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Corrective Action Plan
SWMU 39
Direct Support Maintenance Facility

Fort Stewart, Georgia

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SWMU 39
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I certify that I am a qualified professional engineer who has received a baccalaureate or post-graduate degree in engineering and have sufficient training and experience in environmental engineering and related fields, as demonstrated by state registration and completion of accredited university courses, to enable me to make sound professional judgments regarding groundwater monitoring and contaminant fate and transport. I further certify that this report was prepared by me or by a subordinate working under my direction.

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Acronyms and Abbreviations

amsl	above mean sea level
ARCADIS	ARCADIS U.S. Inc.
CAA	Corrective Action Alternative
CAOs	Corrective Action Objectives
CAP	Corrective Action Plan
cm/sec	centimeters per second
COC	Constituent of Concern
COPC	Constituent of Potential Concern
COPEC	Constituent of Potential Ecological Concern
CSM	Conceptual Site Model
DCE	cis-1,2-dichloroethene
DPT	Direct Push Technology
DSMF	Direct Support Maintenance Facility
EA	Environmental Assessment
EC	Electrical Conductivity
ELCR	Excess Lifetime Cancer Risk
ERD	Enhanced Reductive Dechlorination
EVO	Emulsified Vegetable Oil
ft	feet
ft bgs	feet below ground surface
GAC	Granular Activated Carbon
GAEPD	Georgia Environmental Protection Division
gpm	gallons per minute
HHRA	Human Health Risk Assessment
HI	Hazard Index
HOT	Heating Oil Tank

Acronyms and Abbreviations

HQ	Hazard Quotient
IC	Institutional Controls
IRP	Installation Restoration Program
ISCO	In-Situ Chemical Oxidation
IWQS	In-Stream Water Quality Standards
K_{oc}	Organic carbon Partition Coefficient
LUCs	Land Use Controls
LNAPL	Light Non-Aqueous Phase Liquid
M60	Mechanized 60
MCL	Maximum Contaminant Limit
µg/L	micrograms per Liter
mg/kg	milligrams per kilogram
mg/L	milligrams per Liter
MIP	Membrane Interface Probe
MNA	Monitored Natural Attenuation
MOEC	Memorandum of Environmental Consideration
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
O&M	Operations and Maintenance
OMM	Operations, Maintenance, and Monitoring
ORC	Oxygen Releasing Compound
PAH	Polynuclear Aromatic Hydrocarbon
PBC	Performance Based Contract
PCE	Tetrachloroethene
POTW	Publically Owned Treatment Works

Acronyms and Abbreviations

ppb	parts per billion
PRE	Preliminary Risk Evaluation
RCRA	Resource Conservation Recovery Act
RFI	RCRA Facility Investigation
ROI	radius of influence
RSL	Regional Screening Level
SSL	Soil Screening Level
SVE	soil vapor extraction
SVOC	Semivolatile Organic Compound
SWMU	Solid Waste Management Unit
TCE	Trichloroethene
USEPA	U. S. Environmental Protection Agency
USGS	United States Geological Survey
UST	Underground Storage Tank
USTMP	Underground Storage Tank Management Program
VAP	Vertical Aquifer Profile
VC	Vinyl Chloride
VOC	Volatile Organic Compound
ZVI	Zero Valent Iron

Executive Summary

This report presents a Corrective Action Plan (CAP) for the Direct Support Maintenance Facility (DSMF), Solid Waste Management Unit (SWMU) 39, at Fort Stewart, Georgia. This CAP addresses media requiring action based on the results of the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI). Based on these results, media that must be addressed are groundwater and subsurface soil. The constituents to address are volatile organic compounds (VOCs), primarily benzene, trichloroethene (TCE), tetrachloroethene (PCE), cis-1,2-dichloroethene (DCE) and vinyl chloride (VC), and arsenic in groundwater, light nonaqueous phase liquid (LNAPL), and Polynuclear Aromatic Hydrocarbons (PAHs) in subsurface soil.

The investigations have sufficiently delineated the vertical and horizontal impacts to shallow and deep groundwater at the Site. No definitive source was identified for the groundwater impacts. The areas requiring remedial evaluation are defined by the monitor wells containing Benzene, PCE, TCE, DCE, arsenic, and LNAPL and are all at levels above the U. S. Environmental Protection Agency (USEPA) maximum contaminant limit (MCL). Based on data from the vertical aquifer profiling (VAP) and monitor wells, an area of higher level PCE, TCE and DCE concentrations in deeper groundwater was identified upgradient of the DSMF with a diffuse low level PCE and TCE (<100 ug/L) plume present across much of the Site.

Based on the analyses of alternatives, the preferred remedy consists of monitoring of the ongoing natural attenuation in the shallow and deep zones, LNAPL recovery via absorbent socks, periodic assessments to ensure the concrete cap is maintained, enhanced reductive dechlorination of deep zone source mass via injection of a carbon substrate and Land Use Controls (LUCs) to prevent use of groundwater as potable water. This alternative would have less impact on Army operations and is most likely to be effective in reducing source mass since the remedy enhances the ongoing reductive dechlorination processes at the Site.

The proposed source area treatment with Enhanced Reductive Dechlorination (ERD) would be via injection of emulsified vegetable oil (EVO). Site data show the presence of dehalogenation daughter products, which indicate naturally occurring biological degradation is ongoing. ERD will serve to enhance these processes further to achieve treatment objectives. Performance monitoring will be conducted to confirm VOC treatment and track the overall longevity of the EVO substrate to guide the timing and need for subsequent injections.

The soil where the low level PAHs were detected is currently capped by 12 inches of concrete preventing direct exposure to the soil or leaching to groundwater. An inspection of the area will be completed semi-annually as part of the site visits to confirm the site conditions and area use have not changed as part of the land use restrictions in accordance with LUCs approved by GAEPD.

Sorbent socks will be installed and maintained through routine change-outs to evaluate the LNAPL recovery rate. The LNAPL levels in the wells will be routinely gauged to evaluate performance. Additional groundwater monitoring for this area will be completed as part of the overall site groundwater monitoring program.

In addition to performance monitoring, a semi-annual groundwater monitored natural attenuation (MNA) monitoring program will be conducted for the low level diffuse chlorinated solvent plume using wells within the existing monitoring network.

Dissolved arsenic, which is above the MCL in two monitor wells, will be monitored during remedial action implementation. Additionally, all performance monitoring samples collected for analysis of concentrations of PCE, TCE and its daughter products will also be analyzed for benzene concentrations. Data trends will be presented in CAP progress reports and recomendations will be made for remedial actions if deemed necessary. Dissolved arsenic and benzene, which have relatively minor impacts at the site, were not included in the screening and selection of remedial technologies.

1. Introduction

This report presents a CAP for the Direct Support Maintenance Facility, SWMU 39, at Fort Stewart, Georgia. This CAP was prepared in accordance with the requirements of the Performance Based Contract (PBC) number W91ZLK-13-D-0009 and follows the submittal of the RFI Report for SWMU 39 (ARCADIS 2014).

1.1 Project Scope and Objectives

This CAP addresses media requiring action based on the results of the RFI, which was approved by GAEPD in letter correspondence (Potter to Baumgardt) dated January 30, 2015 (GAEPD 2015). Based on these results, media that must be addressed are groundwater and subsurface soil. The main constituents to address are VOCs, primarily TCE, PCE, DCE and VC in groundwater, LNAPL, and PAHs in subsurface soil. PCE and TCE were identified in the RFI report as the sole risk drivers for impacts to human health. The objective of the CAP is to evaluate a range of remedial actions to minimize or eliminate potential risks associated with PCE, TCE, DCE, VC, arsenic and benzene in groundwater and with LNAPL, and on the basis of that evaluation select appropriate remedies. A conceptual design and cost estimate is provided with each remedial alternative.

1.2 Regulatory Background

Ongoing investigation and corrective action activities at Fort Stewart are managed using the criteria defined in the Georgia Environmental Protection Division (GAEPD) Facility Permit #HW-045(S) Section III.E dated August 2007. This CAP has been prepared in accordance with the subject permit.

1.3 Report Organization

This CAP is divided into 9 sections as follows:

- Executive Summary
- Section 1: A general introduction to SWMU 39, the objectives and scope of the CAP, and the current regulatory status of the SWMU.
- Section 2: A summary of Site background, investigation efforts and interim remedial efforts at SWMU 39, including the results of human health and ecological risk assessments.

- Section 3: A conceptual site model (CSM).
- Section 4: A statement of the objectives of corrective action and identification of specific areas to apply correctives actions.
- Section 5: Identification and screening of remedial technologies.
- Section 6: Analysis of corrective action alternatives.
- Section 7: Description of the proposed remedy.
- Section 8: References utilized in this report.

2. Site Characterization and Investigation Results

2.1 Site Location

Fort Stewart is located in portions of Liberty, Bryan, Long, Tattnall, and Evans Counties, Georgia, approximately 40 miles west-southwest of Savannah, Georgia (**Figure 2-1**). The cantonment, or garrison area is located within the Liberty County portion on the southern boundary of the installation. Hinesville, Georgia is the nearest city to the garrison area and is located immediately outside of the installation boundary.

2.2 Site Description and History

The Direct Support Maintenance Facility (DSMF) SWMU 39 is a fenced facility with controlled access covering approximately 10 acres. Surrounding the fenced area along the southern and eastern sides of the Site is undeveloped land covered with grass, some shrub vegetation, and pine trees. A drainage ditch runs along the south and southwest portion of the fence. Rail lines are located south and southeast of the DSMF with a spur running next to the drainage ditch along the southern side of the fence (**Figure 2-2**). The groundwater impacts extend beyond the fenced DSMF to the south, east and west. The area of groundwater requiring remedial evaluation is approximately 26 acres in the shallow zone and approximately 17 acres in the deep zone which partially overlaps the shallow zone impacts. The total impacted area is approximately 31 acres.

Historically, the DSMF was used as a vehicle wash/service rack. Two former underground storage tanks (USTs), USTs 59 and 60, and their associated heating oil tanks (HOTs) were located west of Building 1160, at the tracked vehicle maintenance platforms (Buildings 1161 and 1163). The HOTs provided fuel oil to a high-pressure washer at the platform. USTs 59 and 60 were 4,000 gallon concrete USTs utilized as non-regulated flow vaults connected to an oil/water separator located at the Mechanized 60 (M60) maintenance platforms. Also, within SWMU 39 an additional 500 gallon UST (61) was located immediately southeast of the tracked vehicle maintenance platform (Building 1161) and was used for the storage of used oil. The 500 gallon used oil UST (61) was removed from the Site and its associated piping was closed in place in August 1995. The CAP Part-A report (U. S. Army Corps of Engineers 1997) was sent to the Georgia Underground Storage Management Program (USTMP). After the review of the CAP Part A, the USTMP requested that an additional investigation of soil and groundwater be initiated and UST 61 was given Facility ID #9-089104. The two HOTs were filled with grout and closed-in-place in 1997. Further investigations were conducted at UST 61 and a CAP Part-B report (SAIC 2000) recommended annual sampling.

In 2004 an Interim Removal Action (IRA) was conducted to isolate the two 4,000 gallon concrete flow-through vessels USTs (59 & 60) at SWMU 39. The flow-through vessels were filled with concrete and sealed. During the second annual sampling event (SAIC 2005) for UST 61, LNAPL was discovered in one of the monitoring wells. Following the discovery of LNAPL at UST 61 an excavation was conducted in 2006 near former UST 61. The release incident associated with former UST #61 received a No Further Action Required designation from GAEPD USTMP in a letter dated January 5, 2009 (GAEPD 2009).

In 2007 Spec Pro Environmental Services conducted an IRA at SWMU 39 near Building 1161 to remove the LNAPL and impacted soil. In April 2008, LNAPL was detected again in another monitor well near Building 1161. In addition to LNAPL, historical groundwater investigations identified a low level diffuse VOC plume, consisting primarily of PCE and TCE concentrations in the low parts per billion (ppb) range.

2.3 Environmental Setting

2.3.1 Topography and Physiology

The Fort Stewart Military Installation is located on the eastern edge of the Lower Coastal Plain physiographic province of Georgia. The topography at Fort Stewart is dominated by a series of relatively flat, Pleistocene-age marine terraces that have been dissected by recent (Holocene) surface water drainage. Four terraces have been identified within the Fort Stewart area, including the Wicomico, Penholoway, Talbot, and Pamlico (Metcalf & Eddy 1996). The terraces progressively descend in elevation in the seaward direction and are bound by steep escarpments that mark the position of ancient shorelines. The garrison area of Fort Stewart is located within the Penholoway Terrace and has an average elevation of approximately 70 feet (ft) above mean sea level (amsl).

As indicated on **Figure 2-1**, SWMU 39 is located in the southern portion of Fort Stewart at the approximate geographic coordinates of 31d 51’ 33” north latitude and 81d 37’ 8” west longitude (United States Geologic Survey [USGS] 1976). The topography slopes gently northwest toward Mill Creek. A drainage ditch dissects the western portion of the Site (**Figure 2-2**). Surface water in the ditch flows northwest before emptying into Mill Creek and the Canoochee River Floodplain. The elevation ranges from approximately 85 ft amsl at the eastern boundary of SWMU 39 to approximately 70 ft amsl at the drainage ditch along the northwestern boundary.

2.3.2 Surface Water Resources

The Ogeechee River is the primary watershed for the Fort Stewart and Savannah, GA area with the Canoochee River as the largest tributary. The watershed generally flows southeast. Numerous creeks and canals dissect the land surface throughout the Fort Stewart area as part of the watershed.

A drainage canal traverses the western and southern boundary of the fenced area at SWMU 39. This canal is typically stagnant during base-flow conditions. Storm water runoff from the fenced area drains into the canal and flows northwest through a system of drainage canals within the southern portion of Fort Stewart. In the area of SWMU 39, canals channel water northwest before emptying into Mill Creek and the Canoochee River floodplain (**Figure 2-3**).

2.3.3 Land Use

The current primary mission for Fort Stewart is a training and maneuver area, providing tank, field artillery, helicopter gunnery, and small arms training for regular Army and National Guard units. The 24th Infantry Division, which was reflagged as the 3rd Infantry Division in May 1996, was permanently stationed at Fort Stewart in 1975.

2.4 Geology

Fort Stewart is located on the lower coastal plain physiographic province, which is typified by low relief that slopes toward the Atlantic Ocean. The sequence stratigraphy within the coastal plain geology of Georgia has been shaped by numerous cycles of marine transgressions and regressions. The unconsolidated sediments form a seaward thickening wedge into the Atlantic Ocean that was deposited from sediment erosion of the Blue Ridge Mountains. The total thickness of the sediments in the Savannah, Georgia, area is over 200 ft. Published investigations have identified at least nine overlapping sets of prograding barrier island depositional sequences across the lower coastal plain. Each barrier island sequence represents the position of the former shoreline as it progressively shifted towards its current position over time. Deposited during the Pleistocene Epoch, these overlying sediments form a disconformity with the underlying Miocene Hawthorne Group clays. Beneath the Hawthorne Group clays is the Suwannee Limestone, deposited during the Oligocene Epoch, followed by the Ocala Limestone, deposited during the Eocene Epoch.

The local geology at Fort Stewart, SWMU 39 is consistent with the barrier island depositional sequence overlying the Hawthorne Group marine clays. The upper 50 feet below ground surface (ft bgs) consists of various sands interbedded with silts. As depth increases the confining unit of the Hawthorne is encountered with increasing amounts of clays.

2.5 Hydrogeology

2.5.1 Groundwater Occurrence

The two most important aquifers in the Fort Stewart area are the Surficial Aquifer and the Floridan Aquifer. The Surficial Aquifer consists of mainly sands with interbeds of silts and clays and is generally limited in vertical extent to approximately 40 to 80 ft bgs with a confining unit at the base that is approximately 200 feet in thickness locally. The regionally extensive Floridan Aquifer is the principal water supply aquifer in the lower coastal plain of Georgia and Florida. It is composed primarily of the Oligocene Suwannee Limestone and the Eocene Ocala Limestone. At Fort Stewart, the top of the Floridan Aquifer is approximately 500 ft bgs (Gonthier 2011). The investigations conducted at SWMU 39 focus solely on groundwater quality in the uppermost portion of the Surficial Aquifer system. This upper portion is underlain by a continuous confining unit that effectively restricts groundwater migration of shallow groundwater to the deeper Floridan Aquifer. A deep test well in Savannah (GGS-3139) projects that the clay units are located approximately 45 ft bgs to 167 ft bgs near Fort Stewart (Huddleston 1988).

2.5.2 Groundwater Flow Directions and Hydraulic Gradients

Groundwater at the Site generally flows to the northwest with both the shallow and deep potentiometric contours following the same general groundwater flow pattern. Based on water levels collected in May 2011, the water table averages 6.66 ft bgs throughout the Site, with the deepest level being 12.75 ft bgs at G4MW048 and the shallowest level being 3.00 ft bgs at G4MW034. **Figure 2-4** displays shallow well potentiometric contours and **Figure 2-5** displays deep well potentiometric contours. **Table 2-1** summarizes the May 2011 water level measurements used for the potentiometric contour maps.

2.5.3 Hydraulic Conductivity

Slug tests performed at five monitor wells in January 2011 produced hydraulic conductivity values that ranged from 10^{-3} to 10^{-5} centimeters per second (cm/sec):

- G4MW038 – 6.6×10^{-5} cm/sec – 35 ft bgs to 45 ft bgs
- G4MW040 – 1.6×10^{-4} cm/sec – 35 ft bgs to 45 ft bgs

- G4MW042 – 1.5×10^{-4} cm/sec – 35 ft bgs to 45 ft bgs
- G4MW043 – 1.1×10^{-3} cm/sec – 14 ft bgs to 24 ft bgs
- G4MW047 – 3.5×10^{-5} cm/sec – 25 ft bgs to 35 ft bgs

The slug test results are consistent with the typical hydraulic conductivity range (10^{-2} to 10^{-5} cm/sec) for silty sand (Freeze and Cherry 1979).

2.6 Historical Investigations and Remedial Actions

A number of historical investigations and remedial actions have been completed to date that lead to an understanding of current site conditions that is discussed in **Section 3** and presented in greater detail in the RFI (ARCADIS 2014). These activities have included the following;

1. Excavation activities at UST 61 with application of Oxygen Releasing Compound (ORC®) to the excavation floor and sidewalls in August 1995. The 500 gallon used oil UST was removed from the Site and its associated piping was closed in place. The CAP Part-A report (U. S. Army Corps of Engineers 1997) was sent to the Georgia USTMP. After the review of the CAP Part A, the USTMP requested that an additional investigation of soil and groundwater be initiated and UST 61 was given Facility ID #9-089104.
2. Two HOTs, which were associated with USTs 59 and 60 and located west of Building 1160 at the tracked vehicle maintenance platforms (Buildings 1161 and 1163), were filled with grout and closed in place in 1997. The HOTs provided fuel oil to a high-pressure washer at the platform.
3. Investigations were conducted in 2001 and 2002 consisting of installation of soil borings and monitor wells in the areas of the USTs and HOTs (GAEPD 2001; STEP 2003). The results indicated the following:
    - Soil results were below standards for PAHs and VOCs,
    - LNAPL was detected in monitor well G4MW002 and G4MW007, and
    - TCE concentrations in groundwater were above standard.
4. A baseline human health risk evaluation was performed using the results of the 2001 and 2002 investigations. The evaluation indicated there was not an unacceptable risk to human health due to exposure to the soil or groundwater. Based on the investigation results, Fort Stewart recommended removal of the LNAPL from G4MW007, inspection and removal of the non-regulated flow-through vessels from service, and additional investigation to delineate the extent of TCE impacts (STEP 2003).

5. An investigation was performed in three phases in 2004 to further evaluate subsurface soil, groundwater, surface water, LNAPL, and evaluate potential remedial approaches.
   - Collection of soil, surface water, sediment and groundwater samples,
   - Installation of twelve (12) additional monitor wells,
   - LNAPL removal from existing wells, and
6. An Interim Removal Action (IRA) was conducted in 2004 to isolate the two 4,000 gallon concrete flow-through vessels USTs (59 & 60) at SWMU 39. The flow-through vessels were filled with concrete and sealed. .
7. During the second annual sampling event (SAIC 2005) for UST 61, LNAPL was discovered in one of the monitoring wells. Following the discovery of LNAPL at UST 61 an excavation was conducted in 2006 near former UST 61. The release incident associated with former UST #61 received a No Further Action Required designation from GAEPD USTMP in a letter dated January 5, 2009 (GAEPD 2009).
8. 2007 Interim Remedial Action consisted of excavating the soils around G4MW007 and G4MW013 to the extent possible and replacement of the wells with larger diameter wells to aid in further remediation of free product. Following the excavation, ORC® was applied to the excavation sidewalls and bottom. Replacement wells G4MW007R and G4MW013R were installed. No free product has been detected in these wells.
9. Investigations conducted in 2008 for further delineation of TCE in groundwater at the request of the GAEPD.
   - Direct push technology (DPT) investigation and screening samples were collected from 19 locations around SWMU 39. Results from the screening showed the continued presence of PCE and TCE in groundwater above MCLs.
   - Seven additional monitor wells were installed (G4MW026 through G4MW032) in March 2008. The new wells were screened from about 10 to 20 ft bgs with one well screened from 35 to 45 ft bgs. The sampling results indicated detections of PCE and TCE south of the DSMF fenced area (and north of Italy Street).
10. An RFI Work Plan was submitted for additional investigation to evaluate the extent of PCE and TCE south of the DSMF fenced area (and north of Italy Street) and to determine how they relate with the impacts reported within the DSMF fenced area. The work plan also includes additional investigations to delineate the extent of LNAPL near G4MW002 (ARCADIS 2010).

11. Investigation activities in 2010 and 2011 included activities for groundwater, LNAPL, background soil, soil, surface water and sediment during multiple mobilizations.
    - Groundwater activities included hydraulic testing (five locations), completion Membrane Interface Probe (MIP) borings (nine locations), Vertical Aquifer Profile (VAP) sampling (29 locations with multiple depths at each location), deep soil boring (one location), well installation (19 locations), and sampling (two events conducted in 2011 for new and existing monitor wells).
    - LNAPL work consisted of eight borings around the remaining LNAPL area (G4MW002).
    - Background soil borings were advanced at four locations around buildings 1161 and 1163 for PAHs and metals characterization.
    - Soil sampling for PAH impacts in area of F39SB010 at six locations.
    - Surface water and sediment samples collected from eight locations in the drainage canal.

2.7 Risk Assessment Summary and Conclusions

2.7.1 Summary of Human Health Risk Assessment (HHRA)

A Human Health Risk Assessment (HHRA) was conducted as part of the SWMU 39 RFI (ARCADIS 2014) to evaluate the potential current and hypothetical future risks and potential hazards to human health associated with constituents detected in surface and subsurface soil, groundwater, sediment and surface water samples collected at SWMU 39. Twenty-nine Constituents of Potential Concern (COPCs) were identified based on detections in surface soil, subsurface soil, combined surface and subsurface soil, sediment, or surface water. The exposure scenarios quantitatively evaluated included exposure to soil by current and future site workers, current and hypothetical adolescent trespasser, hypothetical construction worker, and hypothetical future adult and child resident; exposure to indoor air by a current and future site worker and a hypothetical future adult and child resident; and exposure to sediment and surface water by current and hypothetical future trespasser.

The groundwater analytical data were reviewed and compared to the USEPA tap water Regional Screening Levels (RSLs) and the drinking water standards. Based on this evaluation, it was determined that use of the groundwater as a potable water supply would yield an unacceptable risk and/or hazard. The constituents that were present in groundwater above their USEPA tap water RSLs also have established federal drinking water standards or MCLs. However, since MCLs are available for all constituents that would pose a risk or hazard if exposure to groundwater were evaluated quantitatively in the risk assessment, MCLs were selected as the remedial goals for the groundwater constituents and exposure to groundwater was not evaluated further. Cancer risks and noncancer hazards were calculated for each potentially or hypothetically exposed receptor included in the risk assessment. With the exception of the hypothetical future child resident exposure to surface soil and subsurface soil, all Excess Lifetime Cancer Risk (ELCR) values were less than or equal to the GAEPD acceptable risk level of 1×10^{-5}. The exceeding pathway was the ELCR for a hypothetical future child resident as a result of direct contact with surface soil (0-1 ft bgs) and subsurface soil (1-8 ft bgs). All other calculated Hazard Indices (HIs) and ELCRs are below the GAEPD acceptable risk levels. The GAEPD in a November 24, 2014 response letter regarding Revision 3 of the RFI (GAEPD 2014) agreed that a target risk level of 1×10^{-5} was appropriate for this site because the current use of the site is as an active military base and the location of SWMU 39 is in an area of the post that is strictly commercial/industrial rather than residential (Appendix A). There are no plans to change land use around SWMU 39 in the foreseeable future.

2.7.2 Summary of Baseline Ecological Risk Assessment

A Preliminary Risk Evaluation (PRE) was conducted for SWMU 39. The DSMF area is approximately ten (10) acres and is almost completely covered with concrete and is fenced. The groundwater impacts extend beyond the fenced DSMF to the south, east and west. The area of groundwater requiring remedial evaluation is approximately 26 acres in the shallow zone and approximately 17 acres in the deep zone.

Therefore, evaluation of soil samples presented in the PRE assumed hypothetical future conditions at SWMU 39 in the event the concrete cover is removed and soil is left exposed. If the site is left undeveloped, the terrestrial habitat most likely will eventually become comprised of evergreen and deciduous plant species, typical of the marshy woodlands of the Coastal Plains. Common fauna that may be expected to occur would include earthworms and other soil-dwelling invertebrates, birds such as robins, and mammals such as gray squirrel, shrews, rabbits, and raccoons.

The storm water drainage ditch associated with SWMU 39 runs for approximately 1500 ft along the west portion of the fence. The ditch is around three (3) ft wide and varies in depth from approximately three (3) to seven (7) ft, with the deeper end near the northwest portion of SWMU 39. The water in the ditch is less than one foot deep with very little flow. This ditch receives drainage both from the parking area at SWMU 39 and from surrounding areas. Flow in the ditch is governed by precipitation runoff and discharge water from military vehicle washing. This ditch is typically stagnant during base-flow conditions. Storm water in the ditch flows northwest through a system of drainage canals present throughout the southern portion of Fort Stewart. The canals channel water northwest before emptying into Mill Creek and the Canoochee River floodplain.

The cycling of dry channel conditions with precipitation and discharge-fed wet channel periods prevents establishment of a robust aquatic community typical of a perennial water body. To support this conclusion, vegetation growing in the ditch appears to be terrestrial, not wetland or aquatic rooted vegetation. This indicates that the ditch only temporarily and sporadically contains surface water. As a result, the ditch is considered an intermittent drainage conveyance providing essentially no viable aquatic habitat.

The PRE evaluated constituents detected in surface soil (0-1 ft bgs). Anthracene, benzo(a)pyrene, fluoranthene, phenanthrene, pyrene, and chromium were identified as Constituent of Potential Ecological Concern (COPECs) in surface soil. Results of the PRE indicate that all calculated Hazard Quotients (HQs) for COPECs in soil were below one with the exception of the HQ for PAHs for mammalian receptors which was only slightly above 1 (i.e., 2). Two sample locations in particular had PAHs at concentrations that exceed the Eco Soil Screening Level (SSL) for mammalian receptors and those are: SB010 and SB013. Those samples reflect an area that is approximately 3500 square ft (or less than 0.1 of an acre) and is currently covered by concrete with no redevelopment plans that will leave those areas exposed. Based on the limited number of locations with HQs >1, the small size of the area with elevated concentrations (less than 0.1 acre) which is less than the de minimis extent typically used in ecological risk assessments, and the fact that the area is covered and there are no plans for redevelopment, adverse impacts are unlikely to occur for ecological receptors potentially exposed in the future to PAHs in the soil. Therefore, no further ecological assessment is considered necessary.

3. Conceptual Site Model

Data collected during the RFI activities have resulted in refinements to the CSM for geology and hydrogeology as well as delineation of the impacts in groundwater. The key elements of the CSM are described in the following sections and are based on detailed geologic logging, MIP/Electrical Conductivity (EC) soundings, soil samples from various depths, completion of hydraulic testing and collection of numerous groundwater samples through sampling by VAP and groundwater monitor wells.

3.1 Geology and Hydrogeology

Soil borings advanced throughout SWMU 39 and other upgradient areas indicate that the subsurface is predominantly silty fine-grained sand with occasional lenses of clay, and coarse sand at thicknesses ranging between 2 inches to 2 ft. Clay lenses are most prevalent in the eastern portion of the Site near F39TW11. Regional and local geologic data shows that a competent confining unit is present at depth and effectively prevents downward migration of Constituents of Concern (COCs) to the upper Floridan Aquifer.

Locally, a combination of soil borings, vertical aquifer profiling, and slug testing of monitor well installation have allowed for the characterization of the Surficial Aquifer. Three cross-sections have been prepared to show the local geology and delineation of TCE across the Site (**Figure 3-1**). Cross section A-A' extends northwest to southeast across the Site, parallel to the groundwater flow direction (**Figure 3-2**). Cross section B-B' (**Figure 3-3**) goes from southwest to northeast in the area of highest PCE and TCE impacts, perpendicular to groundwater flow at the eastern end of the Site. Cross section C-C' (**Figure 3-4**) goes south to north across the Site, near the western portion of the Site. As shown in all of the cross sections, the Site is underlain by silty fine-grained sands which range from 25 ft to 40 ft thick across the Site with silt and clay content increasing with depth. In the eastern portion of the Site, near G4MW055, a 55 foot thick section of interbedded clay and clayey fine sand is present, followed by a layer of coarse-grained sand with two clay layers at 12 ft thick and 7 ft thick present between 58 ft bgs and 85 ft bgs. A layer of clayey fine-grained sand appears at approximately 25 ft bgs to 30 ft bgs beneath the overlying silty fine-grained sand in the western portion of the Site near Building 1160. Slug tests performed at five monitor wells in January 2011 returned hydraulic conductivity values that ranged from 10^{-3} to 10^{-5} cm/sec, which are consistent with the silty sand geology.

3.2 Nature and Extent of Impacts

3.2.1 Groundwater Quality

Groundwater investigations conducted during 2004, 2008, 2010 and 2011 identified and delineated low level VOCs in groundwater. The impacts were primarily related to PCE and TCE. Investigations to date confirmed a diffuse low-level PCE and TCE (<100 micrograms per liter [ug/L]) plume is present across much of site with higher concentrations of PCE and TCE (>1,000 ug/L) in deeper groundwater up-gradient of SWMU 39. **Figure 3-5** displays the 2010 temporary well sample results. **Figure 3-6** displays the 2011 shallow zone groundwater results for PCE, TCE, DCE, and VC from the permanent monitor wells. **Figure 3-7** displays the 2011 deep zone groundwater results for PCE, TCE, DCE, and VC from the permanent monitor wells. The highest concentrations were detected in the 2010 temporary wells near F39TW11 and F39TW13 (**Figure 3-5**) and in monitor wells G4MW041 and G4MW051 installed in the same area (**Figure 3-7)**.

3.2.1.1 Shallow Groundwater

TCE, VC, benzene, and chloroform were detected in the shallow groundwater above the tap water RSL. The TCE impacts to shallow groundwater extend from G4MW029 located east of the DSMF to G4MW043 located west of the DSMF to G4MW014 located next to Building 1160 and G4MW048 located south of the DSMF.

- The highest TCE concentration in shallow groundwater detected during the 2011 groundwater monitoring event was within the fenced DSMF area in monitor well G4MW033 at a concentration of 33 ug/L.
- VC was detected in shallow monitor well G4MW010 at a concentration of 2.5 ug/L and G4MW048 at a concentration of 0.56 ug/L. Based on the isolated locations of the detections and the low concentrations, it is believed that the detections are a result of biodegradation of TCE.
- Benzene was detected above the RSL and MCL in shallow monitor well G4MW035. The detection appears to be localized with concentrations in nearby monitor wells either below screening criteria or below detection.
- Chloroform was detected above the tap water RSL in shallow monitor well G4MW046 at an estimated concentration of 0.55 ug/L. Chloroform was not detected in any of the nearby monitor wells.
- Total arsenic was detected above the tap water RSL in multiple shallow wells.

- Total chromium, total lead and total mercury were detected above the tapwater RSL in one or two shallow wells.
- In shallow wells, mercury and chromium were not detected above their respective tap water RSL or MCL in the dissolved samples. Dissolved arsenic was detected above the tap water RSL of 0.000052 mg/L in 6 monitor wells at concentrations ranging from an estimated concentration of 0.004 mg/L to an estimated concentration of 0.0099 mg/L. Dissolved lead was detected in monitor well G4MW029 slightly above the MCL of 0.015 mg/L at a concentration of 0.017 mg/L.

It is believed that these detections for total metals may be attributable to high turbidity, which averaged 154 nephelometric turbidity units (NTU) with a maximum of 791 NTU during the January 2011 sampling, and are not representative of the groundwater.

3.2.1.2 Deep Groundwater

Several VOCs including PCE, TCE, DCE, benzene, and chloroform were detected in the deep groundwater above the tap water RSL. The impacts to deep groundwater are delineated vertically at G4MW055. During drilling, a clay layer was encountered in G4MW055 at approximately 58 ft bgs. During the VAP investigations, not enough water was present to collect samples deeper than 55 ft bgs. The vertical impacts to groundwater appear to be contained above this clay layer. Additional observations concerning deep groundwater are:

- The highest chlorinated VOC impacts during the VAP investigations and subsequent groundwater monitoring were detected near F39TW11 and G4MW041/G4MW051 (**Figure 3-5** and **3-7**).
- Benzene was detected above the RSL but below the MCL in deep monitor well G4MW037. The detection is localized with concentrations in nearby monitor wells either below screening criteria or below detection.
- Chloroform was detected above the tap water RSL in deep monitor wells G4MW047 and G4MW055 at concentrations of 1.1 ug/L and 0.72 ug/L, respectively.
- Total arsenic was detected above the tap water RSL in multiple deep wells. Total chromium and total lead were detected above the tap water RSL in one deep well. Total mercury was detected above the tap water RSL in two deep wells.
- In deep wells, chromium, mercury and lead were not detected above their respective tap water RSL or MCL in the dissolved samples. Dissolved arsenic was detected above the tap water RSL of 0.000052 mg/L in 8 monitor wells at concentrations ranging from 0.0042 mg/L to 0.024 mg/L (**Figure 3-8**).

It is believed that these detections for total metals may be attributable to high turbidity, which averaged 154 nephelometric turbidity units (NTU) with a maximum of 791 NTU during the January 2011 sampling, and are not representative of the groundwater.

3.2.1.3 Overall Groundwater Quality

The investigations have sufficiently delineated the vertical and horizontal impacts to shallow and deep groundwater at the Site. No definitive source was identified for the groundwater impacts. Utility maps for the area indicate the presence of sewer and water lines where potentially spent solvents could have been disposed and a concrete utility pipe was detected approximately 9.5 ft bgs during the investigations conducted in 2010/2011. The groundwater impacts have been delineated and appear to initiate close to where the spent solvents were reportedly disposed. It is believed that the sewer lines leaked over time, creating the localized higher level VOC plume in deep groundwater. These sewer lines may have also contributed to the lower level PCE and TCE detections across the Site by providing a pathway for contaminant migration. Both water and sewer lines were identified in the area traveling west towards the DSMF.

3.2.2 LNAPL

LNAPL associated with historical maintenance operations at Buildings 1161 and 1163, has been detected in G4MW002 and G4MW001. During the May 2011 monitoring event, approximately 0.65 ft of product was measured in G4MW001 and 3.26 ft of product was measured in G4MW002. Eight soil borings were collected around these wells in 2010 to estimate the extent of LNAPL impacts. No evidence of LNAPL was identified in any of the borings indicating LNAPL is localized near the monitor wells. An estimate of the extent of LNAPL impacts is shown on **Figure 3-9**.

3.2.3 Soils

Between 2004 and 2011, 10 surface soil and 35 subsurface soil samples were collected within the fenced DSMF area. The DSMF is a paved area, so the surface soil samples were collected immediately below the concrete. Subsurface soil samples were collected at various depths up to 10 ft bgs. The samples were analyzed for VOCs, SVOCs, and metals. Low level VOCs, PAHs and metals were detected in surface and subsurface soil with delineation of impacts sufficient (**Figures 3-10** and **3-11**, respectively).

3.2.3.1 Surface Soil

The 2010 surface soil samples contained low level PAHs above the RSL and SSL. The highest concentrations were detected just below the concrete pad on the southwest side of Building 1160 in borings F39SB013 and F39SB010. PAHs were not detected in soil samples collected in 2011 from monitor well G4MW053 located on the opposite side of Building 1160, to the northeast. F39SB016 and F39SB015, collected to the northwest and southeast of F39SB013 and F39SB010 also did not contain detectable concentrations of PAHs.

Several metals were detected in the surface soil samples at concentrations similar to background levels. Lead was detected in the surface soil sample collected at F39SB009 at a concentration of 43 milligrams per kilogram (mg/kg) above the background concentration of 8.81 mg/kg and the MCL based SSL of 14 mg/kg.

3.2.3.2 Subsurface Soil

Subsurface soil samples collected in 2010 at F39SB001 through F39SB006, F39SB008, F39SB009, F39SB011, and F39SB012 were non detect or below the industrial soil RSL and the SSLs. Concentrations of benz(a)anthracene and benzo(b)fluoranthene exceeded the risk-based SSLs in the subsurface soil sample collected at F39SB007. The F39SB010 subsurface soil sample reported decreasing concentrations with depth with exceedances of the risk based SSL for benzo(a)anthracene and benzo(b)fluoranthene. Subsurface soil samples collected in 2011 at F39SB014, F39SB015, F39SB016, and G4MW053 were non detect or below the SSLs and industrial soil RSLs for PAHs. The concentration of 4-chlorobenzeneamine exceeded the risk-based SSL in the subsurface soil sample collected from F39SB015. Concentrations of several PAHs in the subsurface soil samples collected at F39SB013 and F39SB017 exceeded the SSLs, and the concentration of benzo(a)pyrene in both subsurface soil samples exceeded the industrial soil RSL.

Because concentrations of benzo(a)anthracene and benzo(b)fluoranthene exceeded the SSLs for the protection of groundwater, site-specific SSLs were calculated for those constituents in the RFI (ARCADIS 2014). A few of the detected concentrations of these constituents were slightly higher than the calculated site-specific SSLs. However, none of these constituents were detected in groundwater samples collected in this area, indicating that the constituents are not leaching to groundwater. Further, it is believed that the PAH impacts to soil are related to the HOTs and USTs located west of Building 1160. This area was historically used for vehicle washing and service and is covered by 12 inches of concrete to support the heavier Army vehicles. The highest PAH detections in soil were found just below

12 inches of concrete (along the southwest side of Building 1160) within fine sand below the concrete which would impede migration to groundwater. Moreover, the concentrations of PAHs in the subsurface soil samples decreased with depth, which is consistent with their Organic Carbon Partition Coefficient (K_{oc}) values that indicate a potential to absorb to soil rather than migrate to groundwater. Therefore, these constituents were not identified as COPCs for the leaching to groundwater pathway in the RFI. However, benzo(a)pyrene was identified as a COPC for the direct contact pathway (ARCADIS 2014).

The concentration of lead in the subsurface soil sample collected at F39SB009 from 3 to 3.5 ft bgs was below both the MCL-based SSL and the background value (11.1 mg/kg) at a concentration of 5.4 mg/kg, indicating that lead is not migrating downward towards groundwater. No other metals were detected in subsurface soils at concentrations exceeding the background concentrations. Low level VOCs, PAHs and metals were detected in surface and subsurface soil.

3.2.4 Surface Water and Sediment

A drainage canal parallels the southwestern DSMF fence line. A storm water outfall discharges from the DSMF into the drainage canal approximately halfway down the fenced area near Building 1161. Seven surface water and eight sediment samples were collected in 2010 (**Tables 3-1** and **3-2** respectively). The 2010 surface water and sediment investigations identified low level SVOC and VOC concentrations below the screening criteria in the drainage canal along the southern edge of the DSMF. Lead and mercury were detected in surface water at concentrations above the In-stream Water Quality Standard (IWQS) and arsenic was detected in the sediment above the residential soil RSL. Mercury was detected in only one surface water sample and was not detected in the adjacent upstream or downstream samples. Lead was detected in all of the surface water samples with the highest concentrations detected near the storm water outfall. The lead concentrations decreased downstream. Arsenic was detected in all of the sediment samples with the highest detection reported upstream adjacent to the rail lines. Both arsenic and lead are commonly found near rail lines. Historically, arsenic and/or lead have been used in old railroad ties, pesticides, and slag, used as railroad bed fill. Based on the close proximity of the rail lines to the drainage canal, it is believed that the metals detected in surface water and sediment are related to the rail lines and are not associated with the historical activities at SWMU 39.

3.3 Risk

Potential receptors were identified in the human health risk assessment, as presented in the RFI Report (ARCADIS 2014), and were summarized in **Section 2.7**. The risk driver for SWMU 39, as determined by the risk assessment, is exposure to TCE in groundwater by hypothetical future residents.

3.4 Contaminant Fate

3.4.1 Process Overview

The primary constituents in groundwater beneath the site are chlorinated VOCs that consist of PCE, TCE, DCE, and VC. The most significant processes that affect the fate and transport of these compounds in groundwater beneath the site are the natural attenuation processes. These processes include biodegradation, dispersion, dilution, sorption, volatilization, and transformation (USEPA 1997). Dual domain effects, the interchange between mobile and immobile porosity via diffusion, is also a process that retards contaminant movement beneath the site. The most significant of these processes that affect the transport of VOCs are dual domain, sorption and biodegradation, with biodegradation being the most significant mass reduction mechanism.

The analytical data from SWMU 39 groundwater samples indicate the presence of TCE degradation daughter products DCE and VC, demonstrating that TCE is being degraded via reductive dechlorination. During reductive dechlorination, more highly chlorinated compounds are reduced to less chlorinated forms and then eventually to harmless end products ethene, ethane, and carbon dioxide. TCE undergoes reductive dechlorination through the following primary pathway:

TCE → DCE → VC → Ethene → Ethane

3.4.2 SWMU 39- Specific Assessment

As discussed in **Sections 2 and 3**, SWMU 39 has two VOC plumes, one in the deep aquifer zone and one of lesser magnitude in the shallow aquifer zone. The PCE and TCE plumes at SWMU 39 appears to be undergoing natural attenuation through reductive dechlorination. The first line of evidence for reductive dechlorination is illustrated by the concentration trend of TCE and by the sustained presence of cis-1,2- DCE throughout the plume footprint. The deep zone impacts are higher in concentration relative to the shallow impacts with the most recent maximum concentration in the deep zone of 590 ug/L TCE in comparison to the shallow zone maximum of 33 ug/L TCE during the same sampling event. Other compounds have a comparable relationship for the shallow impacts versus the deep impacts. Generally the deep and shallow impact concentrations decrease along the plume flow paths downgradient from the higher concentration areas.

4. Justification and Approach for Corrective Action

4.1 Corrective Action Objectives

Based on the results of the risk assessments conducted for SWMU 39, the primary goal of the corrective action is protection of human health from the effects of potential future exposures to groundwater by ingestion. Currently, drinking water is supplied by the public system and the groundwater is not consumed as drinking water. There is no plan in the future to utilize groundwater as drinking water. As a result, there is no completed risk pathway and no immediate risk. HHRA results for potential future residents indicate some potential for risk; therefore, protection of human health is directly related to land use. The remedial response objective is to prevent possible future exposures by preventing groundwater consumption. Reducing the concentrations of PCE, TCE and its daughter products DCE and VC, as well as benzene and dissolved arsenic in groundwater to levels that are below USEPA MCLs is also an important goal.

This section develops the corrective action objectives (CAOs) that will provide the basis for evaluating the remedial alternatives that may be implemented at SWMU 39. The corrective action objectives are established to provide remedial goals for SWMU 39. As provided by USEPA in the RCRA Corrective Action Plan Guidance (USEPA 1994), these objectives include:

- Protection of human health and the environment.
- Attainment of media-specific cleanup standards.
- Control of source releases to reduce or eliminate to the extent practicable, further releases that may pose a threat to human health and the environment.
- Compliance with applicable standards for the management of wastes.

4.2 Evaluation of Remedial Levels

As presented in **Section 2**, investigation, evaluation, and risk assessment efforts were carried out for SWMU 39 surface soil, subsurface soil, surface water, groundwater, and sediment. Constituents exceeding USEPA MCLs in groundwater, surface soil and the presence of LNAPL in the DSMF area were identified as potential risks requiring further evaluation.

4.2.1 Remedial Levels for Groundwater

Groundwater remedial levels are based on the USEPA MCLs for Drinking Water (June 2015). The MCLs for constituents requiring remedial evaluation are:

- PCE – 5 µg/L
- TCE – 5 µg/L
- DCE – 70 µg/L
- VC – 2 µg/L
- Benzene – 5 µg/L
- Arsenic – 10 µg/L

4.2.2 Remedial Levels for Soil

Low level PAHs have been detected in the surface and subsurface soil near monitor wells G4MW001 and G4MW002. During the risk assessment, the exceeding pathway was the ELCR for a hypothetical future child resident as a result of direct contact with surface soil (0-1 ft bgs) and subsurface soil (1-8 ft bgs). All other calculated HIs and ELCRs are below the GAEPD acceptable risk levels. The GAEPD, in a response letter to Revision 3 of the RFI (GAEPD 2014), agreed that a target risk level of 1×10^{-5} was appropriate for this site because of the current use of the site as an active military base and the location of SWMU 39 in an area of the post that is strictly commercial/industrial rather than residential (Appendix A). There are no plans to change land use around SWMU 39 in the foreseeable future. Therefore, no remedial levels were developed for surface or subsurface soil.

However, LNAPL was detected in monitor wells G4MW001 and G4MW002. An evaluation of potential remedial alternatives to recover LNAPL near G4MW001 and G4MW002 will be completed as part of this CAP.

4.2.3 Remedial Levels for Surface Water and Sediment

Low level metals were detected in surface water and sediment in the drainage ditch next to the DMSF. It is believed that these are related to the adjacent rail line and not associated with the activities at SWMU 39. No remedial levels are recommended for the surface water and sediment.

4.3 Summary of Areas Requiring Remedial Evaluation

The areas requiring remedial evaluation are defined by the monitor wells containing Benzene, PCE, TCE, DCE, arsenic, and LNAPL and are all at levels above the USEPA MCL. Based on data from the VAP and monitor wells, an area of higher level PCE, TCE and DCE concentrations in deeper groundwater was identified upgradient of the DSMF with a diffuse low level PCE and TCE (<100 ug/L) plume present across much of the Site. **Table 4-1** identifies each well and its respective screen interval and **Table 4-2** presents the 2011 sampling data for Benzene, PCE, TCE, DCE, VC, and arsenic. **Figures 3-6** and **3-7** show the approximate areas within the shallow and deep zones of the aquifer where PCE, TCE, and DCE are greater than the MCL and require remedial evaluation. The area of groundwater requiring remedial evaluation is approximately 26 acres in the shallow zone and is approximately 17 acres in the deep zone.

5. Identification and Screening of Remedial Technologies

The first step in the corrective measures evaluation involves identification and initial screening of potentially applicable technologies for affected groundwater. In identifying and listing applicable technologies, consideration is given to the suitability of each remedial technology to meet the stated overall and media-specific corrective action objectives. The technologies considered can include innovative treatment technologies, if applicable. Innovative technologies are defined in the RCRA Corrective Action Plan Guidance (USEPA 1994) as "those technologies utilized for remediation other than incineration, solidification/stabilization, and pumping with conventional treatment for contaminated groundwater." Innovative treatment technologies may require extra effort to gather information, analyze options, conduct treatability studies or perform on-site pilot scale studies. Dissolved arsenic, which is above the MCL in two monitor wells, will be monitored during remedial action implementation. Additionally, all performance monitoring samples collected for analysis of concentrations of PCE, TCE and its daughter products will also be analyzed for benzene concentrations. Data trends will be presented in CAP progress reports and recomendations will be made for remedial actions if deemed necessary. Dissolved arsenic and benzene, which have relatively minor impacts at the site, were not included in the screening and selection of remedial technologies.

5.1 Screening Criteria

Three general criteria are used to perform initial screening of considered technologies: effectiveness, implementability, and cost. Further information regarding these criteria is provided below. The intent of the initial screening for effectiveness, implementability, and cost is to determine whether technologies and their specific process options would be retained for use in developing site-specific corrective action alternatives.

5.1.1 Effectiveness

This criterion evaluates if and to what extent the technology accomplishes the corrective action objectives, reduces overall risk and protects human health and the environment. The degree of permanence of the remedy is also evaluated with respect to reduction of toxicity, mobility, or volume, and the degree to which the technology provides sufficient long-term controls and reliability to prevent future exposures that exceed protective levels.

Corrective action remedies must be protective of human health and the environment. Remedies may include those measures that are needed to be protective, but are not directly related to media cleanup (e.g., providing alternate drinking water). Therefore, any short-term requirements that are necessary to achieve protection of human health and the environment are included in the effectiveness evaluation.

5.1.2 Implementability

The implementability criterion involves the technical and administrative feasibility of constructing, operating, and/or maintaining the technology/process option. Implementability is often a determining factor in the development of possible corrective action alternatives. Aspects such as local restrictions; required permits, approvals, or rights-of-way (either state or local); constructability; and availability of services, storage, off-site treatment, equipment, or materials are considered in the evaluation of implementability.

5.1.3 Cost

The cost criterion is used to provide comparative estimates of relative cost of the technologies considered. Relative costs are based on engineering judgment and are evaluated on a high, moderate, and low basis relative to the other technologies considered.

5.2 Identification and Screening of Corrective Action Technologies for Groundwater

The corrective action technologies listed in the following subsections were evaluated using the screening criteria. Elements that pertain to all actions include current land use, physical barriers, and topographic/natural features. The current land use at Fort Stewart is for military purposes and is expected to remain so in the near and distant future. Specifically, current and future use at SWMU 39 and surrounding wooded areas is industrial. There are no plans for residential land use at SWMU 39.

The physical barriers that exist at the site are the drainage canal, fencing, railroad tracks, utilities, and buildings. Natural features to be considered are the wetlands and tributaries of Mill Creek located near the DSMF of SWMU 39 and the steep topography in proximity to Mill Creek (**Section 2.3.1**).

5.2.1 Land Use Controls

LUCs are those corrective actions that control land use and site access through physical constraints, public agencies, and/or legal documents. As an active military base, site access is already controlled at SWMU 39. The LUCs considered include groundwater use restrictions and well installation prohibitions. Although LUCs are not considered a remedial technology, they can be essential in protecting human health and the environment and will be retained as components of remedial alternatives to be evaluated for SWMU 39.

In addition, although groundwater and surface water monitoring are also not remedial technologies, they are often used with remedial technologies to track the progress of remediation and/or ensure that the remedy selected remains protective of human health and the environment until the CAOs are achieved. Consequently, groundwater monitoring will be retained as a component of remedial alternatives under consideration for the Site.

5.2.2 Containment

Containment refers to mechanisms to control or prevent the movement of impacted groundwater. Containment can be in the form of physical barriers which are constructed using grout injection, slurry walls, and/or sheet piling or hydraulic barriers through use of extraction wells. Both of these types of barriers are designed to prevent further downgradient transport of groundwater.

Physical barriers are most effective for shallow plumes where a low-permeability geologic layer is present, and into which a barrier wall can be keyed. Physical barriers are generally used to control migration of impacted groundwater from source areas which, at SWMU 39, would be located near monitor wells G4MW041 and G4MW051 in the deep zone, and near the DSMF for the shallow zone. The depth of groundwater impacts at the deep zone is approximately 45 feet. Due to site infrastructure constraints such as rail lines, a physical barrier would be difficult to install that would effectively prevent the migration of impacted groundwater without disruption to base activities. Subsequently, physical barriers were not retained for further evaluation as a remedial technology for the Site.

Containment can also include hydraulic barriers where a system of horizontal or vertical extraction wells are positioned near the downgradient edge of impacted groundwater to control further migration of impacted groundwater away from the Site. A hydraulic barrier would be installed downgradient of the areas of highest concentration to prevent COCs in impacted groundwater from discharging to the tributaries and associated wetlands located south of SWMU 39. The components of a hydraulic barrier system would include an extraction system (wells or interceptor trenches), above-ground treatment system, and disposal system. Hydraulic barriers are retained as a alternative and are discussed in greater detail in the sections below.

5.2.3 Collection

Collection refers to groundwater extraction systems that are designed to remediate a groundwater plume or to form a hydraulic barrier to prevent further downgradient movement of COCs. Collection is generally accomplished via horizontal or vertical extraction wells and/or interceptor trenches. An extraction-well system would be located in the immediate vicinity of, and downgradient from, the suspected source area east of the DSMF to remediate the COC impacted groundwater using groundwater collection, treatment, and disposal. In this area, the depth to groundwater and the depth to TCE-impacted groundwater would preclude the use of horizontal wells and/or interceptor trenches. The only means of groundwater extraction in this area is vertical wells.

Horizontal wells and/or interceptor trenches could be incorporated into a hydraulic barrier system located further downgradient from the DSMF, at lower land surface elevations to prevent discharge of COC-impacted groundwater to surface water. However, implementation of these technologies in the downgradient areas may be difficult due to access and constructability issues within a heavily wooded area and area of wetlands. For these reasons, a system of vertical extraction wells may be preferred.

Although vertical extraction wells could be installed as a means of extracting TCE impacted groundwater, their effectiveness may be limited due to the hydraulic conductivity of the aquifer. As presented earlier in this report, slug testing yielded conductivity ranges from 10^{-3} to 10^{-5} cm/sec near the deep treatment zone. Due to the proximity of the shallow and deep plumes for PCE and TCE, placing two separate extraction systems for each zone would need to be considered for implementation.

Collection via vertical extraction wells is retained as a technology alternative for the Site.

5.2.4 Disposal

Disposal is generally accomplished by discharges of extracted groundwater to publicly owned treatment works (POTW), beneficial re-use discharge, discharge to surface waters, and groundwater reinjection. Discharge to a POTW may not be possible due to the proximity of a discharge point and limited capacity of Fort Stewart's POTW and is not retained. There is a lack of beneficial reuse options on base. Re-injection may be problematic in the shallow zone due to the generally low permeability of the aquifer but is retained for the deep plume. Consequently, discharge to surface water in accordance with a National Pollutant Discharge Elimination System (NPDES) permit would be the most likely disposal option for a groundwater extraction and above-ground treatment alternative.

5.2.5 Ex-situ Treatment

Ex-situ treatment consists of aboveground treatment systems that may be required prior to disposal of extracted groundwater and/or treatment of vapors. Ex-situ treatment includes air stripping, granular carbon adsorption, gravity oil/water separator, thermal oxidation, and catalytic oxidation. For groundwater impacted with PCE and TCE, the treatment technologies that are most applicable are air stripping and carbon adsorption. Air stripping may require pretreatment for dissolved iron and carbon adsorption would require pretreatment for dissolved iron to maximize the effectiveness of the granular activated carbon (GAC).

The treated groundwater may also be required to meet standards imposed by a NPDES permit. Air stripping and carbon adsorption for treatment of extracted groundwater prior to disposal have both been retained.

5.2.6 In-situ Treatment

In-situ treatment consists of physical, chemical or biological systems that are implemented in-situ to treat impacted groundwater systems. Physical in-situ treatment systems include aquifer sparging/soil vapor extraction (SVE), in-well stripping, and thermal heating. The presence of a clay unit in the deep zone of the area of greatest impact makes air sparging and in well stripping difficult to implement effectively. Subsequently, air sparging and in well stripping are not retained for further evaluation as a remedial technology.

Chemical in-situ treatment includes ozone oxidation, Fenton's Reagent oxidation, persulfate oxidation, and permanganate oxidation. For purposes of this evaluation, zero-valent iron (ZVI) is also considered for chemical in-situ treatment. All of these chemical in-situ treatment technologies require direct contact between the dissolved-phase COC and the reactive media (i.e., oxidant or ZVI). Furthermore, the majority of available oxidants such a Fenton's Reagent (hydrogen peroxide) have rapid reaction kinetics that result in reduced longevity after injection. ZVI is deployed in the solid-phase either through installation of a permeable reactive barrier or via injection. The depth to impacted groundwater precludes installation of a permeable reactive barrier near the railroad using ZVI. Chemical in situ treatment via persulfate oxidation is retained for further evaluation as a remedial technology for the deep zone. Persulfate has less rapid reaction kinetics and more longevity in-situ than many available oxidants. Because of the low concentrations over a large area in the shallow zone, in situ chemical oxidation would be difficult to implement and cost inefficient in the shallow zone.

Biological in-situ treatment includes monitored natural attenuation (MNA), anaerobic bioremediation, aerobic bioremediation, and phytoremediation. MNA is the reliance on naturally occurring attenuation that is coupled with groundwater monitoring to document remedial progress and track the capacity of natural attenuation to achieve the remedial objectives. MNA, with biotransformation via reductive dechlorination being the predominant degradation mechanism, has been documented at the Site as discussed earlier in this CAP. Consequently, MNA will be retained for further evaluation as a remedial technology. PCE and TCE are not amenable to aerobic biodegradation and aerobic based technologies are not retained.

Phytoremediation can only occur at this Site near groundwater discharge areas since the depth to groundwater in other areas is beyond the capabilities of root systems to intercept the groundwater. Phytoremediation is not retained for further evaluation.

Anaerobic bioremediation is suitable for treatment of PCE and TCE and would be implemented by injection of a carbon substrate into impacted groundwater. Potential carbon substrates include molasses, lactate, whey and/or emulsified vegetable oil (EVO). Anaerobic bioremediation is an enhancement of natural attenuation processes and is often referred to as enhanced reductive dechlorination (ERD). Implementation of ERD would require a system of injection wells or a trench to deliver the carbon substrate to the zone targeted for remediation. EVO is a longer acting carbon substrate that requires less frequent injection in comparison to other substrates. ERD using EVO was retained for further evaluation as a remedial technology for the deep zone impacts. Because of the low concentrations over a large area in the shallow zone, ERD would be difficult to implement and would not be cost effective in the shallow zone.

5.3 Identification and Screening of Corrective Action Technologies for LNAPL

5.3.1 Land Use Controls

LUCs are those corrective actions that control land use and site access through physical constraints, public agencies, and/or legal documents. As an active military base, site access is already controlled at SWMU 39. The LUCs considered include site restrictions and a site management plan. Although LUCs are not considered a remedial technology, they can be essential in protecting human health and the environment and will be retained as components of remedial alternatives to be evaluated.

5.3.2 Removal

For LNAPL, excavation is the primary removal technology. Excavation of the soil matrix containing the LNAPL would be highly effective in removing the source mass. Because of the infrastructure and ongoing activities, this option could be costly and intrusive.

Material that is removed would be transported off site for disposal. Treatment on site would be much more expensive and time consuming than off site disposal and is not retained further. Excavation with off site disposal is retained for further evaluation.

5.3.3 In-situ Physical Recovery and Treatment

In-situ physical treatments include collection with absorbent socks, recovery with soil vapor extraction and recovery thru LNAPL collection wells with specialized pumps. The LNAPL at the site is weathered with less volatile organic mass such that recovery thru soil vapor extraction would not be effective. Because of the small area impacted by LNAPL, additional wells for LNAPL recovery would not be beneficial. The mobile fraction of LNAPL is likely a small portion of the residual LNAPL and there may be no significant movement of LNAPL to a product recovery well. A product recovery pump in a well could recover LNAPL that flows into the well but would require infrastructure and maintenance. An LNAPL absorbent sock could also recover LNAPL that flows into a well. Both recovery methods are retained for further evaluation.

6. Corrective Action Alternatives

Tables 6-1 and 6-2 summarize the process options screening summary for groundwater and LNAPL respectively. Based on the retained technologies, the following corrective action alternatives (CAA) were assembled for further evaluation:

- CAA 1: No Action
- CAA 2: Land Use Controls, Monitored Natural Attenuation, Excavation of Surface Soil and LNAPL, and In-Situ Chemical Oxidation (ISCO).
- CAA 3: Land Use Controls, Monitored Natural Attenuation, Passive LNAPL Recovery, and ERD.
- CAA 4: Land Use Controls, Monitored Natural Attenuation, Active LNAPL Recovery, Deep Groundwater Recirculation System, and a Shallow Groundwater Extraction System

6.1 Evaluation Criteria

A more in-depth evaluation of the CAAs was conducted to further assess:

- Effectiveness – long-term reliability and effectiveness; reduction in toxicity, mobility and volume of PCE and TCE-impacted groundwater;
- Implementability – specific implementability, short-term effectiveness, effect on natural resources; and
- Cost – detailed, site-specific cost.

The effectiveness of each proposed remedial alternative to protect human health and the environment is dependent primarily on its ability to prevent ingestion of COC-impacted groundwater, ensure that discharges of COC-impacted groundwater do not exceed the MCLs, and to reduce the concentration of PCE, TCE and daughter products in groundwater without adversely affecting the aquifer or geologic formation.

Implementability is often a determining factor in remedy selection. Aspects of specific implementability to a given site include: permitting or local approval, physical barriers or restrictions, the ability to implement without causing adverse effects, constructability; time required for implementation and results, and availability of necessary equipment, materials or disposal options.

Life-cycle costs are included as a criterion for evaluation to obtain a realistic understanding of the capital construction, operation and maintenance (O&M), administrative requirements, engineering design, and contingency. A detailed present-worth cost estimate of each corrective action alternative was prepared to obtain an accuracy of +50 percent to –30 percent. The cost estimate includes an analysis of both direct (construction) and indirect (non-construction and overhead) capital costs, and operation, maintenance and monitoring (OMM) costs as applicable.

6.2 Description and Screening of Corrective Action Alternatives

Based on the screening of technologies, four remedial alternatives have been developed for detailed analysis as presented below. According to the risk assessment, current use scenarios do not pose a risk based on ELCR and Hazard Index (HI) calculated values. ELCR values exceeded USEPA benchmarks for the hypothetical future child resident and future 30-year adult resident. HI values for hypothetical future adult and child residents and future 30-year resident exceeded USEPA benchmarks. The current land use is military and there are no plans for future long-term residents in the vicinity of SWMU 39. **Table 6-3** summarizes the Corrective Action Alternatives Screening.

6.2.1 Remedial Alternative CAA-1: No Action

For this alternative, no action would be taken in regards to remediation, monitoring, or institutional controls. The Site would be left in its present condition. This alternative serves as a baseline for comparison to the other CAAs presented.

6.2.1.1 Effectiveness

Remedial Alternative CAA-1 is not effective. It would not be protective of public health, safety and welfare and the environment as it would not mitigate exposure to risks mentioned previously. A course of no action would not prevent the contaminant plume from migrating further downgradient, which would potentially affect areas outside the Site boundaries.

6.2.1.2 Implementability

This remedial alternative is easily implementable.

6.2.1.3 Cost

There is no cost associated with this alternative.

6.2.2 Remedial Alternative CAA-2: Land Use Controls, Monitored Natural Attenuation, Excavation of Soil and LNAPL, and ISCO

Remedial Alternative CAA-2 includes LUCs to prohibit installation of water wells within or downgradient of SWMU 39, excavation of soil and localized LNAPL, ISCO via injection of an oxidant such as sodium persulfate into the deep source zone and MNA. Under this alternative, LUCs would entail prohibition of potable water well installation and prohibition of groundwater consumption to address unacceptable potential risks to hypothetical future adult and child residents exposed to groundwater via ingestion. Although the shallow nature and hydraulic conductivity of the impacted aquifer likely makes it unsuitable for potable water wells, restrictions would be applied to provide assurances that potable use of groundwater does not occur. Restrictions would remain in place until groundwater quality is consistently below MCLs for PCE, TCE, DCE, VC, and benzene. Implementation of ICs is already included in Fort Stewart's existing installation planning process which requires approval from the Directorate of Public Work Environmental Division prior to installation of water wells. The LUC Plan would restrict the installation of potable and/or drinking water wells near SWMU 39. As stated in **Section 4.2.2**, remedial action levels were not developed for soil. The soil where the low level PAHs were detected is currently capped by 12 inches of concrete thereby preventing direct exposure to the soil or leaching to groundwater. PAHs were not detected in the groundwater. Based on the concrete cap, and the low levels detected in soil, LUCs are recommended to ensure maintenance of the current concrete and continued use restrictions.

Remedial Alternative CAA-2 includes excavation of the area surrounding G4MW001 and G4MW002, where LNAPL was recently observed. The excavation would remove the LNAPL and impacted soils. The extent of the LNAPL and excavation area is shown in **Figure 6-1**. Based on current data on the extent of the LNAPL, the excavation will be approximately 16 ft long, 16 ft wide and 9 ft deep (~3 ft below the water level). As shown in **Figure 6-1**, part of a building falls within the excavation area. Thus, the building must be demolished to ensure that all LNAPL has been removed. This building is an open air structure consisting of a roof and supports with a 4,000 gallon concrete vault (filled with grout) beneath the roof.

Groundwater would be remediated by a combination of natural attenuation and ISCO. ISCO introduces oxidizing compounds to the aquifer for the purpose of chemically destroying contaminants. ISCO would be deployed for remediation of the deep source zone through a network of injection wells within the confines of the railroad tracks and Veterans Parkway. MNA would be relied upon to treat residual COCs in the shallow zone and downgradient areas to achieve the CAOs. The oxidizing chemistry that would most likely be optimal is sodium persulfate (oxidizer) and an activator such as sodium hydroxide. In the treatment area, sodium persulfate and sodium hydroxide would be injected into a well network within the vicinity of G4MW041 and G4MW051.

The approximate location of the deep zone injection well network is shown on **Figure 6-2** and would consist of 13 injection wells installed on 30 foot centers. The interval targeted for injection would be 30-45 feet bgs. The injection wells would be installed with 10 foot well screens to depths of up to 45 ft bgs.

A temporary above-ground injection system would be constructed to deliver the ISCO solution to the injection wells in the treatment area. It is envisioned that solid sodium persulfate and liquid sodium hydroxide would be mixed with water to a predetermined dilution ratio within two separate tanks. Each compound would be injected and mixed in-line. The solution could potentially be delivered to all 13 injection wells concurrently via gravity feed as long as flow rates remain above approximately 0.5 gallons per minute (gpm) per well. If the flow rate drops below 0.5 gpm per well, solution will be injected into the wells under low pressure via pumps. Three injection events are projected at an estimated frequency of one event every two year.

A groundwater monitoring program would be implemented to track the progress of remediation, to ensure that conditions remain favorable for continued natural attenuation, and to determine when the CAOs have been achieved. The long-term monitor well network would incorporate some of the existing monitor wells plus newly installed monitor wells as necessary. Low-flow or no-purge sampling technology will be used to collect groundwater samples for VOCs and other analytes.

6.2.2.1 Effectiveness

Prohibiting groundwater consumption and the installation of potable water wells is an effective approach to protect human health. LUCs restrictions, which are defined in Paragraph 7.5, would mandate the use of an alternate water supply which is already in place and utilized at Fort Stewart. This aspect of CAA-2 accomplishes the CAOs to reduce overall risk and protect human health and the environment during remedy implementation. After the CAOs are achieved, restrictions could be removed. However, groundwater use restrictions would remain in effect as long as Fort Stewart remains a military installation.

ISCO using sodium persulfate and sodium hydroxide in the immediate vicinity of the wells where PCE and TCE have most impacted the aquifer historically, along with MNA in the shallow and peripheral areas would provide for a reduction in toxicity and volume of PCE, TCE and related daughter products in groundwater. ISCO would chemically destroy these products in the deep groundwater zone (**Figure 6-2**). Effectiveness of ISCO using sodium persulfate and sodium hydroxide at SWMU 39 is directly related to the ability to inject the solution into the designated treatment zones. This effectiveness may be compromised by the variable geology of the proposed treatment zone. As mentioned earlier in this CAP, slug testing from January 2011 yielded hydraulic conductivity data ranging from 10^{-3} to 10^{-5} cm/sec. ISCO may inhibit the ongoing natural biodegradation of COCs in some areas of the Site.

Remedial Alternative CAA-2 includes groundwater monitoring to track continued attenuation of groundwater COCs. The monitoring program would demonstrate the long-term reliability and effectiveness of the remedy.

6.2.2.2 Implementability

The LUCs proposed in CAA-2, which are delineated in Paragraph 7.5, are implementable. Some of the necessary LUCs are currently incorporated into Fort Stewart's existing installation planning process.

The equipment required to inject the ISCO solution includes tanks to mix the chemicals and a series of pumps, flow meters, control valves, and pressure gauges to inject the solution. These are all readily obtainable. The solid sodium persulfate would be purchased in bags and delivered on pallets directly to the site. The liquid sodium hydroxide would be purchased in drums and delivered directly to the site. Injection wells can be drilled to the target depths and the permits needed to implement this technology are obtainable. The ISCO solution can likely be injected into the treatment zones although injection rates may be low (<1 gpm).

Groundwater monitoring has been conducted in the area of SWMU 39 and can be implemented for the anticipated duration of the remediation period. The plume exists in an industrial area of the site, far from the downgradient base property line, and has shown no evidence of migrating downgradient. CAA 2 would have some adverse effects on natural resources associated with construction activity, including constructing the infrastructure associated with the ISCO system and the access routes.

6.2.2.3 Cost

The cost for this alternative, assuming a time to achieve CAOs of 30 years, is approximately $2,478,665 with a present worth of $1,655,623 as summarized in **Appendix B**.

6.2.3 Remedial Alternative CAA-3: Land Use Controls, Monitored Natural Attenuation, Absorbent Socks, and ERD

Similar to Remedial Alternative CAA-2, Remedial Alternative CAA-3 includes LUCs to prohibit installation of water wells within or downgradient of SWMU 39. Under this alternative, LUCs, as delineated in Paragraph 7.5, would entail prohibition of potable well installation and prohibition of groundwater consumption to address unacceptable potential risks to hypothetical future adult and child residents exposed to groundwater via ingestion. Although the shallow nature and hydraulic conductivity of the aquifer makes it unsuitable for potable water wells, restrictions would be applied to provide assurances that potable use of groundwater does not occur. Restrictions would remain in place until groundwater quality is consistently below MCLs for PCE, TCE, DCE, VC, and benzene. Some of the necessary restrictions are currently included in Fort Stewart's existing installation planning process which requires approval from the Directorate of Public Works Environmental Division prior to installation of water wells within the Base. The LUC Plan would restrict the installation of potable and/or drinking water wells near SWMU 39. As stated in **Section 4.2.2**, remedial action levels were not developed for soil. The soil where the low level PAHs were detected is currently capped by 12 inches of concrete thereby preventing direct exposure to the soil or leaching to groundwater. PAHs were not detected in the groundwater. Based on the concrete cap, and the low levels detected in soil, ICs are recommended to ensure maintenance of the current concrete and continued use restrictions.

Historical data shows that daughter products DCE and VC from the natural attenuation of PCE and TCE are present throughout the plume, indicating that the processes of natural attenuation are working to reduce the concentration of PCE and TCE. This alternative would document that these processes continue to remain active in reducing the extent and concentration of PCE and TCE in groundwater until achievement of CAOs.

Groundwater would be remediated by a combination of natural attenuation and ERD. The implementation of ERD would occur as a network of injection wells within the confines of the railroad tracks and Veterans Parkway for the deep zone source area (**Figure 6-3**). MNA would be relied upon to treat residual COCs in the shallow zone and the downgradient areas to achieve the CAOs. The carbon substrates that may be used to enhance the naturally occurring reductive dechlorination include molasses, lactate, and EVO or a combination of these substrates. EVO is selected as the optimal substrate based on the slow dissolution rate which allows less frequent injections and less disruption to facility operations. EVO will be injected into the well network within the vicinity of G4MW041 and G4MW051. Baseline monitoring, which will include analysis of VOCs and light gases (methane, ethane and ethene) will be utilized to assess the extent of the naturally occurring reductive dechlorination. If incomplete dechlorination is occurring, indicated by a lack of VC and light gases, the first injection may include a soluble carbon donor (e.g., molasses or lactate) in addition to the EVO to provide a higher available concentration of substrate for initial utilization. Due to the low solubility and dissolution rate of EVO, subsequent injection events would be completed 18-24 months apart. The injection frequency will be based on the utilization rate of the carbon as measured by performance monitoring.

The approximate location of the deep zone injection well network is shown on **Figure 6-3** and would consist of 2 transects of 3 injection wells each installed on 30 foot centers. The injection wells would be installed with 10 foot screen sections to depths of up to 45 ft bgs.

A temporary above-ground injection system would be constructed to deliver the EVO solution to the injection wells. The system would be constructed on a mobile trailer to allow for movement across the site area. It is envisioned that the EVO would be premixed with water to a predetermined dilution ratio in 10,000 gallon Baker™ tanks. The EVO solution would potentially be delivered to all 6 injection wells simultaneously via gravity feed as long as flow rates remain above approximately 0.5 gpm per well. If the flow rate drops below 0.5 gpm per well, solution will be injected into the wells under pressure via pumps. Injection strategy would be adjusted based on the actual injection rates. Three injection events are projected at an estimated frequency of one every two years.

As mentioned in Remedial Alternative CAA-2, LNAPL was observed in the area of G4MW001 and G4MW002. To effectively recover LNAPL located in and around G4MW001 and G4MW002, Remedial Alternative CAA-3 includes the installation of absorbent socks in the two wells. Based on 2015 liquid level data, G4MW002 had 1.12 feet of product and G4MW001 had 0.08 feet of product (**Table 2-1**). Intervals for change outs of absorbent socks will be adjusted based on the rate of the LNAPL recharge.

A groundwater monitoring program would be implemented to track the progress of remediation, to ensure that conditions remain favorable for continued natural attenuation, and to determine when the CAOs have been achieved. The long-term monitor well network would incorporate existing monitor wells plus monitor wells installed as part of the active remedy. Low-flow or no-purge sampling technology will be used to collect groundwater samples for VOCs and other analytes.

6.2.3.1 Effectiveness

Prohibiting groundwater consumption and the installation of potable water wells is an effective approach to protect human health. Restrictions would mandate the use of an alternate water supply which is already in place and utilized at Fort Stewart. This aspect of CAA-3 accomplishes the CAOs to reduce overall risk and protect human health and the environment during the period of remediation. After the CAOs are achieved, restrictions could be removed. However, groundwater use restrictions would remain in effect as long as Fort Stewart remains a military installation. All necessary controls and restrictions are included in Paragraph 7.5.

ERD using EVO as a carbon substrate in the immediate vicinity of the wells where PCE and TCE have most impacted the aquifer historically (source), along with MNA in the shallow zone and downgradient areas would provide for a reduction in toxicity and volume of PCE, TCE and related daughter products in groundwater. Natural processes are currently reducing PCE and TCE to its daughter products. Successful delivery of carbon donor in deep groundwater in the most impacted areas (**Figure 6-3**) would enhance these processes. Effectiveness of ERD at SWMU 39 is directly related to the ability to inject the solution into the designated treatment zones. As mentioned earlier in this CAP, slug testing from January 2011 yielded hydraulic conductivity data ranging from 10^{-3} to 10^{-5} cm/sec. The injection well network in the deep zone has 30 foot spacing for the transects perpendicular to groundwater flow (15 ft radius of influence [ROI]).

Absorbent socks would be effective at removing LNAPL from the groundwater and surrounding soil. Frequent change outs of absorbent socks may be required for efficient removal. If the recovery rate is high enough to require frequent removal events, a skimming system that operates on solar power (i.e. solar sipper) will be installed to optimize the total LNAPL recovery while reducing maintenance time on site.

Remedial Alternative CAA-3 includes groundwater monitoring to track continued attenuation of groundwater COCs. The monitoring program would demonstrate the long-term reliability and effectiveness of the remedy.

6.2.3.2 Implementability

The ICs proposed in CAA-3 are implementable. All required controls and restrictions are included in Paragraph 7.5.

The equipment required to inject the EVO is commonly available and includes tanks to mix the emulsion, and a series of pumps, flow meters, control valves, and pressure gauges for injection. The EVO would be delivered directly to the site. Injection wells can be drilled to the target depths and the permits needed to implement this technology are obtainable. EVO solution can likely be injected into the treatment areas with screen intervals set in more permeable zones.

Groundwater monitoring has been conducted at SWMU 39 and can be implemented for the anticipated duration of the remediation period. The plume exists in an industrial area of the site, far from the downgradient base property line, and has shown no evidence of migrating downgradient. CAA-3 would have some adverse effects on natural resources associated with construction activity, including constructing the infrastructure associated with the ERD system and the access routes.

Utilizing absorbent socks as a passive LNAPL recovery method would be implementable. Absorbent socks are easily obtainable and installed. By completing removal of the LNAPL through the use of the existing wells without removal of the building structure, the area can be used by the Army as currently configured with minimal disruptions to current operations and removal can be completed concurrently with other remedial actions.

6.2.3.3 Cost

The cost for this alternative, assuming a time to achieve CAOs of 30 years, is approximately $2,149,592 with a present worth of $1,261,010 as summarized in **Appendix B**.

6.2.4 Remedial Alternative CAA-4: Land Use Controls, Monitored Natural Attenuation, Active LNAPL recovery, Deep Groundwater Recirculation System, and a Shallow Groundwater Extraction System

Similar to Remedial Alternatives CAA-2 and CAA-3, Remedial Alternative CAA-4 includes ICs to prohibit installation of water wells within or downgradient of SWMU 39. Under this alternative, ICs would entail prohibition of potable water installation and prohibition of groundwater consumption to address unacceptable potential risks to hypothetical future adult and child residents exposed to groundwater via ingestion. Although the hydraulic conductivity of the aquifer makes it unsuitable for potable water wells, restrictions would be applied to provide assurances that potable use of groundwater does not occur. Restrictions would remain in place until groundwater quality is consistently within MCLs for PCE, TCE, DCE, VC, and benzene. All restrictions would be defined in the LUCs that would be submitted to GAEPD for approval. Some LUCs are included in Fort Stewart's existing installation planning process which requires approval from the Directorate of Public Works Environmental Division prior to installation of water wells within the Base. The LUCs would restrict the installation of potable and/or drinking water wells near SWMU 39. As stated in **Section 4.2.2**, remedial action levels were not developed for soil. The soil where the low level PAHs were detected is currently capped by 12 inches of concrete thereby preventing direct exposure to the soil or leaching to groundwater. PAHs were not detected in the groundwater. Based on the concrete cap, and the low levels detected in soil, ICs are recommended to ensure maintenance of the current concrete and continued use restrictions.

Groundwater would be remediated by a combination of natural attenuation, groundwater extraction and groundwater reinjection. The deep zone would utilize a groundwater extraction and reinjection system to extract, treat, and re-inject groundwater to create a hydraulic gradient. Reinjection of treated groundwater can accelerate remediation through changing the hydraulic gradient and increasing pore flush exchange. The groundwater extraction and reinjection system, two extraction wells and six injection wells, would be deployed within the confines of the railroad tracks and Veterans Parkway. MNA would be relied upon to treat residual COCs in the downgradient areas to achieve the CAOs. Two GAC units (one lead, one lag) and a low-profile air stripper would be used to treat the influent groundwater. A multimedia filter would also be a part of the treatment system to remove any large particles in the influent groundwater in order to maximize efficiency of the GAC units and the air stripper. The effluent groundwater would then be injected in the vicinity of G4MW041 and G4MW051.

The shallow zone would utilize a similar extraction system as the deep zone, but would not include the reinjection portion of the technology. Two GAC units (one lead, one lag) and a low-profile air stripper would be used to treat the influent groundwater. A multimedia filter would also be a part of the treatment system to remove any large particles in the influent groundwater in order to maximize efficiency of the GAC units and the air stripper. The effluent groundwater would then be discharged to surface water drains, located around the perimeter of the buildings, which would require NPDES permitting. MNA would be relied upon to treat residual COCs in the downgradient areas to achieve the CAOs.

Testing may be required prior to full-scale design to confirm the installation locations of the extraction and injection wells, to develop design parameters for full-scale systems, and to perform pump tests on both zones to ensure that a gradient can be created in both zones. The approximate location of the deep zone extraction and reinjection well network is shown on **Figure 6-4**. The deep well network would consist of six injection wells installed on 20 foot centers, and two extraction wells installed on 50 foot centers. The interval targeted for extraction and reinjection would be 30-45 feet bgs. The injection and extraction wells would be installed with 10 foot well screens at depths of 45 ft bgs based on geology and coincidence of impacts. The extraction wells would have a larger diameter (no less than 4-inches) than the injection wells in order to maximize the productivity of each well, thus, influencing more groundwater. The approximate location of the shallow zone extraction transect is shown on **Figure 6-5**. The shallow well network would consist of 10 extraction wells installed on 50 foot centers. The interval targeted for extraction would be 2-15 ft bgs. The extraction wells would be installed with 10 foot well screens (5 to 15 ft bgs).

To house all equipment for the extraction systems, treatment buildings will be constructed for both systems. Excavation would be required to lay piping going from the treatment buildings to the respective extraction/injection wells for both systems. Trenches would be dug to a depth of 3 ft bgs, and piping would be installed. After each length of pipe is installed, the trench will be backfilled with native material. Well vaults would be installed at each extraction and injection well for both systems. The shallow and deep systems will draw groundwater from all extraction wells concurrently. The deep recirculation system will inject the treated groundwater into all six injection wells as long as the effluent groundwater meets remedial levels. The groundwater recirculation system would also be designed to allow for the addition of an amendment to the injected groundwater (e.g. carbon donor or oxidant). Based on the hydrogeology in the deep treatment area, two extraction wells are expected to influence all six injection wells. The extraction well transects would be designed to capture the groundwater flux, thus eliminating migration beyond the extraction transect.

As mentioned in Remedial Alternatives CAA-2 and CAA-3, LNAPL was observed in an area surrounding G4MW001 and G4MW002. To effectively recover LNAPL located in and around G4MW001 and G4MW002, Remedial Alternative CAA-4 includes active LNAPL recovery via bladder pumps. LNAPL from G4MW001 and G4MW002 would be extracted using the bladder pump and disposed of off-site at an approved disposal facility. G4MW001 and G4MW002 would continue to be pumped on a regular basis until LNAPL is no longer present.

A groundwater monitoring program would be implemented to track the progress of remediation, to ensure that conditions remain favorable for continued natural attenuation, and to determine when the CAOs have been achieved. The long-term monitor well network would incorporate some of the existing monitor wells plus new monitor wells installed as part of the active remedy. Low-flow sampling technology will be used to collect groundwater samples for VOCs and other analytes.

6.2.4.1 Effectiveness

Prohibiting groundwater consumption and the installation of potable water wells is an effective approach to protect human health. Restrictions would mandate the use of an alternate water supply which is already in place and utilized at Fort Stewart. This aspect of CAA 4 accomplishes the CAOs to reduce overall risk and protect human health and the environment during the period of remediation. Once the CAOs are achieved, restrictions could be removed. Groundwater use restrictions would be effective as long as Fort Stewart remains a military installation. Restrictions are delineated in Paragraph 7.5.

Groundwater extraction and reinjection systems implemented in the immediate vicinity of the wells where PCE and TCE have most impacted the aquifer historically, along with MNA in the downgradient areas would provide for a reduction in toxicity and volume of PCE, TCE and related daughter products in groundwater. Natural processes are currently underway to degrade PCE, TCE and its daughter products. Effectiveness of extraction and reinjection systems at SWMU 39 is related to the ability to extract and inject the groundwater (enhance pore flushing) in the designated treatment zones. As mentioned earlier in this CAP, slug testing from January 2011 yielded hydraulic conductivity data ranging from 10^{-3} to 10^{-5} cm/sec.

Active LNAPL recovery via bladder pump would be an effective method for removing the LNAPL around G4MW001 and G4MW002.

6.2.4.2 Implementability

The LUCs proposed in CAA-4 are implementable. All restrictions and controls are defined in Paragraph 7.5.

To implement the recirculation system, extraction and injection wells would be installed. Construction of a treatment building would be required for housing the GAC vessels and other pertinent treatment equipment. Trenching would be required to connect the reinjection and extraction wells to the treatment system. The equipment required for the recirculation system is obtainable.

Utilization of a bladder pump as an active LNAPL recovery method can be implemented. The only equipment required would be a pump, tubing, air compressor and a disposal tank, which are readily obtainable.