infrastructure associated with the alternatives (that is, permanent injection wells). Therefore, all remedial activities are encompassed in the RAO phase.
- RAO: Treatment chemical and material use, transportation of personnel, transportation of equipment, labor hours, and water consumption
  - Alternative 3 involves injection of 12,000 pounds of WilCLear Plus, a 35 percent lactate amendment (vegetable oil was used as a proxy in SiteWise), delivered via 80 direct-push technology (DPT) injections; approximately 10,400 gallons of dilution water will be required. A second injection event will include injection of 9,600 pounds of WilClear Plus; approximately 8,300 gallons of dilution water will also be required. It is assumed that one DPT rig will be onsite performing the work, operating 8 hours per day.
  - Alternative 4 involves injection of 35,200 pounds of 40 percent mixture of zero valent iron (ZVI) and carbon substrate (plant fiber), delivered via 100 DPT injections. 9,800 gallons of water will be required for dilution. It is assumed that one DPT rig will be onsite performing the work, operating 8 hours per day.
  - Alternative 5 involves injection of 38,570 pounds of 40 percent sodium permanganate, with 91,000 gallons of dilution water, delivered via 57 DPT injections. It is assumed that one DPT rig will be onsite performing the work, operating 8 hours per day.
- LTM: Includes personnel transport and investigation-derived waste (IDW) handling for all groundwater sampling events
  - Alternative 2 includes quarterly sampling of 19 wells for 1 year, semiannual sampling of 19 wells for 4 years, annual sampling of 19 wells for 2 years, and annual sampling of eight wells for 2 additional years (16 events).
  - Alternatives 3, 4, and 5 all include quarterly sampling of 19 wells for 1 year, semiannual sampling of 19 wells for 4 years, annual sampling of 19 wells for 2 years, and annual sampling of nine wells for 2 additional years (18 events).

General Assumptions

The following overall assumptions are used for the SiteWise tool evaluation:

- Distance to IDW landfill: Assume waste is non-hazardous and landfill is located 45 miles away from the site. A specific landfill has not been chosen for the project.
- All oversight workers and LTM samplers will be traveling from Virginia Beach, Virginia, which is approximately 110 miles roundtrip to the site.
- The complete environmental footprint for production of equipment used, or production of the vehicles used for transportation, is not considered in this analysis.

- For materials being shipped onsite, the transportation of these materials was captured using the EQUIPMENT TRANSPORTATION sections.
- Road transportation was assumed for all equipment and materials shipment. Capacity for equipment and materials was assumed to be no greater than 30 tons.
- Water is available near the site, so impacts from water transportation are considered minimal compared with the overall footprints for EISB, ISCR, and ISCO.
- The following average distances traveled were used unless specific distances were known:
  - Oversight and Monitoring Support – 110 miles roundtrip
  - Utility Location – 110 miles roundtrip
  - Surveying – 25 miles roundtrip
  - Drilling Transportation and Injection Support – 440 miles roundtrip

Results and Conclusions

Comparative Analysis of Results

The overall quantitative footprints for each alternative were developed along with the relative impact of each alternative in each footprint (**Figure E-1** and **Table E-6**). The relative impact is a qualitative assessment of the relative footprint of each alternative, and a rating of high, medium, or low was assigned to each alternative based on its performance against the other alternatives. The tool assigns a ranking of high to the highest footprint in each category and assigns the rankings of other alternatives based on the difference in the data between alternatives. The ranking is based on a 30 percent difference - if the footprints of two alternatives are within 30 percent of each other they will be given the same rating and there is, in effect, no difference between the alternatives. This allows for uncertainty inherent in the assumptions used in the model.

Alternative 1 has no sustainability impacts because no action occurs; however, because this alternative does not meet removal goals, it is not considered viable. Alternative 2 has the lowest footprints in all categories because it involves the least material usage and transportation. Alternatives 3, 4, and 5 have high GHG and total energy footprints. The GHG and energy footprints for Alternative 5 are primarily from the production of injection chemicals, and GHG and total energy footprints of Alternatives 3 and 4 are attributable to injection material production and transportation. Alternative 5 has the highest water-use footprint for injections compared to the other alternatives. Alternatives 4 and 5 both have high criteria air pollutant footprints (NO_X, SO_X, and PM_{10}) from equipment use and transportation of materials to the site. Alternative 3 has medium criteria air pollutant footprints because there is significantly less injection time and equipment use estimated. The accident risk footprints for Alternatives 3, 4, and 5 are all considered high from a mixture of transportation and onsite labor hours.

Individual Results

Tables E-6 through **E-9** present the detailed quantitative environmental footprint metrics of each main activity (excluding No Action) for the groundwater remedial alternatives. **Figures E-2** through **E-5** graphically present these results. The environmental footprint for each alternative is discussed as follows.

- *Alternative 1— No Action*

Alternative 1 has no sustainability impacts because no action occurs.

- *Alternative 2— MNA with LUCs*

Residual handling (transportation of IDW to landfill) and the transportation of personnel and equipment account for the majority of the GHG, total energy, and of NO_X, SO_X, and PM_{10} footprints for this alternative. Onsite labor hours account for the majority of the accident and fatality risks. MNA and LUCs has the lowest relative impact compared with the other alternatives. Results are provided in **Table E-6** and on **Figure E-2**.

- *Alternative 3—EISB and Performance Monitoring with MNA and LUCs*

The injections accounted for the majority of the GHG, total energy, water consumption, and NO_X, SO_X, and PM_{10} footprints. Substrate manufacturing accounted for the majority of the GHG and total energy footprints. Drilling and injection activities were the primary contributors to water consumption and NO_X, SO_X, and PM_{10} footprints. Onsite labor hours during the LTM phase account for the majority of the accident and fatality risk footprints. Results are provided in **Table E-7** and on **Figure E-3**.

- *Alternative 4— ISCR and Performance Monitoring with MNA and LUCs*

The injections accounted for the majority of the GHG, total energy, water consumption, and NO_X, SO_X, and PM_{10} footprints. ZVI manufacturing and transportation of materials and equipment to the site contributed to the majority of the GHG and total energy footprints, while drilling and injection operations were the primary contributors to water consumption and the NO_X, SO_X, and PM_{10} footprints. Onsite labor hours during the LTM phase account for the majority of the accident and fatality risks. ISCR with MNA and LUCs had the highest relative NO_X, SO_X, and PM_{10} footprints and fatality and accident risks. Results are provided in **Table E-8** and on **Figure E-4**.

- *Alternative 5— ISCO and Performance Monitoring with MNA and LUCs*

The injections accounted for the majority of the GHG, total energy, water consumption, and NO_X, SO_X, and PM_{10} footprints. Permanganate manufacturing and transportation of materials and equipment to the site contributed to the majority of the GHG and total energy footprints, while drilling and injection operations were the primary contributors to water consumption and the NO_X, SO_X, and PM_{10} footprints. Onsite labor hours during the LTM phase account for the majority of the accident and fatality risks. ISCO with MNA and LUCs had the highest relative water use, GHG, and total energy footprints. Results are provided in **Table E-9** and on **Figure E-5**.

Uncertainty Assessment

The SiteWise tool does not include an option for the WilCLear Plus to be used in the EISB injections. WilCLear Plus is a proprietary substrate composed sodium lactate, sodium propionate, sodium acetate, sodium butyrate, and carbohydrates. It was assumed that the WilCLear Plus impacts could be considered equivalent to 35 percent by weight pure vegetable oil. The SiteWise footprint for vegetable oil is generally lower than other referenced sources (generally by a factor of 5 to 10). Most emulsified vegetable oil (EVO) used is typically soybean oil, which has a footprint of 1.98 kilograms CO_2e per kilogram oil (compared to 0.33 kilogram CO_2e in SiteWise).

Also, it is important to note that SiteWise does not track impacts for NO_X, SO_X, and PM_{10} for materials (such as polyvinyl chloride [PVC], chemicals, and oil) so these metric results are biased low.

The SiteWise tool does not include an option for the injection of sodium permanganate. It was assumed another ISCO injectant (hydrogen peroxide) was the closest to the sodium permanganate in composition and therefore used in this analysis.

The iron that is used in the ZVI is a scrap material but it is processed to a granular form that requires energy and emits pollutants. The SiteWise tool may under estimate this impact. The SiteWise tool does not include impact values for the complex carbon plant fibers that encompass 60 percent of the ISCR material.

Recommendations

It is important to note that the lowest alternative footprint does not necessarily mean the alternative is preferable to other alternatives. Therefore, a comparison of the results of the alternatives needs to be made in the context of the benefits (such as applicable or relevant and appropriate requirement [ARAR] compliance, contaminant reduction, cost effectiveness, and other such considerations) of each of the alternatives.

The estimates from the SiteWise tool were used to estimate the environmental footprint of the alternatives. Once the alternative is selected, it is recommended that the footprint of the selected alternative be further evaluated in the design phase of the projects to explore opportunities to optimize the environmental footprint of the project and integrate sustainable remediation best practices in the design, construction, and operation of the alternative.

References

Battelle. 2011.*SiteWise™ Version 2 User Guide.* UG-2092-ENV. June.

Table E-1
Alternative 2 – Monitored Natural Attenuation and Land Use Controls Assumptions
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

Sitewise Tab	**Assumptions**
Remedial Investigation	**No Actions**
Remedial Action Construction	**LUCs Survey**
Personnel Transportation - Road	Oversight - 1 vehicle, 1 person, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 1 trip)
	Surveying - 2 people, 25 miles R/T (1 trip)
Labor Hours	30 hours (10 hours/day/person for 1 day)
Remedial Action Operations	**No Actions**
Longterm Monitoring	**Semiannual sampling of 19 wells for 5 years, annual sampling of 19 wells for 12 years, and annual sampling of 8 wells for 2 additional years (20 events total) and annual inspection**
Labor Hours	1,600 hours (2 people, 4 days, 10 hours per day for 20 events)
Well Abandonment	1,250 linear feet, abandoned with typical cement
Transportation	
Personnel Transportation - Road	Assume 1 vehicle, 2 people, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 20 trips)
Residual Handling	
Residual Disposal/Recycling	Assume low-flow sampling, 4 drums per event (approx 450 lbs per drum = 1800 lbs, 0.9 tons) per event, transported to landfill located 45 miles away (one way), 20 trips
Empty	45 miles away (one way), 20 trips

Notes:
R/T = round trip

Table E-2
Alternative 3 – Enhanced *In Situ* Bioremediation and Performance Monitoring with Monitored Natural Attenuation and Land Use Controls Assumptions
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

SITEWISE TAB	**Assumptions**
Remedial Investigation	No Actions
Remedial Action Construction	**LUCs Survey**
Personnel Transportation - Road	Oversight - 1 vehicle, 1 person, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 1 trip) Surveying - 2 people, 25 miles R/T (1 trip)
Labor Hours	30 hours (10 hours/day/person for 1 day)
Remedial Action Operations	**Injection activities**
Material Production	
Treatment Chemicals and Materials	proxy "Vegetable Oil" for WilClear Plus assuming 35% "vegetable oil" by weight (22,200 lbs of assumed 35% vegetable oil =7,770 lb dry weight of vegetable oil) *Assume that bioaugmentation culture has negligible impacts compared with EVO production
Transportation	
Personnel Transportation - Road	
Injection oversight	2 person from Virginia Beach, light duty truck, gas powered, 110 miles R/T, 2 trips
Utility Locate	1 person from Virginia Beach, light duty truck, gas powered, 110 miles R/T, 2 trips
Survey	Assume local travel approx 25 miles R/T, 2 people, light duty truck, gas powered
Drilling/Injection Support Crew	2 person crew, heavy duty truck, diesel powered, 440 miles R/T (2 trip)
Equipment Transportation - Road	
EISB Substrate	12,000 lbs (6 tons) for trip one, 10,200 lbs (5.1 tons) for trip 2. transported from Kansas City. (1200 miles one way), 2,400 miles empty
Drill Rig Transport	Assume Geoprobe 6610DT or equivalent (5000 lb - 2.5 tons) 1 rigs transported using heavy duty diesel truck, tooling adds 1 ton. 440 mile R/T, load is 3.5 tons, 2 trips
Injection Equipment Transport	Assume tanks, pumps, and associated injection equipment weigh a total of 15 tons (440 miles R/T) 2 trips
Empty Trips	2,400 miles (2 Lactate return trips, negligible weight)
Equipment Use	
Drilling/Injection	Assume 1 DPT rig, operating for 7 total days (4 days event 1, 3 days event 2) = 7 days x 8 hr/day = 56 hrs, assume rig powers pumps for injections
Residual Handling	
Residual Disposal/Recycling	assume waste is negligible for DPT injections (solid cores)
Labor Hours	320 hours (injections = 4 people for 7 days, 10 hrs/day; survey = 2 people for 1 day, 10 hrs/day; utility locate= 1 person for 2 days, 10 hrs/day)
Other Known Onsite Activities	Water Use = 20,350 gallons
Longterm Monitoring	**Quarterly sampling of 19 wells for 1 year, semiannual sampling of 19 wells for 4 years, annual sampling of 19 wells for 2 years, and annual sampling of 9 wells for two additional years(16 events)**
Labor Hours	1,200 hours (2 people, 4 days, 10 hours per day for 16 events)
Well Abandonment	1,250 linear feet, abandoned with typical cement
Transportation	
Personnel Transportation - Road	
LTM Sampling	Assume 1 vehicle, 2 people, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 16 trips)
Residual Handling	
Residual Disposal/Recycling	Assume low-flow sampling, 4 drums per event (approx 450 lbs per drum = 1800 lbs, 0.9 tons) per event, transported to landfill located 45 miles away (one way), 16 trips
Empty	16 trips, 45 miles

Notes:
DPT = direct push technology
R/T = round trip
EVO = emulsified vegetable oil
hrs = hours

Table E-3
Alternative 4 – *In Situ* Chemical Reduction and Performance Monitoring with Monitored Natural Attenuation and Land Use Controls Assumptions
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

SITEWISE TAB	Assumptions
Remedial Investigation	No Actions
Remedial Action Construction	**LUCs Survey**
Personnel Transportation - Road	Oversight - 1 vehicle, 1 person, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 1 trip)
	Surveying - 2 people, 25 miles R/T (1 trip)
Labor Hours	30 hours (10 hours/day/person for 1 day)
Remedial Action Operations	**ISCO Injections through DPT**
Material Production	
Treatment Chemicals and Materials	42,615 lb 40% solution ZVI and carbon substrate mix (17,046 lbs dry weight ZVI)
Transportation	
Personnel Transportation - Road	
Injection oversight	2 people from Virginia Beach, light duty truck, gas powered, 110 miles R/T, 1 trip
Utility Locate	1 person from Virginia Beach, light duty truck, gas powered, 110 miles R/T, 1 trip
Survey	Assume local travel approx 25 miles R/T, 2 people, light duty truck, gas powered
Drilling/Injection Support Crew	2 person crew regionally located, heavy duty truck, diesel powered, 440 miles R/T 1 trip
Equipment Transportation - Road	
Drill Rig Transport	Assume Geoprobe 6610DT or equivalent (5000 lb - 2.5 tons) 1 rigs transported using heavy duty diesel truck, tooling adds 1 ton. 440 mile R/T, load is 3.5 tons, 1 trips
ISCR Chemical	42,615 lbs (21.3 tons) transported from Des Moines, IA (1,200 miles one way)
Injection Equipment Transport	Assume regionally located injection support: tanks, pumps, and associated injection equipment weigh a total of 15 tons transported (440 miles R/T) 1 trips
Empty	1200 miles (ZVI return trip , negligible weight)
Equipment Use	
Drilling/Injection	Assume 1 DPT rigs, operating for 21 days = 21 days x 8 hr/day = 168 hrs , assume rig powers pumps for injections
Other Known Onsite Activities	Water use for injections: 11,644 gallons
Labor Hours	870 hours (injections = 4 people for 21 days, 10 hrs/day; survey = 2 people for 1 day, 10 hrs/day; utility locate= 1 person for 1 day, 10 hrs/day)
Residual Handling	
Residual Disposal/Recycling	assume waste is negligible for DPT injections (solid cores)
Longterm Monitoring	**Quarterly ground water sampling of 19 wells for 1 year, semiannual sampling of 19 wells for 4 years, annual sampling of 19 wells for 4 years, and annual sampling of 8 wells for two additional years. (18 events)**
Labor Hours	1,440 hours (2 people, 4 days, 10 hours per day for 18 events)
Well Abandonment	1,250 linear feet, abandoned with typical cement
Transportation	
Personnel Transportation - Road	
LTM Sampling	Assume 1 vehicle, 2 people, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 18 trips)
Residual Handling	
Residual Disposal/Recycling	Assume low-flow sampling, 4 drums per event (approx 450 lbs per drum = 1800 lbs, 0.9 tons) per event, transported to landfill located 45 miles away (one way), 18 trips
Empty	18 trips, 45 miles

Notes:
DPT = direct push technology
R/T = round trip
hrs = hours

Table E-4

Alternative 5 – *In Situ* Chemical Oxidation and Performance Monitoring with Monitored Natural Attenuation and Land Use Controls Assumptions

Feasibility Study Report for Groundwater at Site 3

Naval Weapons Station Yorktown

Yorktown, Virginia

SITEWISE TAB	**Assumptions**
Remedial Investigation	No Actions
Remedial Action Construction	**LUCs Survey**
Personnel Transportation - Road	Oversight - 1 vehicle, 1 person, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 1 trip)
	Surveying - 2 people, 25 miles R/T (1 trip)
Labor Hours	30 hours (10 hours/day/person for 1 day)
Remedial Action Operations	**ISCO Injections through DPT**
Material Production	
Treatment Chemicals and Materials	Proxy Hydrogen Peroxide for Permanganate as injection chemical, 45,720 lb 40% solution (18,288 lbs dry weight)
Transportation	
Personnel Transportation - Road	
Injection oversight	2 people from Virginia Beach, light duty truck, gas powered, 110 miles R/T, 1 trip
Utility Locate	1 person from Virginia Beach, light duty truck, gas powered, 110 miles R/T, 1 trip
Survey	Assume local travel approx 25 miles R/T, 2 people, light duty truck, gas powered
Drilling/Injection Support Truck	Assume regionally located (440 mile R/T), Diesel, heavy duty truck, 2 people, 1 trip
Equipment Transportation - Road	
Drill Rig Transport	Assume Geoprobe 6610DT or equivalent (5000 lb - 2.5 tons) 1 rigs transported using heavy duty diesel truck, tooling adds 1 ton. 440 mile R/T, load is 3.5 tons, 1 trips
ISCO Chemical	45,720 lbs (22.9 tons) transported from LaSalle, IL (925 miles one way)
Injection Equipment Transport	Assume regionally located injection support: tanks, pumps, and associated injection equipment weigh a total of 15 tons transported (440 miles R/T) 1 trips
Empty	925 miles
Equipment Use	
Drilling/Injection	Assume 1 DPT rigs, operating for 19 days = 16 days x 8 hr/day = 152 hrs , assume rig powers pumps for injections
Labor Hours	790 hours (injections = 4 people for 19 days, 10 hrs/day; survey = 2 people for 1 day, 10 hrs/day; utility locate= 1 person for 1 day, 10 hrs/day)
Other Known Onsite Activities	Water use for injections: 103,600 gallons
Residual Handling	
Residual Disposal/Recycling	assume waste is negligible for DPT injections (solid cores)
Longterm Monitoring	**Quarterly ground water sampling of 19 wells for 1 year, semiannual sampling of 19 wells for 4 years, annual sampling of 19 wells for 4 years, and annual sampling of 8 wells for two additional years. (18 events)**
Labor Hours	1,440 hours (2 people, 4 days, 10 hours per day for 18 events)
Well Abandonment	1,250 linear feet, abandoned with typical cement
Transportation	
Personnel Transportation - Road	
LTM Sampling	Assume 1 vehicle, 2 people, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 18 trips)
Residual Handling	
Residual Disposal/Recycling	Assume low-flow sampling, 4 drums per event (approx 450 lbs per drum = 1800 lbs, 0.9 tons) per event, transported to landfill located 45 miles away (one way), 18 trips
Empty	18 trips, 45 miles

Notes:

DPT = direct push technology

hrs = hours

R/T = round trip

Table E-5

Relative Impact of Alternatives

Feasibility Study Report for Groundwater at Site 3

Naval Weapons Station Yorktown

Yorktown, Virginia

Remedial Alternatives	GHG Emissions	Total energy Used	Water Used	NO_x emissions	SO_x Emissions	PM10 Emissions	Accident Risk Fatality	Accident Risk Injury
	metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Alternative 1 - No Action	0	0	0	0	0	0	0	0
Alternative 2 - MNA and LUCs	4.8	55	0	1.34E-03	3.10E-05	1.48E-04	1.99E-04	4.15E-02
Alternative 3 - EISB, MNA, and LUCs	17.1	228	20,350	9.77E-03	7.35E-04	9.17E-04	2.57E-04	4.58E-02
Alternative 4 - ISCR, MNA, and LUCs	21.9	216	11,644	1.85E-02	1.98E-03	1.74E-03	3.10E-04	6.41E-02
Alternative 5 - ISCO, MNA, and LUCs	22.3	318	103,600	1.67E-02	1.79E-03	1.58E-03	2.97E-04	6.16E-02

Remedial Alternatives	GHG Emissions	Total energy Used	Water Used	NO_x emissions	SO_x Emissions	PM10 Emissions	Accident Risk Fatality	Accident Risk Injury
	metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Alternative 1 - No Action	Low	Low	Low	Low	Low	Low	Low	Low
Alternative 2 - MNA and LUCs	Low	Low	Low	Low	Low	Low	Medium	Medium
Alternative 3 - EISB, MNA, and LUCs	High	High	Low	Medium	Medium	Medium	High	High
Alternative 4 - ISCR, MNA, and LUCs	High	Medium	Low	High	High	High	High	High
Alternative 5 - ISCO, MNA, and LUCs	High	High	High	High	High	High	High	High

The relative impact is a qualitative assessment of the relative footprint of each alternative, a rating of High for an alternative is assigned if it is at least 70 percent of the maximum footprint, a rating of Medium is assigned if it is between 30 and 70 percent of the maximum footprint, and a rating of Low is assigned if it is less than 30 percent of the maximum footprint.

Notes:

MMBTU - million British Thermal Unit

NOx - Nitrogen Oxides

SOx - Sulfur Oxides

PM10 - Particulate Matter

GHG - Greenhouse Gases

Table E-6

Alternative 2 - MNA and LUCs Results

Feasibility Study Report for Groundwater at Site 3

Naval Weapons Station Yorktown

Yorktown, Virginia

Phase	Activities	GHG Emissions	Total Energy Used	Water Used	NO_x Emissions	SO_x Emissions	PM_{10} Emissions	Accident Risk Fatality	Accident Risk Injury
		metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Remedial Action Construction	Consumables	0.00	0.00	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.07	0.94	NA	3.1E-05	9.7E-07	4.4E-06	1.2E-06	1.0E-04
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.7E-06	6.9E-04
	Residual Handling	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	0.07	0.94	0.00E+00	3.09E-05	9.72E-07	4.41E-06	3.99E-06	7.90E-04
Long-Term Monitoring	Consumables	0.97	5.07	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	1.21	15.29	NA	5.0E-04	1.6E-05	7.2E-05	3.4E-05	2.8E-03
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.5E-04	3.7E-02
	Residual Handling	2.55	33.25	NA	8.0E-04	1.4E-05	7.1E-05	1.4E-05	1.1E-03
	Sub-Total	4.72	53.61	0.00E+00	1.30E-03	3.00E-05	1.43E-04	1.95E-04	4.07E-02
Total		**4.8**	**54.6**	**0.00E+00**	**1.34E-03**	**3.10E-05**	**1.48E-04**	**1.99E-04**	**4.15E-02**

Notes:

MMBTU - million British Thermal Unit

NOx - Nitrogen Oxides

SOx - Sulfur Oxides

PM10 - Particulate Matter

NA - Not Applicable

GHG - Greenhouse Gases

Table E-7

Alternative 3 - EISB, MNA, and LUCs Results

Feasibility Study Report for Groundwater at Site 3

Naval Weapons Station Yorktown

Yorktown, Virginia

Phase	Activities	GHG Emissions	Total Energy Used	Water Used	NO_x Emissions	SO_x Emissions	PM_{10} Emissions	Accident Risk Fatality	Accident Risk Injury
		metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Remedial Action Construction	Consumables	0.00	0.00	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.07	0.94	NA	3.1E-05	9.7E-07	4.4E-06	1.2E-06	1.0E-04
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.7E-06	6.9E-04
	Residual Handling	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	0.07	0.94	0.00E+00	3.09E-05	9.72E-07	4.41E-06	3.99E-06	7.90E-04
Remedial Action Operations	Consumables	1.16	28.39	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	1.46	19.76	NA	5.0E-04	1.9E-05	4.7E-05	1.9E-05	1.6E-03
	Transportation-Equipment	9.90	129.15	NA	3.1E-03	5.5E-05	2.8E-04	5.1E-05	4.1E-03
	Equipment Use and Misc	0.50	6.09	2.0E+04	5.1E-03	6.4E-04	4.7E-04	3.4E-05	8.6E-03
	Residual Handling	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	13.03	183.39	2.04E+04	8.70E-03	7.10E-04	7.98E-04	1.05E-04	1.43E-02
Long-Term Monitoring	Consumables	0.97	5.07	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.97	12.23	NA	4.0E-04	1.3E-05	5.8E-05	2.7E-05	2.2E-03
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.1E-04	2.8E-02
	Residual Handling	2.04	26.60	NA	6.4E-04	1.1E-05	5.7E-05	1.1E-05	9.0E-04
	Sub-Total	3.97	43.91	0.00E+00	1.04E-03	2.40E-05	1.15E-04	1.48E-04	3.07E-02
Total		**17.1**	**228.2**	**2.04E+04**	**9.77E-03**	**7.35E-04**	**9.17E-04**	**2.57E-04**	**4.58E-02**

Notes:

MMBTU - million British Thermal Unit

NOx - Nitrogen Oxides

SOx - Sulfur Oxides

PM10 - Particulate Matter

NA - Not Applicable

GHG - Greenhouse Gases

Table E-8

Alternative 4 - ISCR, MNA, and LUCs Results

Feasibility Study Report for Groundwater at Site 3

Naval Weapons Station Yorktown

Yorktown, Virginia

Phase	Activities	GHG Emissions	Total Energy Used	Water Used	NO_x Emissions	SO_x Emissions	PM_{10} Emissions	Accident Risk Fatality	Accident Risk Injury
		metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Remedial Action Construction	Consumables	0.00	0.00	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.07	0.94	NA	3.1E-05	9.7E-07	4.4E-06	1.2E-06	1.0E-04
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.7E-06	6.9E-04
	Residual Handling	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	0.07	0.94	0.00E+00	3.09E-05	9.72E-07	4.41E-06	3.99E-06	7.90E-04
Remedial Action Operations	Consumables	9.66	66.32	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.74	9.97	NA	2.5E-04	9.7E-06	2.4E-05	9.8E-06	7.9E-04
	Transportation-Equipment	5.51	71.95	NA	1.7E-03	3.1E-05	1.5E-04	2.6E-05	2.1E-03
	Equipment Use and Misc	1.51	18.26	1.2E+04	1.5E-02	1.9E-03	1.4E-03	9.5E-05	2.4E-02
	Residual Handling	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	17.43	166.50	1.16E+04	1.73E-02	1.95E-03	1.60E-03	1.30E-04	2.67E-02
Long-Term Monitoring	Consumables	0.97	5.07	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	1.09	13.76	NA	4.5E-04	1.4E-05	6.5E-05	3.1E-05	2.5E-03
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-04	3.3E-02
	Residual Handling	2.29	29.93	NA	7.2E-04	1.3E-05	6.4E-05	1.3E-05	1.0E-03
	Sub-Total	4.35	48.76	0.00E+00	1.17E-03	2.70E-05	1.29E-04	1.75E-04	3.66E-02
Total		**21.9**	**216.2**	**1.16E+04**	**1.85E-02**	**1.98E-03**	**1.74E-03**	**3.10E-04**	**6.41E-02**

Notes:

MMBTU - million British Thermal Unit

NOx - Nitrogen Oxides

SOx - Sulfur Oxides

PM10 - Particulate Matter

NA - Not Applicable

GHG - Greenhouse Gases

Table E-9

Alternative 5 - ISCO, MNA, and LUCs Results

Feasibility Study Report for Groundwater at Site 3

Naval Weapons Station Yorktown

Yorktown, Virginia

Phase	Activities	GHG Emissions	Total Energy Used	Water Used	NO_x Emissions	SO_x Emissions	PM_{10} Emissions	Accident Risk Fatality	Accident Risk Injury
		metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Remedial Action Construction	Consumables	0.00	0.00	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.07	0.94	NA	3.1E-05	9.7E-07	4.4E-06	1.2E-06	1.0E-04
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.7E-06	6.9E-04
	Residual Handling	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	0.07	0.94	0.00E+00	3.09E-05	9.72E-07	4.41E-06	3.99E-06	7.90E-04
Remedial Action Operations	Consumables	11.16	180.84	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.74	9.97	NA	2.5E-04	9.7E-06	2.4E-05	9.8E-06	7.9E-04
	Transportation-Equipment	4.64	60.52	NA	1.5E-03	2.6E-05	1.3E-04	2.1E-05	1.7E-03
	Equipment Use and Misc	1.37	16.52	1.0E+05	1.4E-02	1.7E-03	1.3E-03	8.6E-05	2.2E-02
	Residual Handling	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Sub-Total	17.90	267.84	1.04E+05	1.55E-02	1.76E-03	1.44E-03	1.17E-04	2.42E-02
Long-Term Monitoring	Consumables	0.97	5.07	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	1.09	13.76	NA	4.5E-04	1.4E-05	6.5E-05	3.1E-05	2.5E-03
	Transportation-Equipment	0.00	0.00	NA	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Equipment Use and Misc	0.00	0.00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-04	3.3E-02
	Residual Handling	2.29	29.93	NA	7.2E-04	1.3E-05	6.4E-05	1.3E-05	1.0E-03
	Sub-Total	4.35	48.76	0.00E+00	1.17E-03	2.70E-05	1.29E-04	1.75E-04	3.66E-02
Total		**22.3**	**317.5**	**1.04E+05**	**1.67E-02**	**1.79E-03**	**1.58E-03**	**2.97E-04**	**6.16E-02**

Notes:

MMBTU - million British Thermal Unit

NOx - Nitrogen Oxides

SOx - Sulfur Oxides

PM10 - Particulate Matter

NA - Not Applicable

GHG - Greenhouse Gases

Table E-10
Contingency Assumptions
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

Remedial Investigation	**No Actions**
Remedial Action Construction	**Well abandon and soil removal**
Well Abandonment	40 linear feet, abandoned with typical cement
Transportation	
Personnel Transportation - Road	Oversight - Assume 1 vehicle, 1 person, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 3 trips) Subs - Assume 1 vehicle, 3 people, light duty, gas powered truck, driving from Virginia Beach (110 mile R/T, 3 trips)
Equipment transport	Excavator - 30 tons, 40 miles R/T
Material Transport	Backfill - 602 cy x 1.5 t/cy = 903 tons, 45 trips, 20 tons per trip, 20 miles one way, 900 miles total (empty trips too)
Equipment Use	Excavator - 1,852 cy excavated + 1,481 cy for benching + 1,389 backfill of excavation areas from stockpile onsite + 1,481 cy backfill of excavation areas from benched soil + 602 cy imported backfill = 6,805 cy
Labor Hours	90 hours (3 days, 4 people onsite, 10 hour days)
Residual Handling	
Residual Disposal/Recycling	695 tons to non-hazardous landfill, 33 trips, 21 tons each, 45 miles away
Empty	45 miles away (one way), 20 trips

Table E-11

Contingency Results

Feasibility Study Report for Groundwater at Site 3

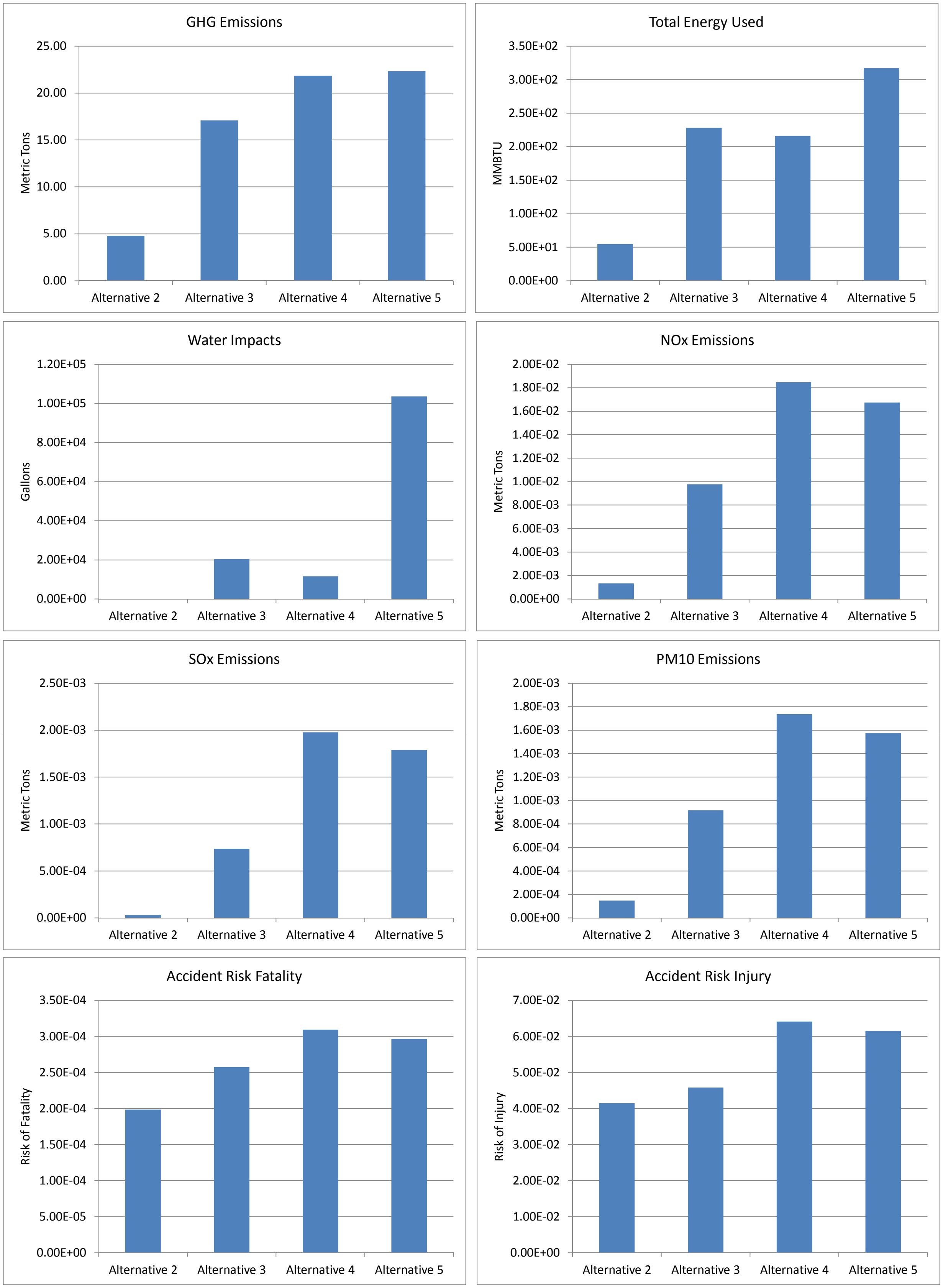
Naval Weapons Station Yorktown

Yorktown, Virginia

Phase	Activities	GHG Emissions	Total Energy Used	Water Used	NO_x Emissions	SO_x Emissions	PM_{10} Emissions	Accident Risk Fatality	Accident Risk Injury
		metric ton	MMBTU	gallons	metric ton	metric ton	metric ton		
Remedial Action Construction	Consumables	0.03	0.16	NA	NA	NA	NA	NA	NA
	Transportation-Personnel	0.36	4.59	NA	1.5E-04	4.8E-06	2.2E-05	1.0E-05	8.3E-04
	Transportation-Equipment	3.53	46.03	NA	1.1E-03	2.0E-05	9.9E-05	1.4E-05	1.2E-03
	Equipment Use and Misc	5.66	95.92	0.0E+00	3.6E-02	8.7E-03	2.5E-03	1.1E-05	2.8E-03
	Residual Handling	12.91	232.22	NA	4.6E-02	2.4E-02	1.3E-01	2.3E-05	1.9E-03
	Total	22.50	378.91	0.00E+00	8.27E-02	3.24E-02	1.29E-01	5.91E-05	6.68E-03

Notes:

Transportation and disposal of soil was the major contributor but equipment use also contributed significantly to the NOx footprint



Notes:
Alternative 2 - MNA and LUCs
Alternative 3 - EISB, MNA, and LUCs
Alternative 4 - ISCR, MNA, and LUCs
Alternative 5 - ISCO, MNA, and LUCs

Figure E-1
Overall Results
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, Virginia

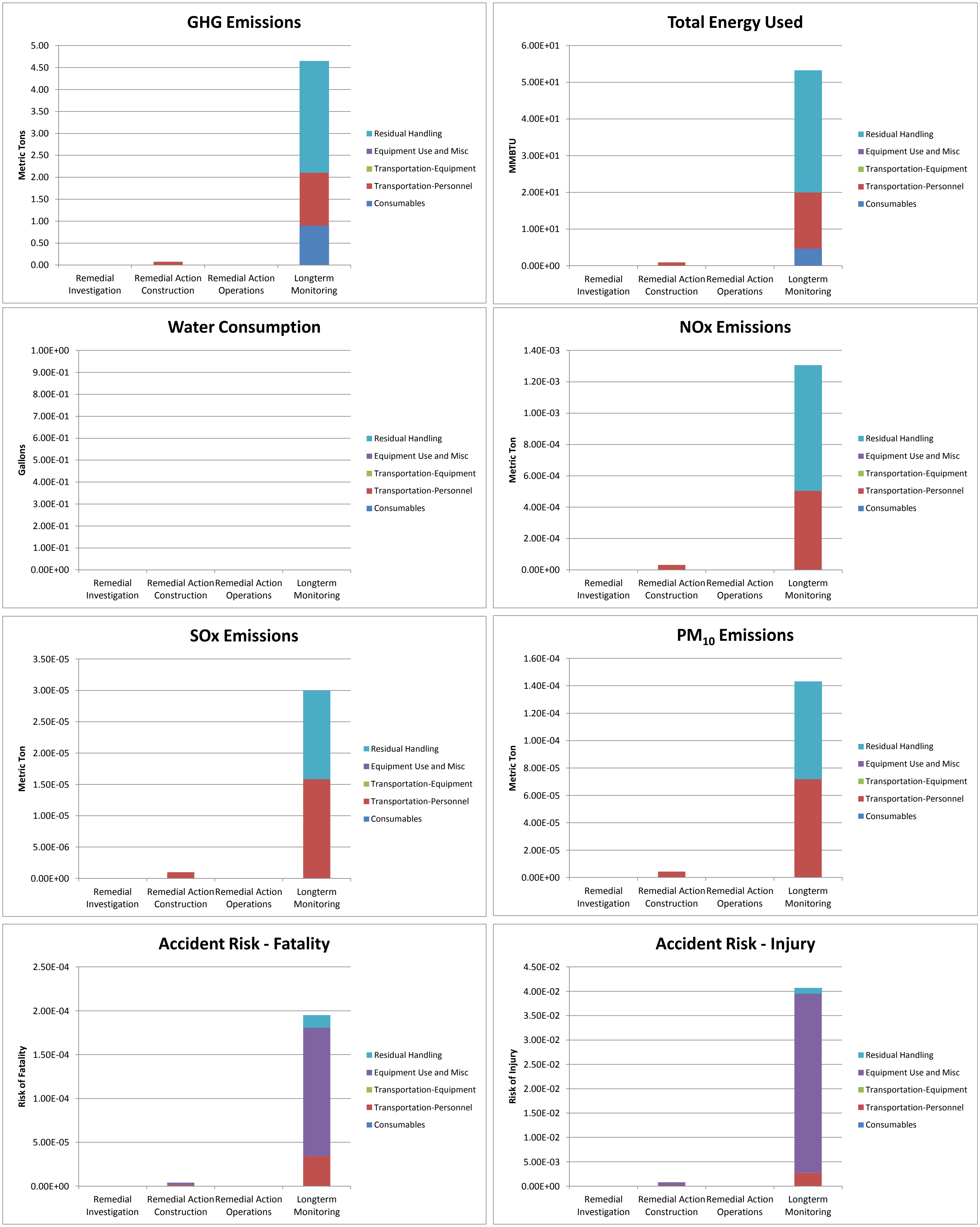


Figure E-2
Alternative 2 - MNA, and LUCs Results
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, VA

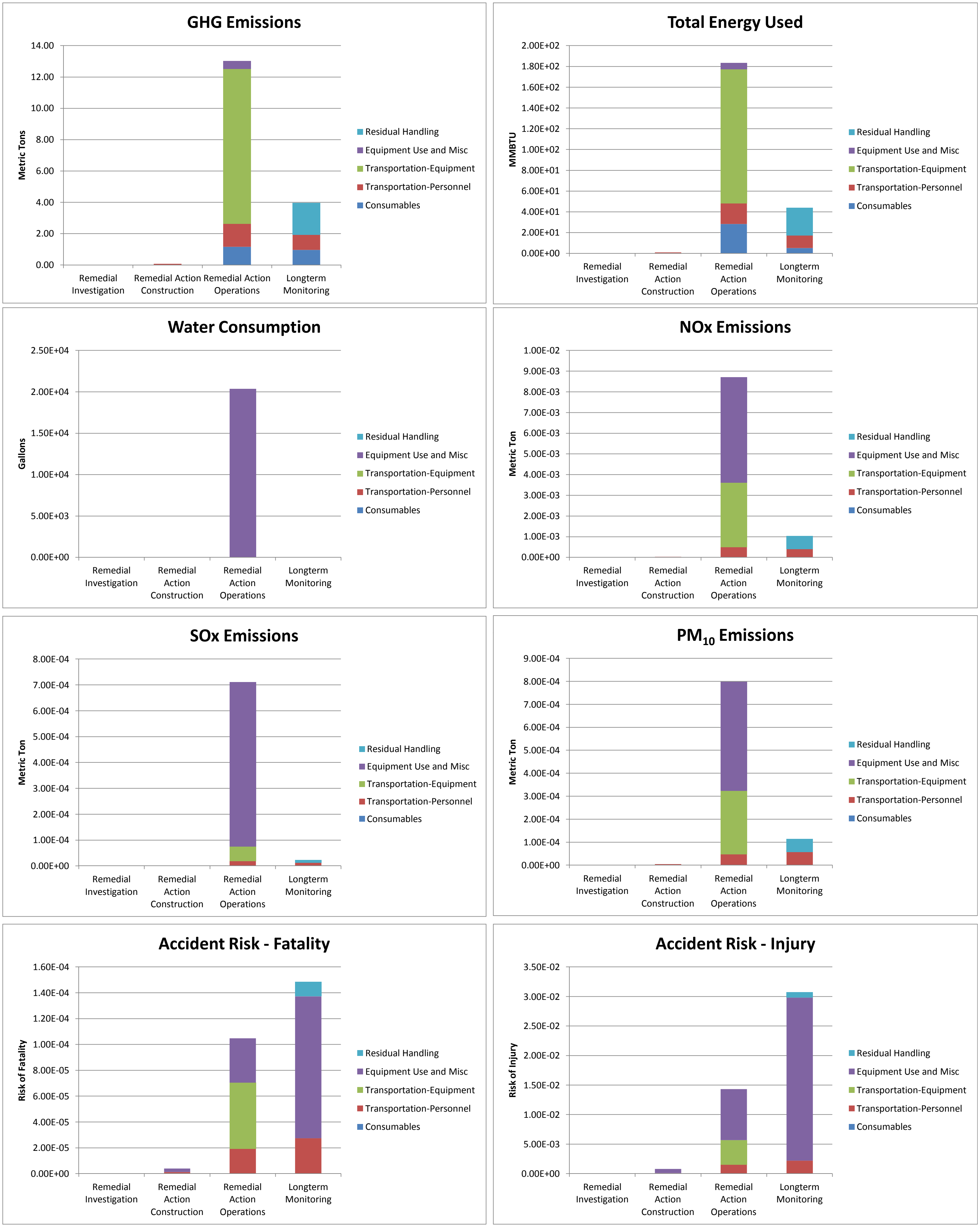
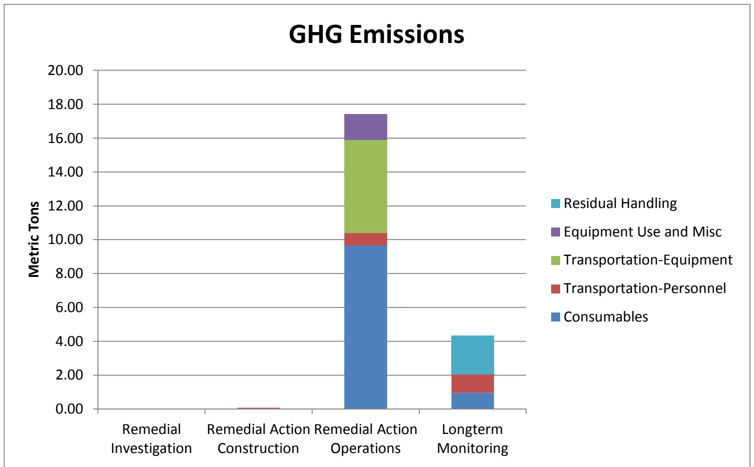
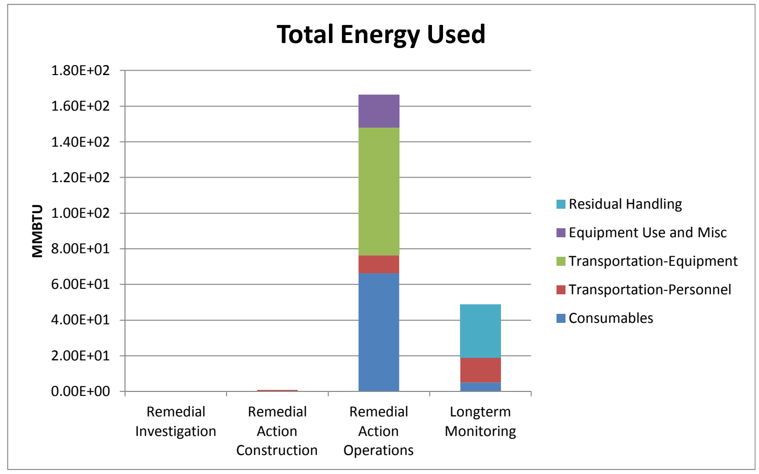
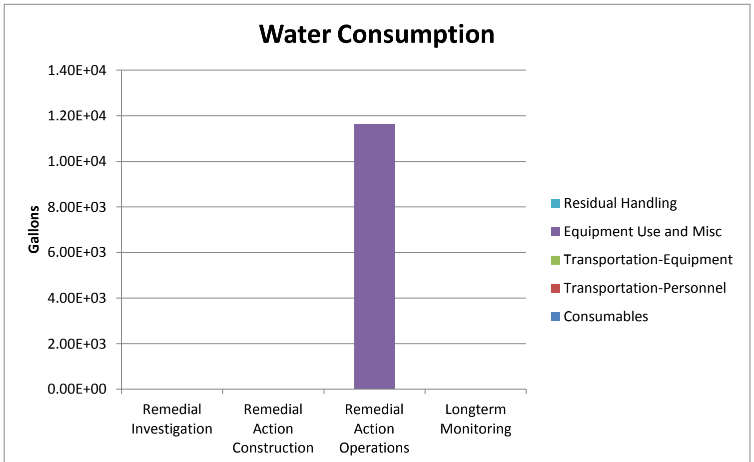
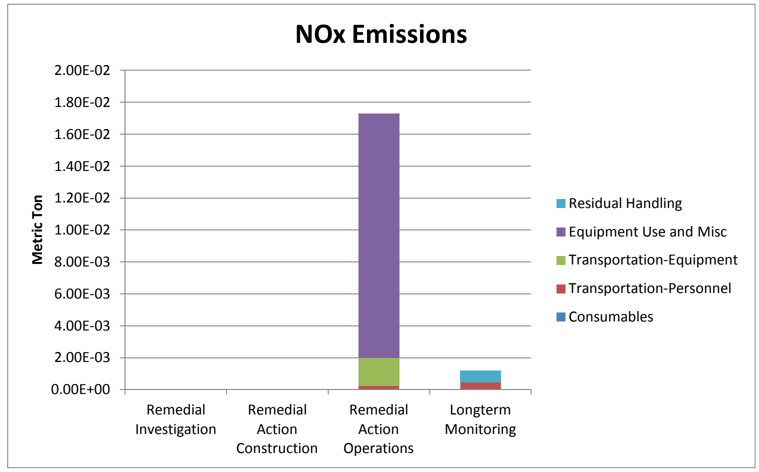


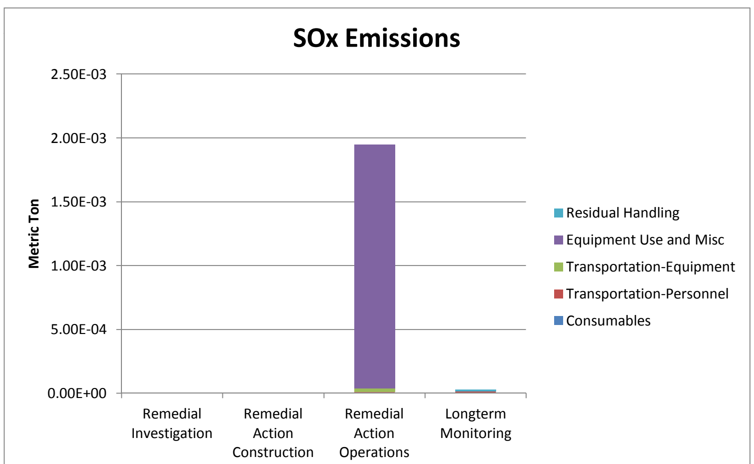
Figure E-3
Alternative 4 - EISB, MNA, and LUCs Results
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, VA

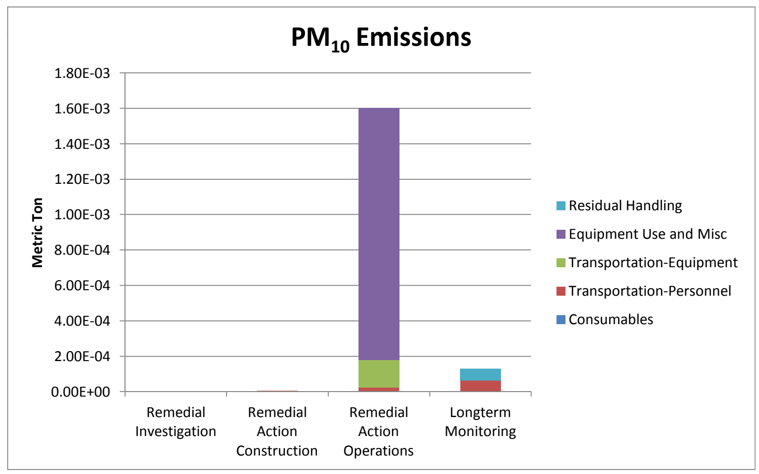


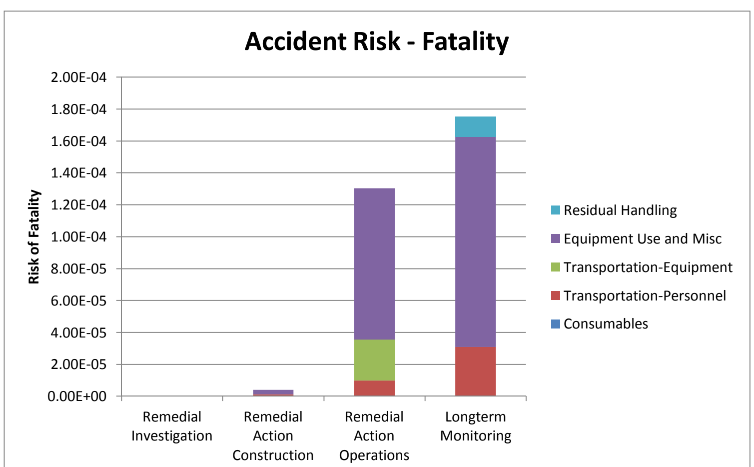












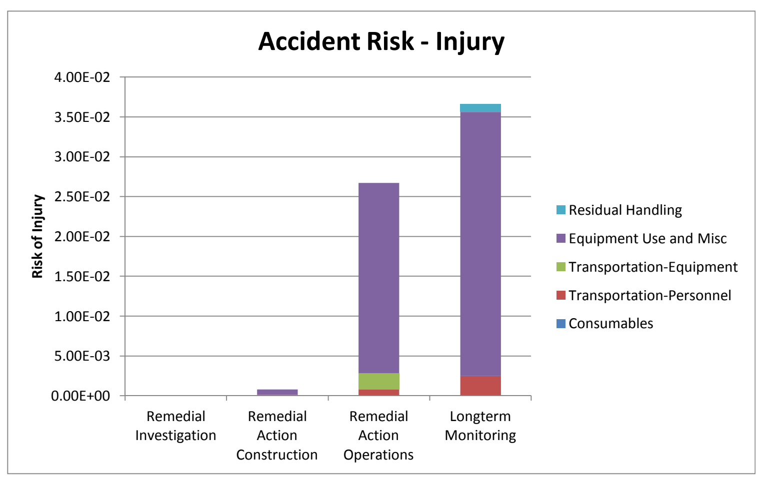
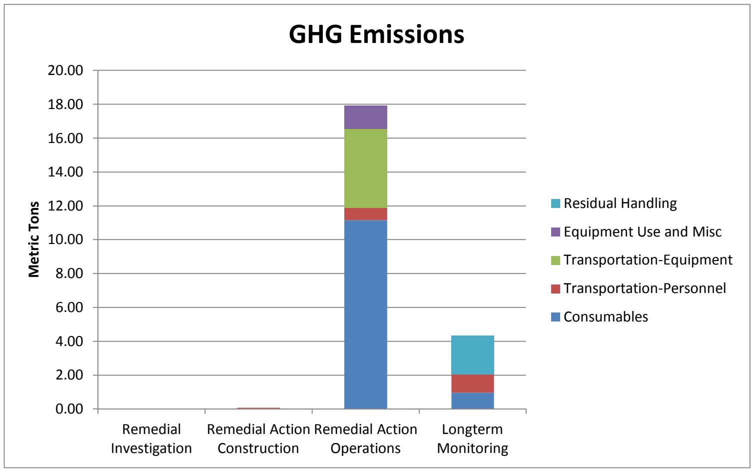
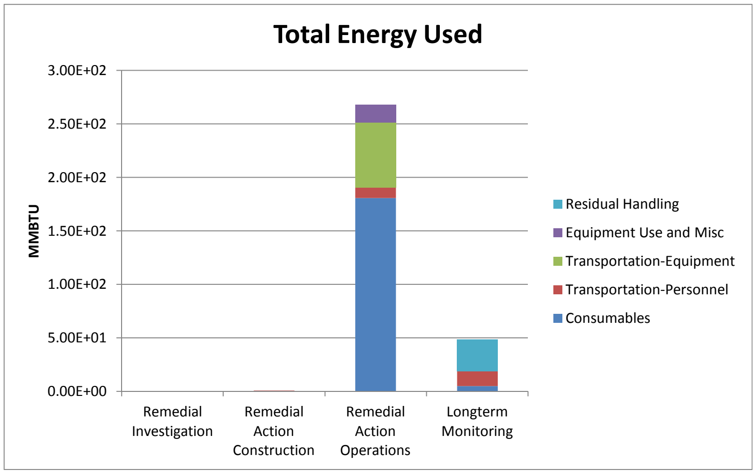
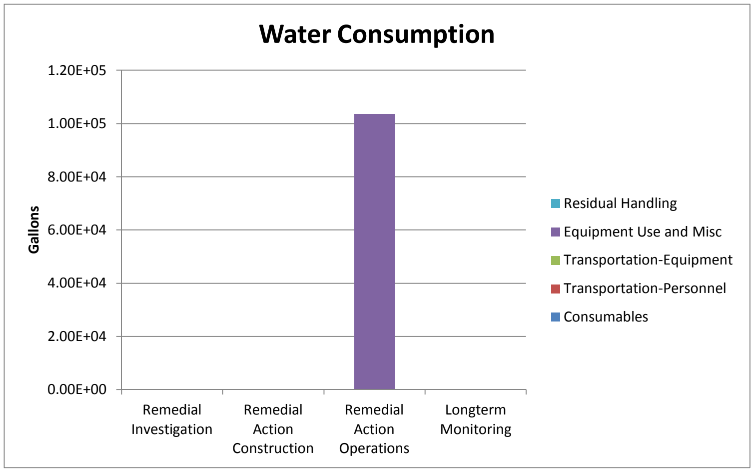
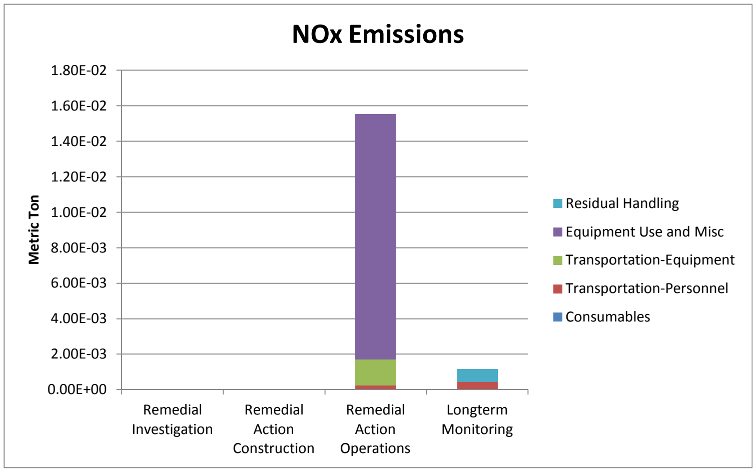


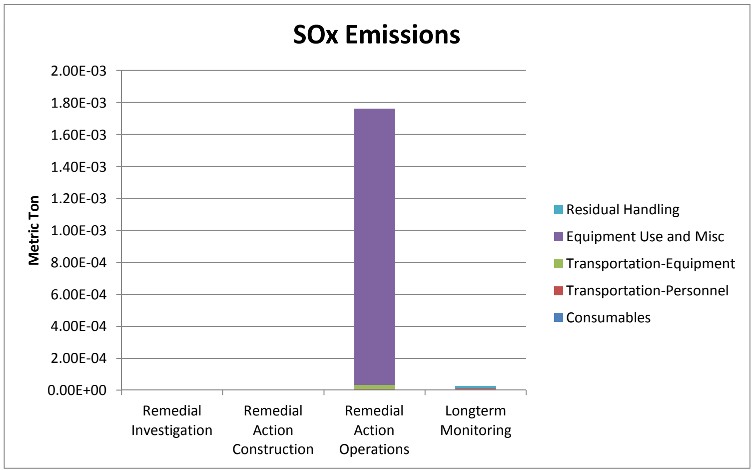
Figure E-4
Alternative 4 - ISCR, MNA, and LUCs Results
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, VA

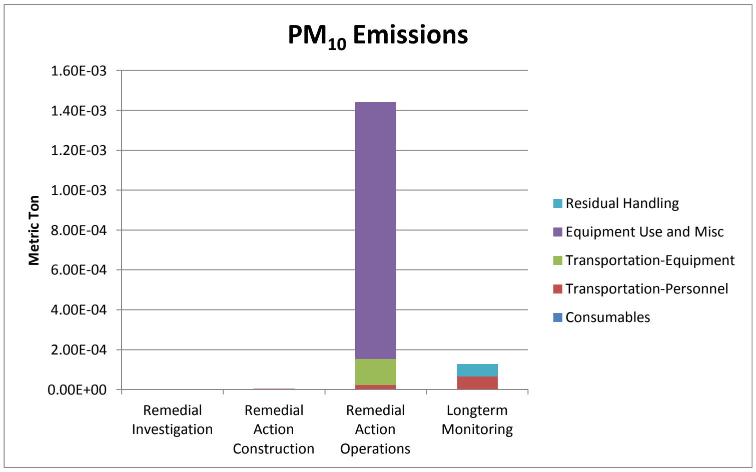


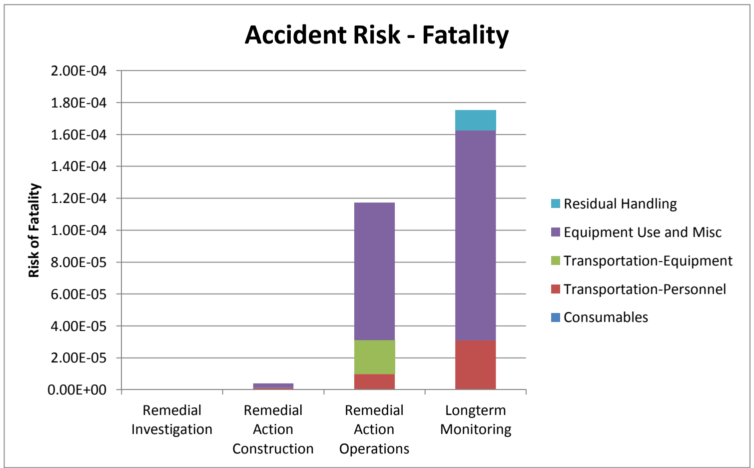












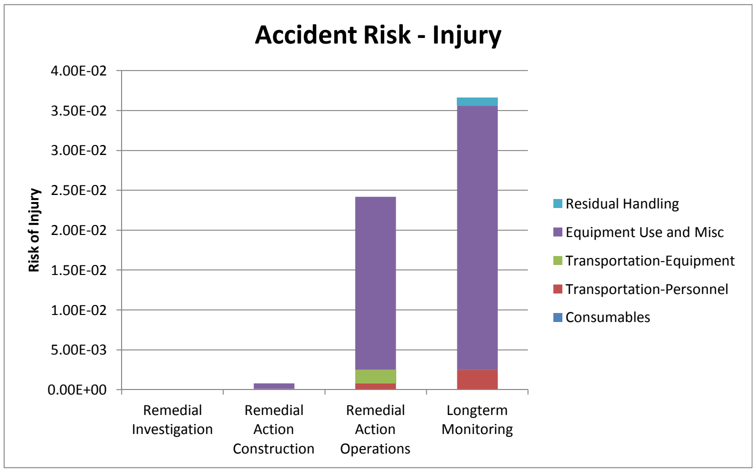


Figure E-5
Alternative 5 - ISCO, MNA, and LUCs Results
Feasibility Study Report for Groundwater at Site 3
Naval Weapons Station Yorktown
Yorktown, VA