Prepared for

Anniston-Calhoun County
Fort McClellan Joint Powers Authority
Anniston, Alabama

FINAL CORRECTIVE MEASURES IMPLEMENTATION (CMI) PLAN FOR GROUNDWATER

LANDFILL 3, PARCEL 80(6) AND FILL AREA NORTHWEST OF REILLY AIRFIELD, PARCEL 229(7)

McCLELLAN, ANNISTON, ALABAMA

Prepared by

Geosyntec consultants

engineers | scientists | innovators

1255 Roberts Boulevard, Suite 200
Kennesaw, Georgia 30144

In cooperation with

Matrix Environmental Services, L.L.C.
Integrated Environmental Solutions

1601 Blake Street
Suite 200
Denver, CO 80202

Project Number GR4116

August 2008

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

1,1,2,2-TeCA	1,1,2,2-Tetrachloroethane
1,1,2-TCA	1,1,2-Trichloroethane
1,2-DCA	1,2-Dichloroethane
ADEM	Alabama Department of Environmental Management
ARBCA	*Alabama Risk-Based Corrective Action Guidance Manual*
AHWMMA	Alabama Hazardous Waste Management and Minimization Act (AHWMMA)
Army	United States Department of the Army
bgs	below ground surface
BRAC	Base Realignment and Closure
c12DCE	cis-1,2-Dichloroethene
CA	Chloroethane
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/sec	Centimeters per Second
CMI Plan	Corrective Measures Implementation Plan
COC	Constituent of Concern
COPC	Constituent of Potential Concern
CSM	Conceptual Site Model
DGGE	Denaturing Gradient Gel Electrophoresis
DNAPL	Dense, Non-Aqueous Phase Liquid
DO	Dissolved Oxygen
DOD	U.S. Department of Defense
DQS	Data Quality Summary
EBS	Environmental Baseline Study
EDTA	Ethylenediamine Tetraacetic Acid
EE/CA	Engineering Evaluation/Cost Analysis
EISB	Enhanced *In Situ* Bioremediation
EPA	U.S. Environmental Protection Agency
ESCA	Environmental Services Cooperative Agreement
ESE	Environmental Science & Engineering, Inc.
EVO	Emulsified Vegetable Oil
FANWR	Fill Area Northwest of Reilly Airfield, Parcel 229(7)
FOSET	Finding of Suitability for Early Transfer
FOST	Finding of Suitability for Transfer

ft	Feet
ft/day	Feet per Day
ft/yr	Feet per Year
g/L	Grams per Liter
Geosyntec	Geosyntec Consultants
HI	Hazard Index
HQ	Hazard Quotient
ILCR	Incremental Lifetime Cancer Risk
ISCO	*In Situ* Chemical Oxidation
JPA	Joint Powers Authority
LF3	Landfill 3, Parcel 80(6)
LIDAR	Light Detection and Ranging
LUCIP	Land Use Control Implementation Plan
McClellan	Fort McClellan
MDC	Maximum Detected Concentration
MES	Matrix Environmental Services, LLC
mg/L	Milligrams per Liter
MNA	Monitored Natural Attenuation
NaOH	Sodium Hydroxide
NCP	National Contingency Plan
NFA	No Further Action
ORP	Oxidation-reduction potential
PCE	Tetrachloroethene
POE	Point of Exposure
QAP	Quality Assurance Plan
RBTL	Risk-Based Target Levels
RCRA	Resource Conservation Recovery Act
RFI	RCRA Facility Investigation
RI	Remedial Investigation
SAIC	Science Applications International Corporation
Shaw	Shaw Environmental, Inc.
SI	Site Investigation
Site	Landfill 3, Parcel 80(6) and Fill Area Northwest of Reilly Airfield, Parcel 229(7)
SRA	Streamlined Human Health Risk Assessment

SSSL	Site-Specific Screening Level
SVOC	Semivolatile Organic Compound
TCE	Trichloroethene
TOC	Total Organic Carbon
U.S.	United States
UIC	Underground Injection Control
USGS	United States Geological Survey
VC	Vinyl Chloride
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

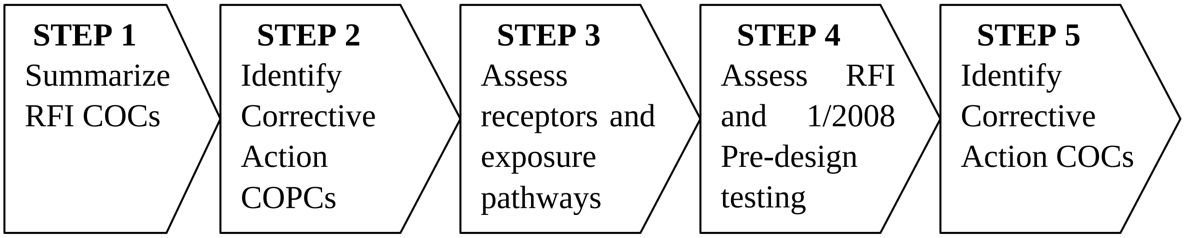
The Anniston-Calhoun County Fort McClellan Development Joint Powers Authority (JPA) has assumed the responsibility for environmental closure of certain sites at Fort McClellan (McClellan) from the United States Department of the Army (Army). Transfer of these sites to the JPA was conducted pursuant to the Comprehensive Environmental response, Compensation, and Liability Act (CERLA) Section 120(h)(3)(C) which allows federal agencies to transfer contaminated property before necessary cleanup has taken place. The basis for the continuing effort at these parcels is an Environmental Services Cooperative Agreement (ESCA) dated September 29, 2003 between the JPA and the Army (Army, 2003), and as amended September 2005, June 2006, and September 2007 (Army 2007a, 2007b, and 2007c). In addition, the JPA has negotiated a Cleanup Agreement, amended November 2005, with the Alabama Department of Environmental Management (ADEM) that describes the responsibilities for completing the investigation and remediation of potentially impacted sites at McClellan (ADEM, 2003).

Landfill 3, Parcel 80(6) (LF3) is currently an inactive landfill with an engineered cover system, approximately 23 acres in size, located in the northwest area of McClellan east of Alabama State Highway 21. LF3 served as the primary sanitary landfill at McClellan from 1946 to 1967. Reports indicate that landfill utilization included the disposal of residential/municipal refuse, industrial wastes (i.e., empty pesticide containers, paint containers, waste oil), and construction debris. Prior to capping in 2007, the inactive landfill was heavily vegetated with a mixed coniferous and deciduous forest.

Fill Area Northwest of Reilly Airfield, Parcel 229(7) (FANWR) is currently a cleared parcel with an engineered cover, approximately eight acres in size, also located in the northwestern corner of McClellan, adjacent to the former Reilly Airfield and west-southwest of Reilly Lake. The FANWR was first identified as a potential disposal area from a 1954 aerial photograph. Wastes reportedly placed in the unit include paint containers, fluorescent bulbs and ballasts, waste oils, and construction debris. Prior to capping in 2007, the inactive FANWR was heavily wooded and vegetated.

The findings of the Final Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) (MES, 2008) and the January 2008 Pre-Design Testing data were the basis for the Corrective Measures Implementation (CMI) Plan discussion of existing site conditions. The RFI first evaluated the groundwater Constituents of Potential Concern (COPCs), then the Constituents of Concern (COCs) that present a risk to human health and the environment for future groundwater use in the vicinity of LF3/FANWR.

The processed used to identify the groundwater COCs in the CMI Plan is summarized as follows:

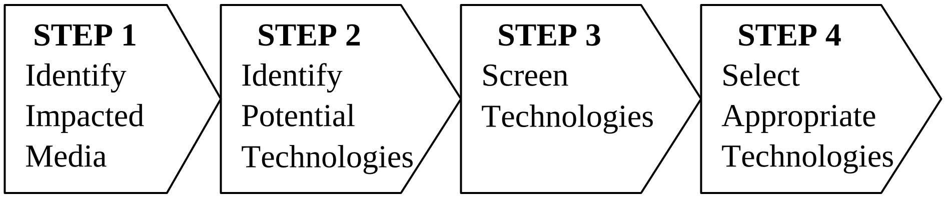


The media-specific Primary Corrective Action COCs are composed of the following volatile organic compounds (VOCs) in the groundwater: 1,1,2,2-Tetrachloroethane (1,1,2,2-TeCA), 1,1,2-Trichloroethane (1,1,2-TCA), Tetrachloroethene (PCE), Trichloroethene (TCE), and Vinyl Chloride (VC). A secondary tier of ancillary COCs was also identified; these COCs play a minor role in groundwater risk levels and are not expected to materially affect remediation needs.

After identifying the media-specific Primary Corrective Action COCs, the Corrective Action Objectives and Performance Standards were developed. The Corrective Action Objectives identified for the contaminated groundwater at the Site include the following:

- prevent exposure to groundwater within the LF3/FANWR properties.
- protect downgradient groundwater in a residential scenario at an acceptable Point of Exposure (POE).
- protect City of Weaver and City of Jacksonville drinking water supplies.
- control ongoing contributions of solvent mass to the off-Site plume.
- reduce solvent mass and plume footprint within the off-Site plume.
- implement corrective action in a manner consistent with existing LF3/FANWR remedy components and future land use.

Following development of the cleanup objectives, the corrective measure alternatives were evaluated to select appropriate technologies for the Site as summarized below:



Based on the foregoing evaluation, Enhanced *In Situ* Bioremediation (EISB), *In Situ* Chemical Oxidation (ISCO), and Monitored Natural Attenuation (MNA) were identified as the technologies that were most suitable for application at the Site. EISB was selected as the primary active treatment technology, whereas ISCO will be reserved for localized areas that either do not respond to EISB or that would benefit from the rapid reduction of COC mass.

The first part of the implementation will include one EISB injection well transect consisting of six to ten injection wells screened in the COC-impacted area of the aquifer. This transect will be installed near the downgradient leading edge of the COC plume that will intercept and treat groundwater migrating downgradient of the LF3/FANWR. Additional upgradient transects will be installed as needed based on performance monitoring.

1. INTRODUCTION

This Corrective Measures Implementation (CMI) Plan has been prepared by Geosyntec Consultants (Geosyntec) in collaboration with Matrix Environmental Services, LLC (MES) and on behalf of the Anniston-Calhoun County Fort McClellan Joint Powers Authority (JPA) to support the development of a groundwater remedy for Landfill 3, Parcel 80(6) (LF3) and the Fill Area Northwest of Reilly Airfield, Parcel 229(7) (FANWR) at the former Fort McClellan (McClellan) in Anniston, Alabama. Figure 1-1 shows a parcel location map of LF3 and FANWR (collectively referred to as the Site). Figure 1-2 shows Site topography.

For the purposes of this document, all references to “Site” refer to the LF3 and FANWR properties and related property east of Alabama State Highway 21 and south of the McClellan boundary; all references to “site” refer to the broader area of investigation and remediation, including “off-Site” areas along and west of Alabama State Highway 21.

1.1 Background

The JPA has assumed the responsibility from the United States (U.S.) Department of the Army (Army) for environmental closure of certain sites at McClellan. Transfer of these sites to the JPA was conducted pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Section 120(h)(3)(C), which allows federal agencies to transfer contaminated property before necessary cleanup has taken place. The basis for the continuing effort at these parcels is an Environmental Services Cooperative Agreement (ESCA) dated September 29, 2003 between the JPA and the Army (Army, 2003). In September 2007 a new ESCA was negotiated into which the 2003 ESCA was incorporated (Army, 2007a, 2007b, and 2007c). In addition, the JPA has negotiated a Cleanup Agreement, amended November 2005, with the Alabama Department of Environmental Management (ADEM) that describes the responsibilities for completing the investigation and remediation of potentially impacted sites at McClellan (ADEM, 2003, 2005).

This CMI Plan has been prepared using the findings and recommendations of the Resource Conservation Recovery Act (RCRA) Facility Investigation (RFI) Report prepared by MES (2008). The RFI summarizes previous environmental investigations relevant to the groundwater at LF3/FANWR. The CMI Plan also incorporates the findings of treatability studies and related Pre-Design Testing performed from December 2007 through April 2008.

1.2 Regulatory Framework

The environmental investigation activities historically undertaken at McClellan by the Army were conducted under the U.S. Department of Defenses' (DOD) delegated authority under CERCLA and the National Contingency Plan (NCP) with oversight from the ADEM and the U.S. Environmental Protection Agency (EPA). Under the ESCA, the JPA agreed to assume responsibility from the Army for completing, as needed, certain environmental investigation, remediation, and related documents necessary to satisfy CERCLA and the NCP requirements at the ESCA Early Transfer Sites. Section 120(h)(3)(D) of CERCLA authorizes the deferral of the covenant that requires all necessary remedial action to be completed before federal property is transferred.

To further expedite transfer of the property, the JPA has entered into a Cleanup Agreement with the ADEM for the investigation and cleanup, as necessary, of the Early Transfer Sites. This Cleanup Agreement is enforced by the ADEM under authority of the Alabama Hazardous Wastes Management and Minimization Act (AHWMMA). In February 2001, the EPA authorized the implementation of the AHWMMA under RCRA. This CMI Plan is designed to meet the requirements for Corrective Action and is identified in Parts III.E and Part IV of the Cleanup Agreement.

1.3 CMI Plan Purpose and Objectives

This CMI Plan is presented to achieve several objectives, as follows:

- Explanation of site setting: The CMI Plan summarizes the site setting information presented in the RFI and other, previous documents and updates existing site conditions through the incorporation of recently collected Pre-Design Testing data.

- Description of Corrective Action Objectives for groundwater: The CMI Plan states Corrective Action Objectives for the site on the basis of the findings and recommendations of the RFI as well as insights gained from Pre-Design Testing. Both risk-/concentration-based and functional objectives are described.

- Nomination, evaluation, and selection of remedy options: A broad range of potential remedial options for groundwater is presented. The CMI Plan continues with an initial screen of technologies, whereby several potential technologies are eliminated from further consideration on the basis of certain salient factors pertaining to the site. The short list of remaining options is subsequently evaluated in greater detail, including an evaluation of some options through treatability testing, leading to a recommendation of a best-value remedy or combination of remedies.

- Implementation strategy: Several sections of the CMI Plan present the necessary steps for the completion and implementation of the remedial design. The steps include the conceptual and preliminary design documents, a performance monitoring approach, and an implementation schedule.

1.4 Plan Organization

The remainder of this document is organized as follows:

- Section 2 presents an updated version of existing Site conditions.

- Section 3 provides a discussion of the Corrective Action Objectives, with a consideration of regulatory requirements.

- Section 4 presents a corrective measures evaluation, in which numerous potential technologies are evaluated for applicability to the Site.

- Section 5 summarizes Pre-Design Testing activities performed to support an update of existing site conditions and remedy selection.

- Section 6 presents the design basis for the preferred remedy.

- Section 7 summarizes a performance, compliance, and monitoring plan.

- Section 8 summarizes design deliverables and schedule.

- Section 9 contains a list of references used in the document.

2. SITE CONDITIONS

This section summarizes Site setting information presented in the RFI (MES, 2008) and other, previous documents and updates existing site conditions through the incorporation of recently collected Pre-Design Testing data. The goal of this CMI Plan is to address groundwater, since other media at LF3 and FANWR have been previously addressed. Therefore, this section provides descriptions and Site background information for LF3 and FANWR groundwaters. It also summarizes the key elements necessary for the formulation of Corrective Action Objectives.

2.1 Site Description and LF3/FANWR History

2.1.1 Site Location and Operational History

LF3 and FANWR are located in the northwestern corner of McClellan just east of Alabama State Highway 21, approximately 4.5 miles north-northeast of central Anniston, AL; 1.3 miles east of central Weaver, AL; and 3.9 miles south-southwest of Jacksonville, AL. Land in the vicinity of LF3 and the FANWR is generally undeveloped, with limited residential and commercial land use clustered along Alabama State Highway 21.

LF3 is approximately 23 acres in size. The landfill is bounded by the Alabama State Highway 21 to the west, Gobbler Road to the east, wooded areas and the boundary of McClellan to the north, and wetlands and Cave Creek to the south. LF3 is unlined and was constructed using trench/fill operations. Waste was placed in trenches to an average depth of 22 feet (ft). It served as the primary sanitary landfill at McClellan from 1946 to 1967. Reports indicate that landfill utilization included the disposal of residential/municipal refuse, industrial wastes (i.e., empty pesticide containers, paint containers, waste oil), and construction debris. Upon closure in 1967, the landfill was not capped with an engineered cover system. Prior to capping in 2007 (see Section 2.1.3), the inactive landfill was heavily vegetated with a mixed coniferous and deciduous forest. Groundwater is encountered at depths between 20 and 50 ft below ground surface (bgs) at LF3 (MES, 2008).

The FANWR is also located in the northwestern corner of McClellan, adjacent to the former Reilly Airfield and west-southwest of Reilly Lake and is approximately eight acres in size. Adjacent to the estimated eastern boundary of the FANWR is an escarpment. The northeastern boundary of the FANWR is adjacent to a number of streams and forested wetlands that form the headwaters of Reilly Lake (MES, 2008).

The FANWR was first identified as a potential disposal area from a 1954 aerial photograph. Wastes reportedly placed in the unit include paint containers, fluorescent bulbs and ballasts, waste oils, and construction debris. The maximum waste depth encountered during field investigation activities was 15 ft. The fill area was not capped with an engineered cover system upon closure circa 1970. Prior to capping in 2007 (see Section 2.1.3), the inactive FANWR was heavily wooded and vegetated (Geosyntec 2008).

During boring and well installation activities, groundwater was generally encountered in clayey sand zones at depths up to 35 ft bgs. Perched groundwater was encountered in some locations in the waste (IT, 2002b).

2.1.2 Investigative History

Numerous investigations have addressed LF3 and FANWR in the Site's history. These investigations can be summarized and grouped as follows:

- Historical investigations:
    - groundwater monitoring by the Army in 1986.
    - a 1992 Site Investigation (SI) by Science Applications International Corporation (SAIC).
    - a 1994-1995 Remedial Investigation (RI) by SAIC.
    - a 1998 Environmental Baseline Study (EBS) performed by Environmental Science & Engineering, Inc. (ESE).
    - 1998 groundwater monitoring by The IT Group (IT).
    - 1999 FANWR SI by IT.
    - 2002 Fill Area Definition Investigations at LF3 and FANWR by IT.
    - a 2002 Engineering Evaluation/Cost Analysis performed by IT.

  - Phase I-III Supplemental RIs performed by Shaw Environmental, Inc. (Shaw).
  - miscellaneous wetland determinations, fill area delineation, and landfill gas investigation performed from 2002 – 2006 by Shaw, MES, and Geosyntec.

- RFI: The RFI (MES, 2008) included the installation of 33 monitoring wells to complement the existing 47 wells. Groundwater was sampled extensively during the RFI, and a streamlined human health risk assessment was performed. The investigative results of the RFI are discussed in Section 2.5 of this CMI Plan.

- Pre-Design Testing: In preparation for the development of this document, hydraulic testing (i.e., slug testing), monitoring well sampling from a select well network, and laboratory treatability testing were performed by MES and Geosyntec. The results of the investigative components of this program are combined with those of the RFI to generate a comprehensive presentation of key Site concepts in Section 2 of this document. Treatability testing results are presented in Section 5. The methods and rationale for the Pre-Design Testing are discussed in further detail in Section 5. Detailed results are presented in Appendix A (Results of Pneumatic Slug Testing), Appendix B VOC Results for 2008 Groundwater Sampling), and Appendix C (Natural Attenuation Parameter Results for 2008 Groundwater Sampling).

2.1.3 LF3/FANWR Capping

Beginning in 2006, Geosyntec proposed an engineering design for final cover systems for LF3 and FANWR. The caps were constructed in 2007; final certification is pending. The final cover systems entail an engineered low-permeability soil cover system comprised of a vegetative layer underlain by low-permeability material. Components of the soil cover system include, from top to bottom, a 6-inch vegetative soil layer (topsoil) and a minimum 18-inch low-permeability (1×10^{-5} centimeters per second [cm/sec]) layer.

The horizontal limits of the final cover systems span the extent of the LF3 and FANWR waste boundaries identified in previous studies, including a December 2006 Light Detection and Ranging (LIDAR) topographic survey. These limits were established to minimize future direct exposure to wastes placed in each location. The low-permeability layer was selected to minimize leaching of contaminants to groundwater by limiting infiltration through the cover system. The final grades for LF3 range from a minimum of 1 percent [100 horizontal to 1 vertical (100H:1V)] to a maximum of 4 percent, and for FANWR, the final grades range from 3 percent to 10 percent. The final grades for both LF3 and FANWR are appropriate for promoting surface water drainage from the cover systems while controlling erosion.

The cover systems for both LF3 and FANWR have also been designed to accommodate the potential or planned future use for each property. The final grades for the LF3 cover system were developed to allow for future active recreational or light industrial use; however, additional engineering design will be required for future development. For FANWR, the final cover system grading incorporates walking trails and a parking area for passive recreational use.

2.2 Regional and Site-Specific Geology

This summary of the geologic and hydrogeologic setting in Sections 2.2 and 2.3, respectively, is based on more detailed information provided in the RFI (MES, 2008). LF3 and FANWR lie primarily within the Valley and Ridge Province, which is part of the Appalachian fold-and-thrust structural belt. The fold and thrust belt generally features southeastward-dipping thrust faults with associated minor folding consisting of Paleozoic sedimentary rocks that have been asymmetrically folded and thrust-faulted with major structures and faults striking in a northeast-southwest direction. Geologic contacts in this region generally strike parallel to the faults, and repetition of lithologic units is common in vertical sequences. These units, from oldest to youngest, include the Cambrian-aged Chilhowee Group, Shady Dolomite, Rome Formation, Conasauga Formation, and Knox Group, and the Ordovician-aged Newala and Little Oak Limestones, as well as various siltstones, sandstones, shales, dolomites and limestones that are mapped as one, undifferentiated unit in some areas of Calhoun County.

Bedrock underlying LF3 is mapped as the Cambrian Rome Formation on the western portion of the landfill and the Cambrian Conasauga Formation on the eastern portion of the landfill as shown in Figure 2-1. Bedrock underlying FANWR is mapped as the Cambrian Conasauga Formation. The Rome Formation consists of grayish-red-purple mudstone, shale, siltstone, and greenish-red and light gray sandstone, with locally occurring limestone and dolomite. The Conasauga Formation is comprised of dark-gray, finely to coarsely crystalline, medium to thick-bedded dolomite with minor shale and chert. A small, tight synclinal fold and a broader anticlinal fold, both plunging towards the north-northeast, are indicated near the Site, and an inferred splay fault dipping towards the southeast exists west of the Site. This splay fault approximately parallels Alabama State Highway 21, and exerts a significant hydrologic influence in the area.

Boring logs recorded within the boundary of LF3 generally indicate a residuum composed of interbedded clay and weathered bedrock composed of claystone, siltstone, and mudstone overlying fractured limestone and dolostone at a depth of approximately 55 to 60 feet bgs. At FANWR, boring logs have identified a clayey or silty residuum interbedded with weathered claystone, mudstone, and siltstone overlying highly fractured limestone and dolostone found at a depth of approximately 30 to 50 feet bgs.

At both LF3 and FANWR, the limestone/dolostone bedrock fractures are extensive and are oriented from horizontal to vertical. Interspersed within the carbonate bedrock are thin layers of sandstone, clay-filled voids, thin layers of shale, and visual evidence of geologic faulting. The highly fractured nature of the bedrock and the variable stratigraphy at the landfills are likely representative of geology affected by the Pell City Fault system, a major feature that underlies the Site and which includes the inferred splay fault identified immediately west of the Site (MES, 2008).

2.3 Hydrogeology

The hydrogeology of Calhoun County has been investigated by the Geologic Survey of Alabama and the U.S. Geological Survey (USGS) in cooperation with ADEM. Groundwater in the vicinity of McClellan generally occurs in residuum derived from bedrock decomposition, within fractured bedrock along fault zones, and from the development of karst frameworks. Water tables in areas with well-developed residuum horizons may subtly reflect the surface topography, but the groundwater flow direction also may exhibit the influence of pre-existing structural features. The main recharge areas for the aquifers in Calhoun County are located in the valleys.

The thrust fault zones typical of the county form large storage reservoirs for groundwater. Points of discharge occur as springs, effluent streams, and lakes. Coldwater Spring is one of the largest springs in the State of Alabama, with a discharge of approximately 32 million gallons per day. This spring serves McClellan and is the main source of water for the Anniston Water Department. The spring is located approximately 5 miles southwest of Anniston and discharges from the brecciated zone of the Jacksonville Fault.

Wells at the Site have been grouped into four hydrogeologic zones:

- Residuum wells are screened from 20 to 50 feet below ground surface (bgs), with an average depth of 30 ft bgs.
- Transition Zone (heavily fractured and weathered zone) wells are screened from 40 to 130 ft bgs, with an average depth of 80 ft bgs.
- Fractured Bedrock wells are screened from 150 to 320 ft bgs, with an average depth of 190 ft bgs.
- Deep Bedrock wells are screened from 250 to 410 ft bgs, with an average depth of 300 ft bgs.

Regional groundwater flow in residuum, transition, and bedrock zones at LF3 and FANWR typically follow Site topography, which generally slopes gently toward the north. The main geologic influence on groundwater flow at the Site is the inferred splay fault located west of the Site that roughly parallels Alabama State Highway 21. Faulted limestone/dolostone and clastic rocks such as those identified at the Site can create a complex, fractured hydrogeologic system with preferential flow along fault lines. Some of these fractures produce large volumes of groundwater flow, as indicated during the drilling of monitoring wells along the inferred splay fault. The large amount of flow within the inferred splay fault creates a potentiometric gradient causing groundwater in the study area to flow toward the fault from the southeast and the southwest before following the fault flow towards the north-northeast.

A regional groundwater flow study conducted by the Geological Survey of Alabama (2004) suggests that there is a westerly component of flow from McClellan to Alabama State Highway 21. This regional groundwater flow was noted to be in contrast to the findings of local Site data, which show a northeasterly flow direction. A more detailed analysis of the Site-specific, local-scale topographic features and Site data was performed during the preparation of the RFI and CMI Plan; the analysis confirmed the local-scale conceptual model in this section, which indicates that flow is to the northeast of the Site along the inferred splay fault corridor.

Previous reports indicate that groundwater flow is controlled by both fracture features in bedrock as well as karst solution features. The bedrock potentiometric surfaces show a clear flow preference for the inferred splay fault trace, an area with relatively few observed voids. Hence, it is possible that while karst features are present, as indicated by very high production in some monitoring wells, they are overall subordinate to fractures in the extent to which they control flow. The ongoing presence of chlorinated solvents in a site that lacks residual sources (see Section 2.6.1) also suggests that fracture flow may be the predominant transport mechanism.

2.4 Groundwater Flow Observations and Parameters

The measured potentiometric surfaces for the Site as presented in the RFI (MES, 2008) show radial flow in the residuum with more coherent, westerly flow towards the inferred splay fault zone in the underlying transition zone and fractured (upper) and lower bedrock. The flow direction shifts toward the north-northeast in the topographic valley and near the inferred splay fault.

Upon review of the local topographic data, there is no evidence to suggest a reason for the radial flow in the residuum; instead, as noted in the RFI, the historical trench-and-fill landfill configuration likely accounts for this through the introduction of an efficient mechanism for recharge. The completion of a low-permeability cap on LF3 and FANWR in December 2007 is anticipated to achieve the following ends: (i) control and route surface water via engineered swales to natural drainage features and (ii) significantly reduce infiltration by capping in these areas and mitigating rainfall flux through the waste. As a result of the installation of the low-permeability cap, it is anticipated that the residuum potentiometric surface will ultimately resemble those of the deeper formations, i.e., flow will be relatively uniform and to the west until the flow direction changes to the north-northeast near the inferred splay fault.

Potentiometric mapping performed in the January 2008 Pre-Design Sampling event and shown in Figure 2-2 confirms the findings of the RFI. While residuum potentiometric mapping was not performed to a sufficient degree to draw a comprehensive potentiometric surface, the surfaces developed for the transition, fractured bedrock, and deep bedrock zones mirror the observations of the RFI datasets. The transition zone shows essentially uniform, northwesterly flow towards the inferred splay fault along Route 21 (transition zone wells are not present west of the highway to bound the flow zone.) Both fractured and deep bedrock zones show convergence along the inferred splay fault. The 2008 water elevations are consistently 5 to 10 ft lower than those of the RFI datasets; this appears to reflect the regional drought conditions experienced in 2007 and early 2008.

The average hydraulic conductivity at LF3, calculated from slug tests conducted at five wells, was reported as 0.131 feet per day (ft/day) in the *Final Fort McClellan Remedial Investigation/Baseline Risk Assessment Report* (SAIC, 2000). However, it is not known which lithologic horizon these values represent. To address this uncertainty, pneumatic slug testing was performed on 14 wells as part of Pre-Design activities in December 2007. Geometric and arithmetic mean hydraulic conductivities, respectively, are presented for the four major lithologic horizons as follows: residuum, 0.25 and 0.25 ft/day; transition zone, 0.43 and 0.77 ft/day; fractured bedrock, 5.98 and 44.34 ft/day; and deep bedrock, 1.84 and 2.82 ft/day. Individual values are shown in Figure 2-3 and Table 2-1; summary values are shown in Table 2-2. A more detailed memorandum of results is included in Appendix A.

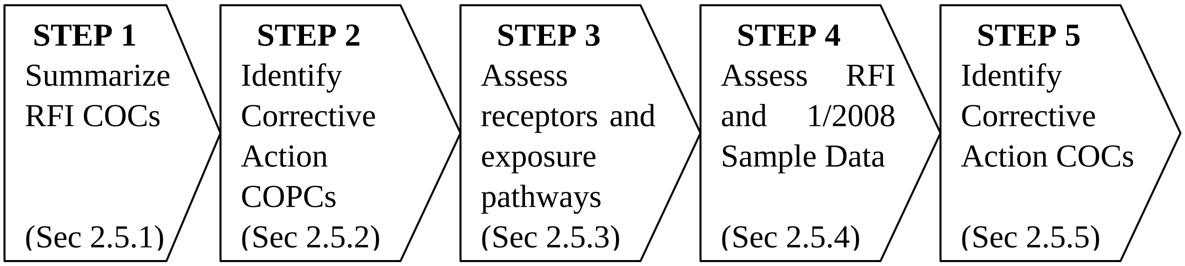
Because the water table was unusually low in the 2008 potentiometric gauging, it is possible that hydraulic gradients may be unrepresentative of long-term conditions. Hence, hydraulic gradients presented in the RFI report are reported herein. Average residuum gradients are in the range of 0.024-0.027 [dimensionless], whereas average transition zone gradients are 0.038 – 0.044 and average fractured bedrock gradients are 0.010 – 0.011 along the inferred splay fault.

Assuming effective porosity values of 20% for residuum and 15% for transition zone/bedrock horizons, unretarded flow velocities are computed to be 12 ft/yr in the residuum and 100 ft/yr in the transition zone/bedrock horizons.

2.5 Groundwater COCs

This section summarizes groundwater constituents of potential concern (COPCs) and constituents of concern (COCs) present at the Site that present risk to human health. Planned future use of the Site is recreational. However, as discussed in greater detail in Section 2.5.2, for the purposes of the CMI Plan, a potential residential reuse scenario has been assumed for groundwater. Other media (soil, sediment, and surface water) and COCs at the Site were previously addressed in the CMI Plan utilized to develop landfill cover systems for LF3 and the FANWR (Matrix, 2006 and Geosyntec, 2008) and are not addressed in this document.

The following process was used to identify the groundwater COCs:



2.5.1 RFI COCs

This section summarizes the process used to identify groundwater COCs at the Site during the RFI performed by MES (2008).

2.5.1.1 Process Used to Identify Groundwater RFI COCs

The identification of the groundwater RFI COCs at the Site consisted of a multi-step approach performed as part of the evaluation of the nature and extent of contamination at the Site and the streamlined human health risk assessment (SRA) conducted during the RFI. Constituents in groundwater with elevated concentrations and considered to be Site-related were compared to human health Site-specific screening levels (SSSLs) for the resident, construction worker, and groundskeeper. SSSLs are medium- and receptor-specific concentrations calculated based on a 10^{-6} carcinogenic risk and noncarcinogenic hazard quotient (HQ) of 0.1. SSSLs are based on Site-Specific exposure assumptions as documented in the Human Health and Ecological Screening Values and PAH Background Summary Report (IT, 2000).

The process used to identify the RFI COCs is explained in greater detail in the RFI (MES, 2008).

2.5.1.2 Site-Specific RFI COCs

A summary of the human health RFI COCs identified in groundwater, including the maximum detected concentrations (MDCs), incremental lifetime cancer risk (ILCR), and hazard index (HI), is presented in Table 2-3. The evaluation and identification of the RFI COCs are explained in greater detail in the RFI (MES, 2008). Groundwater-specific RFI COCs include nine VOCs, three pesticides, and two metals (Table 2-3).

2.5.2 Corrective Action COPCs

In the RFI, COCs with an incremental lifetime carcinogenic risk greater than 10^{-6} or a noncarcinogenic hazard greater than or equal to 0.1 for the residential receptor were identified. The following subsections describe the selection of the Corrective Action COPCs.

2.5.2.1 Potential Receptors and Exposure Pathways

For the purposes of this CMI Plan, a resident was selected as the most sensitive human receptor because impacted groundwater has migrated outside the property boundary of McClellan in the vicinity of the Site, and there is a concern that a downgradient drinking water source could be impacted. There are no ecological receptors exposed to groundwater at this Site because the groundwater is not accessible to these receptors. Potential receptor exposure route scenarios based on the proposed future residential land use include exposure to drinking water via consumption, dermal contact, and inhalation of volatilized chemicals from groundwater. Potential exposure pathways for the Site are explained in further detail in the RFI (MES, 2008).

2.5.2.2 Human Health Corrective Action COPCs

The *Alabama Risk-Based Corrective Action Guidance Manual (ARBCA)* (ADEM, 2008), allows a cumulative carcinogenic risk for remediation of 10^{-5}, and a noncarcinogenic cumulative hazard index of less than or equal to 1. Therefore, risk-based target levels (RBTLs) are based on a 10^{-5} for carcinogenic risk or 1 for non-carcinogenic hazard for Corrective Action COCs.

For the purposes of the CMI Plan, the human health RFI COCs exceeding the RBTLs for the residential user exposure scenario were identified as the Primary Corrective Action COPCs. Table 2-3 compares the human health RFI COCs to the residential RBTLs. The constituents exceeding a carcinogenic risk of 10^{-5} or a noncarcinogenic hazard of 1 and thus considered Primary Corrective Action COPCs for the Site are the following: 1,1,2,2-Tetrachloroethane (1,1,2,2-TeCA), 1,1,2-Trichloroethane (1,1,2-TCA), Tetrachloroethene (PCE), Trichloroethene (TCE), and Vinyl Chloride (VC). The biodegradation pathways for the Primary Corrective Action COPCs, all of which are either chlorinated ethenes or chlorinated ethanes, are presented in Figure 2-4.

Some RFI COCs that are not included in this group of primary human health Corrective Action COPCs include selected VOCs, pesticides, and metals. These parameters, hereafter referred to as Ancillary COCs, have maximum values that fall in the 10^{-6} to 10^{-5} risk range or a hazard quotient ranging from 0.1 to 1. For reasons discussed in Section 7, these Ancillary COCs are not expected to materially affect remedy requirements. However, the Ancillary COCs will be addressed during compliance monitoring as discussed in Section 7 to ensure that the groundwater remedy comprehensively addresses cumulative risk reduction per the *ARBCA*.

2.5.3 Current Conditions

2.5.3.1 2008 Analytical Data and Data Quality Review

The analytical data for the January 2008 samples are provided in Appendices B and C. MES reviewed the analytical data in accordance with the *Quality Assurance Plan (QAP)* (MES, 2007) to assess compliance with the quality assurance objectives, and to assess hard copy and electronic deliverable consistency and integrity. The results of the data quality review for the groundwater samples collected in January 2008 are presented in the *Data Quality Summary* (*DQS*) in Appendix D. Based on the data quality review, the analytical data generated for this investigation were adequate to fulfill program objectives and may be used to support the selection and implementation of appropriate corrective measures.

2.5.3.2 Data Assessment and Risk Reduction

Corrective Action COPCs in groundwater at the Site were initially identified as 1,1,2,2-TeCA, 1,1,2-TCA, PCE, TCE and VC (Section 2.5.2.2). These constituents were detected at concentrations greater than the RBTL in at least one groundwater sample collected in association with the RFI. Table 2-4 compares the January 2008 groundwater VOC sample results for the Corrective Action COPCs with RFI analytical results for the monitoring wells that contained Corrective Action COPCs at concentrations above the RBTLs. If no concentration in the RFI exceeded an RBTL, no comparison to January 2008 results was made. In addition, if a well was not sampled in 2006, no comparison to January 2008 results was made.

Figures 2-5 through 2-8 show the locations of samples that contain VOC concentrations greater than the RBTL for residuum, transition, bedrock, and deep bedrock monitoring wells, respectively. Concentrations posted are from the most recent sampling event discussed in the RFI for each monitoring well location. If a sample was collected in January 2008, these results are also posted for informational purposes.

2.5.4 Corrective Action COCs

Based on the data assessment described in Section 2.5.3.2, 1,1,2,2-TeCA, 1,1,2-TCA, PCE, TCE, and VC in groundwater are considered Primary Corrective Action COCs for the purpose of this CMI Plan. Figures 2-5 through 2-8 present the Primary Corrective Action COCs in residuum, transition, bedrock, and deep bedrock groundwater monitoring wells, respectively.

2.6 Solvent Occurrence, Fate, and Transport

2.6.1 Overview of Solvent Occurrence

The RFI report and COC discussion in Section 2.5 identified two major parameter groupings, chlorinated ethenes and chlorinated ethanes, as the most widespread chemicals present in groundwater and the most significant contributors to Site risk. As a result, the 2008 Pre-Design Sampling described in Section 5 included analyses for VOCs to focus on these parameters. The chlorinated ethene and ethane series each consist of four parameters, which can be organized by decreasing degree of chlorination. As shown in Figure 2-4, the highest order (fully chlorinated) parameter can degrade to the lowest order parameter in its series through reductive dechlorination, although other degradation mechanisms are possible. Hence, examining each parameter series allows both an overall assessment of groundwater-related risk as well as an indication of the degree of intrinsic degradation. The solvent distributions in this section, depicted in Figures 2-9 through 2-16, are compared to RBTLs discussed in Section 2.5. These figures show data for the three most recent sampling events (2004, 2006, and 2008.)

Five of the eight chlorinated ethenes and ethanes are Primary Corrective Action COCs; their distribution can be described as follows:

- Tetrachloroethene (PCE): PCE was present in concentrations above the RBTL of 1.21 µg/L in previous sampling rounds (2004 and 2006) in wells along the inferred splay fault axis. However, no wells included in the 2008 sampling round indicated any exceedances of the RBTL. Figure 2-9 shows the PCE distribution.

- Trichloroethene (TCE): TCE concentrations exceed the RBTL of 38.3 µg/L in several locations along the inferred splay fault axis as shown in Figure 2-10. It is also detected in numerous locations underneath LF3/FANWR and in the most downgradient inferred splay fault axis wells, but not at levels that exceed the RBTL.

- Vinyl chloride (VC): VC is prevalent throughout the footprints of LF3 and FANWR at concentrations that readily exceed the RBTL of 0.918 µg/L as shown in Figure 2-12. However, while it is detected above the RBTL approximately 300 feet downgradient of FANWR, it does not exceed the RBTL in any locations downgradient of the immediate vicinity of LF3 or in the inferred splay fault axis.

- 1,1,2,2-Tetrachloroethane (1,1,2,2-TeCA): As shown in Figure 2-13, 1,1,2,2-TeCA is prevalent in the inferred splay fault axis at concentrations exceeding and in many cases more than 10 times the RBTL of 2.03 µg/L. However, it does not exceed the RBTL beyond the OLF-G33/OLF-G34 cluster, approximately 800 ft downgradient of LF3.

- 1,1,2-Trichloroethane (1,1,2-TCA): A degradation product of 1,1,2,2-TeCA, 1,1,2-TCA is found downgradient of the immediate vicinity of LF3 along the inferred splay fault axis. However, as shown on Figure 2-14, it does not appear to exceed the RBTL of 7.2 µg/L beyond the OLF-G12/OLF-G22/OLF-G36 cluster, approximately 120 ft downgradient of LF3.

Three remaining chlorinated ethenes and ethanes are not Primary Corrective Action COCs; however, their distributions assist in explaining the distributions of the Primary Corrective Action COCs. Their distribution can be described as follows:

- cis-1,2-Dichloroethene (c12DCE): c12DCE is present above the RBTL of 15.5 µg/L primarily under LF3, with more limited downgradient presence in the inferred splay fault axis. Most inferred splay fault axis concentrations are below the RBTL. See Figure 2-11.

- 1,1,2,2-TeCA degradation products (1,2-dichloroethane [1,2-DCA] and chloroethane [CA]) are detected in numerous locations throughout the Site but with virtually no exceedances of RBTLs, as shown in Figures 2-15 and 2-16.

Several observations concerning the characteristics of chlorinated solvents are apparent through a detailed review of Site monitoring data. First, a review of maximum detected concentrations indicates that the potential for residual chemical product is very low. The highest percentage of solubility observed is 0.02% (1,1,2,2-TeCA in OLF-G12); this value is far below the 1% threshold commonly applied as an indication of the potential presence of Dense, Non-Aqueous Phase Liquid (DNAPL) or residual saturation thereof (Kram et al. 2001). Moreover, a review of plan-view depictions of chlorinated solvent concentrations indicates that peak concentrations for parent (i.e., source) constituents are detected west of LF3 as opposed to within its footprint, as shown on Figures 2-9 through 2-16. Hence, the solvent plumes are “detached” from the LF3 source. Taken together, these observations suggest that there is not a dominant, continuing source of groundwater contamination, such as residual DNAPL, that sustains peak concentrations of chlorinated solvents in groundwater. This conclusion has important implications for remediation options, because it suggests that aggressive source remediation is not likely to be required as a component of a broader remedy.

While not presented in detail in the CMI Plan, a review of depth of groundwater impacts as presented in the RFI also indicates that the chlorinated solvent plume gradually descends with distance from the Site. Beginning within 50 ft of the ground surface near the landfills, the plume descends to a depth of approximately 400 ft bgs at the farthest north monitoring wells.

2.6.2 Overview of Transport Mechanisms

While the behavior of the eight chlorinated solvents described above varies from one parameter to the next, in general, it is apparent that dissolved-phase solvents migrate from LF3 west-northwest to the inferred splay fault zone then migrate to the north-northeast along the Alabama State Highway 21 corridor. This is consistent with the flow regime depicted in the potentiometric surfaces (Figure 2-2.)

FANWR, however, shows different behavior. While dissolved-phase solvents, most notably vinyl chloride, are observed in its vicinity and the potentiometric surface indicates flow to the west to the inferred splay fault corridor, solvents do not appear to migrate in detectable levels downgradient of FANWR to the inferred splay fault axis. Attenuation mechanisms, as discussed in Section 2.6.3, appear to affect solvents present in the FANWR to a degree sufficient to prevent detection in downgradient locations.

2.6.3 Review of Bioattenuation Potential

A key component of the Pre-Design Testing included groundwater sampling and analysis for bioattenuation parameters. The following analyses were performed to evaluate the potential for bioattenuation:

- solvent parent and daughter products, used as primary indicators of partial degradation.
- dissolved gases (ethane, ethene, and methane), used as indicators of complete degradation.
- chloride, another indicator of degradation.
- sulfate, nitrate, nitrite, and field measurements of dissolved oxygen (DO), oxidation-reduction potential (ORP), and ferrous iron, all of which are used to better understand the geochemical environment and its amenability to degradation.
- total organic carbon (TOC), used to assess the abundance of electron donors to support reductive dechlorination.

Figures 2-17 and 2-18 present the results of chemical fingerprinting performed for the ethene and ethane dechlorination series, shown on Figure 2-4, for the 2004, 2006, and 2008 sampling periods. Each sampling location is represented as a “pie chart” that indicates the relative proportions of parent and daughter products in a given sample, with overall magnitude represented through changes in “pie” area.

The chlorinated ethene series mapping shows a distinct difference in the groundwater character between (i) groundwater underneath or immediately adjacent to the LF3 and FANWR and (ii) downgradient groundwater. The groundwater near LF3 and FANWR is generally dominated by VC, the result of multiple degradation steps from PCE or TCE. Conversely, downgradient groundwater is predominantly TCE with lesser fractions of c12DCE.

Figures 2-19a-c are natural attenuation parameter diagrams that help to explain these observations. These diagrams include several key bioattenuation parameters in a “spider plot” format. Elevated values for axes on the top-right side of the chart, DO and

ORP, favor aerobic conditions that do not support reductive dechlorination, the most common intrinsic degradation process. Conversely, higher values for axes to the lower-left side, chloride, dissolved gases, and TOC, tend to indicate conditions that promote or are indicative of reductive dechlorination. By drawing a polygon that connects a given well's series of data points on each axis, one can obtain a quick, visual sense of the bioattenuation potential. If the polygon is weighted to the top-right side (aerobic conditions), then little intrinsic reductive dechlorination is likely occurring. The opposite is true if the polygon is weighted to the lower-left side. Figures 2-19a-c break the dataset up into three conceptual zones, of which each has a characteristic geochemical signature: Figure 2-19b focuses on background, peripheral, FANWR, and far downgradient locations, Figure 2-19a focuses on LF3 proper, whereas Figure 2-19c focuses on the inferred splay fault axis.

Examination of oxidation-reduction potential (ORP) and dissolved oxygen data, shown as a component of Figures 2-19a-c, explains the observations in the daughter product pie charts. Strongly reducing conditions generally prevail underneath or immediately adjacent to LF3 and FANWR. This is likely due to an abundance of organic carbon introduced by landfill leachate and reflected in Figure 2-19a. As indicated in the RFI report, this organic carbon serves as a suitable electron donor to support intrinsic anaerobic dechlorination.

In addition to the depressed dissolved oxygen content and negative ORP in the LF3 and FANWR areas, dissolved nitrate (see Appendix C) is depleted, an indication of intrinsic microbial activity. The conversion of ferric iron to soluble ferrous iron and the depletion of sulfate (Appendix C) are indicators of microbial activity at some locations; however, concentrations were low enough at this Site that these indicator parameters provided no additional insights into the occurrence of intrinsic biodegradation. Low ambient concentrations of nitrate, iron, and sulfate are favorable for the operation of engineered anaerobic bioremediation systems.

While some of the VC appears to have degraded to ethene underneath the landfill as shown in Figure 2-19a, VC frequently degrades more slowly under anaerobic conditions than the other chlorinated ethenes, which accounts for its continuing presence under the landfill. Further downgradient of the landfill, the VC is replaced as the most abundant chlorinated ethene with higher-order products (PCE, TCE, c12DCE.) This shift can be explained by the change in ORP from reducing conditions underneath the landfills to oxidizing conditions downgradient of the landfills as shown in Figures 2-19b-c.

With the shift to oxidizing conditions, the recently generated vinyl chloride from underneath the landfills is now more amenable to intrinsic aerobic degradation, which can explain its disappearance altogether. The higher-order products that apparently escaped from the anaerobic landfill zone before dechlorination are now in an aerobic environment that is not favorable for their degradation. As a result, these higher-order products migrate several thousand feet downgradient with little change in the proportions of chlorinated solvents. An increase in the c12DCE fraction is observed downgradient, likely brought about by c12DCE's somewhat preferential mobility compared to TCE. c12DCE has a lower soil sorption coefficient than TCE, which means that it is less retarded by the aquifer matrix, thereby resulting in measurably greater mobility.

The chlorinated ethane series in Figure 2-18 shows little evidence of degradation. The gradual decrease in 1,1,2,2-TeCA concentrations suggests a low rate of natural attenuation, which is likely due to sorption and dilution. The single-bond structure of 1,1,2,2-TeCA, which is more stable than those of chlorinated ethenes, renders 1,1,2,2-TeCA a more recalcitrant COC than the chlorinated ethenes. 1,1,2,2-TeCA does abiotically transform to TCE at a rate positively correlated with temperature; however, the abiotic transformation rate is typically very slow at ambient groundwater temperatures.

2.6.4 Review of Chemical and Physical Attenuation Processes

Intrinsic biodegradation is usually the only destructive process that occurs in groundwater. However, EPA guidance on natural attenuation recognizes other processes that beneficially affect chlorinated solvent concentrations in groundwater (EPA, 1998). As described above, 1,1,2,2-TeCA may slowly and abiotically transform to TCE; however, this reaction does not rapidly contribute to overall groundwater restoration. Other processes that affect groundwater concentrations include dilution, dispersion, and sorption of chlorinated solvents into or onto the aquifer matrix, i.e., non-flowing fractures, rock pores, and soil particles. These processes do not require special ORP conditions, and the activity of indigenous microbes appears to be the primary attenuation mechanism for chlorinated solvents along the downgradient perimeter of the area of impacted groundwater. These processes have the potential to reduce solvent concentrations in groundwater, limit downgradient migration of solvents, and provide a useful complement to active remediation approaches.

2.7 Future Uses of Groundwater

This section provides an overview of the potential for future groundwater use in the vicinity of LF3/FANWR. This review is a key component in the formulation of Corrective Action objectives as discussed in Section 3.

2.7.1 Population Centers and Water Sources

The following population centers of greatest significance are present closest to the Site; for each population center, the municipal water supply is described:

- Anniston: Central Anniston is located 4.5 miles south-southwest of the Site. Its primary water supply is Coldwater Spring, located 5 miles southwest of the city. Due to its long distance from the Site, it is unlikely that the LF3/FANWR plume will impact Anniston's primary water supply.

- Weaver: The City of Weaver's center is located 1.3 miles west of the Site. Based on a well and spring user survey conducted by Shaw (Shaw, 2003), the Weaver Water Supply Well #2 is closest to the Site at a distance of approximately 1.75 miles to the west-northwest. Not only is this supply well at a considerable distance from the Site, it is also located on the far side of southwest-northeast trending topographic ridges from the Site as shown in Figure 2-20. These ridges indicate zones of low-permeability bedrock due to the observed lack of weathering. Hence, both the distance of the supply well and the intervening geologic structural features render a very low probability of LF3/FANWR plume impacts to this supply well; available data show that no impacts have been detected to date.

- Jacksonville: The city boundary for Jacksonville is located 3.9 miles from the Site. According to the Shaw survey, no municipal supply wells for Jacksonville are located within two miles of the Site, a distance that is far downgradient from the point at which LF3/FANWR COC concentrations fall below RBTLs. Therefore, it unlikely that the LF3/FANWR plume will impact Jacksonville's municipal supply wells.

2.7.2 Private Well and Spring Survey

A component of Shaw's 2003 well survey entailed contacting residents through direct mail and follow-up visits to assess the status of private well and spring use. A total of 565 property owners in a survey area north of LF3 were contacted. Of these property owners, 111 owners were identified with wells and/or springs. Of these, 19 owners used a well for drinking water, and one owner used a spring for drinking water. The closest private well used for drinking water was identified at a distance of approximately one mile downgradient of the nearest RBTL exceedance associated with LF3/FANWR. Private wells along the Alabama State Highway 21 corridor closer to the Site are not used for drinking water and are presumably too shallow to intercept the plume. In support of this presumption, available data for these wells indicate that no chlorinated solvent impacts have been observed.

2.7.3 Landfill Institutional Controls

A Land Use Control Implementation Plan (LUCIP) is in place for the LF3/FANWR properties. The current LUCIP includes Deed Notices that restrict land use at the Site in perpetuity.

2.8 Summary of Key Conceptual Elements

The following characteristics of the LF3/FANWR Site summarize the key elements necessary for the formulation of Corrective Action Objectives (Section 3) and remedial selection (Sections 4 and 6):

- LF3 and FANWR served as unlined landfills until the 1960s and 1970s, at which point they were closed without an engineered cover system. Engineered cover systems were installed in 2007.

- LF3 and FANWR are located in the Valley and Ridge Physiographic Province. Mudstone, shale, siltstone, sandstone, limestone, and dolomite are present on Site. Groundwater flow predominantly occurs in bedrock and the bedrock/residuum transition zone.

- While some karst features have been observed, flow appears to be controlled on a local scale by fracturing and on a site to subregional scale by faulting, including primary and splay faults. Bedrock potentiometric surfaces show a clear flow preference for the inferred splay fault trace, an area with relatively few observed voids. Hence, it is possible that while karst features are present, as indicated by very high production in some monitoring wells, they may be overall subordinate to fractures in the extent to which they control flow.

- Potentiometric mapping shows that groundwater flows from the LF3/FANWR footprints west-northwest to the inferred splay fault system along the Alabama State Highway 21 corridor, at which point flow moves to the north-northeast. The inferred splay fault system is a convergent feature that appears to capture flow from the Site. Unretarded flow velocities are estimated to be 12 ft/yr in the residuum and 100 ft/yr in bedrock and transition zone.

- Chlorinated solvents, most notably the full PCE degradation series (PCE, TCE, c12DCE, and VC) and 1,1,2,2-TeCA, are present in groundwater and migrate off-Site into the inferred splay fault system. A north-northeast trending plume with a length of approximately 2000 ft is observed along Alabama State Highway 21. Figure 2-21 presents an overview of the solvent plume footprint.

- A review of maximum detected concentrations indicates that the potential for residual chemical product is very low. The highest percentage of solubility observed is 0.02% (1,1,2,2-TeCA in OLF-G12); this value is far below the 1% threshold commonly applied as an indication of the potential presence of DNAPL or residual saturation thereof (Kram et. al. 2001). Hence, the potential for DNAPL or residual saturation is low. Moreover, a review of plan-view depictions of chlorinated solvent concentrations indicates that peak concentrations for parent (i.e., source) constituents are detected west of LF3 as opposed to within its footprint. Hence, the solvent plumes are “detached” from the LF3 source. Taken together, these observations suggest that there is not a dominant, continuing source of groundwater contamination, such as residual DNAPL, that sustains peak concentrations of chlorinated solvents in groundwater.

- Natural attenuation mechanisms play a role in solvent fate and transport. Significant reductive dechlorination of PCE and TCE to VC occurs within the LF3/FANWR footprints as demonstrated by primary and bioattenuation data. In the transition from the reducing landfill footprints to the more ambient, aerobic conditions immediately downgradient, the VC is degraded to carbon dioxide, water, and hydrochloric acid. However, some TCE/c12DCE and essentially all 1,1,2,2-TeCA leave the reducing conditions of the landfill footprints and enter the inferred splay fault flow system without experiencing degradation. While degradation does not appear to play a role within the inferred splay fault system, dilution and sorption mechanisms do bring concentrations below RBTLs with distance from the Site. Figure 2-22 presents an understanding of existing Site conditions that incorporates the geologic and geochemical factors that govern contaminant fate and transport.

- Assuming a potential residential exposure scenario, 1,1,2,2-TeCA, 1,1,2-TCA, PCE, TCE, and VC have been identified as Primary Corrective Action COCs for the Site based on 1×10^{-5} cancer risk objectives and a hazard index of 1.

- A detailed assessment of potential groundwater exposures has been conducted through well use surveys. The three most significant population centers in the Site vicinity, Anniston, Weaver, and Jacksonville, do not appear to be susceptible to impacts to drinking water supplies due to the distance of supply intakes from the Site and key structural features that impede groundwater flow. Similarly, while some private wells are located in relatively close proximity to the Site (one mile), impacts to private wells have not been observed, and the current plume configuration suggests that impacts are unlikely.

3. CORRECTIVE ACTION OBJECTIVES AND PERFORMANCE STANDARDS

Based on the updated understanding of site conditions as discussed in Section 2, Section 3 presents the goals for Corrective Action at LF3/FANWR. This section describes (i) the Corrective Action Objectives and (ii) the media-specific and regulatory Performance Standards proposed for groundwater Corrective Action.

3.1 Corrective Action Objectives

Corrective Action Objectives include overall goals for the remedy for the site, taking into consideration risk-based objectives, realistic exposure scenarios, and anticipated future land use.

The overall objective entails the implementation of a remedy that is protective of human health and the environment. The following specific Corrective Action Objectives have been developed for LF3/FANWR:

- Prevent exposure to groundwater within the LF3/FANWR properties. This entails the implementation of existing institutional controls to control groundwater exposures within the LF3/FANWR properties.

- Protect downgradient groundwater in a residential scenario at an acceptable Point of Exposure (POE). This entails the selection of an appropriate downgradient POE in accordance with the 2008 *ARBCA*.

- Protect City of Weaver and City of Jacksonville drinking water supplies. This entails remedy components (most likely to be monitoring-related) specifically geared to the protection of these two exposure scenarios.

- Control ongoing contributions of solvent mass to the off-Site plume. This entails the interception of ongoing solvent flux from the landfill footprints to the off-Site plume through the installation of a groundwater remedy in close proximity to the landfill boundaries. This will mitigate growth of the plume footprint.

- Reduce solvent mass and plume footprint within the off-Site plume. This entails setting and attaining quantitative measures of plume mass reduction which, when attained, will allow cessation of remedial activities followed by monitoring for rebound conditions.

- Implement corrective action in a manner consistent with existing LF3/FANWR remedy components and future land use. This component requires that any remedy selected will neither compromise the existing cover systems at LF3/FANWR nor materially reduce the recreational land use value of these landfills.

Note that these objectives only apply to Site groundwater or to other media only insofar as they may be adversely affected by groundwater remediation (e.g., compromising the cover system during groundwater remedy implementation.) Considerations for other media, e.g. direct contact exposures from the landfills, have been addressed through the landfill cover systems designed and installed in 2007.

The downgradient residential POE will be designated as OLF-G52. This well is located approximately 800 ft downgradient of the estimated extent of chlorinated solvent above RBTLs. OLF-G52 is screened in the currently impacted deep bedrock groundwater flow zone. It is therefore representative of a downgradient location where a receptor could come in contact with COCs under current and the most likely future conditions. It is important to note that this well is not currently, nor is it expected to be in the future, used as a drinking water source.

3.2 Performance Standards

Performance standards for the Site include the following:

- media and chemical-specific cleanup standards.
- other statutory and regulatory requirements/standards.

It should be noted that the information presented in the following subsections specifically summarizes those performance standards that apply to the Corrective Actions relevant to contaminated groundwater at the Site. Many other potential regulatory requirements were considered during the development of the CMI Plan, but do not apply based on Site characteristics, Site location, and corrective measures alternatives considered.

3.2.1 Media-Specific Standards

The five Primary Corrective Action COCs (1,1,2,2-TeCA, 1,1,2-TCA, PCE, TCE, and VC) shall be monitored and compared to the RBTLs established in Section 2. The RBTL for each Primary Corrective Action COC is presented in Table 3-1. These goals have been established in accordance with the *ARBCA* guidance, which utilizes a 10^{-5} cancer risk or 1 hazard index goal. In addition, analyses for ancillary COCs will be performed to support a more comprehensive review of cumulative risk level attainment as discussed in Section 7.

3.2.2 Other Regulatory Standards

In light of the anticipated groundwater remedy as discussed in Section 6 of the CMI Plan, the following additional statutory and regulatory performance standards for the Corrective Action are anticipated to be applicable to LF3/FANWR remediation:

- location-specific limitations, and
- cleanup and control requirements, standards, criteria, or limitations setting performance, design, or operational controls or restrictions on activities related to the Corrective Action.

These requirements or standards typically address the particular activities that are selected to accomplish a Corrective Action and indicate how the selected remediation alternative must be designed, operated, and managed.

3.2.2.1 Land Use Controls

ADEM Administrative Code Rule 335-15-4.05 states that "for those sites that do not meet the unrestricted cleanup classification, restrictions on site use shall be applied to achieve cleanup standards. Restrictions shall include, but are not limited to land use controls. The restrictions imposed upon a site shall be media specific and may vary according to site-specific conditions." At the Site, Land Use Controls (LUCs) restricting the use of groundwater as drinking water will be implemented. Appropriate LUCs designed to minimize exposure to hazardous constituents and to limit inappropriate uses of the contaminated areas of the facility must be established. The following notice in a deed, mortgage, deed to secure debt, lease, rental agreement, or other instrument given or caused to be given by the owner or operator which creates an interest in the facility or the contaminated area of the facility shall be inserted:

> *This property has been cleaned up to standards less stringent than those required for unrestricted residential use due to the presence of substances regulated under state law. Certain uses of this property may require additional cleanup. Contact the property owner or the Alabama Department of Environmental Management for further information concerning this property.*

This notification must also be submitted as a survey plat with a note to the local jurisdiction over local land use (ADEM 335-14-5-.07).

3.2.2.2 Hazardous Waste Management

Alabama waste management regulations (ADEM Rule 335-14) govern hazardous waste management and are based on EPA regulations. Minor quantities of characteristic hazardous waste, such as monitoring well purge water during performance monitoring, may be generated during remedy implementation. If generated, such wastes will require profiling, storage, and disposal in accordance with RCRA regulations; for example, hazardous waste cannot be stored on-Site for more than 90 days without a RCRA permit.

3.2.2.2 Underground Injection Control

ADEM regulates underground injection to ensure that contamination is not introduced into the groundwater. If the groundwater Corrective Action entails underground injection, an application to ADEM using ADEM Form 468 will be required that will describe in detail several relevant aspects, including the nature of the proposed injection and the hydrogeologic characteristics of the injection site.

4. CORRECTIVE MEASURES EVALUATION

4.1 Basis of Design for a Preferred Remedial Approach

The selection of an appropriate and effective remedial action for the site groundwater is bounded by the understanding of existing site conditions, regulatory requirements, and local concerns. Several technologies described below will be evaluated based on (i) their ability to meet Corrective Action Objectives; (ii) the constructability of the application in the targeted aquifer; (iii) operation and maintenance complexity, costs, and operational life; and (iv) overall total project costs.

4.1.1 Ability to Meet Objectives

Appropriate remedial technologies must be able to achieve the following objectives once the technology is fully implemented:

- protection of groundwater at approved downgradient POE locations where dissolved chlorinated solvent concentrations meet the prescribed risk objectives.
- protection of City of Weaver and City of Jacksonville drinking water.
- containment of chlorinated solvents such that the extent of impacted groundwater does not expand.
- reduction of solvent mass in groundwater.

The other two objectives listed in Section 3.1 (preventing groundwater exposure at the landfill properties and preserving landfill cap integrity) are achieved by any technology recommended for site application. Specifically, all feasible remediation technologies will neither compromise the existing cover systems at LF3/FANWR nor materially reduce the redevelopment (i.e., light industrial or recreational) land use value of these landfills.

Table 4-1 provides a list of remediation technologies that have been applied to sites where groundwater was impacted with chlorinated solvents. Each technology was evaluated based on its ability to achieve the objectives described above. With the exception of the No Further Action alternative, each technology has the potential to achieve some or all of the Corrective Action Objectives. Therefore, each of these technologies was further evaluated against the remaining criteria.

4.1.2 Constructability

Implementation of remediation technologies is challenged by Site hydrogeology. As described previously in Section 2, impacts exist in overburden soil, shallow bedrock, and deep bedrock. The hydraulic conductivity varies among and within these strata which include porous media; weathered, competent, and fractured rock; and a major inferred splay fault. These features influence the design of remediation systems. The primary constraint in remediation technology design is delivery of the technology to the contaminated medium. Therefore, constructability of technologies is a crucial criterion in the selection of technologies that can achieve Corrective Action Objectives. Several technologies fail to achieve this criterion because of the depth of contamination, the inability to construct the remedy in deep bedrock, or the challenges in establishing reliable hydraulic control in the fractured rock.

4.1.3 Maintenance Costs and Anticipated Operational Life

Long-term maintenance is usually either the first- or second-most costly component of any remediation system. Active technologies often have complicated maintenance requirements, while passive technologies may have few maintenance needs. Furthermore, the anticipated life of a technology influences overall maintenance costs. In order to control maintenance costs, technologies that have longer operational lives will be designed for passive operation and minimal aboveground equipment. More complicated maintenance requirements and extensive aboveground equipment can often be justified for aggressive technologies with short operational lives.

4.1.4 Cost Evaluation

An accurate cost estimate cannot be prepared prior to the engineering design of the selected technology(ies); therefore, the cost evaluation only provides relative costs at this point.

4.2 Technology Screening & Selection

Several technologies were evaluated for their ability to achieve remediation objectives as shown in Table 4-1. A summary of the technologies is presented below and in Table 4-2.

4.2.1 No Further Action (NFA)

The No Further Action alternative is presented to provide contrast with other alternatives that employ some form of treatment. The No Further Action alternative will support the continuation of groundwater monitoring, but no other actions to remove COC mass or remediate groundwater will be initiated under this alternative.

4.2.2 Monitored Natural Attenuation (MNA)

MNA employs naturally occurring processes for treatment of source and dissolved COC areas. The groundwater monitoring program is modified to include potential COC degradation products, groundwater geochemistry parameters that indicate the occurrence of intrinsic biodegradation, and chlorinated solvent data analysis to support evaluation of COC concentration trends over time. Implementation is assumed to use only existing monitoring wells.

4.2.3 Enhanced *In Situ* Bioremediation (EISB)

Enhanced *In Situ* Bioremediation (EISB) is accomplished by stimulating reductive dechlorination of the COCs through the injection of a degradable organic carbon source (electron donor) and possibly a microbial culture known to be able to dechlorinate the COCs. EISB may be implemented by injecting either or both soluble and insoluble electron donors into the source area and in select downgradient locations. Injection strategies may include a recirculating system to facilitate distribution of the electron donor, injection of an electron donor that is allowed to flow passively with the COCs, or direct injection through multiple injection wells.

EISB can be applied directly in high-concentration areas if any exist, although none are expected to be present. Active biodegradation alters the rate of dissolution so that the rate of source area remediation can be measurably increased beyond the rate achieved by natural attenuation or groundwater extraction (Moretti, 2005 and EPA, 2003).

Impacted groundwater outside the source area may also be treated by EISB. The application involves the construction of reactive zones that span the width of an impacted area. The reactive zones may be constructed by directly injecting a slow-release electron donor such as emulsified vegetable oil into highly fractured, high flow zone bedrock. The biologically reactive zone may be bioaugmented to improve COC treatment. The number and spacing for the biologically reactive zones are designed based on groundwater flow velocity and the acceptable time for groundwater remediation.

A recirculation system consisting of injection and recovery wells may also be used to treat a dissolved COC area. The recirculation system can be used to construct reactive zones or, with a much larger system, the entire impacted portion of the aquifer. For the purpose of this alternative, the EISB area is constructed as a series of biologically active zones that will remediate COCs as groundwater migrates through the active zones. This approach can be designed to prevent further migration of COCs.

A modification to this alternative is the use of EISB only in the source area with MNA in the dissolved COC area

There are some potential drawbacks to the use of EISB, including the sensitivity of the microbial cultures and the need to test the amenability of the aquifer. These can be examined through treatability testing.

4.2.4 *In Situ* Chemical Oxidation (ISCO)

In Situ Chemical Oxidation (ISCO) has been widely applied for the treatment of chlorinated solvents in groundwater. The technology works by exposing dissolved chlorinated solvents to strong oxidizers which typically include permanganate salts, persulfate, ozone, and Fenton’s or modified Fenton’s reagent. Permanganate salts have been successfully used to treat chlorinated ethenes. However, permanganate does not oxidize chlorinated ethanes; therefore, a different oxidant is required for chlorinated ethane or mixed ethene/ethane situations. Sodium persulfate, activated with chelated iron, high pH, or high temperature, is capable of oxidizing both chlorinated ethenes and ethanes.

ISCO is applied by injecting the oxidant solution into the groundwater using an injection well or a direct push point. For bedrock applications, injection wells are usually required. The oxidant is allowed to react until the oxidant is consumed. In a successful application, a measureable concentration reduction is observed; however, ISCO applications are highly prone to experience rebound in dissolved chlorinated solvent concentrations after the oxidant is expended. This phenomenon is due to the dissolution or desorption of solvents from soil or rock where the solvents were shielded from oxidation. This situation leads to the need for multiple oxidant applications at most sites.

4.2.5 *In Situ* Reduction

In situ reduction is a relatively new approach for generating strongly reducing conditions that support the abiotic and biotic dechlorination of chlorinated solvents. The technology combines reactive metal chemistry with anaerobic biodegradation. The technology has been applied in barrier applications where the system can be constructed in a trench or by soil mixing. In these cases, particulate zero valent iron and finely ground plant fibers were installed into the barriers to generate very reducing conditions. Liquid materials are commercially available for application in groundwater. The approach requires the injection of dissolved iron compounds and complex water soluble organics using approaches similar to those discussed for ISCO. The ability of the liquid materials to achieve the same reducing conditions as the particulate materials has not been field tested.

4.2.6 *In Situ* Thermal

In situ heating is applied to the source zone for the rapid removal through volatilization of COC mass. Heating may be accomplished by electrical resistive heating, conductive heating, or steam injection. During engineering design, the heating method will be selected; however, steam injection has the benefit of directing heat through fractures. Conductive heating will heat groundwater and rock. Electrical resistive heating may be the least effective of the heating options depending on the electrical conductivity of the bedrock.

The installation of an *in situ* heating system requires the placement of heating points (electrodes, heaters, or steam injection wells) at multiple locations within the treatment zone. Heating points are typically placed 15 to 30 ft apart throughout the area to be treated. A soil vapor extraction system should be installed in the vadose zone above the heated area to capture vapors generated by *in situ* heating.

Depending on heating point placement and the thermal conductivity of the aquifer, the initial heating process typically requires three to six months. After the aquifer has been heated, the temperature is sustained to volatilize COCs. When COC recovery becomes asymptotic in the vapor extraction system, *in situ* heating is discontinued. Mass removal accomplished by *in situ* heating may reduce COC concentrations to the point that natural attenuation can be relied upon to complete groundwater remediation. An alternative to MNA is the application of EISB as described above.

An enhancement to *in situ* heating that has been suggested for some locations is to supplement heating with heat-activated persulfate ISCO of residual COCs. This approach should be effective in treating COCs; however, local geology will affect technology performance. The penetration of the oxidant solution into the rock and low flow voids and fractures may be limited by diffusion.

4.2.7 Sparge/Vent

Air sparging requires the injection of air into groundwater to strip volatile COCs. A vapor extraction system is usually installed in the vadose zone above the sparging zone to capture volatile COCs stripped from the groundwater. The effectiveness of sparge/vent systems is influenced by the depth of sparging below the groundwater elevation. Deeper sparging requires higher pressure, which results in lower air volume. Sparging into bedrock has been applied; however, depth, degree of fracturing, and fracture connection to the overburden influence the effectiveness. Sparge/vent applications are best applied in shallow setting, i.e., less than 40 feet into an aquifer composed of a porous medium (e.g., soil).

4.2.8 Flushing

Surfactant/co-solvent flushing uses injection wells in delivery flushing solution to the aquifer. Groundwater pumping is required to recover the flushing solution. Aboveground treatment attempts to remove COCs while recovering the surfactant or co-solvent for reuse. Practice suggests surfactant or co-solvent recovery is marginally effective and often does not justify the added water treatment costs. Three to ten aquifer pore volume exchanges are typically performed. Risks associated with this alternative include mobilizing previously immobile chlorinated solvents through surfactant-mediated changes in surface tension and incomplete capture of flushing solution, which contains very high concentrations of dissolved COCs.

4.2.9 Permeable Reactive Barrier

Permeable reactive barriers are designed to intercept impacted groundwater. Zero-valent iron is a common reactant loaded into barriers. Barriers may be constructed in trenches or in overlapping columns of soil with iron mixed in using a large auger. Biological permeable reactive barriers are also possible by loading the trench with materials that will support biodegradation.

Permeable reactive barrier installations require subsurface conditions that allow soil mixing or trenching. Deep applications or applications into rock are not feasible.

4.2.10 Pump & Treat

Groundwater pumping with aboveground treatment and disposal can be implemented to provide COC containment. This alternative is not expected to achieve groundwater remediation but it may reduce or prevent further impairment of the groundwater through hydraulic control. To be effective, pumping wells must be installed through the thickness of the impacted aquifer to capture groundwater.

4.3 Comparative Analysis of Technologies

Remedy alternatives under RCRA are typically evaluated against criterion specific to the facility permit. Because the Cleanup Agreement is not specific about evaluation criteria, CERCLA criteria have been adopted.

Alternatives may be evaluated against threshold, balancing, and modifying criteria. Threshold criteria include an evaluation of the ability of the alternative to protect human health and the environment and to comply with regulations and standards which may be COC-, technology-, and location-specific. Balancing criteria include long-term effectiveness and permanence; reduction of toxicity, mobility, or volume because of treatment; short-term effectiveness; implementability; and cost. Modifying criteria include regulatory agency acceptance and community acceptance. For the purpose of this focused survey, only threshold and balancing criteria were used to evaluate groundwater remediation alternatives. Modifying criteria are important issues but they will be addressed during discussion of the CMI Plan with ADEM.

Balancing criteria represent the primary factors by which the remediation alternatives are assessed. The various balancing criteria are more fully defined below:

- Long-term effectiveness and permanence.
- Reduction of toxicity, mobility, or volume through treatment.
- Short-term effectiveness.
- Implementability.

- Cost.

Evaluation of each alternative with respect to the threshold and balancing criteria is provided in Tables 4-1 to 4-3.

4.4 Alternative Comparison

Comparison of the alternatives for the selection of appropriate technologies was made based on the ability of each technology to achieve cleanup objectives, to be constructible within the constraints of the complicated existing Site conditions, and to provide reasonable cost to benefit. This assessment eliminated several technologies because of constructability issues and excessive cost (Table 4-3). The technologies found to be most suitable for implementation at the Site were EISB and ISCO. Both technologies can be implemented in soil or bedrock and at varying depths, they may be operated in active or passive modes, and they have the potential to reduce chlorinated solvent mass in the groundwater. MNA was also considered to be a potentially acceptable technology because of evidence of its current contribution to groundwater remediation near LF3 and FANWR. While MNA may not be an appropriate stand-alone technology, it may provide value if coupled with other technologies.

4.5 Recommended Groundwater Corrective Measure

Based on the foregoing evaluation, EISB, ISCO, and MNA were identified as the technologies that were most suitable for application at the Site. The maximum benefit of each technology may be achieved when they are applied selectively to areas of the Site where their specific strengths can be applied to the best advantage. For example, the best cost/benefit application of ISCO is likely to occur when ISCO is applied to selected high-concentration areas followed by EISB or MNA for final treatment. EISB is expected to be most advantageous in the treatment of larger, lower-concentration areas where the need for multiple ISCO applications would be cost-prohibitive and technically challenging. MNA is likely to provide greatest advantage at the low-concentration periphery of the impacted area and near LF3 and FANWR where leachate supports natural reductive dechlorination of chlorinated solvents.

As described in Sections 4 and 6, EISB and ISCO with appropriate sentinel monitoring should meet the requirements of protecting downgradient residential drinking water supply and treat contaminated groundwater beneath and in the vicinity of LF3/FANWR and downgradient of LF3/FANWR. MNA should be at least partially successful at achieving these objectives and may become more effective if coupled with EISB or ISCO. Section 6 provides a conceptual overview of the application of these technologies to the Site. The application of each recommended technology will be refined during the preparation of the remedial design.

5. PRE-DESIGN TESTING ACTIVITIES

5.1 Hydraulic Parameter Testing Via Slug Testing

As part of Pre-Design Testing activities, hydraulic conductivity data for the various hydrogeologic zones were obtained from pneumatic slug testing of selected monitoring wells located downgradient of LF3/FANWR. These data were collected to aid in estimating groundwater flow rates using the Darcy equation and to quantify the required amount and rate of addition of various treatment amendments to the aquifer. The test methods and analysis methods used are described in “McClellan Landfill 3/Fill Area Northwest of Reilly (LF3/FANWR) Pneumatic Slug Testing Results” (Geosyntec, 2007), which has been included as Appendix A.

Pneumatic slug testing was successfully performed on 14 selected monitoring wells. Several monitoring wells did not have sufficient water above the well screen, and one location (OLF-G52) was inaccessible due to truck traffic from a nearby fill dirt hauling operation. Hydraulic conductivities and associated field data are presented on Table 2-1 and shown on Figure 2-3. The computed hydraulic conductivities ranged from 0.13 ft/day (4.45×10^{-5} centimeters per second [cm/sec]) to 210 ft/day (7.41×10^{-2} cm/sec).

A summary of hydraulic conductivities by zone is presented in Table 2-2 and discussed in Section 2. In addition to both maximum and minimum values by zone, both arithmetic and geometric means are shown (the geometric mean may be a more appropriate measure of central tendency for broadly distributed conductivity value populations; the bedrock dataset is an example).

5.2 Dechlorination Treatability Testing through Microcosm Testing

EISB has been selected as a potentially useful remediation technology for the Site. However, available monitoring data did not provide adequate evidence to support a conclusion as to the effectiveness of EISB for treating Site COCs. To further evaluate EISB, a treatability study was conducted by SiREM Laboratory using Site groundwater. The test evaluated the reductive dechlorination of TCE and 1,1,2,2,-TeCA and their partial dechlorination products under conditions that can be engineered in groundwater. Specific treatments included the following:

- an untreated, biologically inhibited treatment to evaluate the abiotic loss of solvents during treatment.

- an anaerobic treatment to represent intrinsic biodegradation with no intervention or amendments.

- a lactate-amended treatment to evaluate the response of indigenous microbes to a readily degradable electron donor.

- an emulsified vegetable oil (EVO) amended treatment to evaluate the response of indigenous microbes to a slowly degradable electron donor.

- a lactate amended and bioaugmented treatment to evaluate the benefit of adding to the aquifer microbes known to be able to dechlorinate Primary COCs.

- an EVO-amended and-bioaugmented treatment to evaluate the benefit of adding to the aquifer microbes known to be able to dechlorinate Primary COCs using a slow- release electron donor.

These treatments represent the general types of engineering designs for EISB applications. The results of the treatability tests are shown in Figure 5-1. The results indicate the following:

- natural biodegradation is not likely.

- electron donor addition alone may stimulate the dechlorination of TCE to c12DCE with no further degradation.

- bioaugmentation with electron donor addition will support the complete biodegradation of all COCs.

Treatments had no adverse affects on groundwater pH. Background concentrations of dissolved oxygen, nitrate, ferrous iron, and sulfate were low in groundwater and caused no observable effects on the reductive dechlorination process.

The positive results from the treatability study indicate that EISB can be highly effective at the Site. The primary constraints in the application of EISB involve the delivery and distribution of electron donor (lactate or EVO) and bioaugmentation culture. The bioaugmentation culture selection will be influenced by the design of the treatment system. A recirculating system that uses lactate as a readily available electron donor can be successfully bioaugmented with WBC-2, a microbial culture capable of the complete dechlorination of 1,1,2,2-TeCA, TCE, and their degradation products. A passive EVO application where the electron donor is injected into the aquifer and allowed to disperse by advection and diffusion will require bioaugmentation by a combination of WBC-2 and KB-1. KB-1 is a well-documented bioaugmentation culture that efficiently degrades TCE but not 1,1,2,2-TeCA in the presence of EVO. WBC-2 will not dechlorinate in the presence of EVO; however, by adding both WBC-2 and KB-1, the cultures act synergistically to completely dechlorinate TCE and 1,1,2,2-TeCA in the presence of EVO as shown in Figure 5-1.

5.3 Treatability Testing of ISCO

ISCO was selected as a potentially useful remediation technology. However, the application of ISCO requires certain Site-specific information that was not available. A simple treatability test was conducted to evaluate the effectiveness of persulfate activated with either ferrous iron or elevated pH to oxidize 1,1,2,2-TeCA and TCE. The oxidant demand of the aquifer was also evaluated.

The treatability test was conducted using groundwater and crushed rock from the aquifer. Twenty grams per liter (g/L) of persulfate was added to treatments of groundwater and crushed rock. Each treatment was also amended with approximately 5 milligrams per liter (mg/L) each of TCE and 1,1,2,2-TeCA. Iron was added to the iron-activated treatment in chelated form as iron ethylenediamine tetraacetic acid (EDTA) at an iron concentration of 300 to 500 mg/L. The pH-activated treatment was adjusted to a pH slightly greater than 10 using sodium hydroxide. The pH was tested after 7 days of treatment and readjusted as needed to increase the pH to greater than 10.

The treatments were analyzed for TCE and 1,1,2,2-TeCA degradation, persulfate utilization, and the amount of Sodium Hydroxide (NaOH) required to maintain the pH greater than 10. The results shown in Figure 5-2 indicate that iron-activated persulfate is effective for TCE but not 1,1,2,2-TeCA. The pH-activated persulfate treated both TCE and 1,1,2,2-TeCA without the formation of degradation products (Figure 5-2). The pH was easily maintained above 10 by the addition of approximately 0.7 g/L NaOH.

In addition to demonstrating the destruction of TCE and 1,1,2,2-TeCA, the residual persulfate was also measured to evaluate the oxidant demand imposed by the aquifer. Each treatment was loaded with 20 g/L persulfate and the residual persulfate was measured after 14 days of treatment. Approximately five grams of persulfate was consumed in each treatment. This result suggests that an appropriate *in situ* application of at least 5 g/L will be needed for the treatment of dissolved COCs.

ISCO treatments rarely achieve complete remediation following a single oxidant injection because only dissolved COCs are treated. Following the dissipation of the oxidant after a few weeks, COCs sorbed into the matrix desorb and dissolve into the groundwater, causing a rebound in concentration. Often, multiple oxidant applications are necessary to expend the sorbed reservoir of COCs.

5.4 Focused Groundwater Sampling Event

As part of Pre-Design Testing data collection activities, a limited number of groundwater samples were collected from wells beneath and in the vicinity of LF3/FANWR. A total of 35 locations were sampled between January 14th and January 18th, 2008. Groundwater samples were analyzed for VOCs, field parameters, and monitored natural attenuation (MNA) parameters.

The 35 Pre-Design Testing sampling locations can be split up into six groups:

- LF3 – Transect through southern portion – 6 locations (residuum, transition, and bedrock hydrogeologic zones)
- LF3 – Transect through northern portion – 6 locations (residuum, transition, bedrock, and deep bedrock hydrogeologic zones)
- FANWR – 2 locations (bedrock and deep bedrock hydrogeologic zones)
- Inferred splay fault axis along Alabama State Highway 21 - 11 locations (transition, bedrock, and deep bedrock hydrogeologic zones).
- Weaver Sentinels – 7 locations west of Alabama State Highway 21 (bedrock and deep bedrock hydrogeologic zones).
- Background Wells – 3 locations upgradient of LF3/FANWR (transition and bedrock hydrogeologic zones).

Table 5-1 provides a list of the Pre-Design Testing Groundwater Sampling Locations. The results of this Pre-Design Testing are discussed as part of the existing site conditions in Section 2. Comprehensive VOC Results for the Pre-Design Testing are presented in Appendix B. Comprehensive natural attenuation parameter results for the Pre-Design Testing are presented in Appendix C. A Data Quality Summary Report for the Pre-Design Testing is presented in Appendix D.

6. DESIGN BASIS OF PREFERRED REMEDY

Section 6 presents the design basis of the technologies for the recommended groundwater corrective measure described in Section 4.5. It includes a (i) description of each technology, (ii) a conceptual overview of remedy implementation, (iii) details of injection and monitoring well construction, and (iv) an overview of the permits and approvals needed for the preferred remedy.

6.1 Technology Description (Capabilities and Limitations)

EISB and ISCO can be implemented on site. Both technologies were shown to achieve complete treatment when properly applied. *In situ* conditions will influence the effectiveness of both technologies. MNA is also potentially useful for managing groundwater contamination at the site within the limitations of its capacity to control COC concentration and migration.

6.1.1 Enhanced *In Situ* Bioremediation

Specific capabilities and limitations of EISB are presented below:

- EISB can achieve remediation of Corrective Action COCs to very low (nondetect) concentrations.

- Implementation requires the delivery of electron donor to the impacted areas, but delivery may be constrained by depth, ability to inject solutions, the interconnectedness of fractures, and washout in high flow zones.

- The influx of aerobic groundwater from upgradient areas may interfere with the generation of anaerobic conditions necessary for complete dechlorination, especially in upgradient parts of the impacted area.

- Bioaugmentation cultures are effective only in areas where anaerobic conditions can be sustained.

- Electron donor may need to be added periodically to sustain anaerobic conditions and electron availability in the aquifer.

- Bioaugmentation cultures are typically self propagating such that only one application is required.

- Bioaugmentation cultures are non-pathogenic, and they die off when chlorinated solvents are degraded or when anaerobic conditions no longer prevail.

- Delivery may be achieved by direct injection, which requires the installation of several injection wells or by the circulation of water to distribute electron donor and microbes between injection and extraction wells. Both approaches have been effectively used at other sites.

6.1.2 *In Situ* Chemical Oxidation

Specific capabilities and limitations of ISCO are listed below:

- ISCO using pH activated persulfate can degrade Corrective Action COCs.

- Treatment requires that the pH of the aquifer within the treatment zone be adjusted to greater than 10.

- The persulfate demand of the aquifer is relatively low at 5 g/L.

- The delivery of persulfate and caustic requires several injection wells that can be reused. This suggests the installation of a number of permanent injection wells into bedrock.

- ISCO treatment is rapid, but concentration rebound is highly likely, making multiple oxidant injections probable.

- ISCO can be used to reduce concentration with residual COCs further treated by EISB or possibly MNA.

6.1.3 Monitored Natural Attenuation

Specific capabilities and limitations of MNA are provided:

- MNA includes biological, chemical, and physical processes that reduce COC concentration in groundwater.

- Intrinsic biodegradation is occurring near LF3 and FANWR and appears limited to chlorinated ethenes. Intrinsic biodegradation is less obvious in groundwater away from the landfills.

- The lower permeability cover systems installed on LF3 and FANWR described in Section 2.1.3 are designed to reduce infiltration (Geosyntec, 2008) thereby decreasing continued contribution of solvents to groundwater.

- MNA downgradient of LF3 and FANWR appears to be dominated by physical processes such as dilution, diffusion, and sorption.

- MNA is likely to be used to address residual contamination in the periphery of the impacted areas and in the LF3 and FANWR areas following more active treatment by ISCO or EISB.

6.2 Conceptual Overview of Remedy Implementation

EISB, ISCO, and MNA are the preferred remediation technologies for groundwater remediation. ISCO will be reserved for localized areas that either do not respond to EISB or that would benefit from the rapid reduction of COC mass. The conceptual implementation of the groundwater remedy will advance through the following steps:

- Available data support the occurrence of intrinsic biodegradation in the LF3 and FANWR areas. This reaction is contributing to the removal of COC mass and the control of COCs that may continue to leach from the landfill until the cap effects cessation of leachate drainage from the landfill. MNA, making use of intrinsic biodegradation, is completely compatible with the landfill cap and will work in conjunction with it to minimize further COC loading to the aquifer.

- EISB will be implemented downgradient of LF3 and FANWR.

- The EISB conceptual design includes the installation of lines of injection wells that transect the primary down gradient flow paths for COCs, i.e., the fractured bedrock zone along the inferred splay fault. This conceptual design is presented in Figure 6-1.

- The most efficient approach to the implementation of EISB involves the installation of one section of the overall planned EISB process.

- The first part of the implementation will include one injection well transect consisting of six to ten injection wells screened in the COC-impacted area of the aquifer. This transect will be installed near the downgradient leading edge of the COC plume. The single test transect will be a full-scale transect that will be incorporated into the total remedial design.

- As part of system performance monitoring, the single transect installation will be intensively monitored for electron donor distribution and utilization, dechlorination culture distribution and dispersion, COC concentration changes, and biogeochemical and microbiological conditions that demonstrate effective EISB. This system performance monitoring is further described in Section 7.1.

- A compliance monitoring network will be implemented to provide data to evaluate the long-term performance of the Corrective Measure with respect to the Corrective Action Objectives. Monitoring locations, sampling and analysis methods, and sampling frequency are outlined in Section 7.1

- Following a period that is sufficiently long to measure system effects (typically six to twelve months), the design of the remainder of the Corrective Action will be modified, if needed, based on performance of the single transect and installed further upgradient from the initial transect. Modification options include an additional EISB transect, ISCO enhancement of the first EISB transect to target persistent hot spots or to accelerate treatment, and finally potential replacement of EISB with ISCO or an alternative remedy. Because the extensive monitoring program from the first installation will provide sufficient information to optimize the design of subsequent system components, the monitoring network and program for the later components will be less intense than those of the initial transect.

- Environmental Covenants, as described in Section 3.2.2.1, may be implemented to prevent exposure to contaminated groundwater between the LF3/FANWR property boundary and the initial downgradient treatment transect.

- Progress toward meeting Corrective Action objectives will be assessed on a semi-annual basis for the first five years. After five years of operation, the appropriateness and effectiveness of the remediation technology and design will be reviewed.

EISB will be implemented by injecting an electron donor such as lactate or emulsified vegetable oil directly into the aquifer through dedicated injection wells. Indigenous microbes will begin to assimilate the electron donor; oxygen, nitrate, and other respiratory substrates will be consumed; the ORP will be driven to a negative value; and geochemical conditions will hence be poised to support reductive dechlorination. Treatability testing suggested that bioaugmentation will be necessary to achieve complete dechlorination of COCs. Bioaugmentation will be performed in a second injection following the delivery of the electron donor and the generation of ORP conditions suitable for reductive dechlorination. A blend of dechlorinating cultures, WBC-2 and KB-1, provided the greatest design flexibility for the EISB application and is recommended for this project. Successful bioaugmentation is usually achieved with a single injection; however, additional electron donor applications may be required to sustain dechlorinating activity.

Both WBC-2 and KB-1 cultures were isolated from natural environments and selected for their ability to biodegrade various chlorinated solvents. There have been no genetic modifications to either culture; they are simply grown under conditions that preserve their intrinsic ability to dechlorinate chlorinated solvents. They have been successfully introduced into groundwater at other chlorinated solvent-impacted sites with no ill consequences. Once the chlorinated solvents are degraded, the microbes no longer have the necessary food source to continue growing, and they die. Both cultures are routinely tested for the presence of human pathogens, and no pathogen has ever been detected.

Specific details concerning the application of bioaugmentation with KB-1 or blends of KB-1 with other dechlorinating cultures include the following:

- applications at over 100 sites in 27 states including Mississippi, Florida, North and South Carolina, Tennessee, and Kentucky.
- applications in three European nations.
- ten peer-reviewed technical journal articles and numerous presentations at regional and national environmental science and technology conferences describing the behavior, microbiology, and field application of KB-1 and related dechlorinating cultures used by Geosyntec.
- recognition by Environment Canada as a level one biohazard (no hazard).

In short, bioaugmentation of groundwater with these cultures is a safe and environmentally sound remediation technology that is widely practiced.

6.3 Injection and Monitoring Well Construction

The injection wells will be 4-inch diameter vertical wells with schedule 80 PVC factory-slotted screens. The well casing above the screens will also be schedule 80 PVC. The well screens will be 0.050-inch slot size with sand filter packs and will be 20-ft in length and completed across targeted flow zones as determined during well installation. A dedicated discharge pipe will be installed in each well for use during amendment injections. The exit point for the discharge pipe will be the midpoint of the well screen. If, during well installation, several flow zones are detected, the injection well will be optimized to include several screen intervals at different depths. Injection well details are shown in Figure 6-2. New monitoring wells will be constructed of 4-inch diameter schedule 80 PVC. Monitoring wells will be installed in accordance with the Monitoring Well Installation Plan (MES, 2004).

6.4 Permits and Approvals

Geosyntec and MES recognize the importance of identifying, preparing, and submitting required permit applications as early as reasonably possible to prevent delays in project implementation. It is also recognized that for the Corrective Measure activities, actual permits may not need to be obtained; rather, only substantive requirements of appropriate permits may need to be met. In order to minimize potential project implementation delays, permit requirements will be identified and reported in the preliminary design phase. Furthermore, draft permit applications may be prepared as a means for demonstrating compliance with substantive requirements.

For construction approval, substantive requirements of the following apply and are anticipated prior to commencing construction activities:

- Notification of Intent to Drill a Water Well and Certification of Completion.
- Underground Injection Control (UIC) Permit.
- City of Anniston building permit.
- City of Anniston business license.
- State of Alabama contractor license.

The required permits listed above should be viewed as a working list and are considered the minimum number of required permits for project implementation.

7. PERFORMANCE, COMPLIANCE, AND MONITORING PLAN

This section presents the anticipated approach to performance monitoring including a discussion of both technical performance and compliance monitoring as well as methods for addressing Primary and Ancillary COCs. It also outlines how system performance will be evaluated.

7.1 Overview of Performance and Compliance Monitoring

Remedy monitoring has two distinct components. First, the performance of the technology is monitored using a variety of specific tests. Second, compliance monitoring is specifically focused on the effect the remedy in achieving the Corrective Action Objectives, especially the reduction of concentration and reduction of mass in the aquifer and the interruption of further COC migration toward potential downgradient receptors.

Performance monitoring will include the following tests which will be performed on a schedule that coincides with expected changes resulting from EISB and natural attenuation:

- Groundwater geochemistry within and downgradient from treatment transects. The parameter list will be refined based on field data that support the value of specific parameters. Likely monitoring parameters will include dissolved oxygen, total organic carbon, nitrate, chloride, and methane.

- Microbiological analysis using culture-specific gene probes and denaturing gradient gel electrophoresis (DGGE) to assess the persistence and distribution of the bioaugmentation cultures. Microcosm testing of groundwater from the treatment zones may be performed to test for its ability to support dechlorination which indicates the viability of the bioaugmentation cultures.

- Degradation product analysis within and downgradient from treatment transects to observe whether COCs are actually being dechlorinated. Ethene and ethane are important dissolved hydrocarbon gases that indicate the complete dechlorination of COCs.

- Geochemistry and degradation product tests in areas of potential MNA.

Performance monitoring will consist of monthly monitoring during the first six to nine months of operation while reducing conditions are established, followed by quarterly sampling during the establishment of the bacterial culture, and finally semi-annual performance monitoring in conjunction with semi-annual compliance monitoring.

Performance objectives include:

- maintaining appropriate geochemical conditions to support biodegradations.
- quantitative confirmation of ethene and ethane production in injection and/or performance monitoring wells.
- declining contaminant concentration trends in injection and/or performance monitoring wells.

The performance monitoring network for the initial EISB transect is shown on Figure 6-1 and will consist of the six to ten injection wells, two monitoring locations upgradient of the EISB transect, and four monitoring locations downgradient of the EISB transect.

The purpose of compliance monitoring is to evaluate whether the remedy is achieving remediation objectives. The important monitoring parameter for compliance is Primary COC concentrations. Primary COCs will be analyzed in groundwater samples on a frequency that is independent of the performance monitoring and that will be scheduled to match the timing of when changes in groundwater chemistry may be detected. Typical quarterly monitoring is of little real value in EISB and MNA remedies because observable changes usually do not occur from one quarter to the next. A six month sampling schedule is adequate to demonstrate compliance of the remedy with Corrective Action Objectives. Therefore, compliance monitoring of selected groundwater monitoring wells is recommended on a semi-annual basis.

Compliance objectives include:

- Declining contaminant concentration trends, reduction of contaminant mass within the plume, and shrinking areal plume extent.
- Achieving chemical-specific RBTLs at the downgradient POE.

- Achieving cumulative point risk goals of 10^{-5} cancer risk and a hazard index of 1.0 at the downgradient POE.

The compliance monitoring network will consist of three groups of wells:

- Inferred splay fault axis along Alabama State Highway 21 including OLF-G52, the downgradient POE - transition, bedrock, and deep bedrock hydrogeologic zones

- Weaver Sentinels – west of Alabama State Highway 21- bedrock and deep bedrock hydrogeologic zones.

- Background Wells – upgradient of LF3/FANWR - transition and bedrock hydrogeologic zones.

The compliance monitoring network will be sampled once before the injection of an electron donor into the aquifer to determine existing baseline groundwater conditions and semi-annually thereafter on a schedule that coincides with expected changes resulting from EISB and natural attenuation.

7.2 Ancillary Corrective Action COCs

Ancillary COCs, as discussed in Section 2, include parameters whose maximum values detected on site are in a marginal risk range of 10^{-6} to 10^{-5} or a Hazard Quotient of 0.1 to 1. These parameters are shown in Table 2-3. It is not expected that these parameters will materially affect Corrective Action requirements. The distribution and Corrective Action outlook for ancillary COCs are as follows:

- Benzene is detected exclusively under or immediately downgradient of LF3. It is not detected along the Alabama State Highway 21 corridor. Benzene commonly degrades under aerobic conditions; hence, the geochemical shift from reducing to aerobic conditions downgradient of LF3 appears to sufficiently attenuate the observed benzene.

- 1,2-dichloroethane (1,2-DCA) is detected underneath or close to the landfills. This compound has not been detected along the Alabama State Highway 21 corridor; moreover, it is expected to be degraded by the proposed EISB remedy.

- c12DCE is located along the Alabama State Highway 21 corridor and is co-located with TCE. As with 1,2-DCA, it is expected to undergo degradation through the proposed EISB remedy.

- Naphthalene and heptachlor epoxide are only detected underneath the LF3 footprint.

- Alpha- and Beta-BHC have both only been detected sporadically.

- Metals are either sparsely detected at low concentrations (i.e., mercury) or, in the case of nickel, are broadly detected at a low risk range, suggesting consistency with local conditions.

These ancillary COCs will be addressed through compliance monitoring by analyzing for them in a subset of monitoring wells for a limited number of sampling events. Point risk calculations will be performed at the POE. If the cumulative risk objectives in Section 3.2.1 are met, then they will be dropped from further consideration, and ongoing compliance monitoring will focus on primary Corrective Action COCs.

7.3 System Performance Evaluation

System performance will be evaluated on a semi-annual basis with the results presented in a semi-annual Corrective Measure Evaluation Report (CMER). This evaluation report includes an interpretation of data trends and presents recommendation for modifications to system operation.

Bench-scale treatability testing as discussed in Section 5.2 provides evidence that EISB is likely to be an effective Corrective Measure. Full-scale EISB using reductive dechlorination has been successfully implemented at multiple sites in a fractured rock setting. EISB implementation will be guided using the implementation logic provided in Figure 7-1. As described in Section 6.2, the primary criteria for the injection of the dechlorinating culture is the establishment of suitable geochemical conditions. If geochemical conditions are not suitable six to nine months after an initial injection of electron donor, either more time or an additional injection of electron donor may be necessary. If geochemical conditions continue to be unsuitable, alternative remediation technologies will need to be evaluated.

After the establishment of the bacterial culture, the system performance will be evaluated using the Corrective Measures Decision Process Flow Chart shown on Figure 7-2. This flow chart outlines the process that will govern decisions on the use of additional EISB transects or ISCO enhancement to target persistent hot spots. It also outlines the decision process to accelerate treatment and/or replace EISB with an alternate remedy.

Further details on performance and compliance monitoring will be provided in a Performance, Compliance, and Monitoring Plan that will accompany the Final Design. This plan will present methods and procedures for sampling media, monitoring the system, and evaluating the progress of groundwater remediation.

8. DESIGN DELIVERABLES AND SCHEDULE

The groundwater remediation design for Landfill 3 and FANWR will include the following major deliverables:

- Conceptual Design.
- Preliminary Design.
- Final Design.

The components of the design deliverables are described in the following sections.

8.1 Conceptual Design

The Conceptual Design submittal summarizes the basic design elements and is presented primarily for planning purposes. The Conceptual Design submittal includes the following elements:

- Design Report: list of anticipated design calculations.
- Technical Specifications: list of anticipated sections.
- Construction Drawings: list of anticipated Construction Drawings and Construction Drawings presenting conceptual level site plans and general details.

The Conceptual Design submittal will be presented to ADEM at a technical "workshop" meeting.

8.2 Preliminary Design

The Preliminary Design submittals consist of the expanded and advanced Conceptual Design submittals. Preliminary Design submittals will include the following information:

- Design Report: outline of anticipated design calculations with statement of objectives, assumptions, and procedures.

- Technical Specifications: outline of anticipated sections.
- Construction Drawings: Construction Drawings with plans for major design elements (i.e. grading plans and surface water management features, details and sections as needed and available).
- Construction Quality Assurance Plan outline.
- Performance, Compliance, and Monitoring Plan outline.
- Land Use Control Implementation Plan: details that will need to be added to the existing McClellan LUCIP to ensure that appropriate institutional controls are in place.

The Preliminary Design will be used to procure a design/build contractor for final design and implementation of the selected remedy.

8.3 Final Design

The Final Design documents will be submitted with the seal and signature of a professional engineer registered in the State of Alabama to ADEM after receipt of ADEM's concurrence with the information presented in the Final CMI Plan. The Final Design will include the following:

- Design Report: including Design Calculations and Quantity Estimates.
- Technical Specifications.
- Construction Drawings.
- Performance, Compliance, and Monitoring Plan.

8.4 Design Schedule

The anticipated design schedule is provided in Figure 8-1. Major design schedule milestones include the submittal of CMI Plan and several technical work meetings.

9. REFERENCES

Alabama Department of Environmental Management (ADEM). 2003. *In the Matter of: Anniston-Calhoun County Fort McClellan Development Joint Power Authority Facility*, Cleanup Agreement No. AL4 210 020 562.

ADEM. 2005. *In the Matter of: Anniston-Calhoun County Fort McClellan Development Joint Power Authority Facility*, Cleanup Agreement No. AL4210020562. November.

ADEM. 2008. *Alabama Risk-Based Corrective Action Guidance Manual (ARBCA)*. April.

Environmental Science & Engineering, Inc. (ESE). 1998. *Final Environmental Baseline Survey, Fort McClellan, Alabama*, prepared for the U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland. January.

Geological Survey of Alabama in cooperation with the Alabama Department of Environmental Management, 2004. *Hydrogeology and Vulnerability to Contamination of Major Aquifers in Alabama: Area 4*. Circular 199 D

Geosyntec Consultants (Geosyntec). 2006. Wetlands Assessment and Delineation, Landfill 3 and Fill Area Northwest of Reilly Airfield, McClellan Landfill Cap Design, McClellan, Anniston, Alabama. July.

Geosyntec. 2008. *Final Corrective Measures Implementation Report. Landfill Cover Systems Landfill 3, Parcel 80(6) and Fill Area Northwest of Reilly Airfield, Parcel 229(7).* April.

IT Corporation (IT). 2000. *Human Health and Ecological Screening Values and PAH Background Summary Report*. July.

IT. 2002a. *Draft Final Engineering Evaluation/Cost Analysis Landfills and Fill Areas, Parcels 78(6), 79(6), 80(6), 81(5), 175(5), 230(7), 227(7), 126(7), 229(7), 231(7), 233(7), and 82(7), Fort McClellan, Calhoun County, Alabama*, prepared for U.S. Army Corps of Engineers, Mobile District. March.

IT. 2002b. *"Site Investigation and Fill Area Definition Report Parcels 78(6), 79(6), 80(6), 81(5), 175(5), 230(7), 227(7), 126(7), 229(7), 231(7), 233(7), and 82(7), Fort McClellan, Calhoun County Alabama,"* Volume 1 of 6, Prepared for US Army Corps of Engineers, Mobile District, Task Order CK09, Revision 1, March.

Kram, M.L., Keller A.A., Rossabi, J., Everett, L.D. 2001. "DNAPL Characterization Methods and Approaches, Part 1: Performance Comparisons." *Ground Water Monitoring and Remediation*. Vol. 21, pp. 109-123.

Matrix Environmental Services, LLC (MES). 2004. *Draft Installation-Wide Sampling and Analysis Plan.* January.

MES. 2006. *Final (Revision 1) Corrective Measures Implementation Plan, Landfill 3 and the Fill Area Northwest of Reilly Airfield, Parcels 80(6) and 229(7).* October.

MES. 2007. *Quality Assurance Plan, Revision 3*. July.

MES. 2008. *Final Resource conservation Recovery Act Facility Investigation Landfill 3, Parcel 80(6) and Fill Area Northwest of Reilly Airfield, Parcel 229(7).* June.

Moretti, L., 2005. In Situ Bioremediation of DNAPL Source Zones. http://www.clu-in.org/download/studentpapers/moretti_dnaplbioremediation.pdf.

SAIC. 2000. *Final Fort McClellan Remedial Investigation/Baseline Risk Assessment Report.* July.

Shaw. 2003. *Results of Well and Spring User Survey North of Landfill No. 3, Parcel 80(6).* June.

U.S. Department of the Army (Army). 2003. *Cooperative Agreement Award, Agreement No: DASW01-03-2-0001*. September.

Army. 2007a. *Cooperative Agreement Award, Agreement No: W9128F-07-2-0163*. September 19.

Army. 2007b. *Cooperative Agreement Award, Agreement No: W9128F-07-2-0163, modification PO0001*. September 28.

Army. 2007c. *Cooperative Agreement Award, Agreement No: W9128F-07-2-0163, modification PO0002*. September 29.

U.S. Environmental Protection Agency (EPA), 2003. *The DNAPL Remediation Challenge: Is There a Case for Source Depletion?* EPA 600-R-03-143, 2003.

EPA. 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water. EPA/600/R-98/128. September.

TABLES

FIGURES

APPENDIX A

Results of Pneumatic Slug Testing
(Pre-Design Testing)

APPENDIX B

VOC Results for
2008 Groundwater Sampling
(Pre-Design Testing)

APPENDIX C

Natural Attenuation Parameter Results for 2008 Groundwater Sampling (Pre-Design Testing)

APPENDIX D

Data Quality Summary Report for 2008 Groundwater Sampling (Pre-Design Testing)