



Defense Logistics Agency

Defense Supply Center Richmond

ADMINISTRATIVE RECORD COVER SHEET

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FINAL

REMEDIAL ACTION WORK PLAN ADDENDUM
OPERABLE UNIT 8
DEFENSE SUPPLY CENTER RICHMOND

Prepared For



Defense Logistics Agency

And



United States Army Corps of Engineers
Baltimore District

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Executive Summary

This Remedial Action Work Plan (RAWP) Addendum describes the proposed follow-up in situ bioremediation (ISB) actions at Operable Unit (OU) 8 at Defense Supply Center Richmond (DSCR). OU 8 designation is the impacted groundwater beneath and downgradient of the former Acid Neutralization Pits (ANP) (OU 5). Remedial actions performed at OU 8 in 2022 and 2023 addressed volatile organic compound (VOC) plume areas in the Building 65, Building 66, and Open Storage Area 75 areas. This included targeted measures in the Building 65 area to address a groundwater source zone centered beneath F Bay of Building 65. The proposed enhanced measures in this work plan will address two remaining diffuse plume areas to the north of Buildings 65 and 66, respectively. Objectives for these actions are to further treat plume areas at OU 8 and mitigate potential plume migration toward downgradient areas and the fence line area closest to Building 66.

Diffuse plumes targeted for additional ISB actions primarily consist of tetrachloroethene and trichloroethene with concentrations greater than established cleanup levels. Cleanup levels for OU 8 consist of maximum contaminant levels contained in the National Primary Drinking Water Regulations. The diffuse plumes in the areas north of Building 65 and north/northeast of Building 65 have areas of approximately 1.89 acres and 1.80 acres, respectively.

The process option of the ISB design in this work plan follows the remedial design/remedial action work plan for OU 8 (AECOM 2013) using metabolic anaerobic reductive dechlorination as the targeted degradation process to treat the chlorinated solvents. In this reaction, microorganisms gain energy as one or more chlorine atoms on a chlorinated ethene or ethane compound molecule are replaced with hydrogen atoms in an anaerobic environment. The chlorinated compound serves as the electron acceptor and molecular hydrogen usually serves as the electron donor (source of energy). Hydrogen used in this reaction is supplied by fermentation of organic substrates or a direct electron donor. Biodegradation of an organic substrate depletes the aquifer of dissolved oxygen, and sequentially reduces native electron acceptors nitrate, manganese, iron, sulfate, and carbon dioxide. In general, metabolic anaerobic reductive dechlorination occurs by sequential removal of chlorine atoms with the sequential reaction consisting of tetrachloroethene → trichloroethene → cis-1,2-dichloroethene → vinyl chloride → ethene.

Primary criteria to select a substrate for the ISB design is distribution across the diffuse plume areas for treatment of lower concentrations of tetrachloroethene and trichloroethene, compatibility with a gravity feed delivery method, and cost effectiveness. Sodium lactate is the selected ISB substrate containing sodium lactate and nutrients; it is widely available with demonstrated effectiveness to support enhanced reductive dechlorination (ERD). Evidence of complete ERD pathways for tetrachloroethene and trichloroethene to ethene and ethane is apparent for previous ISB injections at OU 8 and treatability studies. Sodium lactate used in the 2018 ISB injections in the Building 65 area showed reduced concentrations across the targeted plume area. Native microbial communities in groundwater at OU 8 have demonstrated the capability to perform dechlorination to end products.

The process option selected for enhanced ISB for the surficial aquifer and treatment of diffuse plume areas is gravity feed injection using wells. For the plume area north of Building 65 where concentrations are highest, this will include three (3) existing 6-inch wells formerly used for a dual-phase extraction system. Overhead power and telecommunication lines limit access in this area to install additional injection wells. For the plume area north of Building 65, the ISB design period for treatment is 0.75 years. For the plume area north and northeast of Building 66, the proposed process option uses seven new injection wells north of Building 66 with a 1-year design period for treatment with three new injection wells northeast of Building 66 with a 0.75-year design period.

The proposed ISB actions will include remedy verification and performance monitoring at nine (9) monitoring locations. Injection process monitoring will track injection progress relative to the design and include field measurements during the injections to evaluate reagent distribution relative the treatment design. Performance monitoring will include a baseline monitoring event in April 2025 with ISB actions scheduled to occur in August/September 2025 followed by one-year of performance monitoring that includes sampling events in October 2025, January 2026, April 2026, July 2026, and October 2026.

Analytical parameters for each location will include field water quality parameters, volatile organic compounds, total organic carbon, geochemical parameters and two locations for microbial parameters.

ISB performance evaluations will: 1) evaluate reagent distribution and persistence relative to the design, 2) evaluate parameter trends along groundwater flow paths and at each performance well, 3) evaluate reduction of contaminant mass using chemical and geochemical data, 4) evaluate changes in plume extent (area) by comparing pre-and post-ISB modeled plumes, and 5) evaluate changes in biodegradation rates.

A project technical memorandum will summarize completed remedial action installation activities. Annual reports for OU 8 will report the results of remedy implementation, performance monitoring, monitored natural attenuation, and long-term monitoring and include data evaluations for the implemented ISB actions. Periodic updates of remedy performance and progress will occur during regulatory planning team meetings and for semi-annual restoration advisory board meetings.

Acronyms and Abbreviations

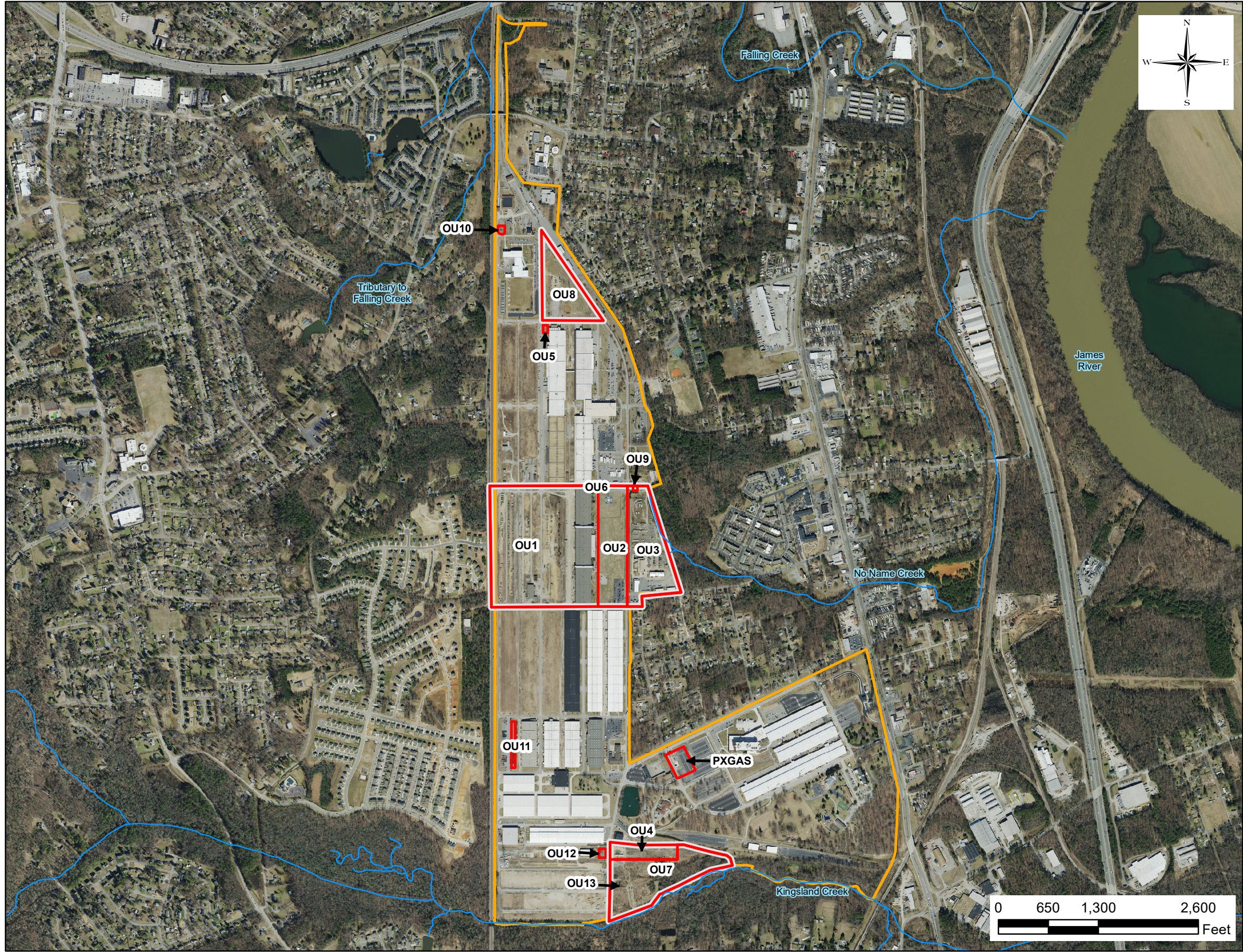
≈	approximate
<	less than
>	greater than
µg/L	micrograms per liter
%	percent
3D	three-dimensional
1,2-DCA	1,2-dichloroethane
ANP	acid neutralization pit
ARC	Army Reserve Center
BDGR	bio-enhanced directed groundwater recirculation
cDCE	cis-dichloroethene
CFR	code of federal regulations
cm/sec	centimeters per sec
COC	constituent of concern
CSM	conceptual site model
DCE	dichloroethene
DEQ	Virginia Department of Environmental Quality
DLA	Defense Logistics Agency
DO	dissolved oxygen
DPE	dual phase extraction
DPT	direct push technology
DSCR	Defense Supply Center Richmond
EPA	United States Environmental Protection Agency
ERD	enhanced reductive dechlorination
EVO	emulsified vegetable oil
ESD	explanation of significant differences
FFA	Federal Facility Agreement
FFS	focused feasibility study
ft.	feet
GIS	geographic information system
GPS	global positioning system
HHRA	human health risk assessment
HPT	hydraulic profiling tool
HRSC	high resolution site characterization
HSA	hollow-stem auger
IBC	intermediate bulk container
IC	institutional control
ISB	in situ bioremediation
IDM	investigative derived material
LAW	Law Environmental Inc.
LTM	long-term monitoring
LUCIP	land use control implementation plan
MCL	maximum contaminant level
Meadows	Meadows CMPG Inc.
mg/L	milligrams per liter
MNA	monitored natural attenuation
MCL	maximum contaminant level
mm	millimeters
mS/cm	millisiemens per centimeter
mV	millivolt
NAVD88	North American Vertical Datum of 1988
NPL	National Priorities List
NPS	National Pipe Straight

ORP	oxidation-reduction potential
OSA	open storage area
OU	operable unit
PCE	tetrachloroethene
ppm	part per million
PDI	pre-design investigation
QAPP	quality assurance project plan
QA/QC	quality assurance/quality control
RAWP	remedial action work plan
RD/RA	remedial design/remedial action
RI	remedial investigation
ROD	record of decision
SVOC	semi-volatile organic compound
SSA	singular spectrum analysis
SSO	Site Safety Officer
SC	specific conductivity
SVE	soil vapor extraction
SSDS	sub-slab depressurization system
TCE	trichloroethene
tDCE	trans-1,2-dichloroethene
TOC	total organic carbon
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VC	vinyl chloride
VOC	volatile organic compound
yr.	year

1. Introduction

This document is a Remedial Action Work Plan (RAWP) Addendum for Operable Unit 8 (OU 8) at Defense Supply Center Richmond (DSCR) prepared under Contract W912DR22C0045 awarded by the United States Army Corps of Engineers (USACE) Baltimore District on September 19, 2022, to Meadows CMPG, Inc. (Meadows). Meadows and teaming partner AECOM have prepared this RAWP Addendum following the contract Performance Work Statement and requirements of Contract Line-Item Number 0026. This document describes the proposed follow-up in situ bioremediation (ISB) actions at OU 8 that target groundwater and diffuse plumes in the surficial aquifer. OU 8 designation is the impacted groundwater beneath and downgradient of the former Acid Neutralization Pits (ANP) (OU 5).

DSCR is the headquarters of the Defense Logistics Agency (DLA) Aviation and is home to various other DLA, Department of Defense, and other federal organizations. The installation is eight miles south of the City of Richmond in Chesterfield County, Virginia. The United States Environmental Protection Agency (EPA) placed DSCR on the National Priorities List (NPL) in 1987. Since 1990, DLA has implemented an environmental restoration program at DSCR under a Federal Facility Agreement (FFA) with the EPA Region 3 and the Virginia Department of Environmental Quality (DEQ). Figure 1-1 has the layout of DSCR and OU locations.



Legend

- Operable Unit Boundaries
- OU 6; OU 7; OU 8 Boundaries
- Installation Boundary

Notes:
OU6 Includes Groundwater Impacts Beneath OU's 1, 2, & 3
OU7 Includes Groundwater Impacts Beneath OU 4
OU8 Includes Groundwater Impacts Beneath OU 5
Orthimagery Source: VGIN (2021)

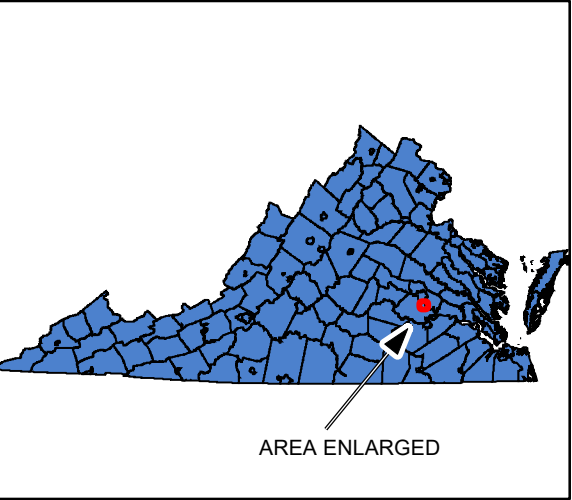


Figure 1-1
DSCR Operable Units

Defense Supply Center Richmond
Richmond, VA

Prepared By: DBC	Reviewed By: KL
Scale: 1" = 1,300'	Date: August 06, 2024

2. Background

Section 2 has background information for OU 8 including a site description, site history, and environmental setting.

2.1 OU 8 Description

OU 8 consists of the groundwater (surficial aquifer) impacted by past operations at the former ANPs (OU 5) in the northern-most area of the Installation (Figure 1-1). Figure 2-1 (page 2-2) shows the OU 8 area, which includes the northern portions of Warehouses (Buildings) 65 and 66, former Building 75 area, former OU 5 area, and open areas extending north to the Dervishian Army Reserve Center (ARC).

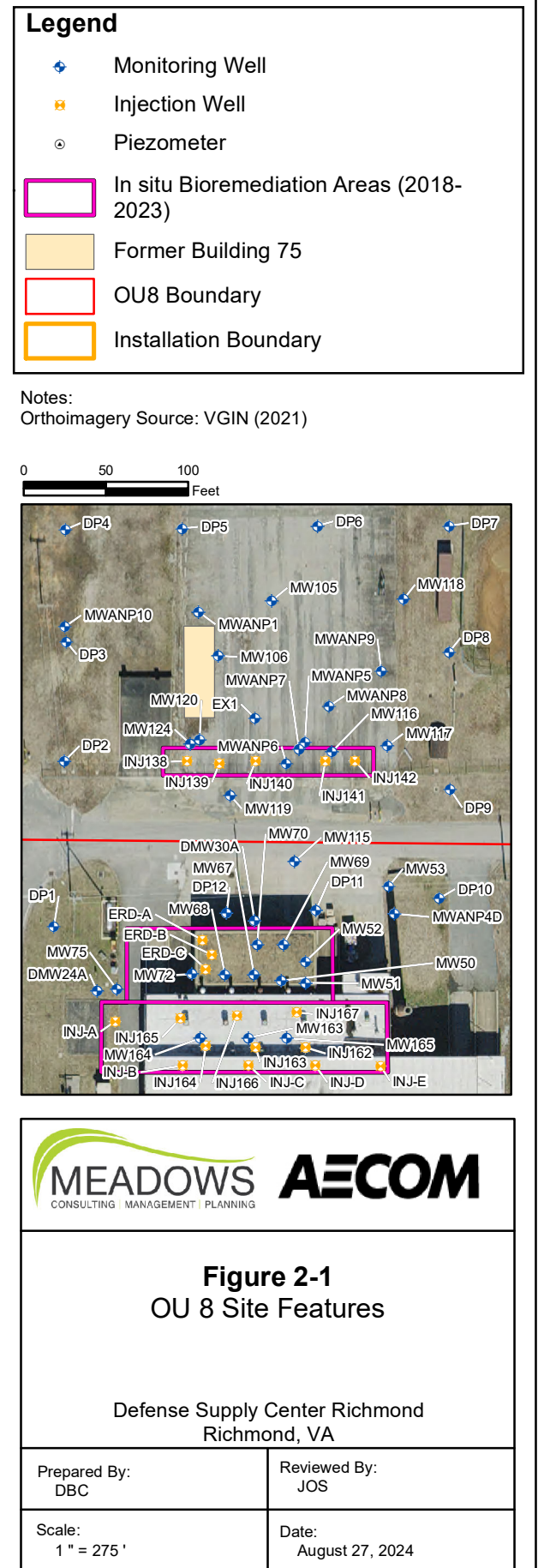
2.2 OU 8 Site History

Land use in the OU 8 area has included warehousing operations at Buildings 65, 66, and former Building 75. Current land use in the OU 8 area includes warehousing activities in Building 65 and 66 with open undeveloped land extending north to the Dervishian ARC. The recently constructed Virginia National Guard Joint Headquarters building is northwest of OU 8. Land use adjacent to the installation in the OU 8 area is residential. Planned future land use at DSCR and OU 8 will not change from the current land use. The drinking water source for DSCR, OU 8, and the adjacent offsite area is the Chesterfield County water system. The surficial and confined aquifers are not a drinking water source at DSCR. Storm drains in the OU 8 area discharge to No Name Creek near the National Guard Area (OU 3 area).

OU 5 includes the ANPs and the surrounding, potentially impacted soil. The ANPs consisted of two former concrete tanks that received wastewater from metal cleaning operations at Warehouse 65 (Building 65). Operations in Building 65 included cleaning (paint and rust removal) and repainting steel combat helmets compressed gas cylinders, and other metal items. These operations occurred from 1958 to the early 1980s. From 1958 to the late 1970s, wastewater from the primary tank discharged to the storm sewer. After the addition of the secondary tank during the late 1970s, wastewater began discharging to the sanitary sewer. Solids accumulated in the bottom of the tanks and periodically the installation had the solids removed and disposed at the Chesterfield County landfill. Leaching procedure analysis of these solids performed in 1979 by the United States Army Environmental Hygiene Agency resulted in a determination of not considered hazardous (Dames & Moore 1989).

Dames & Moore completed a remedial investigation (RI) in the ANP area in 1986-1988 (Dames & Moore 1988). The RI identified acids, bases, heavy metals, sodium, and chloride as potential contaminants associated with metals cleaning operations. The RI report indicated that elevated levels of some organics may occur in the ANP area because of potential use and/or improper disposal of solvents associated with thinning of paint prior to application and cleaning of paint equipment. This related to painting activities conducted in Warehouse 65 as part of the refurbishment of combat helmets and compressed gas cylinders with some solvents potentially used to remove grease and dirt in preparation of painting of metals items. Disposal of any solvents used in this area may have occurred in the wastewater discharged into the acid tanks or directly into the ANPs (Dames & Moore 1988). No known documentation exists for solvents use during metal cleaning operations.

In 1984, the installation developed plans and specifications to refurbish the caustic tank room in Warehouse 65-E (now designated F Bay) (DGSC 1984). This plan identified a cleaning process for the tanks that involved brush scrubbing using a grease-cutting solvent and thorough rinsing. Other elements of the plan included cleaning of all walls, ducts, grate supports, insulated pipes, floor, and other elements. (DGSC 1984). Given the date of the design plan (May 1984) and closure of the ANPs in 1985, it is unlikely that the installation undertook the tank cleaning task process for future operations.



Closure of the ANPs occurred in 1985, which included sludge removal, washing of residual sludge from the tank bottoms, and backfilling the tanks with clean soil. Noted conditions found at the time of the closure included broken and cracked concrete on the sides and bottom of the tanks (Dames & Moore 1989). Work completed by Arcadis for the design and installation of the bio-enhanced directed groundwater recirculation (BDGR) system in 2016 and 2017 discovered the existence of the former tank pit (including a caustic tank and rinse tank), vitrified clay pipe waste lines, and impacted perched water beneath the floor slab in F Bay. The waste lines connected to the primary acid and water neutralizing tank (OU 5) west of Building 65.

Figure 2-2 (page 2-4) shows the Building 65 area and adjacent OU 5 area features. This figure has a general schematic of the former ANPs and metal cleaning operations in F Bay of Building 65 and shows former waste lines (vitrified clay pipe), tank pit, and tanks beneath the floor slab of F Bay. The former metals cleaning infrastructure remains below the concrete floor slab in F Bay.

2.2.1 Installation Assessment

The U.S. Army Toxic and Hazardous Materials Agency completed the first environmental assessment at DSCR, and their installation assessment report noted operations at Warehouse 65 related to refurbishment of steel combat helmets and gas cylinders and storage of hazardous substances.

2.2.2 National Priorities Listing and Federal Facility Agreement (1987)

The EPA placed DSCR on the NPL in 1987 with a Hazard Ranking System score of 33.85; this listing related to volatile organic compounds (VOCs) in on-site groundwater, potential off-site migration of VOC-contaminated groundwater, and groundwater discharge into surface water. In 1990, EPA, DEQ, and DSCR entered a FFA to continue monitoring the installation and to develop and implement remedial action plans. The FFA identified 13 OUs and the PX Gas Station; this included OUs 5 and OU 8 (see Figure 1-1).

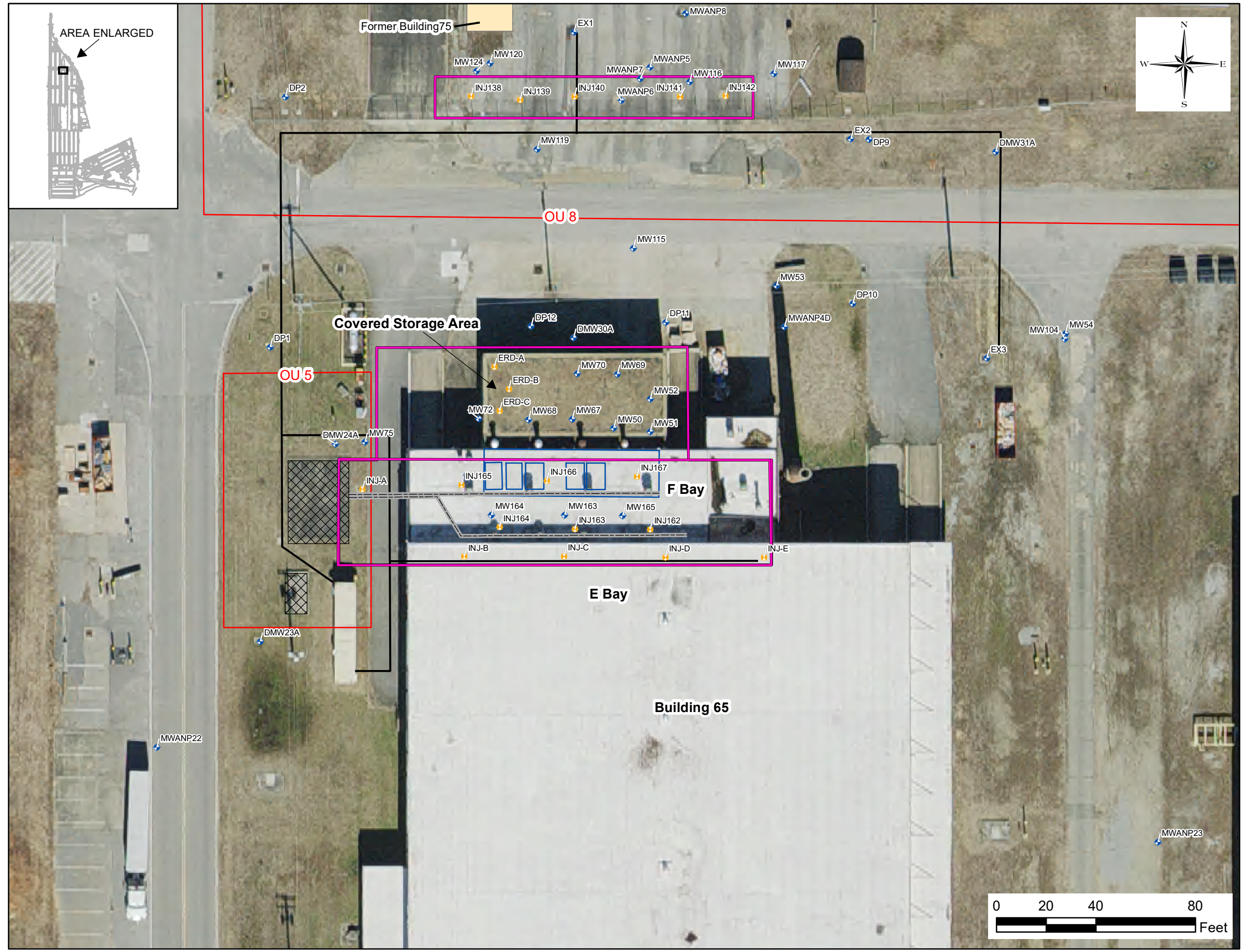
2.2.3 OU 5 Remedial Investigation (1986-1988)

Dames & Moore completed an RI in the ANP area in 1986-1988 with results included in a 1989 RI Report (Dames & Moore 1989). This RI included completion of two (2) borings for soil sampling in the ANP area and six (6) borings for installation of four monitoring wells and two (2) piezometers.

In January 1987, the RI sample collected at well DMW-24A located immediately north and downgradient of the ANPs had detected concentrations of tetrachloroethene (PCE), trichloroethene (TCE), and trans-1,2-dichloroethene (tDCE) greater than (>) current maximum contaminant levels (MCLs)¹ for these constituents. A later RI sample collected from DMW-24A in November 1988 had a PCE concentration of 1,700 micrograms per liter (µg/L), TCE concentration of 940 µg/L, and a total-1,2-dichloroethene (DCE) of 110 µg/L.

In June 1988, the RI samples collected at DMW-30A located 45 ft. north of Building 65 had detected concentrations of PCE (2,600 µg/L) and TCE (610 µg/L) > current MCLs with a detected total 1,2-DCE concentration of 140 µg/L. A later RI sample collected from November 1988 had a PCE concentration of 3,700 µg/L, a TCE concentration of 850 µg/L, a 1,2-DCE (total) concentration of 140 µg/L of total 1,2-DCE with no detected concentration of trans-1,2-DCE indicate that the 1,2-DCE consists of cis-1,2-dichloroethene (cDCE).

¹ Code of Federal Regulations, Title 40 Chapter I Subchapter D Part 141 Subpart G—National Primary Drinking Water Regulations: Maximum Contaminant Levels and Maximum Residual Disinfectant Levels. <https://www.ecfr.gov/current/title-40/chapter-I/subchapter-D/part-141/subpart-G>



Legend

- Monitoring Well
- Injection Well
- In situ Bioremediation Areas (2018-2023)
- Former ANPs
- Former Waste Lines
- Former Tank Pit
- BDGR Conveyance Piping
- OU Boundary

Notes:
Orthoimagery Source: VGIN (2021)

Figure 2-2
Building 65 Area

Defense Supply Center Richmond
Richmond, VA

Prepared By: DBC	Reviewed By: JOS
Scale: 1" = 40'	Date: August 06, 2024

2.2.4 OU 5 Record of Decision, Remedial Action, and ESD (1992 and 1996)

A record of decision (ROD) dated March 1992 identified the selected remedy for the OU 5 soils as soil vapor extraction (SVE) and construction of concrete covers over the tanks. An SVE pilot test performed in December 1992 indicated low concentrations of chlorinated VOCs present in the SVE influent. The analytical results from December 1992 soil borings collected before and after the SVE test showed no concentrations > OU 5 ROD action levels. An explanation of significant differences (ESD) for OU 5 signed in 1996 documented modification of the remedy at OU 5 to cease SVE operations with no further actions.

2.2.5 Area Supplemental Remedial Investigation (1992-1993)

In 1992-1993, Law Environmental Inc. (Law) completed a supplemental RI for groundwater to the north and northeast of Building 65 that included installation of four monitoring wells designated MWANP-1, -2, -3, and -4D. Law collected samples from these wells for analysis of VOCs, semi-volatile organic compounds (SVOC), and target analyte list inorganics. Sample results from wells screened in the surficial aquifer, MWANP-1, -2, and -3, had concentrations of PCE and TCE > MCLs. The sample collected from well MWANP-4D screened in the confined aquifer did not have VOC detections (Law 1995).

2.2.6 Focused Feasibility Study (1998)

A focused feasibility study (FFS) completed for OU 8 included design and implementation of a dual phase extraction (DPE) system. This system operated from July 1997 until July 1998 and had 12 extraction wells, 6 air injection wells, and an air stripper with operations occurring within an approximate 1.4-acre area north of the Building 65 area. DSCR continued system operations beyond the treatability test phase. The FFS evaluated several alternatives for remediation of groundwater and recommended DPE as the final alternative for implementation (Law 1998).

2.2.7 Dual Phase Extraction System (1997-2004)

DSCR operated the DPE and air injection system at OU 8 from July 1997 until January 2004 to address chlorinated VOCs in the surficial aquifer. During operation, the system created a hydraulic gradient toward the square grid of DPE wells to capture, treat, and discharge treated groundwater. Post DPE system shutdown sampling indicated apparent reductions in chlorinated VOC plume areas and concentrations with no significant rebound in concentrations observed after shutdown. DPE system decommissioning occurred in February 2008.

2.2.8 Revised Focused Feasibility Study (2006)

A revised FFS finalized in April 2006 identified, screened, and evaluated remedial alternatives using a revised Human Health Baseline Risk Assessment (HHRA) that characterized potential risks and hazards under an industrial land use scenario (MACTEC 2006).

2.2.9 OU 8 Record of Decision (2007)

A ROD dated February 2007 identified the selected remedy for OU 8 groundwater as monitored natural attenuation (MNA) and institutional controls (ICs) with a contingency remedy of ISB. The ROD identified threshold levels and conditions for implementation of the contingency remedy including evidence of attenuation processes, plume stability, and potential for offsite migration. Remedial cleanup levels established by the ROD for constituents in groundwater consist of Federal MCLs contained in Title 40 of the Code of Federal Regulations (CFR) Part 141 Subpart G § 141.61.

2.2.10 Remedial Action (2008)

Earth Tech AECOM prepared a remedial design/remedial action (RD/RA) work plan finalized in September 2008 that outlined remedy elements for MNA and ICs (Earth Tech AECOM 2008). DSCR modified the Land Use Control Implementation Plan (LUCIP) to include OU 8-specific ICs. The OU 8 ICs included designation of the land use solely for non-residential purposes until conditions allow for unlimited use and unrestricted exposure to groundwater. The ICs also included the requirement for a pre-construction assessment before construction activities can occur at OU 8. DSCR finalized the LUCIP addendum in November 2007 (DSCR 2007).

The RD/RA outlined additional groundwater characterization activities to support implementation of MNA and long-term monitoring (LTM) for the remedy. AECOM implemented the additional characterization (2008-2009) and semi-annual monitoring of groundwater (beginning in 2009) and reported these activities in a Final Remedial Action Monitoring Report dated March 2011 (AECOM 2011). This report indicated limited evidence of natural biodegradation and rebound of plume concentrations in the former DPE area.

2.2.11 In Situ Bioremediation Test (2010)

In April/May 2010, AECOM completed an ISB test downgradient of the ANPs and in the covered area north of Building 65. The test involved injecting approximately 6,700 gallons of a 3 percent (%) emulsion of emulsified vegetable oil (EVO) into the surficial aquifer to evaluate the effectiveness of organic carbon addition to the chlorinated VOC degradation processes at OU 8. Injections occurred in 0.75-inch diameter injection wells at low injection rates. Post-injection monitoring of groundwater indicated in situ biodegradation of chlorinated VOCs in this area (AECOM 2012).

2.2.12 OU 8 Record of Decision ESD (2011)

An ESD for the ROD finalized in August 2011, specified implementation of the ISB contingency remedy identified in the ROD (DSCR 2011). The ESD triggered preparation of RD/RA Addendum to implement the contingency remedy.

2.2.13 Remedial Action Addendum (2013)

AECOM prepared a RD/RA Work Plan Addendum finalized in May 2013 (AECOM 2013). This work plan identified four ISB treatment areas with injection wells to distribute EVO as the carbon substrate to stimulate reductive dichlorination. AECOM completed treatability tests in 2011 to support the remedial design. The remedial design included installation of additional monitoring wells for remedy effectiveness and MNA evaluations with continued semi-annual groundwater monitoring.

AECOM implemented remedial actions at OU 8 in 2013 and 2014, which included well installation, ISB injections, vapor monitoring, semi-annual groundwater monitoring, and annual IC inspections. The modified remedy incorporated an expanded semi-annual monitoring program that included offsite locations along Strathmore Road beginning in 2012 and additional downgradient locations in 2014/2015.

In 2015, USACE completed an ISB pilot test north of Building 65 and began operating a single-well pumping test in the northern plume area at OU 8. This pumping test operated from May 2015 until October 2019. In 2016, Arcadis implemented a second single-well pumping test east of Building 66; this pumping test operated from May 2016 until February 2021.

2.2.14 Human Health Risk Assessment for Buildings 65 and 66

In 2014, AECOM completed an HHRA to evaluate potential risks to indoor workers at Buildings 65 and 66 via inhalation of VOCs migrating from the OU 8 groundwater plume to indoor air. The risk assessment used the results of sub-slab vapor and indoor air samples collected at each building as part of the January 2014 subsurface vapor intrusion investigation conducted for OU 8.

The HHRA calculated risks and hazards for current indoor workers at Buildings 65 and 66 fell below the target risk and hazard levels. The HHRA included the sub-slab soil vapor analytical results from Building 65 to evaluate future worker risk. The HHRA estimated risks fell below the target risk and the estimated hazard exceeded the target hazard with PCE and TCE identified as constituents of concern (COCs). At Building 66 using sub-slab soil vapor results, the HHRA estimated risks and hazard for Building 66 fell below the target risk and hazard levels.

The results of this HHRA resulted in implementing vapor intrusion mitigation measures in F Bay of Building 65 in 2014. A sub-slab depressurization system (SSDS) began operating in F Bay in 2014 with system upgrades completed in 2015 and 2018 to increase the level and extent of depressurization below the floor slab in F Bay. Annual air sampling and SSDS evaluations have indicated continued effectiveness of the SSDS mitigation measures.

2.2.15 Bio-Enhanced Directed Groundwater Recirculation System (2017-2021)

In February 2017, Arcadis implemented a BDGR system at OU 8 as an enhanced ISB measure. The BDGR focused on the groundwater plume area extending from Building 65 to the Open Storage Area (OSA) 75 and had three (3) extraction wells and five (5) reinjection wells primarily along the northern interior wall of E Bay of Building 65 immediately upgradient of F Bay. This system operated from February 2017 until February 2021.

BDGR operations extracted groundwater from the diffuse plume area north and northeast of the source zone beneath Building 65 resulting in low rates of VOC mass removal. Because of the low flows, the BDGR had limited capture zones around the extraction wells and could not completely hydraulically contain the plume in the Building 65 area. System influent concentrations peaked shortly after system startup and decreased through the operational period. The system also had progressively lower flow and extraction rates over time, which required rehabilitation of extraction and injection wells to maintain continuous operations.

2.2.16 Remedial Action Addendum (2018)

Arcadis prepared a RA Work Plan finalized in July 2018 (Arcadis 2018). This work plan addendum to the 2008 RA/RD identified additional ISB treatment beneath F Bay of Building 65 and expanded ISB treatment areas at existing downgradient injection well transects. Arcadis completed pre-design investigation (PDI) activities in 2016 and 2018 to support design and implementation of the ISB measures. PDI included completion of soil borings and high-resolution site characterization (HRSC) using direct push technology (DPT).

The scope of ISB included installation of six injection wells in F Bay and six additional injection wells at existing downgradient injection well transects. Arcadis implemented ISB injections in September 2018, which included soluble substrate (lactate) in the Building 65 area and semi-soluble substrate (EVO) in the downgradient locations.

2.2.17 Building 65 Investigation and Conceptual Site Model Update (2020)

AECOM-Meadows completed a soil investigation within F Bay and E Bay of Building 65 in June 2020 that delineated a residual chlorinated VOC source zone in soil beneath the building. The scope of work included completion of 17 soil borings inside of Building 65 to depths extending into the saturated zone of the surficial aquifer. Vertical profiling of soils at each boring included analysis for VOCs at three depth intervals, collection of eight soil samples for VOC leaching evaluation by the Synthetic Precipitation Leaching Procedure (SW846 Method 1312) and supporting analysis for total organic carbon (TOC) and physical soil properties.

This source zone consists primarily of PCE and TCE with PCE having higher concentrations and greater extent. This source zone occurs within an approximate 4,300 square foot area primarily beneath F Bay extending into the northern portion of E Bay. A high concentration source zone remains beneath a former degreasing tank and drain line with the highest concentration near the saturated zone of the surficial aquifer. Soil concentrations exceed the calculated soil saturation limit for PCE. The vertical extent of the residual source zone extends into the surficial aquifer.

AECOM and Meadows incorporated the Building 65 investigation into a higher resolution, digital conceptual site model (CSM) developed for the Building 65 area and OU 8 using a combination of historical and new data.

2.2.18 Remedial Action Addendum for Building 66 Area (2021)

AECOM-Meadows prepared a RA Work Plan Addendum finalized in February 2022 that identified follow-up ISB treatment east of the Building 66 area (AECOM and Meadows 2022a). ISB targeted accelerated plume treatment and degradation following the interim pumping test that operated in the area from 2016-2021. The remedy optimization completed at OU 8 in February 2022 included 15 DPT ISB injection points within a 100 x 10-foot grid targeting the surficial aquifer containing chlorinated VOCs. The substrate used for ISB consisted of EVO with bioaugmentation. Post-injection performance monitoring included one year of quarterly monitoring followed by semi-annual monitoring.

2.2.19 Remedial Action Addendum for Former Building 75 Area (2021)

AECOM and Meadows prepared a RA Work Plan Addendum finalized in February 2022 that identified follow-up ISB treatment in the former OSA 75/Building 75 area (AECOM and Meadows 2022b). ISB targeted treatment of residual chlorinated VOCs in groundwater in the former OSA 75/Building 75 area, reduction of VOC flux from the Building 65 source zone, and the accelerated reduction of downgradient plume areas. The remedy optimization completed in the former OSA 75/Building 75 area in February-March 2022 consisted of ISB injections at six existing injection wells using EVO with bioaugmentation. Post-injection performance monitoring included one year of quarterly monitoring followed by semi-annual monitoring.

2.2.20 Remedial Action Addendum for Building 65 Area (2023)

AECOM and Meadows prepared a RA Work Plan Addendum finalized in January 2023 that identified follow-up ISB treatment in F Bay of Building 65 (AECOM and Meadows 2023). ISB targeted direct treatment of the residual chlorinated VOC source zone, reduction of VOC flux from the source zone, and acceleration of plume degradation downgradient of this source zone. The remedy optimization completed in the Building 65 area in March 2023 consisted of ISB injections at 11 existing injection wells using EVO with bioaugmentation. Post-injection performance monitoring included one year of quarterly monitoring followed by semi-annual site-wide monitoring of groundwater at OU 8.

2.3 Environmental Setting

Section 2.3 describes the environmental setting for OU 8.

2.3.1 Physical Setting

DSCR lies east of the Fall Line that separates the Atlantic Coastal Plain physiographic province to the east from the Piedmont physiographic province to the west. The Coastal Plain physiographic province has level to gently rolling terrain, broad stream valleys, and extensive wetlands. Piedmont areas have rolling terrain and higher elevations than the Coastal Plain with narrower stream valleys and less extensive non-tidal wetlands.

2.3.2 Topography and Surface Water Drainage

Ground surface elevations in the OU 8 area range from approximately 117 to 124 feet (ft.) with reference to the North American Vertical Datum of 1988 (NAVD88). Site development has slightly altered the surface grade at OU 8. Surface water drainage is through overland flow to storm sewer drains within OU 8. OU 8 is in the Falling Creek Tributary watershed. Stormwater outfalls associated with OU 8 discharge to tributaries of Falling Creek. Falling Creek and tributaries are located north and northeast of DSCR, as shown on Figure 1-1.

2.3.3 Geology

DSCR lies near the western edge of the Virginia Coastal Plain. General stratigraphy found beneath OU 8 includes four coastal plain formations present above the Petersburg Granite bedrock from youngest to oldest: the Eastover Formation, Calvert Formation, Aquia Formation, and Potomac Formation. Table 2-1 provides general stratigraphy information for the OU 8 area.

Table 2-1 OU 8 General Stratigraphy

Geologic Formation	Age	Origin	Approximate Thickness (ft.)	Primary Lithology Types
Eastover	Pliocene	Alluvial	23-25 ¹	Upper unit: clay (CL), clayey sand (SC), and silty sand (SM), Lower unit: poorly graded sand with gravel (GP)
Calvert	Miocene	Marine	2.6-7 ²	Clay (CH) and organic sand silt (OL)
Aquia	Paleocene	Marine	<3-12	Silty sand (SM)

Geologic Formation	Age	Origin	Approximate Thickness (ft.)	Primary Lithology Types
Potomac	Early Eocene	Alluvial	20-35	Clayey sand with gravel (SC), deeper zones contain variable silt (MH) with sand
Petersburg Granite	Mississippian	Bedrock	--	Granite to Granodiorite Bedrock

Notes: ¹Thickness in northernmost part of study area is 31 to 33 feet. ²Thickness in northernmost part of study area is less than 2 feet.

The Eastover Formation consists of reddish brown to yellowish brown, variable silty clay, and fine-to-medium silty sand, overlying a basal layer consisting of poorly graded sand with variable gravel. This formation is approximately 23 to 25 ft. thick in OU 8. In the Dervishian ARC northwest of OU 8 the Eastover thickness increases to 31 to 33 ft. The poorly graded sand with gravel lithologic unit ranges from 8 to 12 ft. thick.

The Calvert Formation is a dark gray highly plastic clay and organic sandy silt with a dry consistency. HRSC borings indicate variable thickness across OU 8. North of Building 65, the Calvert thickness is approximately 3.5 ft and decreases to 2.5 ft. along the northern fence line area. East and northeast of Building 66 the Calvert thickness averages 7 ft. near the fence line and decreases to approximately 3 ft. along the fence line in the southern ARC area. Near the northwest corner of the ARC, the Calvert thickness decreases to approximately 1 ft.

The Aquia Formation is a fining-upward, well sorted, dark green, glauconitic silty sand with a basal gravel stratum. HRSC borings performed in the northern OU 8 area indicated variable thickness of 6 to 12 ft. with an increase in thickness toward the north from Building 65.

Potomac Formation sediments at DSCR consist of an upper lithologic zone of greyish-green clayey sand with gravel ranging in thickness from 20 to 35 ft. and a lower lithologic zone of grayish-green, clayey sand with gravel with a texturally finer basal layer varying from elastic silt with sand to clayey sand. The thickness of the lower lithologic zone is variable.

Bedrock in the study area is the Petersburg Granite described by the United States Geological Survey (USGS) as chlorite rich granodiorite (USGS 1987).

2.3.4 Hydrostratigraphy

The updated CSM includes a refined hydrostratigraphy model developed by integrating the geologic model with existing hydrogeologic data and HRSC data. Table 2-2 summarizes the refined hydrostratigraphy for OU 8 and associated hydraulic properties defined in the digital CSM.

Table 2-2 OU 8 Hydrostratigraphy

Hydro. Unit	Type	Description	Relative Permeability	Estimated K (cm/sec)
Eastover	Aquifer	Unconfined (formerly designated upper water bearing unit)	High	1.0E-02 to 5.3E-02 ² 4.6E-02 ¹
Calvert	Confining Zone	Leaky unit	Very Low	4.8E-08 to 1.8E-06
Aquia	Aquifer	Semi-confined, bulk matrix of formation (formerly designed as part of confining unit)	Low-High	<1.0E-04 to 3.5E-02 ² 1.8E-06 to 1.6E-05 ³
Potomac	Aquifer	Semi-confined, bulk matrix of formation (formerly designated lower water bearing unit)	Very Low-Moderate	2.5E-03 to 6.5E-03 ⁴ 2.3E-07 to 3.5E-05 ⁵
Bedrock	Aquifer	Confined in fractures	Not determined	--

Notes: ¹Pumping test performed by AECOM northeast of Building 66, ²Field testing with hydraulic profiling tool, ³Laboratory core testing at OU 8 (vertical), ⁴Pumping test at OU 8 fence line by USGS in 1986, ⁵Laboratory core testing (horizontal) at OU 8, K= hydraulic conductivity, cm/sec = centimeters per second,

The Eastover hydrostratigraphic unit corresponds to the Eastover Formation and groundwater within this unit is an unconfined water table. The surficial aquifer (also identified as upper water bearing unit for previous site work and investigations) is the principal unit monitored at OU 8. Depth to groundwater is 12 to 14 ft. below ground surface with the saturated zone principally occurring in the poorly graded sand with variable gravel lithologic unit. Hydraulic profiling tool (HPT) and pumping test data indicate that this lithologic unit has a high hydraulic conductivity as illustrated in Table 2-2.

The Calvert hydrostratigraphic unit corresponds to the Calvert Formation and is a leaky confining zone that ranges from 2.5 to 7 ft. thick, except in the northwestern ARC where the Calvert is less than 2 ft. thick. It has a low vertical hydraulic conductivity based on laboratory core testing (Table 2-2) and high HPT pressures (100-110 pounds per square inch). The Calvert separates the overlying Eastover hydrostratigraphic unit from the underlying Aquia and Potomac hydrostratigraphic units. At OU 8, vertical migration of VOCs from the surficial aquifer to the confined aquifer implies vertical groundwater flow through Calvert at DSCR.

The Aquia hydrostratigraphic unit corresponds to the Aquia Formation and is a semi-confined zone of groundwater that ranges from less than 3 to 12 ft. thick. HPT profiling indicates that the horizontal hydraulic conductivity of the Aquia varies by more than two orders of magnitudes (Table 2-2) with discrete zones having values greater than $1\text{E-}02$ centimeters per second (cm/sec). For work at OU 6, the USGS and Remedial Investigation determined vertical hydraulic conductivities in the range of 3 to 4 orders of magnitude lower than horizontal conductivities (Table 2-2). OU 6 data indicates that the Aquia and underlying Potomac have similar horizontal groundwater flow patterns and hydraulic gradient.

The Potomac hydrostratigraphic unit corresponds to the Potomac Formation. This unit is a confined zone of groundwater with low to moderate permeability. Limited monitoring of this confined aquifer occurs for vertical extent determinations in residual source zones. The USGS pumping test conducted at the OU 8 fence line indicated moderate permeability (see Table 2-2). This hydrostratigraphic unit has a dense bulk matrix with HPT profiling and testing indicating consistent maximum pressure responses of 110 pounds per square inch. Clean water injection testing and laboratory testing performed at OU 6 indicate low to very low permeability for the Potomac. Samples collected from monitoring wells installed into the confined aquifer (Potomac) at OU 8 do not have detectable VOCs.

3. Groundwater Current Conditions Summary

Section 3.0 presents a current conditions summary for the surficial aquifer at OU 8 using the most recent sampling event completed in October 2024. VOCs in surficial groundwater have concentrations greater than cleanup levels corresponding to Federal MCLs². Samples collected from the confined aquifer at OU 8 do not have detections of VOCs.

3.1 Groundwater Flow

Figure 3-1 (page 3-2) has potentiometric surface elevation contours for the surficial aquifer (Eastover) for the October 2024 event. The three-dimensional (3D) model used site-wide groundwater elevation data for wells screened in the surficial aquifer and geostatistical analysis (kriging) to develop these maps.

Equation 1 calculates the approximate horizontal velocity range of groundwater flow within the surficial aquifer using a form of Darcy's velocity equation:

$$(1) \quad V = \frac{Ki}{n_e}$$

Where:

V = groundwater flow velocity (ft./yr)
K = hydraulic conductivity (feet per day [ft/day])
i = hydraulic gradient (ft/ft)
n_e = effective porosity (unitless)

Input values for Equation 1 for the surficial aquifer include:

- An average hydraulic conductivity (K) of 125.2 ft/day (based on the 2011 AECOM pumping test completed north of Building 66 at well MWANP-26).
- Estimated effective porosity of 0.25 based on the poorly graded sand with gravel soil type for the primary groundwater zone within the surficial aquifer.
- Average hydraulic gradient of 1.5E-03 for the October 2024 sampling event (Figure 3-1).

The estimated horizontal groundwater flow velocity calculated for the surficial aquifer using the above input values is 7.5E-01 ft./day (273.8 ft./yr.) for the October 2024 event.

3.2 Water Quality Parameter Data Distribution

Section 3.2 has a summary of water quality parameter results (2024) for pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and specific conductivity (SC). Exhibit 3-1 (page 3-3) has box plots displaying data distributions for these parameters for the October 2024 monitoring event.

pH

For October 2024, the data distribution range for pH is 2.75 with a mean of 5.07 and median of 4.86. The distribution 25th and 75th percentiles are 4.37 and 5.82, respectively. Forty-eight of 92 data observations have a pH less than 5.

²Code of Federal Regulations, Title 40 Chapter I Subchapter D Part 141 Subpart G—National Primary Drinking Water Regulations: Maximum Contaminant Levels and Maximum Residual Disinfectant Levels. <https://www.ecfr.gov/current/title-40/chapter-I/subchapter-D/part-141/subpart-G>



Legend

- Monitoring Well
- Potentiometric Surface Contour Line
- OU 8 Boundary
- Installation Boundary
- Groundwater Flow Direction

Notes:
Contours in NAVD88 feet
Orthoimagery Source: VGIN (2021)

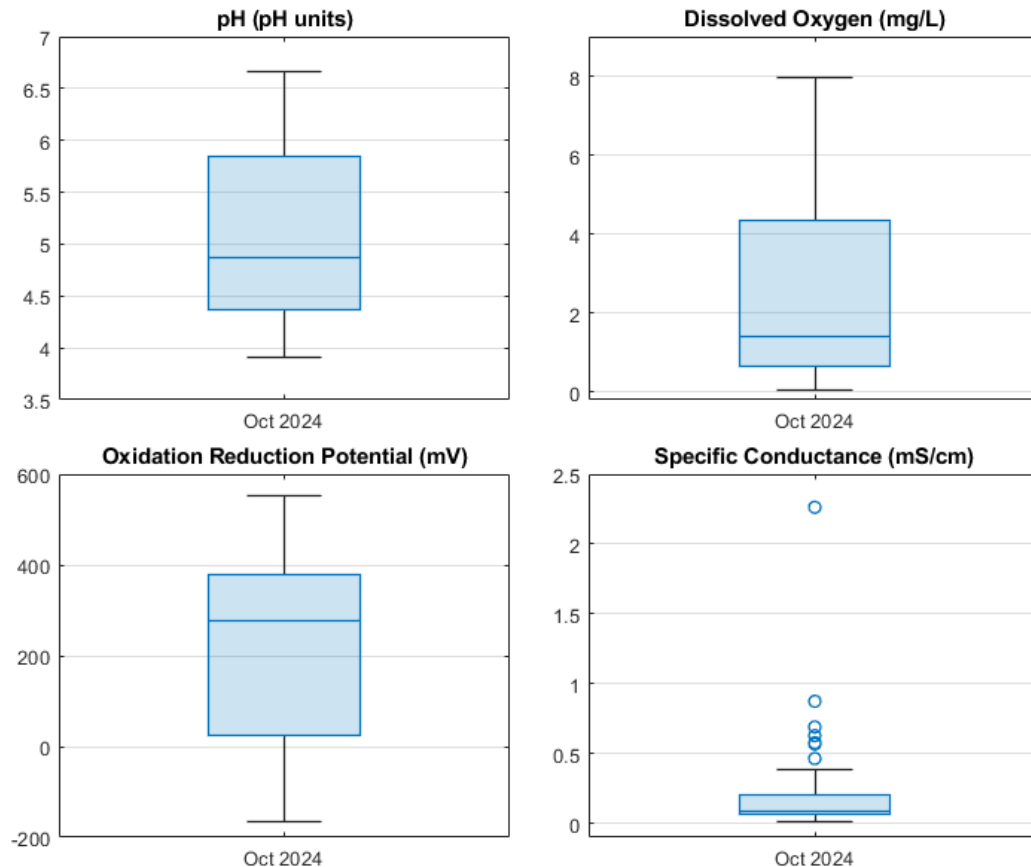


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Figure 3-1
OU 8 Surficial Aquifer Potentiometric
Surface Map (October 2024)
Defense Supply Center Richmond
Richmond, VA

Prepared By: JLD	Reviewed By: JOS
Scale: 1" = 271'	Date: February 27, 2025

Exhibit 3-1 Water Quality Parameter Data Distribution for Surficial Aquifer (October 2024)



Dissolved Oxygen

For October 2024, the data distribution range for DO is 7.94 milligrams per liter (mg/L) with a mean of 2.54 mg/L and median of 1.59 mg/L. The distribution 25th and 75th percentiles are 0.67 mg/L and 4.34 mg/L, respectively. Thirty-three of 92 data observations have a DO less than or equal to 1 mg/L.

Oxidation Reduction Potential

For October 2024, the distribution range for ORP is 717.2 millivolts (mV) with a mean of 216.6 mV and median of 280.8 mV. The distribution 25th and 75th percentiles are 27.9 mV and 377.8 mV, respectively. Ten of 92 data observations have an ORP less than 50 mV.

Specific Conductance

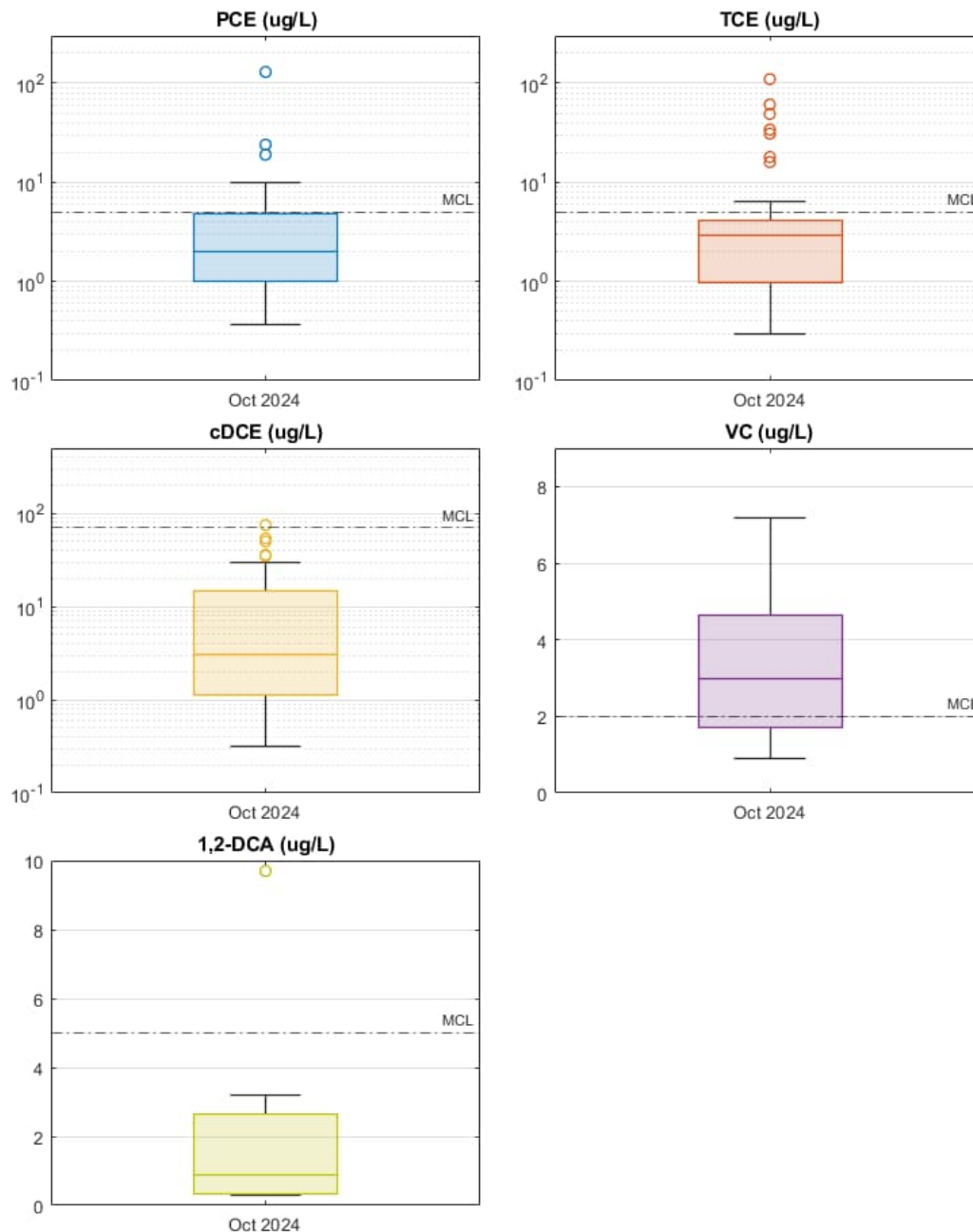
For October 2024, the distribution range for SC is 2.25 millisiemens per centimeter (mS/cm) with a mean of 0.174 mS/cm and median of 0.088 mS/cm. The distribution 25th and 75th percentiles are 0.061 mS/cm and 0.198 mS/cm, respectively. The maximum result reported (2.263 mS/cm) is a distribution outlier.

3.3 VOC Data Distribution

VOCs detected in the surficial aquifer at concentrations greater than MCLs for the October 2024 sampling event include PCE, TCE, cDCE, vinyl chloride (VC), and 1,2-dichloroethane (1,2-DCA). Exhibit 3-2 (page 3-4) has box plots displaying data distributions for these parameters for the October 2024 monitoring event.

Tetrachloroethene (PCE)

For October 2024, 39 of 91 samples had detections of PCE and detected concentrations ranging from 0.37 µg/L to 130 µg/L. Mean and median concentrations for PCE are 7.05 µg/L and 2 µg/L, respectively, with nine (9) samples having concentrations greater than MCL of 5 µg/L. Distribution 25th and 75th percentiles for PCE are 1 µg/L and 4.88 µg/L, respectively.

Exhibit 3-2 VOC Data Distribution for Surficial Aquifer (October 2024)**Trichloroethene (TCE)**

For October 2024, 49 of 91 samples had detections of TCE and detected concentrations ranging from 0.30 µg/L to 110 µg/L. Mean and median concentrations for TCE are 8.48 µg/L and 2.9 µg/L, respectively, with nine (9) samples having concentrations greater than MCL of 5 µg/L. Distribution 25th and 75th percentiles for TCE are 0.98 µg/L and 4.12 µg/L, respectively.

cis-1,2-Dichloroethene (cDCE)

For October 2024, 41 of 91 samples had detections of cDCE and detected concentrations ranging from 0.28 µg/L to 110 µg/L. Mean and median concentrations for cDCE are 11.8 µg/L and 3.1 µg/L, respectively, with one (1) sample having a concentration greater than MCL of 70 µg/L. Distribution 25th and 75th percentiles for cDCE are 1.14 µg/L and 14.5 µg/L, respectively.

Vinyl Chloride (VC)

For October 2024, 15 of 91 samples had detections of VC and detected concentrations ranging from 0.91 µg/L to 7.2 µg/L. Mean and median concentrations for VC are 3.2 µg/L and 3 µg/L, respectively, with 10 samples having concentrations greater than MCL of 2 µg/L. Distribution 25th and 75th percentiles for VC are 1.7 µg/L and 4.8 µg/L, respectively.

1,2-Dichloroethane (1,2-DCA)

For October 2024, 8 of 91 samples had detections of 1,2-DCA and detected concentrations ranging from 0.31 µg/L to 9.7 µg/L. Mean and median concentrations for 1,2-DCA are 2.21 µg/L and 0.88 µg/L, respectively, with one (1) sample having a concentration greater than MCL of 5 µg/L. Distribution 25th and 75th percentiles for 1,2-DCA are 0.34 µg/L and 2.65 µg/L, respectively.

3.4 Geochemical Parameter Data Distribution

Section 3.4 discusses the data distribution for geochemical parameters analyzed for 56 of the samples collected for the October 2024 sampling event at OU 8.

Chloride

Chloride is a daughter product of chlorinated ethene degradation with levels 2 times greater than background providing evidence of reductive dechlorination processes (EPA 1998, 39). Background chloride levels at OU 8 are typically less than 2 mg/L (AECOM and Meadows 2024, 5-3). For October 2024, chloride concentrations ranged from 1.2 mg/L to 70 mg/L with mean and median concentrations of 18 mg/L and 11 mg/L, respectively. Distribution 25th and 75th percentiles for chloride are 8 mg/L and 18 mg/L, respectively. One sample collected in October 2024 had a chloride concentration less than 2 mg/L.

Nitrate

For October 2024, 32 of 56 samples had detections of nitrate with detected concentrations ranging from 0.024 mg/L to 8.6 mg/L. Mean and median concentrations for nitrate are 1.5 mg/L and 1.1 mg/L, respectively, with 17 samples having concentrations greater than 1 mg/L. Distribution 25th and 75th percentiles for nitrate are 0.15 mg/L and 2 mg/L, respectively. At levels greater than 1 mg/L, nitrate may compete with the reductive pathway for chlorinated ethenes (EPA 1998, 29). When oxygen is depleted nitrate becomes a substrate for microbial respiration (EPA 1998, 19).

Sulfate

Higher sulfate concentrations greater than 20 mg/L may compete the reductive pathway for chlorinated ethenes (EPA 1998, 29). Sulfate is a substrate for microbial respiration (EPA 1998, 20). For October 2024, 36 of 55 samples had detections of sulfate and detected concentrations ranging from 0.43 mg/L to 24 mg/L. Mean and median concentrations for sulfate are 3.8 mg/L and 2.6 mg/L. Distribution 25th and 75th percentiles for sulfate are 1.04 mg/L and 3.95 mg/L, respectively. One sample at MW-164 had a sulfate concentration greater than 20 mg/L.

Sulfide

The presence of sulfide at concentrations greater than 1 mg/L indicates the possibility of a reductive pathway (EPA 1998, 29). For October 2024, 6 of 55 samples had detections of sulfide and detected concentrations ranging from 0.84 mg/L to 1.1 mg/L. Mean and median concentrations for sulfide are 0.90 mg/L and 0.965 mg/L, respectively, with four (4) samples having concentrations less than 1 mg/L. Distribution 25th and 75th percentiles for sulfide are 0.91 mg/L and 1.1 mg/L, respectively.

Sulfide as Hydrogen Sulfide

For October 2024, 5 of 56 samples had detections of sulfide and detected concentrations ranging from 0.89 mg/L to 1.1 mg/L. Mean and median concentrations for sulfide are 1.03 mg/L and 1.10 mg/L, respectively, with two (2) samples having concentrations less than 1 mg/L. Distribution 25th and 75th percentiles for sulfide are 0.96 mg/L and 1.1 mg/L, respectively.

Ferrous Iron

The presence of ferrous iron at concentrations greater than 1 mg/L indicates the possibility of a reductive pathway due to the depletion of oxygen, nitrate, and manganese (EPA 1998, 18, 29). VC can oxidize under ferric iron reducing conditions (EPA 1998, 29). For October 2024, ferrous iron concentrations ranged from 0.01 mg/L to 35.2 mg/L with mean and median concentrations of 2.94 mg/L and 1.17 mg/L, respectively, with 26 samples having concentrations greater than 1 mg/L. Distribution 25th and 75th percentiles for ferrous iron for October 2024 are 0.05 mg/L and 4.64 mg/L, respectively.

Manganese

Sampling for manganese evaluates if anaerobic biological activity is solubilizing manganese from the material of aquifer bulk matrix (EPA 1998, 18). For October 2024, manganese concentrations ranged from 2.2 µg/L to 6,100 µg/L with mean and median concentrations of 345 µg/L and 88 µg/L, respectively. Distribution 25th and 75th percentiles for manganese are 31 µg/L and 270 µg/L, respectively.

Alkalinity

Alkalinity at levels more than 2 times greater than background results from the interaction of carbon dioxide and surficial aquifer materials where carbon dioxide production occurs during bioremediation processes. Background levels of alkalinity for the surficial aquifer at OU 8 are less than 5 mg/L (AECOM and Meadows 2024, 5-3). For October 2024, 34 of 56 samples had detectable alkalinity levels ranging from 2.4 mg/L to 150 mg/L with mean and median concentrations of 46.8 mg/L and 35.5 mg/L, respectively. Distribution 25th and 75th percentiles for alkalinity are 10 mg/L and 75 mg/L, respectively.

Carbon Dioxide

Background carbon dioxide levels are typically less than 10 mg/L for the surficial aquifer at OU 8 (AECOM and Meadows 2024, 5-3). Carbon dioxide levels greater than 2 times background are indicative bioremediation processes where carbon dioxide production occurs by oxidative processes either aerobically or by iron reduction (EPA 1998, 27). For October 2024, 49 of 56 samples had detections of carbon dioxide at concentrations ranging from 6.4 mg/L to 380 mg/L with mean and median concentrations of 85.1 mg/L and 63 mg/L, respectively. Distribution 25th and 75th percentiles for carbon dioxide are 33.8 mg/L and 102.5 mg/L, respectively.

Ethene

Ethene is an end product of reductive dechlorination of PCE (EPA 1998, 27). For October 2024, 24 of 56 samples had ethene detections with concentrations ranging from 1 µg/L to 19 µg/L with mean and median concentrations of 4.3 µg/L and 2 µg/L, respectively. One sample had an ethene concentration greater than 10 µg/L. Distribution 25th and 75th percentiles for ethene for are 1.32 µg/L and 4.18 µg/L, respectively. Ethene occurrence in groundwater is in the enhanced ISB area, which includes the Building 65 area where injections occurred in February 2023.

Ethane

Ethane is an end product of reductive dechlorination of chlorinated ethanes and ethenes (EPA 1998, 27). For October 2024, 6 of 56 samples had ethane detections with concentrations ranging from 1.2 µg/L to 11 µg/L with mean and median concentrations of 4.97 µg/L and 2.35 µg/L, respectively. Two samples had a concentration greater than 10 µg/L. Distribution 25th and 75th percentiles for ethane are 1.8 µg/L and 11 µg/L, respectively. Ethane occurrence in groundwater is in the enhanced ISB area, which includes the Building 65 where injections occurred in February 2023.

Methane

Methane generation occurs under reducing conditions with levels less than 500 µg/L favoring oxidation processes for vinyl chloride and levels greater than 500 µg/L favoring reductive processes (EPA 1998, 29). For October 2024, 51 of 56 samples had methane detections with concentrations ranging from 0.99 µg/L to 20,000 µg/L with mean and median concentrations of 4,009 µg/L and 790 µg/L, respectively. Twenty-eight of the 56 samples had methane concentrations greater than or equal to 500 µg/L where reducing conditions support reductive dichlorination processes. Distribution 25th and 75th percentiles for methane are 7.5 µg/L and 6.950 µg/L, respectively.

Total Organic Carbon

A TOC threshold of 20 mg/L in groundwater provides an energy source for enhanced bioremediation (EPA 1998, 29). For October 2024, 44 of 56 samples had detections of TOC at concentrations ranging from 0.52 mg/L to 1,000 mg/L with mean and median concentrations of 30.5 mg/L and 1.85 mg/L, respectively. Four of 56 samples had TOC concentrations greater than 20 mg/L at locations within recent enhanced ISB actions including the Building 65 area. Distribution 25th and 75th percentiles for TOC are 0.98 mg/L and 4.3 mg/L, respectively.

3.5 Primary VOC Plumes in Groundwater

VOC plumes occur in the surficial aquifer at OU 8 principally as separate degraded plume areas in the Building 65, 66, and OSA 75 areas. Currently, diffuse PCE and TCE plume areas exist with definable cDCE plumes absent with concentrations greater than MCLs. Limited VC plumes exist within or proximate to the most recent enhanced ISB areas in the Building 65 area. VC plumes at OU 8 typically form temporarily after ISB actions but do not persist or significantly accumulate. For the October 2024 semi-annual sampling event for OU 8, Figures 3-2, 3-3, 3-4, and 3-5 show the lateral extent of PCE, TCE, cDCE, and VC plumes in the surficial aquifer at concentrations greater than or equal to MCLs, respectively (pages 3-8, 9, 10, 11).

Tetrachloroethene (PCE)

A diffuse PCE plume area of approximately 1.89 acres is located to the northwest of Building 65 and extends approximately 350 ft. to the north with a maximum width of approximately 330 ft (Figure 3-2). The maximum PCE concentration occurs at DP-2 (130 µg/L). Limited low concentration PCE plume areas occur north of Building 66, around well MWANP-26, and farther downgradient around well MW-156.

Trichloroethene (TCE)

Diffuse TCE plumes occur northwest of Building 65 and north/northwest of Building 66 (Figure 3-3). The TCE plume northwest of Building 65 has an area of approximately 0.97 acres contained within a larger PCE plume. A maximum TCE concentration of 110 µg/L occurs at well DP-2 that also has the maximum PCE concentration.

The TCE plume north/northwest of Building 66 has an area of approximately 1.8 acres, extends approximately 270 ft. north of this building with a maximum width (east-west) of 470 ft. This plume has a maximum detected concentration of 61 µg/L at well MWANP-3.

cis-1,2-Dichloroethene (cDCE)

A limited cDCE plume with concentrations greater than or equal to MCL of 70 µg/L occurs around the immediate area of well MWANP-26 (Figure 3-4). The reported concentration of cDCE at this well is 75 µg/L.

Vinyl Chloride (VC)

Limited VC plume areas occur in the Building 65 area in the 2023 ISB injection area and around DP-2, which has the highest PCE and TCE concentrations for the October 2024 sampling event.

3.6 TOC Distribution in Groundwater

Figure 3-6 (page 3-12) shows the lateral extent of TOC in the surficial aquifer at OU 8 with concentrations greater than or equal to 20 mg/L. This TOC area encompasses wells MW-163 (1,000 mg/L), MW-164 (110 mg/L), and MW-165 (30 mg/L) in the Building 65 area.



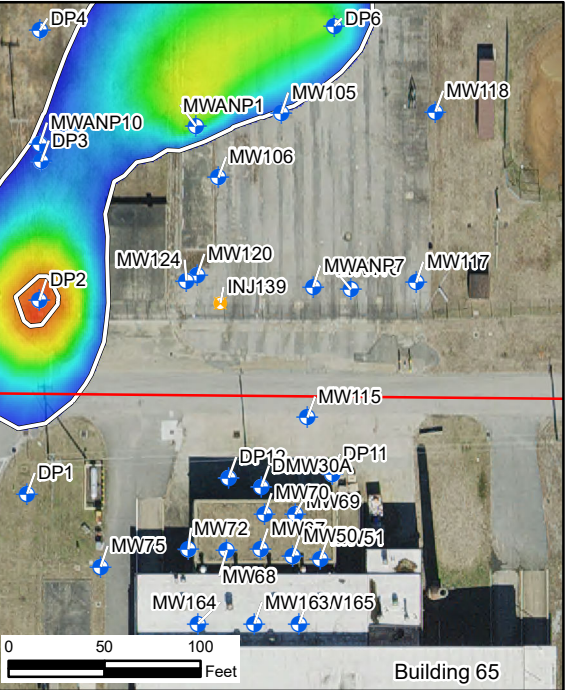
Legend

- Monitoring Well
- Injection Well
- OU 8 Boundary
- Installation Boundary
- PCE Isoconcentration Line
- Groundwater Flow Direction

PCE Concentration (ug/L)

5 10 30 100

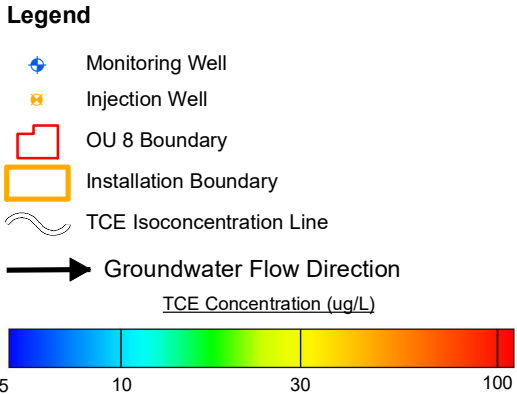
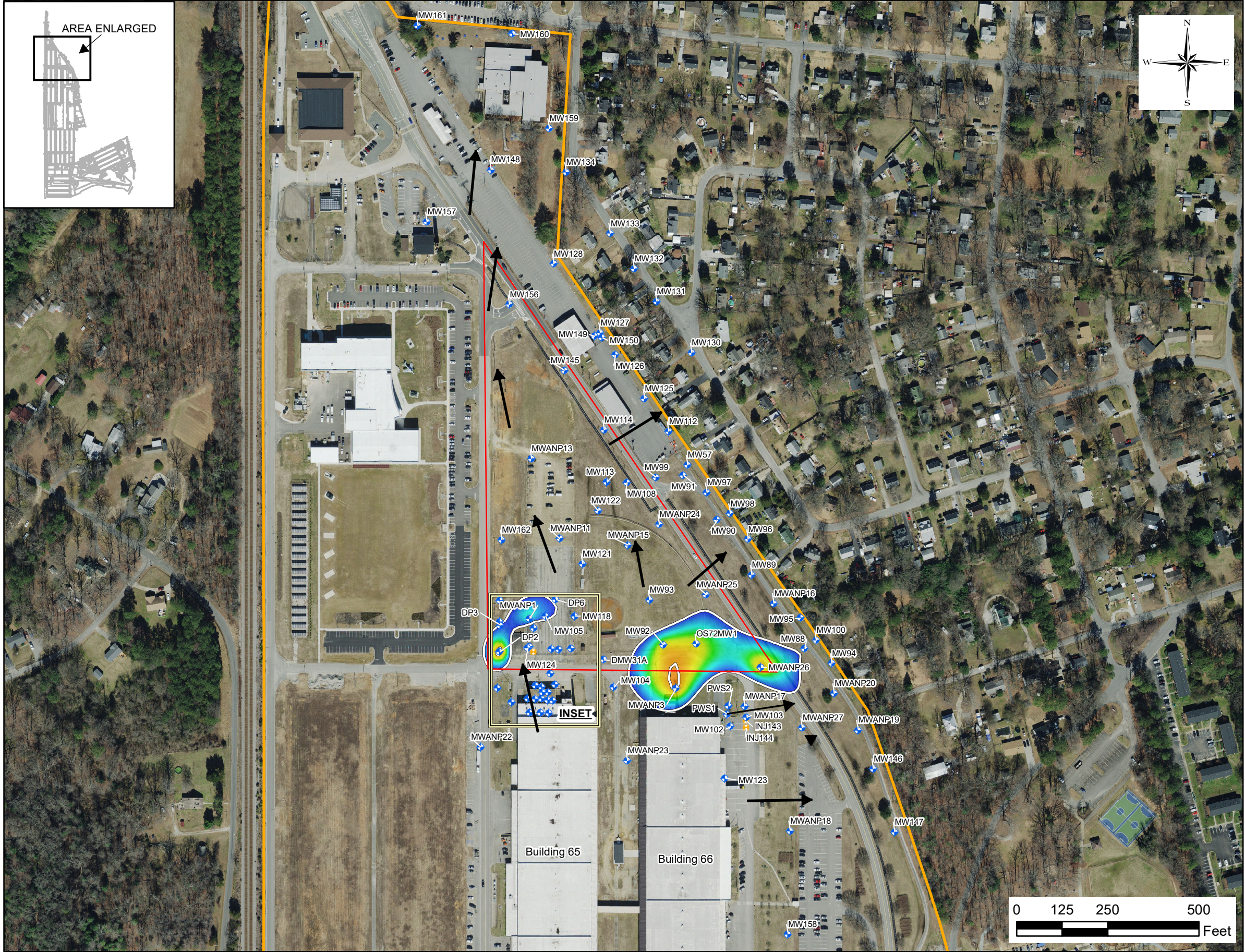
Notes:
Orthoimagery Source: VGIN (2021)
Overall groundwater flow directions shown based on potentiometric data from 2012-2024 and advective plume movement for this period



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Figure 3-2
Lateral Distribution of PCE in
the Surficial Aquifer (October 2024)
Defense Supply Center Richmond
Richmond, VA

Prepared By: JLD	Reviewed By: JOS
Scale: 1" = 275'	Date: February 27, 2025



Notes:
Orthoimagery Source: VGIN (2021)
Overall groundwater flow directions shown based on potentiometric data from 2012-2024 and advective plume movement for this period

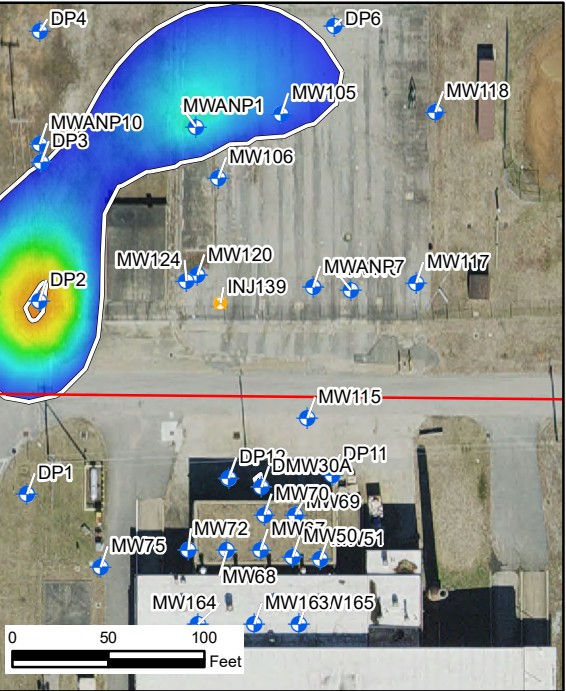
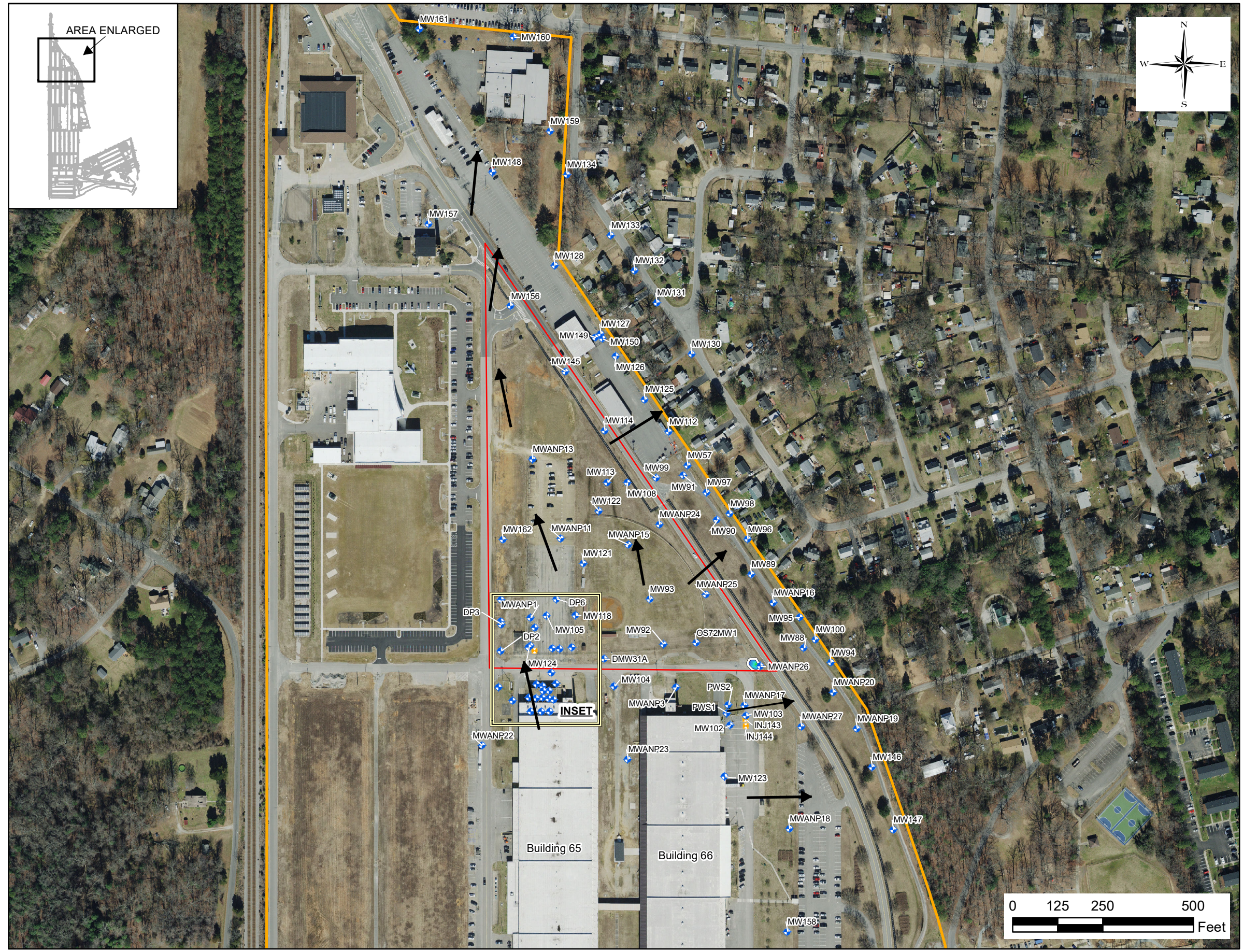


Figure 3-3
Lateral Distribution of TCE in
the Surficial Aquifer (October 2024)
Defense Supply Center Richmond
Richmond, VA

Prepared By: JLD	Reviewed By: JOS
Scale: 1" = 275'	Date: February 27, 2025



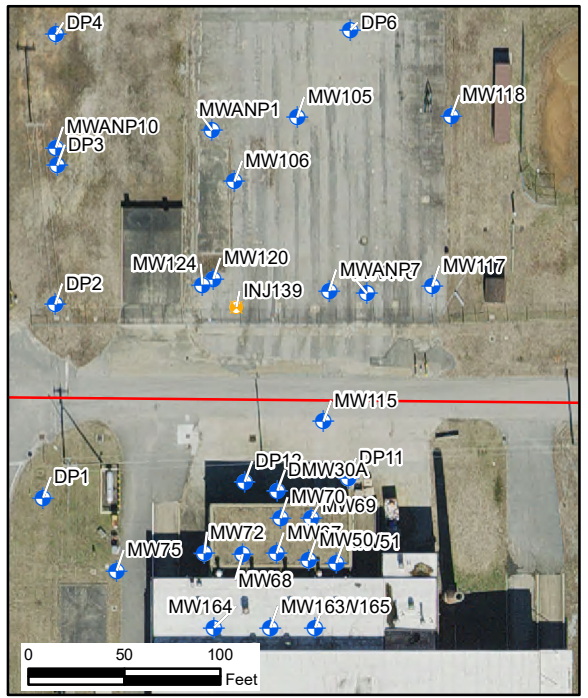
Legend

- Monitoring Well
- Injection Well
- OU 8 Boundary
- Installation Boundary
- cDCE Isoconcentration Line
- Groundwater Flow Direction

cDCE Concentration (ug/L)

70 100 106

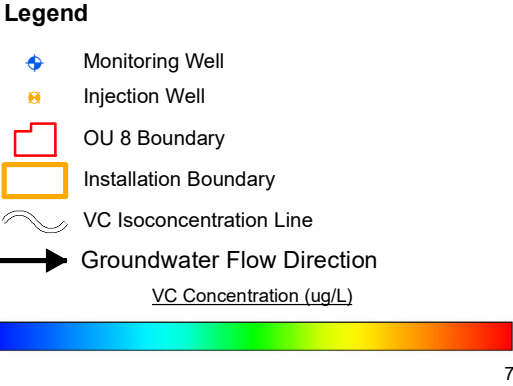
Notes:
Orthoimagery Source: VGIN (2021)
Overall groundwater flow directions shown based on potentiometric data from 2012-2024 and advective plume movement for this period



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Figure 3-4
Lateral Distribution of cDCE in
the Surficial Aquifer (October 2024)
Defense Supply Center Richmond
Richmond, VA

Prepared By: JLD	Reviewed By: JOS
Scale: 1" = 275'	Date: February 27, 2025



Notes:
Orthoimagery Source: VGIN (2021)
Overall groundwater flow directions shown based on potentiometric data from 2012-2024 and advective plume movement for this period

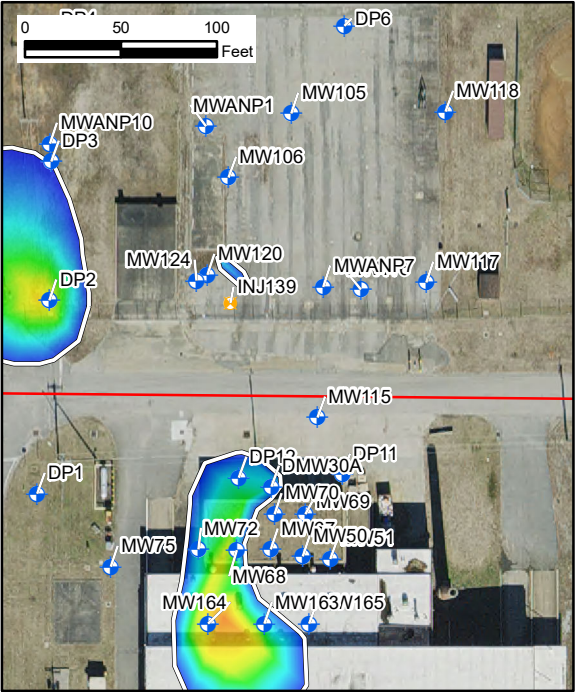


Figure 3-5
Lateral Distribution of VC in
the Surficial Aquifer (October 2024)
Defense Supply Center Richmond
Richmond, VA

Prepared By: JLD	Reviewed By: JOS
Scale: 1" = 275'	Date: February 27, 2025



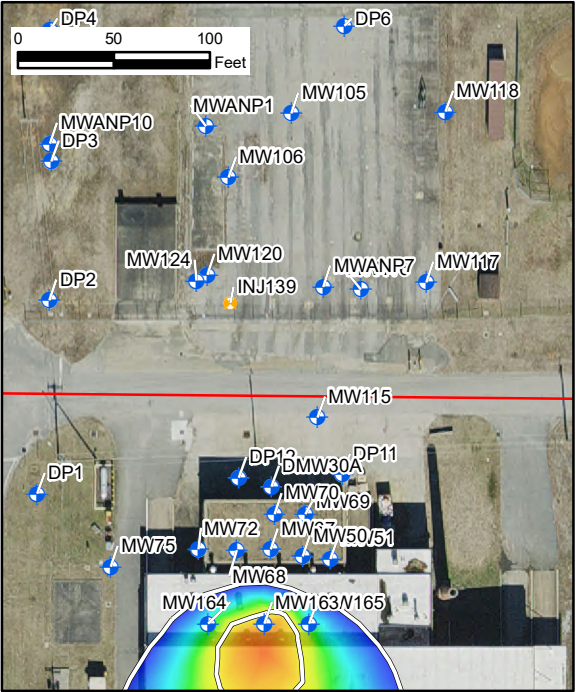
Legend

- Monitoring Well
- Injection Well
- OU 8 Boundary
- Installation Boundary
- TOC Isoconcentration Line
- Groundwater Flow Direction

TOC Concentration (mg/L)

20 30 100 300 1,000

Notes:
Orthoimagery Source: VGIN (2021)
Overall groundwater flow directions shown based on potentiometric data from 2012-2024 and advective plume movement for this period



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Figure 3-6
Lateral Distribution of TOC in
the Surficial Aquifer (October 2024)
Defense Supply Center Richmond
Richmond, VA

Prepared By: JLD	Reviewed By: JOS
Scale: 1" = 275'	Date: February 27, 2025

4. Remedial Design

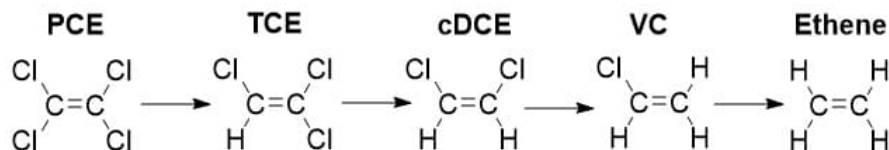
Section 4 presents the remedial design for follow-up enhanced ISB actions at OU 8.

4.1 Remedial Design Basis

Remedial actions performed at OU 8 in 2022 and 2023 addressed VOC plume areas in the Building 65, Building 66, and OSA 75 areas. This included targeted measures in the Building 65 area to address a groundwater source zone centered beneath F Bay of Building 65. The proposed enhanced measures in this RAWP addendum will address two remaining diffuse plume areas to the north of Buildings 65 and 66, respectively. Objectives for these actions are to further treat plume areas at OU 8 and mitigate potential plume migration toward downgradient areas and the fence line area closest to Building 66.

The process option of the ISB design in this work plan follows the remedial design/remedial action work plan for OU 8 (AECOM 2013) using metabolic anaerobic reductive dechlorination (enhanced reductive dechlorination or ERD) as the targeted degradation process to treat the chlorinated solvents. In this reaction, microorganisms gain energy as one or more chlorine atoms on a chlorinated ethene, or ethane compound molecule are replaced with hydrogen atoms in an anaerobic environment. The chlorinated compound serves as the electron acceptor and molecular hydrogen usually serves as the electron donor (source of energy). Hydrogen used in this reaction is supplied by fermentation of organic substrates or a direct electron donor. Biodegradation of an organic substrate depletes the aquifer of DO and sequentially reduces native electron acceptors nitrate, manganese, iron, sulfate, and carbon dioxide. In general, metabolic anaerobic reductive dechlorination occurs by sequential removal of chlorine atoms. Exhibit 4-1 illustrates the reductive dechlorination pathway for PCE the parent compound. Primary COCs for the targeted constituent plume for ISB treatment include PCE and TCE with limited areas of cDCE, and VC.

Exhibit 4-1 Reductive Dechlorination Treatment Pathway



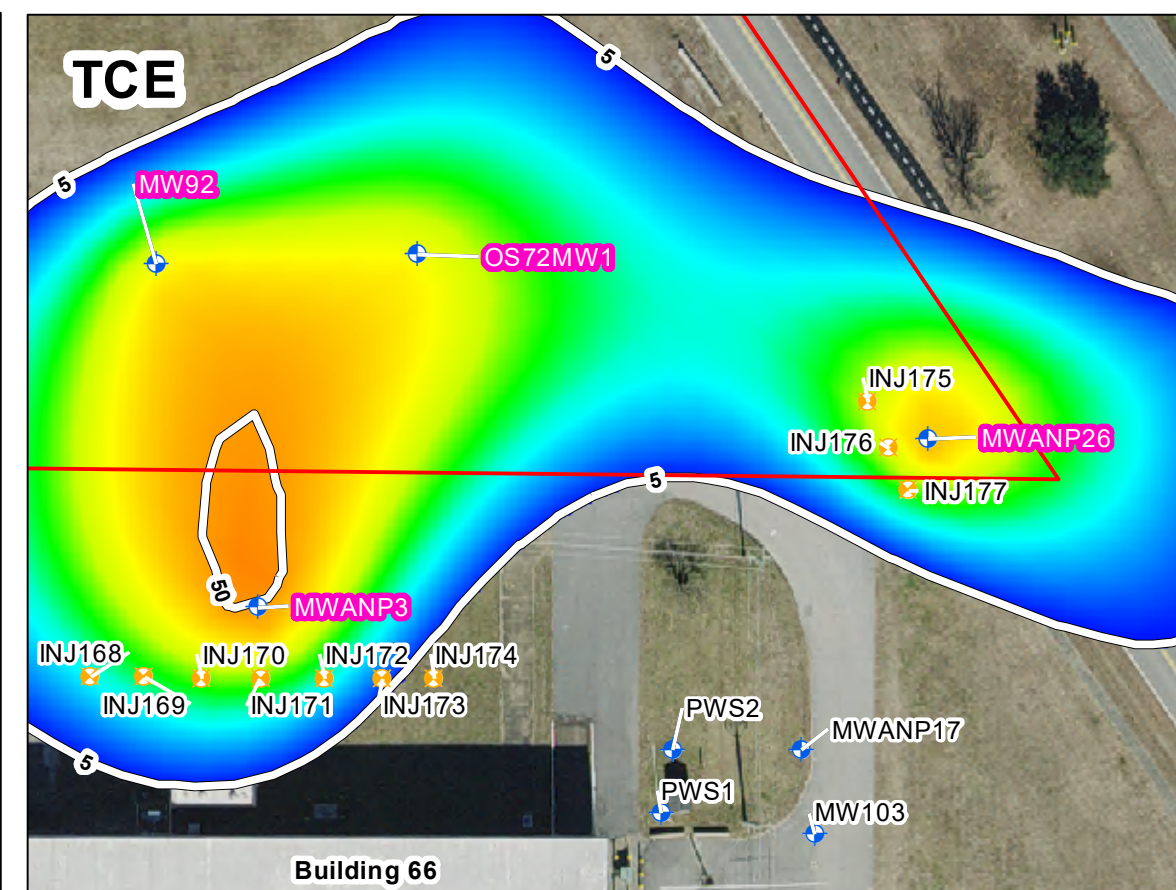
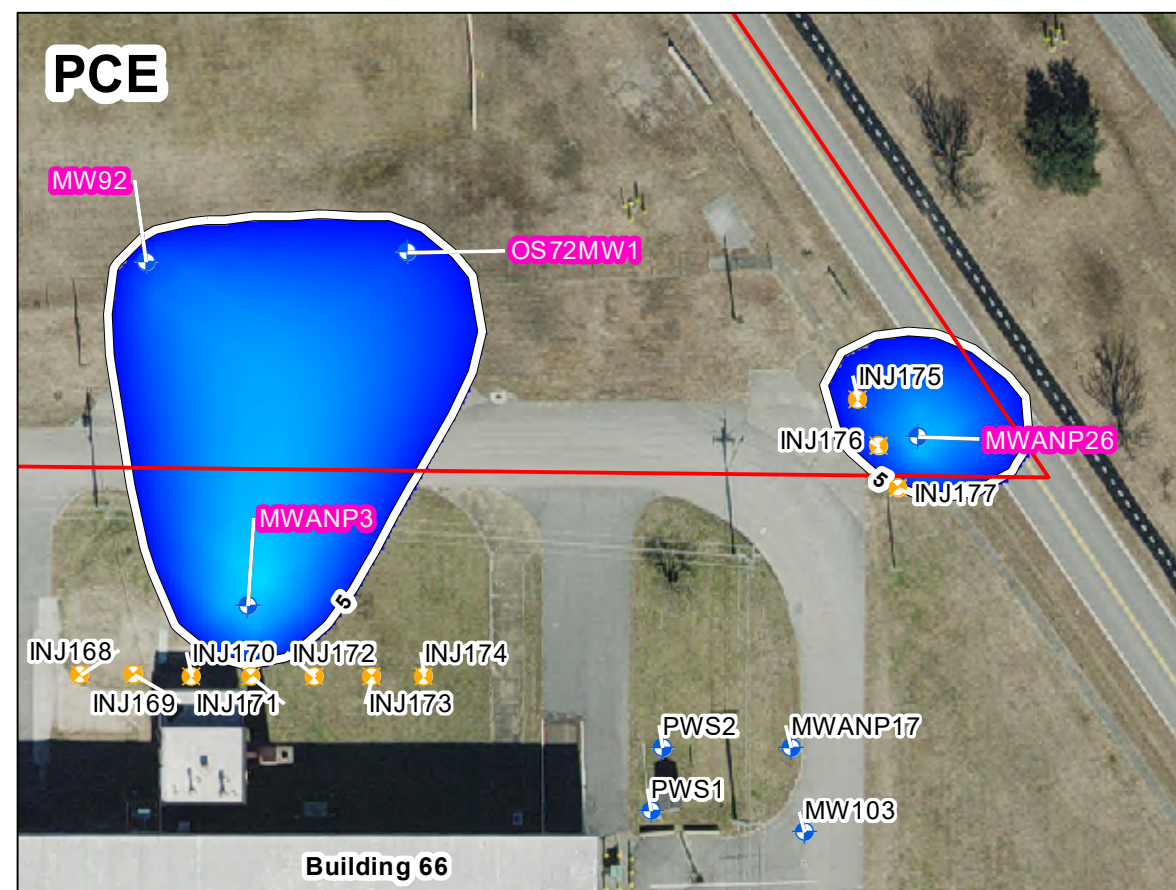
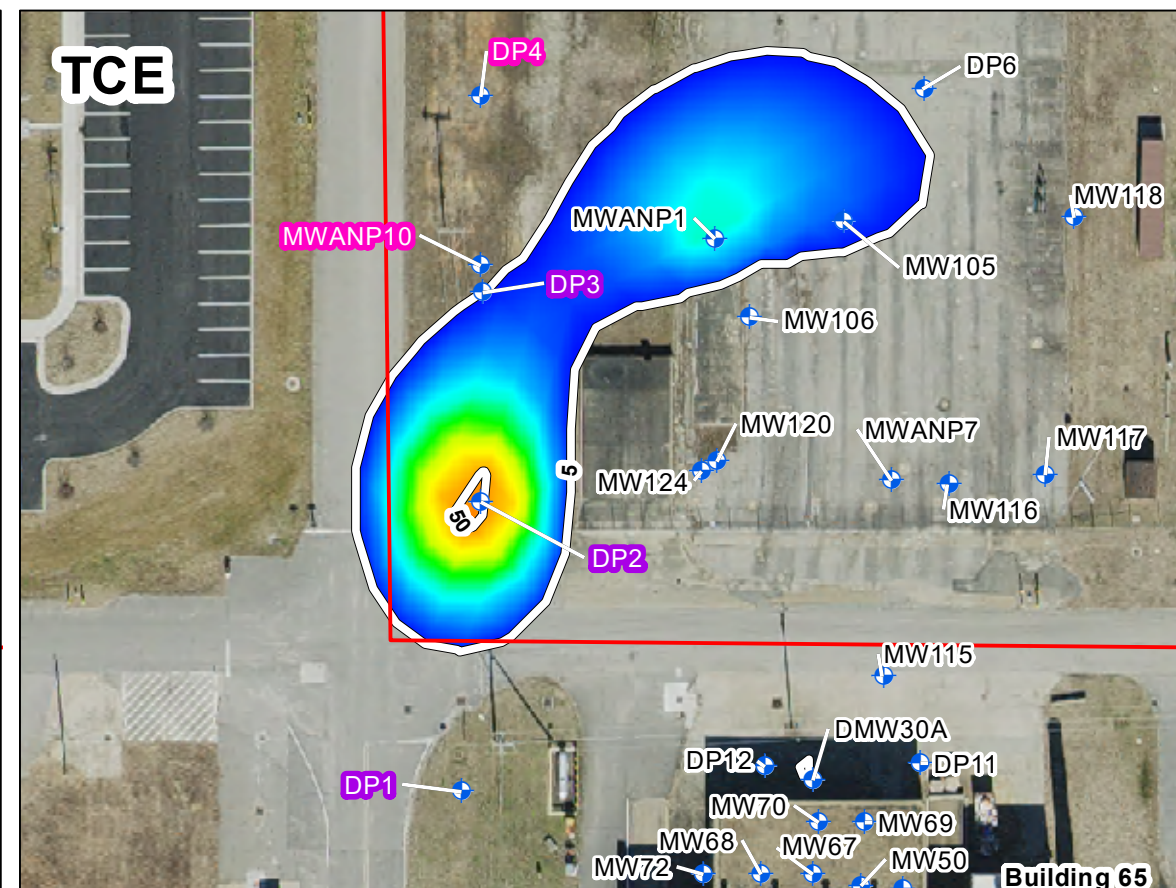
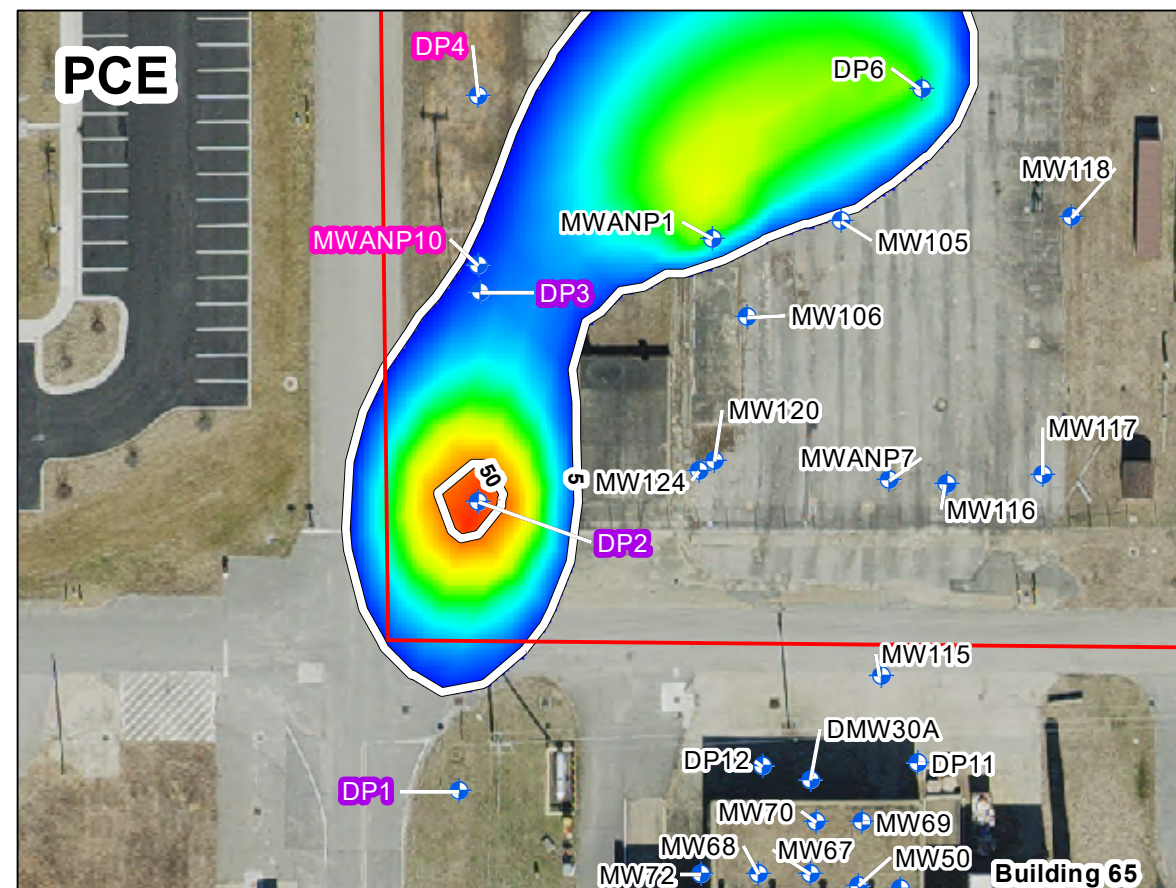
The specific ISB design in this work plan considers the results from previous treatability studies (AECOM, 2010) and remedial implementation for the surficial aquifer at OU 8 (AECOM 2013, 2021, 2022, 2023, Arcadis 2018) and the current conditions presented in Section 3.

4.2 Plume Areas Targeted for Enhanced ISB Treatment

Section 4.2 describes the plume areas targeted for enhanced ISB treatment areas and the conditions in these areas.

4.2.1 Plume Area North of Building 65

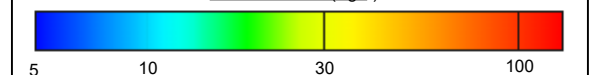
The upper two tiles in Figure 4-1 (page 4-2) show the diffuse plume with PCE and TCE concentrations greater than MCLs north of Building 65 targeted for enhanced ISB measures. These tiles show the proposed ISB treatment areas TA-65A, TA-65B, and TA-65C and proposed gravity feed locations at existing wells DP-1, DP-2, and DP-3. Exhibit 4-1 (page 4-3) has data plots for monitored wells in this plume area with singular spectrum analysis (SSA) plotted trends. Table 4-1 (page 4-4) has a summary of October 2024 concentration data and trend test results (2018-2024) for PCE, TCE, cDCE, and VC for wells monitored in the plume area.



Legend

- Monitoring Well
- New Injection Well
- In-situ Treatment Areas
- OU8 Boundary
- Isoconcentration Contours
- Gravity Feed Injection and Performance Monitoring Location
- Performance Monitoring Location

Concentration (ug/L)



Notes:
Orthimagery Source: VGIN (2021)

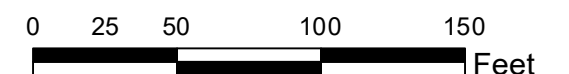
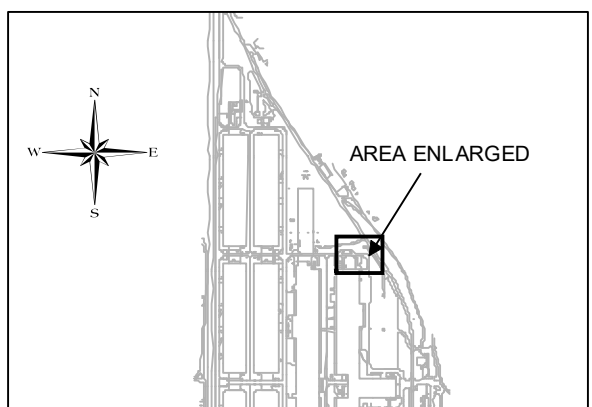


Figure 4-1 OU8 Enhanced ISB Treatment Areas and Performance Monitoring Locations

Remedial Action Work Plan Addendum
Defense Supply Center Richmond
Richmond, VA

Prepared By:
JLD

Reviewed By:
JOS

Scale:
1" = 67'

Date:
May 02, 2025

Exhibit 4-1 Data Plots for Wells North of Building 65 and In Open Storage Area 75 (2018-2024)

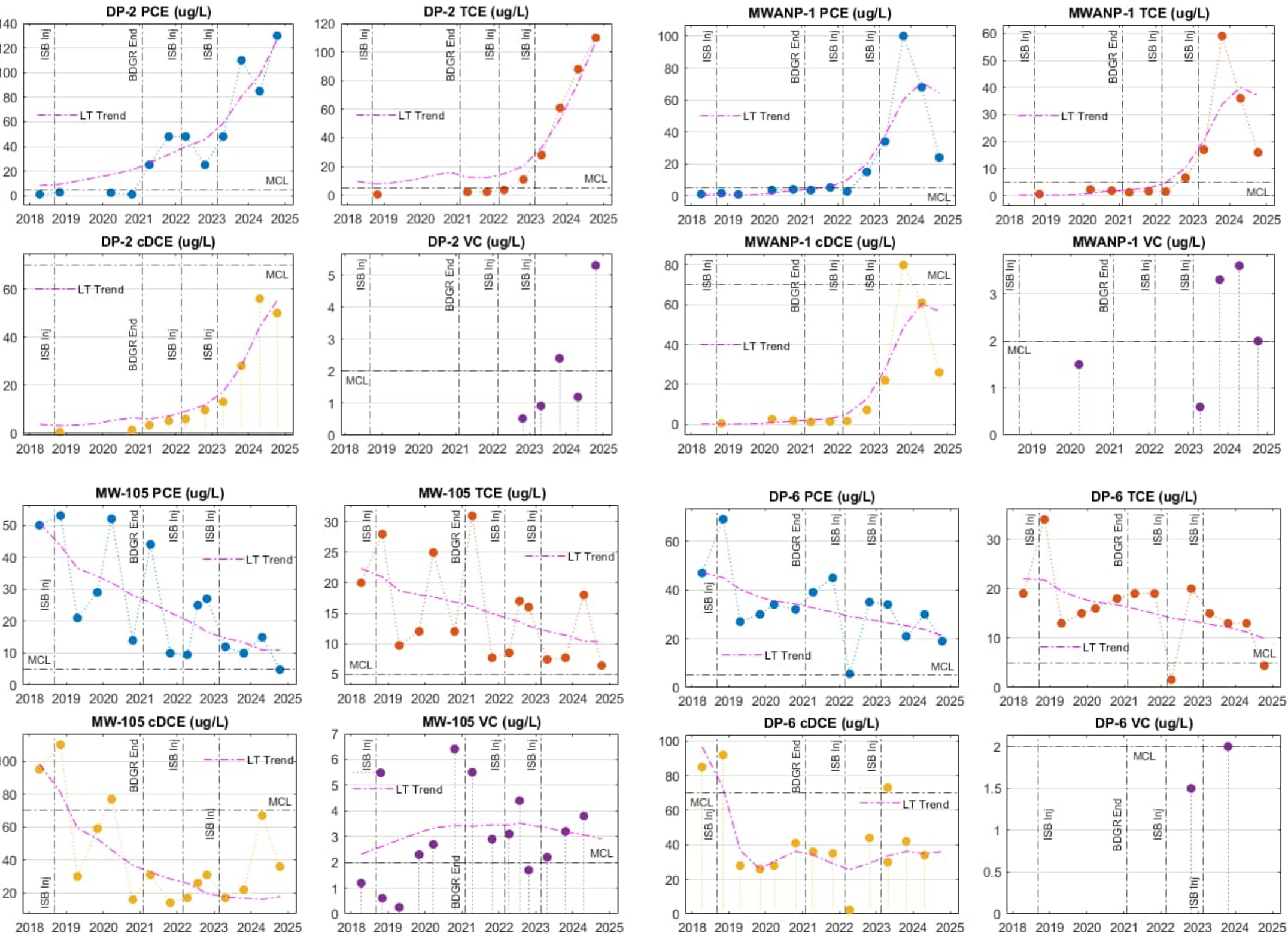


Table 4-1 Concentration and Trend Results for Plume Area North of Building 65 and in OSA 75

Location	Concentration (Oct. 2024, µg/L)				M-K Trend (2014-2018) One-Way, $\alpha = 0.05$				SSA Trend (2018-2024)			
	PCE	TCE	cDCE	VC	PCE	TCE	cDCE	VC	PCE	TCE	cDCE	VC
DP-2	130	110	50	5.3	SS (+)	SS (+)	SS (+)	SS (+)	↑	↑	↑	--
DP-3*	38	16	13	0.52	--	--	--	--	--	--	--	--
MWANP-1	24	16	26	2	SS (+)	SS (+)	SS (+)	No	↑	↑	↑	--
MW-105	4.8	6.4	36	ND	SS (-)	SS (-)	No	No	↓	↓	↓	→
DP-6	19	4.4	ND	ND	SS (-)	No	No	No	↓	↓	→	→

Notes: * = sample collected April 2024, PCE = tetrachloroethene, TCE = trichloroethene, cDCE = cis-1,2-dichloroethene, VC = vinyl chloride, µg/L = micrograms per liter, M-K = Mann-Kendall, $\alpha = 0.05$ = alpha significance of 0.05 or 5 percent. SS (+) = statistically significant increasing trend at a significance of 5 percent, SS (-) = statistically significant decreasing trend at a significance of 5 percent, SSA = singular spectrum analysis, ↑ = SSA increasing trend, ↓ = SSA decreasing trend (year of trend change), and → = SSA no trend. Concentration greater than cleanup level. -- = insufficient data for statistical and trend analysis, cleanup levels are 5 µg/L for tetrachloroethene and trichloroethene, 70 µg/L for cis-1,2-dichloroethene, and 2 µg/L for vinyl chloride.

In the area of well DP-2, plume instability is apparent with statistical evidence of increasing concentration trends for PCE, TCE, and cDCE (2018-2024). DP-2 and wells DP-3 and MWANP-10 to the north are located beneath an overhead utility line corridor (electric power and communications) that parallels C Road and North 4th Street. MWANP-1 located 120 ft. northeast of DP-2 has lower concentrations of PCE and TCE than DP-2. Data plots for this well show a short-term concentration increase (Oct. 2022 to Oct. 2023) followed by decreasing concentrations in 2024. For 2018-2024, SSA indicates decreasing long-term trends for VOC concentrations at wells MW-105 and DP-6.

The technical approach for enhanced ISB of the diffuse plume area will use a soluble carbon substrate and gravity feed injection in wells. This method will distribute soluble reagents across the plume area at the rate of advective groundwater flow estimated at 1 ft per day in this plume area. The overhead utility corridor in the highest concentration area at DP-2 extending up to DP-3 will limit gravity feed injections to existing wells in this area.

4.2.2 Plume Area North of Building 66

The lower two tiles of Figure 4-1 (page 4-2) show a diffuse plume with PCE and TCE concentrations greater than MCLs in the area north and northeast of Building 66 targeted for enhanced ISB measures. These tiles show the proposed ISB treatment areas TA-66A and TA-66B and the proposed seven new injection wells in TA-66A and proposed three new injection wells in TA-66B. Table 4-2 (page 4-6) has a summary of October 2024 concentration data and trend test results (2018-2024) for PCE, TCE, cDCE, and VC for wells monitored in the plume area. Exhibit 4-2 (page 4-7) has data plots for monitored wells in this plume area with SSA plotted trends.

Monitoring data indicates a degree of plume instability with variable concentrations over time. For 2018-2024, local maxima for VOC concentrations occurred in Oct. 2022 for MWANP-3 closest to Building 66, Oct. 2023 for OS72-MW1, and Oct. 2024 for MW-92 and MWANP-26.

The technical approach for enhanced ISB of the diffuse plume area will use a soluble carbon substrate and gravity feed injection in wells. This method will distribute soluble reagents across the plume area at the rate of advective groundwater flow estimated at 0.75 ft per day in this plume area.

Table 4-2 Concentration and Trend Results for Plume Area North/Northeast of Building 66

Location	Concentration (2024, µg/L)				M-K Trend (2014-2018) One-Way, $\alpha = 0.05$				SSA Trend (2018-2024)			
	PCE	TCE	cDCE	VC	PCE	TCE	cDCE	VC	PCE	TCE	cDCE	VC
MWANP-3	10	61	35	ND	SS (+)	SS (+)	No	No	↑	↑	↑	--
MW-92*	6.7	34	54	ND	No	No	SS (+)	--	↑	↑	↑	--
OS72-MW1	5.8	31	30	ND	SS (+)	SS (+)	SS (+)	--	↑	↑	↑	--
MWANP-26	9.5	49	75	1.6	SS (-)	No	No	No	↓	↓	→	→

Notes: * MW-92 data from 2019-2024, PCE = tetrachloroethene, TCE = trichloroethene, cDCE = cis-1,2-dichloroethene, VC = vinyl chloride, µg/L = micrograms per liter, M-K = Mann-Kendall, $\alpha = 0.05$ = alpha significance of 0.05 or 5 percent. SS (+) = statistically significant increasing trend at a significance of 5 percent, SS (-) = statistically significant decreasing trend at a significance of 5 percent, SSA = singular spectrum analysis, ↑ = SSA increasing trend, ↓ = SSA decreasing trend (year of trend change), and → = SSA no trend. Concentration greater than cleanup level. -- = insufficient data for statistical and trend analysis, cleanup levels are 5 µg/L for tetrachloroethene and trichloroethene, 70 µg/L for cis-1,2-dichloroethene, and 2 µg/L for vinyl chloride.

4.3 Substrate Selection

Primary criteria to select a substrate for the ISB design is distribution across the diffuse plume areas for treatment of lower concentrations of PCE and TCE, compatibility with a gravity feed delivery method, and cost effectiveness.

Sodium lactate is the selected ISB substrate containing sodium lactate and nutrients; it is widely available with demonstrated effectiveness to support ERD. Evidence of complete ERD pathways for PCE and TCE to ethene and ethane is apparent for previous ISB injections at OU 8 and treatability studies. Sodium lactate used in the 2018 ISB injections in the Building 65 area showed reduced concentrations across the targeted plume area. Native microbial communities in groundwater at OU 8 have demonstrated the capability to perform dechlorination to end products.

Terra Systems, Wilmington Delaware, will provide injection ready sodium lactate identified as 60% QRS™ SL Plus Sodium Lactate Quick Release Substrate with nutrients added. Table 4-3 provides data on this sodium lactate product as contained in the manufacturer's information sheet.

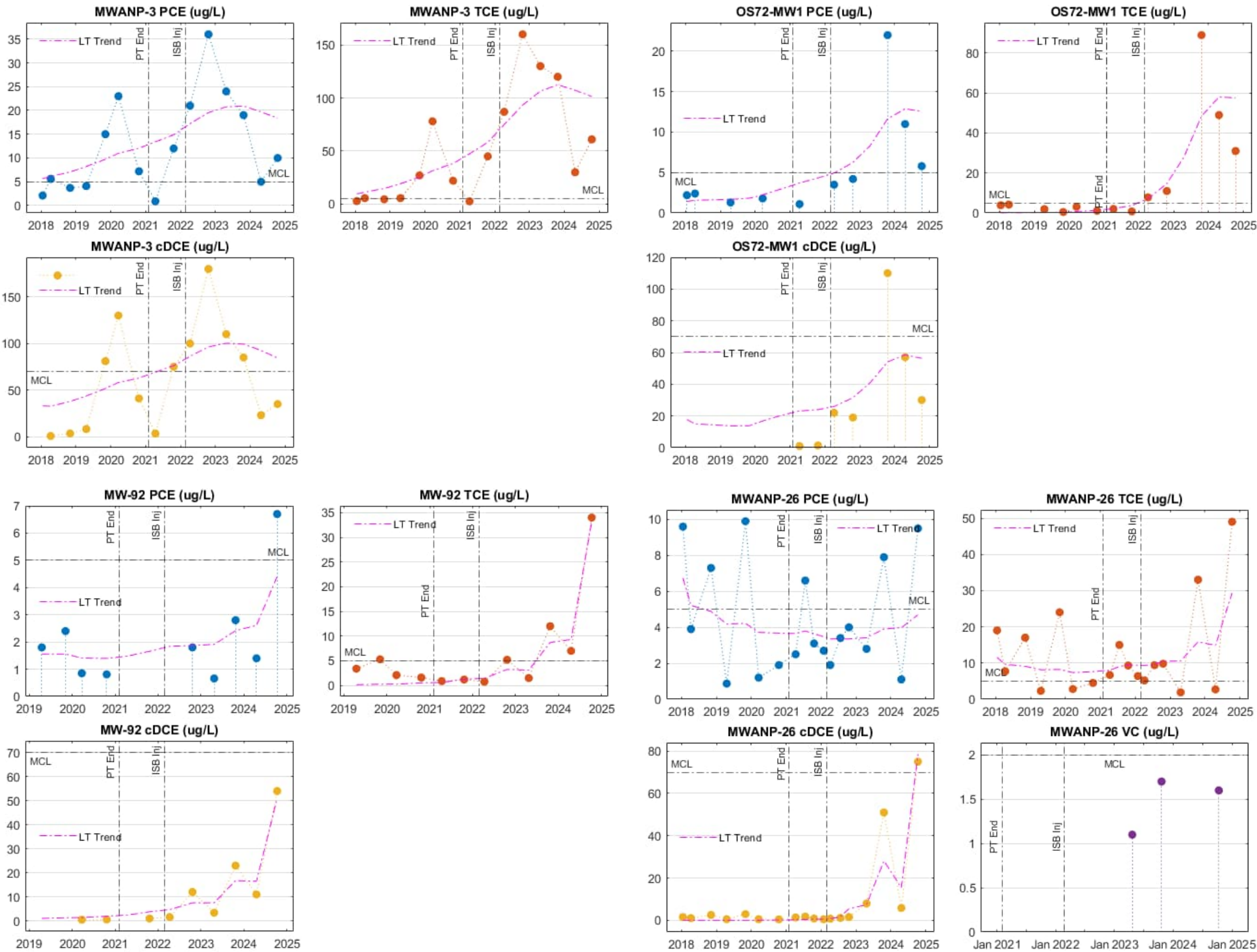
Table 4-3 Terra Systems Inc. 60% QRS™ SL Plus Sodium Lactate Specifications

Element	CAS#	Percent	Description	Benefit
Sodium lactate	72-17-3	60%	Rapidly biodegradable soluble substrate, miscible in water	Fast release source of carbon and hydrogen, rapidly generates reducing conditions, high radius influence, provides 60% fermentable carbon
Organic nutrients, inorganic nutrients, and surfactants	Mixture	1 to 5%	--	Supports enhanced in situ bioremediation and increases dechlorination kinetics and donor efficiency
pH	--	--	pH of product is 6.5-7	Optimum range for microbial activity
Organic carbon (weight %)	--	60%	--	Provides 60% fermentable carbon
Biobased content of substrate	--	100%	--	Product designated as Generally Recognized Safe by the United States Food and Drug Administration

Notes: Source: Terra Systems, Inc. Technical Data Sheet, and Safety Data Sheet for QRS™-Plus-SL included in Appendix A.1.

Appendix A.1 has a technical data sheet and safety data sheet for the selected sodium lactate substrate.

Exhibit 4-2 Data Plots for Wells North and Northeast of Building 66 (2018-2024)



4.4 Injection Process Option Selection

The process option selected for enhanced ISB for the surficial aquifer and treatment of diffuse plume areas is gravity feed injection using wells. For the plume area north of Building 65 where concentrations are highest, this will include three (3) existing 6-inch wells formerly used for the DPE system where overhead power lines limit access to the area. For the plume area north and northeast of Building 66, the proposed process option uses new injection wells.

4.5 Substrate Loading Rates

Enhanced ISB substrate mass and loading rates will need to satisfy native and contaminant electron acceptor demand in the reactive treatment zone to stimulate anaerobic reductive dechlorination processes. Too low of a substrate loading rate may result in reducing conditions that are insufficient to support anaerobic dechlorination of COCs. Too high of a substrate loading rate can lead to inefficiencies and uncontrolled reactions that lower pH and result in excessive methanogenesis, degradation of groundwater quality and/or accumulation of methane in the vadose zone. Determining appropriate substrate loading rates is therefore a primary objective of the enhanced ISB design.

Substrate demand for enhanced ISB of chlorinated VOCs is a function of: (1) contaminant electron acceptor supply, (2) native electron receptor supply, and (3) non-specific demands (microbial cell growth, etc.). Following previous pilot tests and remedial designs for OU 8, the theoretical demand for substrate is determined in this work plan through stoichiometric calculations using site data; these calculations quantify the amount of electron donor (hydrogen) required to completely reduce contaminant and native electron receptors based on the substrate used and levels of acceptors present.

The pore water of the aquifer and the solid aquifer matrix contain native electron receptors (such as DO and iron hydroxide materials) that the electron donor may react with preferentially over chlorinated VOCs. Substrate loading rates in the enhanced ISB design account for the stoichiometric demand to completely reduce these native electron receptors before the complete reductive dechlorination of COCs can occur.

The enhanced ISB design for this work plan addendum uses the Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents Version 1.2 (ESTCP 2010) to calculate substrate requirements, demand, and loading rates. Appendices B.1, B.2, and B.3 contain the design work books for the diffuse plume area north of Building 65. Appendices B.4 and B.5 contain the design work books for the diffuse plume area north and northwest of Building 66.

For this work plan, the enhanced ISB design uses data from each treatment area when available. The design for this work plan also applies a design factor of 10 to the calculated total hydrogen demand to account for microbial efficiency (4-times design factor), uncertainties in electron acceptor demand (4-times design factor), and loss of substrate leaving the reaction zone (2-times). The three individual design factors sum to a total design factor of 10. The design or safety factor used for enhanced ISB designs typically ranges from 2 to 10 (AFCEC 2004).

4.5.1 Injection Design for Plume Area North of Building 65

Section 4.5.1 presents the injection design for the diffuse plume area north of Building 65. Table 4-4 has a summary of the injection designs for the three planned treatment areas designated as TA-65A, TA-65B, and TA-65C. Figure 4-1 shows the locations and configuration of these treatment areas. The focus for treatment is in the higher concentration area centered at DP-2 where plume instability is apparent (increasing concentration trends for PCE and TCE). The lower concentration area encompassing wells MWANP-1, MW-105, and DP-6 has lower concentrations with decreasing concentration trends approaching MCLs. Because of these conditions this work plan does not propose additional treatment in this area.

Table 4-4 ISB Injection Design, Volumes, and Loading (TA-65A, B, C)

Treatment Area	Treatment Area Dimensions	No. of IWs	IW Spacing (ft.)	Sodium Lactate Product ¹ per IW (gal)	Total Sodium Lactate Product ¹ (gal)	Effective Concentration (mg/L) ²
TA-65A	20 ft.(W) x 100 ft.(L)	DP-1	--	254	254	1,153
TA-65B	20 ft.(W) x 75 ft.(L)	DP-2	--	237	237	1,152
TA-65C	20 ft.(W) x 75 ft.(L)	DP-3	--	139	139	632

Notes: ¹Sodium lactate product is 60 percent sodium lactate by weight, ²Effective concentration is for total volume of groundwater treated. ft. = feet, IW = injection well, gal = gallon, mg/L = milligrams per liter. Treatment width (W) is perpendicular to predominant flow direction and treatment length (L) is parallel to predominant flow direction.

Treatment Area TA-65A

TA-65A has design dimensions of 20 ft width by 100 ft. length with a 10 ft. thick treatment interval in the surficial aquifer (see Figure 4-1). The design period of performance is 0.75 yrs. with a design factor of 10 as described in Section 4.5. In Appendix B.1, the design workbook has the input parameters used for hydrogeologic properties, native electron acceptors, contaminant electron acceptors, and aquifer geochemistry.

The design uses existing 6-inch diameter well DP-1 (former DPE well) located northwest of Building 65 and 100 ft. upgradient of DP-2. The semi-annual groundwater monitoring program implemented in 2012 at OU 8 has not used DP-1 as a monitoring location. The injection process will consist of batch gravity flow this well at the quantity identified in Table 4-4 (254 gallons) with reagent distribution by advective groundwater flow at an estimated rate of 1 ft./day. The pore volume of the effective treatment zone is 37,410 gallons with an estimated treatment of 139,984 gallons over the design life of 0.75 years.

Treatment Area TA-65B

TA-65B has design dimensions of 20 ft width by 75 ft. length with a 10 ft. thick treatment interval in the surficial aquifer (see Figure 4-1). The design period of performance is 0.75 yrs. with a design factor of 10 as described in Section 4.5. In Appendix B.2, the design workbook has the input parameters used for hydrogeologic properties, native electron acceptors, contaminant electron acceptors, and aquifer geochemistry.

The design uses existing 6-inch diameter well DP-2 (former DPE well). The injection process will consist of batch gravity flow at DP-2 at the quantity identified in Table 4-4 (237 gallons) with reagent distribution by advective groundwater flow at an estimated rate of 1 ft./day. The pore volume of the effective treatment zone is 28,058 gallons with an estimated treatment of 130,631 gallons over the design life of 0.75 years.

Treatment Area TA-65C

TA-65C has design dimensions of 20 ft width by 100 ft. length with a 10 ft. thick treatment interval in the surficial aquifer (see Figure 4-1). The design period of performance is 0.75 yrs. with a design factor of 10 as described in Section 4.5. In Appendix B.3, the design workbook has the input parameters used for hydrogeologic properties, native electron acceptors, contaminant electron acceptors, and aquifer geochemistry.

The design uses existing 6-inch diameter well DP-3 (former DPE well). The semi-annual groundwater monitoring program implemented in 2012 at OU 8 has not used DP-3 as a monitoring location. The injection process will consist of batch gravity flow at DP-3 at the quantity identified in Table 4-4 (139 gallons) with reagent distribution by advective groundwater flow at an estimated rate of 1 ft./day. The pore volume of the effective treatment zone is 37,410 gallons with an estimated treatment of 139,984 gallons over the design life of 0.75 years.

4.5.2 Injection Design for Plume Area North and Northeast of Building 66

The injection design for the diffuse plume area north and northeast of Building 66 has two treatment areas designated TA-66A and TA-66B. Table 4-5 has a summary of the injection designs for these treatment areas. Figure 4-2 shows the locations and configuration of these treatment areas.

Table 4-5 ISB Injection Design, Volumes, and Loading (TA-66A, B)

Treatment Area	Treatment Area Dimensions	No. of IWs	IW Spacing (ft.)	Sodium Lactate Product ¹ per IW (gal)	Total Sodium Lactate Product ¹ (gal)	Effective Concentration (mg/L) ²
TA-66A	140 ft.(W) x 150 ft.(L)	7	20	159	1,115	638
TA-66B	50 ft.(W) x 100 ft.(L)	3	20	99.7	299	664

Notes: ¹Sodium lactate product is 60 percent sodium lactate by weight, ²Effective concentration is for total volume of groundwater treated. ft. = feet, IW = injection well, gal = gallon, mg/L = milligrams per liter. Treatment width (W) is perpendicular to predominant flow direction and treatment length (L) is parallel to predominant flow direction.

Treatment Area TA-66A

TA-66A has design dimensions of 140 ft width by 150 ft. length with a 10 ft. thick treatment interval in the surficial aquifer (see Figure 4-1). The design period of performance is 1 yr. with a design factor of 10 as described in Section 4.5. In Appendix B.4, the design workbook has the input parameters used for hydrogeologic properties, native electron acceptors, contaminant electron acceptors, and aquifer geochemistry.

The design includes installation of seven (7) injection wells spaced at 20 ft. on centers along an east-west transect parallel to Building 66 and perpendicular to the overall groundwater flow direction. The injection process will consist of batch gravity flow into each well at the quantities identified in Table 4-5 (159 gallons) with reagent distribution by advective groundwater flow at an estimated rate of 0.75 ft./day. The pore volume of the effective treatment zone is 392,805 gallons with an estimated treatment of 1,110,821 gallons over the design life of 1 year.

Treatment Area TA-66B

TA-66B has design dimensions of 50 ft width by 100 ft. length with a 10 ft. thick treatment interval in the surficial aquifer (see Figure 4-1). The design period of performance is 0.75 yrs. with a design factor of 10 as described in Section 4.5. In Appendix B.5, the design workbook has the input parameters used for hydrogeologic properties, native electron acceptors, contaminant electron acceptors, and aquifer geochemistry.

The design includes installation of three (3) injection wells spaced at 20 ft. on centers along a transect perpendicular to the overall groundwater flow direction. The injection process will consist of batch gravity flow into each well at the quantities identified in Table 4-5 (approximately 100 gallons) with reagent distribution by advective groundwater flow at an estimated rate of 0.75 ft./day. The effective treatment zone pore volume is 93,525 gallons with an estimated treatment of 285,851 gallons over the design life of 0.75 years.

5. Remedial Field Activities

Section 5 describes field activities associated the proposed remedial actions described in this work plan.

5.1 Utility Clearance

Utility avoidance will include marking of proposed injection well locations for utility clearance following the DSCR dig permit process including:

- Meadows or their designated contractor will contact the Virginia One Call Center (811) for mark out of utility locations. 811 notifications require a three-day notice.
- Meadows will coordinate and provide notification to DSCR Installation Management for utility designation and location in the proposed disturbance areas.
- Meadows will contract with a private utility locating company to survey and mark the proposed disturbance areas (20 ft. scan radius) using ground penetrating radar and magnetic locating equipment.
- The project team will review of available utility maps and other information when proposing subsurface intrusion and disturbance locations (i.e., boring and wells).

The planned locations for utility clearance are at the proposed new injection well locations within the enhanced ISB treatment areas shown on Figures 4-1 and 4-2.

5.2 Injection Well Installation

Proposed ISB actions for this RAWP addendum will include installation of 10 additional injection wells to implement ERD treatment (gravity feed injections) across diffuse plume areas north of Building 66 (see Figure 4-1). Table 5-1 has summary information for the injection wells include location, identification, well type and construction, and drilling method.

Table 5-1 Injection Well Construction

Treatment Area	Injection Wells ¹	Type	Screen	Screen Interval (ft. bgs)	Drilling Method
TA-66A	INJ-168, 169, 170 171, 172, 173, 174	FM 2-inch Sch 40 PVC	2.0-inch ID, 10 ft. 304 stainless steel vee-wire, pre-pack 20/40 mesh sand, 0.010-inch slots	15-25 (MWANP-3) ³	4.25-inch ID hollow-stem auger, SPT split spoon sampling
TA-66B	INJ-175, 176, 177	FM 2-inch Sch 40 PVC	2.0-inch ID, 10 ft. 304 stainless steel vee-wire, pre-pack 20/40 mesh sand, 0.010-inch slots	15-25 ⁵ (MWANP-26) ⁵	4.25-inch ID hollow-stem auger, SPT split spoon sampling

Notes: ¹Injection well identification is OU-INJ-XXX, FM = flush mount, " = inch, Sch 40 PVC = schedule 40 polyvinyl chloride, ID = inside diameter, ft. bgs = feet below ground surface. ^{2,3,4,5} Well construction based on identified boring logs and well construction information.

The drilling method for monitoring well installation is hollow-stem auger (HSA) drilling following the procedures outlined in ASTM designation D5784/D5784M-18 Standard Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water Quality Monitoring Devices. The drilling procedure for borings will use 4.25-inch inner diameter HSA (9-inch borehole diameter) to provide for sufficient borehole diameter to allow for installation of single cased monitoring wells (Type II) constructed with 2-inch inner diameter well casing and screen.

HSA operations will involve continuous soil sampling with a 2-ft split barrel sampler following ASTM designation D1586/D1586M-18 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils to characterize lithologic conditions and verify well element installation zones.

Monitoring well installation procedures will follow *ASTM designation D5092/D5092M-16 Standard Practice for Design and Installation of Groundwater Monitoring Wells*. A field geologist will oversee drilling operations, sampling, and monitoring well installation and prepare boring logs and construction documentation for each monitoring well location. Boring logs will include the location, geotechnical data, and sample description information for each material identified in the borehole using symbol and word descriptions. Description and identification of soils will follow *ASTM designation D2488-17e1 Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)*. Schematic completion diagrams will document well construction.

Well construction will consist of 2-inch inner diameter, Schedule 40 PVC with 10-slot (0.010 inch slotted) 304 stainless steel screen. The screen specification is a vee-wire well screen (pre-pack 20/40 sand) with 10 ft. screen length. Placement of an approximate 3 ft. thick fine-sand filter above the pre-pack screen will create an annular seal, followed by 2-ft. thick bentonite seal, and a bentonite-cement grout within the remaining annulus to the surface. Surface completion will include a flush mouth manhole to match existing grade.

5.3 Well Development

Development of newly installed injection wells will commence 24 to 48 hours after emplacement of the final bentonite grout annular seal to allow sufficient time for curing. Well development will remove suspended solids from disturbance of geologic materials during installation and to improve the hydraulic characteristics of the filter pack and the hydrologic unit adjacent to the intake. The well development process will include two phases: preliminary development and development and follow procedures identified in ASTM designation D5521/D5521M-18 Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers.

Preliminary development will involve mechanical surging, bailing, and potentially other techniques such as air lift pumping to apply sufficient energy in the well to address potential formation damage from the drilling process and remove fine-grained sediment from the screen, filter pack, and geologic formation adjacent to the filter pack. Gradual application of the well development will occur with an increase in intensity, if the well responds to the processes with an increase yield of water and fine-grained sediment.

The final phase of development will involve well pumping with the degree of over pumping, surging, and backwashing required determined based on the results of the predevelopment. Development will continue until the discharge water from the well is visibly clear, or until the turbidity of water is reduced to the extent practical. Additional criteria for completion of well development is the stabilization of water quality indicator parameters pH, temperature, SC, ORP, and DO.

5.4 Field Location of Injection Wells and Well Survey

The project geodatabase in the geographic information system (GIS) will contain the spatial location information for design locations for new injection wells. For each location, this will include: 1) horizontal coordinates (northing and easting) using the North American Datum of 1983, State Plan – Virginia South, and 2) vertical elevation (North American Vertical Datum of 1988) estimated using the horizontal coordinates in the digital elevation model³ for OU 8.

The field team will locate the established injection well locations in the field using a Trimble handheld global positioning system (GPS) unit with submeter accuracy. The GPS unit has a general design accuracy of 10 millimeters (mm) plus 1 part per million (ppm) for horizontal and 15 mm plus 1 ppm for vertical. If boring offsets are required, the project team will use the GPS to determine the revised horizontal coordinates to update the project GIS geodatabase.

Surveying of new injection wells by a Commonwealth of Virginia licensed surveyor will occur and include: 1) survey of the horizontal coordinates (northing and easting) of each monitoring well using the North American Datum of 1983, State Plane – Virginia South, and 2) survey of the vertical elevation of each monitoring well using NAVD88 including the elevation of the top of the inner well casing used for measuring water levels and the ground surface adjacent to the well location.

³ Digital Elevation Model, Virginia Geographic Information Network, <https://vgin.vdem.virginia.gov/search?tags=dem>

5.5 Enhanced ISB Injection Field Implementation

This section describes field implementation activities and methods for gravity feed ISB injections.

5.5.1 Mobilization and Setup

Site mobilization will include delivery of reagents and rental equipment to the site at OU 8 and mobilization of Meadows personnel, equipment, and materials. The design will require delivery of eight (8) intermediate bulk container (IBC) totes (275 gallon) of sodium lactate. The planned central staging area for material and equipment is the covered storage area north of Building 65. Meadows will use a forklift to manage and place spill containment pallets and ISB containers in the staging and work areas.

Setup for gravity feed injections will occur at individual well locations north of Building 65 and at the injection well transects north of Building 66. The gravity flow setup will include the use of an IBC spill containment pallet when performing gravity feed injections. Appendix A.2 has a manufacturer's technical data sheet for proposed the spill containment pallet. This pallet has a secondary containment capacity of 365 gallons to contain 132% of the full contents of the 275-gallon tote with accommodation for precipitation. The spill pallet has dimensions of 62-inches by 62 inches, a 52-inch by 52-inch deck and has a 28-inch height that when combined with the height of tote drain valve will facilitate gravity flow and adjustment of flow rate. A bucket shelf provides additional containment for connection and dispensing. The spill pallet will also have a drain valve and pullover cover to prevent precipitation from entering the sump when not in use. Forklift slots on the spill pallet facilitate movement and placement of the pallet at the desired locations.

IBC setup for gravity feed operations will include installation of a liquid level gauge in the tote to monitor flow rates, reagent usage, and control application to the design volume. Gravity feed operations setup at each well will include connection of a feed assembly from the IBC tote to the injection well. This assembly will consist of 0.75-inch braided PVC hose that has a 2-inch female National Pipe Straight (NPS) fitting to connect directly to the IBC tote that has a 2-inch drain valve with male-quick disconnect coupler. This PVC hose will extend from the tote and connect to a well head assembly with a coupled fitting configured with a drop tube for gravity feed. The well head assembly will have a fitting to attach a pressure indicator for injection process monitoring.

Set up for gravity injections will include traffic cones and cone bars to delineate the work area exclusion zone. Other actions for setup will include staging and deployment of spill prevention measures in addition to the IBC spill pallet.

5.5.2 Gravity Feed Reagent Application

Reagent shipped to the site will not require preparation before gravity feed application. Gravity feed injection operations will occur after completion of setup for the injection well and application as described in Section 5.5.1. Pre-injection water level measurements will provide baseline data for injection operations and monitoring.

Gravity feed injection will commence by opening the IBC drain valve to allow reagent to flow under gravity into the injection well at a rate that limits mounding inside the well and promotes flow into the aquifer. Flow rate adjustment will occur as needed during the injection process to optimize the flow, minimize mounding, and avoid pressure buildup. If needed, the gravity flow process will temporarily cease to stabilize well conditions before continuing injection operations. Gravity flow injection will continue until the volume injected is equal to the design volume. Injection flow monitoring will use liquid level gauge measurements in the tote and a calibration chart for the tote to calculate injection volumes.

The injection process will include injection of 25 gallons of chase water (dechlorinated) to mitigate potential well fouling from gravity feed injections.

5.6 Injection Process Monitoring

Table 5-2 (page 5-4) describes process monitoring that will occur during the gravity injections performed at OU 8. Injection data will track injection progress relative to the design and identify variations in physical

and hydraulic properties of the confined aquifer. Water level measurements (electronic water level indicator) at monitoring well locations in the vicinity of the injection areas will monitor hydraulic influence from injections. Visual checks and water quality measurements at monitoring wells in the vicinity of the injection areas will evaluate distribution of reagents in the targeted areas. Leading indicators at monitoring wells include visual evidence of reagents (cloudy, watercolor change, and odor) and changes in water quality parameters including increased specific conductivity and turbidity levels.

Table 5-2 Remedy Installation Monitoring

Monitoring Element	Parameters	Measures	Locations	Frequency
Injection data	Daily field conditions, injection flow, volume, well head pressure at each injection location	Injection performance vs. design	IBC Tote Injection Well(s)	Daily and cumulative
Hydraulic data	Water level measurement	Injection effects on aquifer	TA-65C: MWANP-10, DP-4 TA-66A: MWANP-3, MW-92, OS72-MW1 TA-66B: MWANP-26	Baseline pre-injection Minimum daily during injections
Visual parameters	Bailer checks of monitoring wells in vicinity of injection area	Distribution of injectate in treatment area	TA-65C: MWANP-10, DP-4 TA-66A: MWANP-3, MW-92, OS72-MW1 TA-66B: MWANP-26	Baseline pre-injection Minimum daily during injections
Water quality parameters	pH, dissolved oxygen, specific conductance, oxidation-reduction potential, temperature, and turbidity	Injectate lateral and vertical distribution and radius of influence	TA-65C: MWANP-10, DP-4 TA-66A: MWANP-3, MW-92, OS72-MW1 TA-66B: MWANP-26	Baseline pre-injection Minimum daily during injections
Aboveground	Inspection of surface around injection areas	Reagent surfacing	Injection areas and vicinity	During injections

Notes: IBC = intermediate bulk container

5.7 Investigative Derived Material Management

Investigative derived material (IDM) generated during implementation of remediation injection related activities will include containerized soil cuttings from drilling, containerized decontamination water and well development water, empty reagent IBC totes, containerized rinse water from totes, personal protective equipment, packaging materials, etc. Monitoring and sampling activities will include purge and decontamination water, personal protective equipment, and disposable materials used during sampling activities.

Table 5-3 identifies planned IDM containerization and disposal based on previous work conducted at OU 8 and DSCR.

Table 5-3 Investigative Derived Material Containerization and Disposal

IDM Type	Container	Expected Waste Characterization	Anticipated Transportation and Disposal
Soil cuttings from drilling	Place in UN certified (Solid) 55-gallon, open head drum	Non-hazardous waste (solid waste), waste characterization testing in Table 5-4.	Shamrock Richmond VA
Personal protection equipment	Place in trash bag and dispose as general solid waste in dumpster at Bldg.40	General solid waste (no testing)	Solid waste for DSCR
Excess packaging materials and	Place in trash bag and dispose as general solid waste in	General solid waste (no testing)	Solid waste for DSCR

IDM Type	Container	Expected Waste Characterization	Anticipated Transportation and Disposal
disposable items	dumpster at Bldg.40		
IBC rinse water, decontamination water, and purge water	Consolidate into holding containers at Building 40 for Vacuum truck pump out	Non-Hazardous Waste (Aqueous), Waste characterization testing in Table 5-4.	Shamrock Richmond VA
Empty reagent 275-gallon totes	Empty reagent 275-gallon totes, pickup at NGA	Offsite recycling	Shamrock Richmond VA

Notes: IDM = investigative derived material, NGA = National Guard Area, PPE = personal protection equipment, Bldg. = building

Waste characterization will include composite sampling and field subsampling following ASTM Designation D6051-15 *Standard Guide for Composite Sampling and Field Subsampling for Environmental Waste Management Activities*. This sampling will determine if IDM is non-hazardous or hazardous according to 40 CFR Part 261 – Identification and Listing of Hazardous Waste and include parameter testing required by the local non-hazardous treatment, storage, and disposal facility (Shamrock Environmental Richmond Virginia). Table 5-4 has a summary of the parameter analysis for characterization of waste (IDM).

Table 5-4 Waste Characterization Parameter Analysis

Characteristic	Regulatory	Method	Parameters	Matrix
Ignitability	40 CFR §261.21	SW846 Method 1030 SW846 Method 1010A	Ignitability Ignitability	Solid Aqueous
Corrosivity	40 CFR §261.22	SW846 Method 9045D SW846 Method 9040C	pH pH	Solid Aqueous
Reactivity	40 CFR §261.23	No test	No test	No reactive media identified at site
Toxicity	40 CFR §261.24	SW846 Method 1311 SW846 8260 SW846 8270 SW846 8081 SW846 8051 SW846 6010 SW846 7470/7471	Table 1 - 40 CFR §261.24 Volatile organics Semi-volatile organics Pesticides Chlorinated herbicides Metals/metalloids Mercury	Solid and Aqueous
Other		SM 2320B SM 2540C SW846 8082A	Alkalinity Total dissolved solids Polychlorinated biphenyls (PCBs)	Aqueous Aqueous Solid and Aqueous

5.8 Spill Response Procedures

The injection related work will include implementation of appropriate product handling procedures and spill response procedures, as applicable. Planned measures will include the use of IBC spill containment pallets for gravity feed operations.

Meadows will have additional containment/berming materials if gravity feed injections cause injected reagents to reach the ground surface. In this case, Meadows will place containment/berm materials around the affected area until removal of all reagents. Meadows will have spill kits and portable vacuums in the work area for immediate deployment if a spill or injectate surfacing occurs during site operations. Meadows will put containment measures in place to protect storm sewer inlets proximate to active injection areas. One storm water inlet is located near well DP-2 planned for gravity feed injection.

6. Remedial Verification and Performance Monitoring

Remedy performance monitoring will evaluate the enhanced ISB actions for the surficial aquifer at OU 8. The technical approach will include baseline pre-injection monitoring and post-injection performance monitoring as outlined in Table 6-1 (page 6-2).

6.1 Monitoring Program

Monitoring locations for the target treatment areas of the diffuse plume area north of Building 65 will include wells DP-1, DP-2, DP-3, MWANP-10, and DP-4 (see Figure 4-1). For the two treatment areas north and northeast of Building 66, the monitoring locations will include wells MWANP-3, MW-92, OS72-MW1, and MWANP-26

The baseline event is part of the semi-annual monitoring event at OU 8 (site-wide) scheduled for April 2025. Projected schedules for implementation of the work are August-September 2025. This work plan proposes six performance monitoring events planned for 30 days post-injection, October 2025, January 2025, April 2026, July 2026, and October 2026 that correspond to the 0.75-to-1-year ISB design periods.

Sampling analytical scope for baseline and performance monitoring at each well will include field water quality parameters, VOCs, TOC, geochemical parameters, and two locations for microbial analysis where VOC concentrations are currently highest in the proposed treatment areas. The monitoring list includes parameters analyzed for the OU 8 semi-annual monitoring program as outlined Worksheet #18 in the project quality assurance project plan (QAPP) supplemented with the microbial analysis.

Table 6-1 identifies the quality assurance and quality control (QA/QC) samples established in the project QAPP (Worksheet #20) applied to the baseline and performance monitoring programs. The field QA/QC samples include one duplicate sample, one matrix spike sample, one matrix spike duplicate sample, one trip blank for each VOC cooler shipped, and one temperature blank for each cooler shipped. The sampling method and procedures will not require a field equipment blank.

6.2 Monitoring Procedures

Prior to sampling, semi-annual monitoring events currently performed in April and October of each year include a synoptic round of water level measurements at all monitoring well locations screened in the surficial aquifer at OU 8. The water level data will input into development of potentiometric surface contour maps to characterize groundwater flow patterns, hydraulic gradient, and to calculate the velocity of groundwater flow.

Table 6-2 (page 6-2) has summary information on groundwater sampling procedures for baseline and performance monitoring that references detailed information contained in the project QAPP (AECOM and Meadows 2024a).

6.3 ISB Performance Evaluation

Performance evaluations for the proposed ISB actions in this work plan will use multiple lines of evaluation as generally described in the 2013 RD/RAWP for OU 8 (AECOM 2013). Table 6-3 (page 6-3) has a summary of planned ISB performance evaluations relative to ISB objectives.

Table 6-1 Performance Monitoring Locations. Scope of Analysis, and Sampling Events

Treatment Area	Well ID	Baseline Monitoring	Injection Process Monitoring	Post Injection Performance Monitoring										Sulfide SM4500 S2-F-2011	Manganese SW6020	Alkalinity SM2320B-2011	Dissolved Gases RSK-175	qPCR	Field Duplicate	MS/MSD	Temp. Blank	Trip Blank
		April 2025	August 2025	30 Day Post-Injection ¹	October 2025	January 2025	April 2026	July 2026	October 2026	WQP	VOCs SW8260D	TOC SW9060	Fe (II) 8146	Anions SW9065								
TA-65A	DP-1	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X				□	*
TA-65B	DP-2	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X			□	*
TA-65C	DP-3	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X				□	*
TA-65C	MWANP-10	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				□	*
TA-65C	DP-4	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X				□	*
TA-66A	MWANP-3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		□	*
TA-66A	MW-92	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X				□	*
TA-66A	OS72-MW1	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X			X	□	*
TA-66B	MWANP-26	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				□	*

Notes: ¹30 day post injection event will include visual inspection of samples, measurement of field water quality parameters for analysis of total organic carbon, WQP = water quality parameters including pH, temperature, dissolved oxygen, oxidation-reduction potential, turbidity, VOCs = volatile organic compounds, TOC = total organic carbon, Fe (II) = ferrous iron (field), Anions include chloride, nitrite as nitrogen, nitrate nitrite as nitrogen, nitrite as nitrogen, and sulfate, Mn = manganese, alkalinity includes total alkalinity, bicarbonate alkalinity as calcium carbonate (CaCO3), carbonate alkalinity as calcium carbonate (CaCO3), Dissolved gases include ethene, ethane, methane, and carbon dioxide, qPCR = quantitative polymerase chain reaction with analysis parameters including Dehalococcoides, tceA Reductase, BAV1 Vinyl Chloride Reductase, and Vinyl Chloride Reductase, MS/MSD = matrix spike/matrix spike duplicate, * one trip blank per cooler shipped containing samples for volatile organic compound analysis, Temp = temperature, □ = one temperature blank per cooler shipped to laboratory.

Table 6-2 Summary of Monitoring Procedures

Procedure Element	Description	Reference
Logs and record keeping	Sampling documentation in logbooks, recordkeeping, sample labeling, and chain of custody	QAPP Worksheets #26 and #27 QAPP Worksheet #21 SOPs P-01, P-02
Sample handling, storage, and shipping	Methods for sample handling, storage, and shipping	QAPP Worksheets #26 and #27, #29 QAPP Worksheet #21 SOP P-03
Planning, preparing, and documenting groundwater sampling events	Methods for planning, preparing, and documenting groundwat3er sampling events	QAPP Worksheets #21 SOPs P-04, P-05, QAPP Worksheet #29 QAPP Appendix B.1 Groundwater sampling form
Groundwater purging and sampling method	Low flow purging and sampling using bladder pump, new disposable bladders, and tubing for each location	QAPP Worksheet #21, SOPs P-07, P-08, P-12, P-13, P-14, P-15, P-16
Field preservation of samples	Methods for preserving samples	QAPP Worksheets #19 and #20 QAPP Worksheet #21, SOP P-09
Field analysis for Ferrous Iron	Field analysis of ferrous iron by Method 8146	QAPP Worksheet #21, SOPs P-11, P-12
Field measurement of water quality parameters and use of flow-through cell	Field measurement of pH, temperature, dissolved oxygen, specific conductivity, and oxidation-reduction potential	QAPP Worksheet #21, SOPs P-19, P-20
Field measurement of turbidity	Field measurement of turbidity	QAPP Worksheet #21, SOPs P-21, P-22
Equipment decontamination	Decontamination of field equipment	QAPP Worksheet #21, SOP P-25
Field measurements with photoionization detector	Use of photoionization detector for field screening of VOCs	QAPP Worksheet #21, SOP P-30

Notes: SOP = standard operating procedure, QAPP = quality assurance project plan.

Table 6-3 Enhanced ISB Performance Evaluation

Evaluation Element	Description
Reagent distribution	Evaluate reagent distribution and persistence relative to treatment design. Perform injection process monitoring to evaluate reagent distribution. Perform post-injection WQP measurements and sampling (TOC, geochemical) ISB objectives: distribute reagents across diffuse plume areas through advective groundwater flow to create plume-wide reactive treatment zones to extent practicable.
Post-injection concentration trends	Evaluate parameter trends at each performance well with the diffuse plume areas (WQP, VOCs, TOC, geochemical) Compare parameter concentrations to baseline + historical results. Time series analysis: visualizations, exploratory data analysis, statistics, trend analysis ISB objectives: mitigate plume instability and reduce PCE and TCE concentrations to less than cleanup levels
Contaminant mass	Evaluate reduction of contaminant mass using chemical and geochemical data Time series analysis: evaluate changes in molar concentrations and ratios along flow paths, at individual wells, plume area analysis. Evaluate depletion of electron acceptors and donors Evaluate increases in metabolic by-product concentrations. Favorable succession of redox conditions ISB objective: reduce contaminant mass (molar) in target plume area.
Contaminant flux	Evaluate changes in contaminant flux by integrating concentration and flow data. Time series evaluation: individual monitoring events, changes over time ISB objective: reduce contaminant flux in diffuse plume areas.
Plume stability and extent	Evaluate changes in plume extent (area) by comparing pre-and post-ISB modeled plumes. Perform time series statistical evaluations for plume stability. ISB objective: mitigate plume instability and reduce the extent of diffuse plume areas.
Biodegradation rates	Use data modeling to calculate rate of change of contaminant mass over time. Compare estimates of pre-ISB biodegradation rates with update estimates after ISB actions Microbiological laboratory or field data that support the occurrence of biodegradation and provide estimated rates of biodegradation. ISB objective: increase biodegradation rates for PCE and TCE.

Notes: WQP = water quality parameters including pH, dissolved oxygen, specific conductivity, oxidation-reduction potential, and turbidity, VOCs = volatile organic compounds, TCE = trichloroethene, cDCE = cis-1,2-dichloroethene, VC = vinyl chloride, ISB = in situ bioremediation.

7. Permitting

Section 7 discusses permitting requirements and activities for implementing ISB actions at OU 8.

7.1 Drilling and Injections

Drilling and subsurface disturbance are subject to the DSCR permitting system requirements for underground facilities protection. Meadows will clear drilling activities through the DSCR excavation permitting system and obtain an excavation permit prior to commencing work. Subsurface utility mark outs and clearing will occur prior to commencing any intrusive activities as described in Section 5.1.

Per previous regulatory correspondence, the proposed ISB injections will not require an underground injection control permit from EPA (Appendix C).

7.2 Site Security and Communications

Meadows will coordinate all remedial activities with DSCR operations personnel to ensure compliance with DSCR physical and operational security requirements. This will include developing transit corridors for vehicles and transport of equipment and materials, participating in training, and participating in security briefings, as appropriate.

Oversight personnel and the project management team will coordinate with DSCR personnel to establish specific lines of communication during remedial activities. These will include providing specific contacts for each phase of work.

7.3 Health and Safety

Remediation work at OU 8 will occur under the project health and safety plan and accident prevention plan, which complies with the applicable requirements of the Occupational Safety and Health Agency General Industry Standards (29 Code of Federal Regulations 1910), Construction Safety Standards (29 Code of Federal Regulations 1926), and Hazardous Waste Operations and Emergency Response Standards (29 Code of Federal Regulations 1910.120) and applicable requirements of USACE Engineer Manual 385-1-1. In addition, the safety program for all work activities will coordinate with applicable DSCR operational and emergency response policies and programs.

The PM Team will designate a task Site Safety Officer (SSO). The SSO will oversee health and safety requirements for task related field activities. The SSO will confer and coordinate with DSCR and/or USACE Safety Officer to identify hazards associated with the planned remedial activities and will ensure any concurrent activities and field work do not interfere installation activities (in cooperation with the PM Team).

8. Reporting

A project technical memorandum will summarize completed remedial action installation activities. Annual reports for OU 8 will report the results of remedy implementation, performance monitoring, MNA and LTM and include data evaluations described in Table 6-3 and integrated analysis of remedy performance. Periodic updates of remedy performance and progress will occur during regulatory planning team meetings and for semi-annual restoration advisory board meetings.

9. References

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Appendix A Reference Information

A.1 Reagent Information



Injection Ready 60% QRS-SL™ Plus Sodium Lactate

Quick Release Substrate with NutriPlus™

a Proprietary Nutrient Package

For Aquifer Remediation and Conditioning

Terra Systems "injection ready" **60% QRS™-SL Plus** Sodium Lactate Quick Release Substrate with nutrients is added to the groundwater to rapidly generate reducing conditions and provide the necessary carbon and hydrogen to support native or introduced microorganisms (*Dehalococcoides*) for the biodegradation of chlorinated solvents such as tetrachloroethene (PCE) and trichloroethene (TCE) to innocuous end products including ethene and ethane (Ellis et al. 2000). The addition of nutrients and Vitamin B₁₂ has been statistically demonstrated to support biodegradation of chlorinated solvents with soluble substrates like lactate and emulsified vegetable oil. (He et al 2007 and Harkness et al 2012).

Key Communication Points

- 60% QRS™-SL Plus sodium lactate with nutrients is an inexpensive, soluble, food grade substrate
- Contains our Proprietary *NutriPlus™* nutrient (Harkness et al 2012) and Vitamin B₁₂ package (He et al 2007), which supports enhanced in-situ bioremediation and increases dechlorination kinetics and donor efficiency.
- It rapidly establishes reducing conditions to support the biodegradation of PCE, TCE, TECA, DNAPL (Sabre Project), Perchlorate, TCA, Cr⁶⁺, TNT, Uranium and Nitrate
- It is one of the most efficient electron donors available
- Provides 60% fermentable carbon
- 100% biobased content. The U.S. Food and Drug Administration have designated 60% QRS™-SL-Plus sodium lactate as Generally Recognized as Safe (GRAS).
- Its low viscosity and high solubility in water allow for rapid transport with groundwater, which enhances distribution in the aquifer and minimizes the number of injection points.
- It arrives as a homogenous ***injection ready substrate***, which results in lower field labor costs
- Proven effective at dry cleaners, semiconductor manufacturers, fabricators, manufacturing firms and military installations, that use and clean metal parts (air conditioners, dishwashers, etc.).

Table I: 60% QRS™-SL Plus Sodium Lactate Specifications

Ingredient	Percent	Description	Benefit
Sodium lactate	60%	Rapidly biodegradable soluble substrate; miscible in water	Fast release source of carbon and hydrogen Rapidly generates reducing conditions High radius of influence Provides 60% fermentable carbon
Proprietary Nutrients	<5%		
pH	6.5 - 7	6.5 - 7	Optimum microbial activity

130 Hickman Road – Suite 1 – Claymont – Delaware – 19703

For More Information Call Michael Free at 302-798-9553 or Email: mfree@terrasystems.net



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Organic Carbon (wt%)	60%		Provides 60% fermentable carbon
Biobased Content	100%		

Packaging: 5-gallon buckets, 55-gallon drums, 275-gallon IBC totes or bulk tankers.



Technical References for the benefits of using a nutrient package for in-situ Bioremediation?

Ellis, D. E., E. J. Lutz, J. M. Odom, R. J. Buchanan, Jr., C. L. Bartlett, M. D. Lee, M. R. Harkness, and K. A. DeWeerd. 2000. Bioaugmentation for accelerated *in situ* anaerobic bioremediation. *Environ. Sci. Technol.* 34:2254-2260.

He, J., V. F. Holmes, P. K. H. Lee, and L. Alvarez-Cohen. 2007. Influence of Vitamin B₁₂ and cocultures on the growth of *Dehalococcoides* isolates in defined medium. *Appl. Environ. Microbiol.* 73(9):2847-2853.

Harkness, M., A. Fisher, M. D. Lee, E. E. Mack, J. A. Payne, S. Dworatzek, J. Roberts, C. Acheson, R. Herrmann, and A. Possolo. 2012. Use of statistical tools to evaluate the reductive dechlorination of high levels of TCE in microcosm studies. *Journal of Contaminant Hydrology* 131(1-4):100-118.



Injection Ready 60% QRS-SL™ Sodium Lactate

Quick Release Substrate

SAFETY DATA SHEET

Effective Date: 01-01-2020

1. Product Identification

Synonyms:	Quick Release Substrate (QRS™-SL); Sodium Lactate; Propanoic acid, 2-Hydroxy Monosodium salt; L-Lactic Acid, Sodium Salt
Recommended Use:	Treatment of groundwater contaminated with chlorinated solvents and other anaerobically degradable compounds.
Supplier:	Terra Systems, Inc. 130 Hickman Road, Suite 1 Claymont, Delaware 19703 Telephone (302) 798-9553 Fax (302) 798-9554 www.terrasystems.net

2. Hazards Identification

Emergency Overview

Caution:	May cause eye irritation.
Health Rating:	1 - Slight
Flammability Rating:	0 - None
Reactivity Rating:	0 - None
Contact Rating:	1 - Slight
Protective Equipment:	Goggles; Proper Gloves
Storage Color Code:	Orange (General Storage)
Potential Health Effects	
Inhalation:	Not expected to be a health hazard
Ingestion:	Not expected to be a health hazard via ingestion
Skin Contact:	No adverse effects expected
Eye Contact:	May cause irritation, possible reddening
Chronic Exposure:	No information found
Aggravation of Pre-existing Conditions:	No information found



3. Composition/Information on Ingredients

Ingredient	CAS#	Percent	Hazardous
Sodium Lactate	72-17-3	60	Yes
Water	7732-18-5	40	No

4. First Aid Measures

Inhalation:	Not expected to require first aid measures. Remove to fresh air. Get medical attention for any breathing difficulty.
Ingestion:	If large amounts were swallowed, give water to drink and get medical advice.
Skin Contact:	Not expected to require first aid measures. Wash exposed area with soap and water. Get medical advice if irritation develops.
Eye Contact:	Immediately flush eyes with plenty of water for at least 15 minutes, lifting upper and lower eyelids occasionally. Get medical attention if irritation persists.

5. Fire Fighting Measures

Fire:	Flash point: 110 C (230 F). Not considered to be a fire hazard.
Explosion:	Not considered to be an explosion hazard.
Fire Extinguishing Media:	Use any means suitable for extinguishing surrounding fire.
Special Information:	In the event of a fire, wear full protective clothing and NIOSH-approved self-contained breathing apparatus with full face piece operated in the pressure demand or other positive pressure mode.

6. Accidental Release Measures

Clean-up personnel may require protective clothing. Absorb in sand, paper towels, "Oil Dry", or other inert material. Scoop up and containerize for disposal. Flush trace residues to sewer with soap and water. Containerized waste may be sent to an approved waste disposal facility.

7. Handling and Storage

Keep in a tightly closed container, stored in a cool, dry, ventilated area. Protect against physical damage. Avoid long storage times. Containers of this material may be hazardous when empty since they do retain product residues (vapors, liquid). Observe all warnings and precautions listed for the product.



8. Exposure Controls/Personal Protection

Airborne Exposure Limits:	None established.
Ventilation System:	Not expected to require any special ventilation.
Personal Respirators (NIOSH Approved):	Not expected to require personal respirator usage.
Skin Protection:	Wear protective gloves and clean body-covering clothing.
Eye Protection:	Use chemical safety goggles and/or a full face shield where splashing is possible. Provide readily accessible eye wash stations and safety showers.
Slips, Trips, and Falls:	Material is slippery when spilled. Clean up with sand, paper towels, or other inert material.

9. Physical and Chemical Properties

Appearance:	Colorless to yellow liquid.
Odor:	Odorless
Solubility:	100% soluble in water.
Specific Gravity (water=1):	1.32. (11.01 pounds per gallon)
pH:	6.5-8.5
% Volatiles by volume @ 21C (70F):	No information found.
Boiling Point:	110 C (230 F)
Melting Point:	17 C (63 F)
Flash Point (F):	No information found
Autoignition Temperature:	No information found
Decomposition Temperature:	No information found.
Vapor Density (Air=1):	0.7
Vapor Pressure (mm Hg):	14 @ 20 C (68 F)
Evaporation Rate (BuAc=1):	No information found
Viscosity @23 C (73 F):	100 centipoises
Partition Coefficient (octanol/water):	No information found

10. Stability and Reactivity

Stability:	Stable under ordinary conditions of use and storage.
Reactivity:	Not reactive under ordinary conditions.
Hazardous Decomposition Products:	Carbon dioxide and carbon monoxide may form when heated to decomposition.
Hazardous Polymerization:	Will not occur.
Incompatibilities:	Strong oxidizers, acids.
Conditions to Avoid:	Incompatibles. Isolate from heat and open flame.



11. Toxicological Information

Oral rat LD50: 2000 mg/Kg. Irritation Data for Sodium Lactate: (Std Draize, rabbit, eye): 100 mg - mild.

-----\Cancer Lists\-----

Ingredient	---NTP Carcinogen---		IARC Category
	Known	Anticipated	
Sodium Lactate (72-17-3)	No	No	None
Water (7732-18-5)	No	No	None

12. Ecological Information

Environmental Fate:	Mobile with water and readily biodegradable
Environmental Toxicity:	Ecological injuries are not known or expected under normal use; (No effect on Daphnia @ 10g/L)
Degradability:	This product is completely biodegradable under both aerobic and anaerobic conditions.
Soil Mobility:	This compound will move with groundwater until the adsorbed onto the soil. Degradation products may be mobile.
Bioaccumulation Potential:	No information found.

13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste disposal facility. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

Not regulated.



15. Regulatory Information

-----\Chemical Inventory Status - Part 1\-----

Ingredient	TSCA	EC	Japan	Australia
Sodium Lactate (72-17-3)	Yes	Yes	Yes	Yes
Water (7732-18-5)	Yes	Yes	Yes	Yes

-----\Chemical Inventory Status - Part 2\-----

--Canada--				
Ingredient	Korea	DSL	NDSL	Phil.
Sodium Lactate (72-17-3)	Yes	Yes	No	Yes
Water (7732-18-5)	Yes	Yes	No	Yes

-----\Federal, State & International Regulations - Part 1\-----

-SARA 302- -----SARA 313-----				
Ingredient	RQ	TPQ	List	Chemical Catg.
Sodium Lactate (72-17-3)	No	No	No	No
Water (7732-18-5)	No	No	No	No

-----\Federal, State & International Regulations - Part 2\-----

-RCRA- -TSCA-			
Ingredient	CERCLA	261.33	8(d)
Sodium Lactate (72-17-3)	No	No	No
Water (7732-18-5)	No	No	No

Chemical Weapons Convention: No TSCA 12(b): No CDTA: No
SARA 311/312: Acute: Yes Chronic: No Fire: No Pressure: No
Reactivity: No (Mixture / Liquid)

16. Other Information

NFPA Ratings:

Health: **1** Flammability: **0** Reactivity: **0**

Date Prepared:

March 28, 2014

Revision Information:

SDS Section(s) changed since last revision of document include: None.

Disclaimer:

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Prepared by:
Phone Number:

Terra Systems, Inc.
(302) 798-9553 (U.S.A.)

A.2 Spill Containment



INTERSTATE PRODUCTS, INC.

“Your Road to Quality Environmental Products Since 1996”

<https://store.interstateproducts.com>

1-800-474-7294

Ultratech IBC Spill Pallet Plus With Drain 1158



Ultratech IBC Spill Pallet 1158 Specifications:

Dimensions: 62" x 62" x 28"

Uniformly Distributed Load: 8,500 lbs

Containment Capacity: 365 Gallons

Weight: 324 lbs

Options: Ultra Bucket Shelf (Part#1160)

Contact us anytime for IPI customer service on all UltraTech IBC Spill Pallet & Spill Containment Products

Key Features:

- Low profile, 28" overall height - allows safe and convenient IBC tank handling and dispensing.
- All polyethylene construction - offers excellent chemical resistance and will not rust or corrode.
- Forkliftable - allows convenient positioning to desired locations.
- Low-cost design with value-added features and benefits.
- Large 52" x 52" deck allows safe and convenient placement of IBC tanks.
- Small footprint - 62" x 62" unit requires minimal floor space.
- 365-gallon sump capacity meets SPCC and EPA Container Storage and Spill Containment Regulations.
- Optional Pull Over Cover keeps rainwater out of the sump and helps comply with Stormwater Management Regulations.
- Five inner polyethylene columns support uniformly distributed loads of up to 8,500 lbs. All components are easily removed for cleaning.
- Optional Bucket Shelf captures spills from dispensing. Spills that exceed 3 gallons are channeled into the 365-gallon sump through a bulkhead fitting.

Appendix B Remedial Design

B.1 Treatment Area TA-65A

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Building 65 Plume Area TA-65A (DP-1)

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.				
	Values	Range	Units	User Notes
1. Treatment Zone Physical Dimensions				
Width (Perpendicular to predominant groundwater flow direction)	20	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	100	1-1,000	feet	
Saturated Thickness	10	1-100	feet	13.8 to 23.8
Treatment Zone Cross Sectional Area	200	--	ft ²	
Treatment Zone Volume	20,000	--	ft ³	
Treatment Zone Total Pore Volume (total volume x total porosity)	52,374	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	37,410	--	gallons	
Design Period of Performance	0.8	.5 to 5	year	0.75 years
Design Factor (times the electron acceptor hydrogen demand)	10.0	2 to 20	unitless	microbial 4X, electron acceptor, 2X substrate loss 2X
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	35%	.05-50	percent	Eastover Data
Effective Porosity	25%	.05-50	percent	Eastover Data
Average Aquifer Hydraulic Conductivity	125.2	.01-1000	ft/day	AECOM PT Bldg 66 Area
Average Hydraulic Gradient	2.00E-03	0.0001-0.1	ft/ft	Area hydraulic gradient (2024)
Average Groundwater Seepage Velocity through the Treatment Zone	1.00	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	365.6	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	136,765	--	gallons/year	
Soil Bulk Density	1.65	1.4-2.0	gm/cm ³	Eastover Data
Soil Fraction Organic Carbon (foc)	0.28%	0.01-10	percent	Eastover Data
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.1	0.01 to 10	mg/L	DP-2
Nitrate	0.04	0.1 to- 20	mg/L	DP-2
Sulfate	1	10 to 5,000	mg/L	DP-2, not detected
Carbon Dioxide (estimated as the amount of Methane produced)	10.0	0.1 to 20	mg/L	Estimate based on previous EISB injections and area
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)	1	0.1 to 20	mg/L	DP-2
Iron (III) (estimated as the amount of Fe (II) produced)	1	0.1 to 20	mg/L	DP-2
4. Contaminant Electron Acceptors				
Tetrachloroethene (PCE)	0.130	--	mg/L	DP-2
Trichloroethene (TCE)	0.110	--	mg/L	DP-2
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.051	--	mg/L	DP-2
Vinyl Chloride (VC)	0.005	--	mg/L	DP-2
Carbon Tetrachloride (CT)	0.000	--	mg/L	Not detected
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	Not detected
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	Not detected
Chloromethane	0.000	--	mg/L	Not detected
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	Not detected
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	Not detected
Dichloroethane (1,1-DCA and 1,2-DCA)	0.003	--	mg/L	DP-2
Chloroethane	0.000	--	mg/L	Not detected
Perchlorate	0.000	--	mg/L	No data
5. Aquifer Geochemistry (Optional Screening Parameters)				
A. Aqueous Geochemistry				
Oxidation-Reduction Potential (ORP)	111	-400 to +500	mV	DP-2
Temperature	21	5.0 to 30	°C	DP-2
pH	5.1	4.0 to 10.0	su	DP-2
Alkalinity	9	10 to 1,000	mg/L	DP-2
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	Estimated
Specific Conductivity	95	100 to 10,000	µs/cm	DP-2
Chloride	20	10 to 10,000	mg/L	DP-2
Sulfide - Pre injection	0.1	0.1 to 100	mg/L	Estimated
Sulfide - Post injection	2.0	0.1 to 100	mg/L	Estimated
B. Aquifer Matrix				
Total Iron	11145	200 to 20,000	mg/kg	CSM 2006 Mean of Subsurface Soil
Cation Exchange Capacity	1	1.0 to 10	meq/100 g	Estimated based on soil data
Neutralization Potential	1.0%	1.0 to 100	Percent as CaCO ₃	Estimated based on soil data

NOTES:

Gravity Feed Design includes DP-1 with treatment area extending to DP-2

Table S.2 Substrate Calculations in Hydrogen Equivalents						
Site Name:		Building 65 Plume Area TA-65A (DP-1)		RETURN TO COVER PAGE		
NOTE: Open cells are user input.						
1. Treatment Zone Physical Dimensions		Values	Range	Units		
Width (Perpendicular to predominant groundwater flow direction)		20	1-10,000	feet		
Length (Parallel to predominant groundwater flow)		100	1-1,000	feet		
Saturated Thickness		10	1-100	feet		
Treatment Zone Cross Sectional Area		200	--	ft ²		
Treatment Zone Volume		20,000	--	ft ³		
Treatment Zone Effective Pore Volume (total volume x effective porosity)		37,410	--	gallons		
Design Period of Performance		0.8	.5 to 5	year		
2. Treatment Zone Hydrogeologic Properties						
Total Porosity		0.35	.05-50			
Effective Porosity		0.25	.05-50			
Average Aquifer Hydraulic Conductivity		125.2	.01-1000	ft/day		
Average Hydraulic Gradient		0.002	0.1-0.0001	ft/ft		
Average Groundwater Seepage Velocity through the Treatment Zone		1.00	--	ft/day		
Average Groundwater Seepage Velocity through the Treatment Zone		365.6	--	ft/yr		
Average Groundwater Flux through the Treatment Zone		136,765	--	gallons/year		
Soil Bulk Density		1.65	1.4-2.0	gm/cm ³		
Soil Fraction Organic Carbon (foc)		0.0028	0.0001-0.1			
3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)						
A. Aqueous-Phase Native Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	0.1	0.04	7.94	0.01	4	
Nitrate (denitrification)	0.0	0.01	12.30	0.00	5	
Sulfate	0.5	0.16	11.91	0.01	8	
Carbon Dioxide (estimated as the amount of methane produced)	10.0	3.12	1.99	1.57	8	
Soluble Competing Electron Acceptor Demand (lb.)				1.59		
B. Solid-Phase Native Electron Acceptors						
(Based on manganese and iron produced)						
Manganese (IV) (estimated as the amount of Mn (II) produced)	0.8	0.96	27.25	0.04	2	
Iron (III) (estimated as the amount of Fe (II) produced)	0.9	1.10	55.41	0.02	1	
Solid-Phase Competing Electron Acceptor Demand (lb.)				0.05		
C. Soluble Contaminant Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.130	0.04	20.57	0.00	8	
Trichloroethene (TCE)	0.110	0.03	21.73	0.00	6	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.051	0.02	24.05	0.00	4	
Vinyl Chloride (VC)	0.005	0.00	31.00	0.00	2	
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8	
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6	
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4	
Chloromethane	0.000	0.00	25.04	0.00	2	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.003	0.00	24.55	0.00	4	
Chloroethane	0.000	0.00	32.00	0.00	2	
Perchlorate	0.000	0.00	12.33	0.00	6	
Total Soluble Contaminant Electron Acceptor Demand (lb.)				0.00		
D. Sorbed Contaminant Electron Acceptors						
(Soil Concentration = Koc x foc x Cgw)						
	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.10	0.20	20.57	0.01	8
Trichloroethene (TCE)	107	0.03	0.07	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.01	0.01	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)				0.01		

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents						
4. Treatment Cell Electron-Acceptor Flux (per year)						
A. Soluble Native Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen		0.1	0.15	7.94	0.02	4
Nitrate (denitrification)		0.0	0.04	10.25	0.00	5
Sulfate		0.5	0.57	11.91	0.05	8
Carbon Dioxide (estimated as the amount of Methane produced)		10	11.41	1.99	5.73	8
Total Competing Electron Acceptor Demand Flux (lb/yr)					5.8	
B. Soluble Contaminant Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)		0.130	0.15	20.57	0.01	8
Trichloroethene (TCE)		0.110	0.13	21.73	0.01	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)		0.051	0.06	24.05	0.00	4
Vinyl Chloride (VC)		0.005	0.01	31.00	0.00	2
Carbon Tetrachloride (CT)		0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)		0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)		0.000	0.00	21.06	0.00	4
Chloromethane		0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)		0.003	0.00	24.55	0.00	4
Chloroethane		0.000	0.00	32.00	0.00	2
Perchlorate		0.000	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)					0.02	
Initial Hydrogen Requirement First Year (lb)					7.5	
Total Life-Cycle Hydrogen Requirement (lb)					6.0	
5. Design Factors						
Microbial Efficiency Uncertainty Factor				2X - 4X		
Methane and Solid-Phase Electron Acceptor Uncertainty				2X - 4X		
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)				1X - 3X		
				Design Factor	10.0	
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)					60.3	
6. Acronyms and Abbreviations						
°C = degrees celsius		meq/100 g = milliequivalents per 100 grams				
µs/cm = microsiemens per centimeter		mg/kg = milligrams per kilogram				
cm/day = centimeters per day		mg/L = milligrams per liter				
cm/sec = centimeters per second		m/m = meters per meters				
ft ² = square feet		mV = millivolts				
ft/day = feet per day		m/yr = meters per year				
ft/ft = foot per foot		su = standard pH units				
ft/yr = feet per year		wt/wt H ₂ = concentration molecular hydrogen, weight per weight				
gm/cm ³ = grams per cubic centimeter						
kg of CaCO ₃ per mg = kilograms of calcium carbonate per milligram						
lb = pounds						

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

[RETURN TO COVER PAGE](#)

Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H ₂ /Mole Substrate
Lactic Acid	C ₃ H ₆ O ₃	90.1	2	0.0448	2 to 3
Molasses (assuming 100% sucrose)	C ₁₂ H ₂₂ O ₁₁	342	8	0.0471	8 to 11
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	C ₆ H ₁₂ O ₆	180	4	0.0448	4 to 6
Ethanol	C ₂ H ₆ O	46.1	2	0.0875	2 to 6
Whey (assuming 100% lactose)	C ₁₂ H ₂₂ O ₁₁	342	11	0.0648	11
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	C ₃₉ H ₅₆ O ₃₉	956	28	0.0590	28
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	C ₁₈ H ₃₂ O ₂	281	16	0.1150	16

Table S.4
Estimated Substrate Requirements for
Hydrogen Demand in Table S.3

Design Life (years): 0.75

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	10.0	1,346	1,346	6.11E+08	1,153
Sodium Lactate Product (60 percent solution)	10.0	1,346	2,793	6.11E+08	1,153
Molasses (assuming 60 percent solution)	10.0	1,279	2,132	5.80E+08	1,095
HFCS (assuming 40% fructose and 40% glucose by weight)	10.0	1,347	1,683	6.11E+08	1,153
Ethanol Product (assuming 80% ethanol by weight)	10.0	689	861	3.12E+08	589
Whey (assuming 100% lactose)	10.0	929	1,328	4.22E+08	796
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	10.0	1,021	1,021	4.63E+08	699
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	10.0	524	524	2.38E+08	449
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	10.0	524	873	2.38E+08	449

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH₃-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid (C₃H₆O₃) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H₂O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC[®] weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents**Site Name:****Building 65 Plume Area TA-65A (DP-1)**[RETURN TO COVER PAGE](#)**1. Treatment Zone Physical Dimensions**

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	20	feet	6	meters
Length (parallel to groundwater flow)	100	feet	30.5	meters
Saturated Thickness	10	feet	3.0	meters
Design Period of Performance	0.75	years	0.75	years

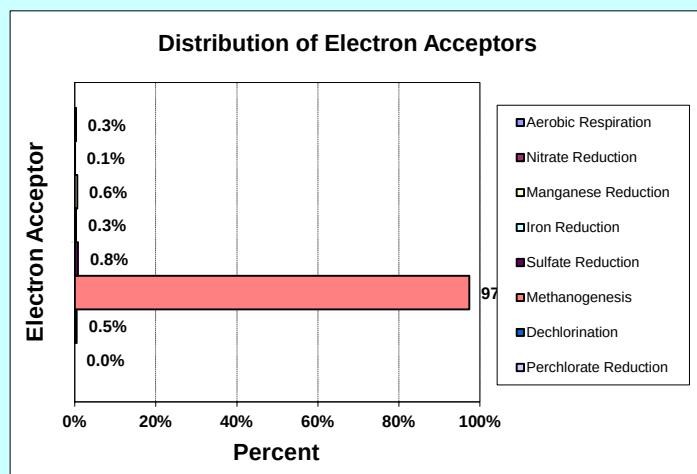
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	125.2	ft/day	4.4E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	1.00	ft/day	3.1E+01	cm/day
Average Groundwater Seepage Velocity	366	ft/yr	111.4	m/yr
Effective Treatment Zone Pore Volume	37,410	gallons	141,608	liters
Groundwater Flux (per year)	136,765	gallons/year	517,697	liters/year
Total Groundwater Volume Treated (over entire design period)	139,984	gallons total	529,881	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.3%	0.019
Nitrate Reduction	0.1%	0.004
Sulfate Reduction	0.8%	0.049
Manganese Reduction	0.6%	0.035
Iron Reduction	0.3%	0.020
Methanogenesis	97.4%	5.870
Dechlorination	0.5%	0.029
Perchlorate Reduction	0.0%	0.000
Totals:	100.00%	6.03

Hydrogen demand in pounds/gallon:	4.31E-05
Hydrogen demand in grams per liter:	5.16E-03

**4. Substrate Equivalents: Design Factor =****10.0**

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	2,793	254	1,153	as lactic acid
2. Molasses Product	2,132	178	1,095	as sucrose
3. Fructose Product	1,683	150	1,153	as fructose
4. Ethanol Product	861	125	589	as ethanol
5. Sweet Dry Whey (lactose)	1,328	sold by pound	796	as lactose
6. HRC®	1,021	sold by pound	699	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	524	67	449	as soybean oil
8. Emulsified Vegetable Oil	873	112	449	as soybean oil

Notes:

- Quantity assumes product is 60% sodium lactate by weight.
- Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
- Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
- Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
- Quantity assumes product is 70% lactose by weight.
- Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
- Quantity of neat soybean oil, corn oil, or canola oil.
- Quantity assumes commercial product is 60% soybean oil by weight.

B.2 Treatment Area TA-65B

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Building 65 Plume Area TA-65B (DP-2)

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NOTE: Unshaded boxes are user input.				
	Values	Range	Units	User Notes
1. Treatment Zone Physical Dimensions				
Width (Perpendicular to predominant groundwater flow direction)	20	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	75	1-1,000	feet	
Saturated Thickness	10	1-100	feet	13.8 to 23.8
Treatment Zone Cross Sectional Area	200	--	ft ²	
Treatment Zone Volume	15,000	--	ft ³	
Treatment Zone Total Pore Volume (total volume x total porosity)	39,281	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	28,058	--	gallons	
Design Period of Performance	0.8	.5 to 5	year	0.75 years
Design Factor (times the electron acceptor hydrogen demand)	10.0	2 to 20	unitless	microbial 4X, electron acceptor, 2X substrate loss 2X
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	35%	.05-50	percent	Eastover Data
Effective Porosity	25%	.05-50	percent	Eastover Data
Average Aquifer Hydraulic Conductivity	125.2	.01-1000	ft/day	AECOM PT Bldg 66 Area
Average Hydraulic Gradient	2.00E-03	0.0001-0.1	ft/ft	Area hydraulic gradient (2024)
Average Groundwater Seepage Velocity through the Treatment Zone	1.00	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	365.6	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	136,765	--	gallons/year	
Soil Bulk Density	1.65	1.4-2.0	gm/cm ³	Eastover Data
Soil Fraction Organic Carbon (foc)	0.28%	0.01-10	percent	Eastover Data
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.1	0.01 to 10	mg/L	DP-2
Nitrate	0.04	0.1 to- 20	mg/L	DP-2
Sulfate	1	10 to 5,000	mg/L	DP-2, not detected
Carbon Dioxide (estimated as the amount of Methane produced)	10.0	0.1 to 20	mg/L	Estimate based on previous EISB injections and area
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)	1	0.1 to 20	mg/L	DP-2
Iron (III) (estimated as the amount of Fe (II) produced)	1	0.1 to 20	mg/L	DP-2
4. Contaminant Electron Acceptors				
Tetrachloroethene (PCE)	0.130	--	mg/L	DP-2
Trichloroethene (TCE)	0.110	--	mg/L	DP-2
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.051	--	mg/L	DP-2
Vinyl Chloride (VC)	0.005	--	mg/L	DP-2
Carbon Tetrachloride (CT)	0.000	--	mg/L	Not detected
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	Not detected
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	Not detected
Chloromethane	0.000	--	mg/L	Not detected
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	Not detected
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	Not detected
Dichloroethane (1,1-DCA and 1,2-DCA)	0.003	--	mg/L	DP-2
Chloroethane	0.000	--	mg/L	Not detected
Perchlorate	0.000	--	mg/L	No data
5. Aquifer Geochemistry (Optional Screening Parameters)				
A. Aqueous Geochemistry				
Oxidation-Reduction Potential (ORP)	111	-400 to +500	mV	DP-2
Temperature	21	5.0 to 30	°C	DP-2
pH	5.1	4.0 to 10.0	su	DP-2
Alkalinity	9	10 to 1,000	mg/L	DP-2
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	Estimated
Specific Conductivity	95	100 to 10,000	µs/cm	DP-2
Chloride	20	10 to 10,000	mg/L	DP-2
Sulfide - Pre injection	0.1	0.1 to 100	mg/L	Estimated
Sulfide - Post injection	2.0	0.1 to 100	mg/L	Estimated
B. Aquifer Matrix				
Total Iron	11145	200 to 20,000	mg/kg	CSM 2006 Mean of Subsurface Soil
Cation Exchange Capacity	1	1.0 to 10	meq/100 g	Estimated based on soil data
Neutralization Potential	1.0%	1.0 to 100	Percent as CaCO ₃	Estimated based on soil data

NOTES:

Gravity Feed Design includes DP-2

Table S.2 Substrate Calculations in Hydrogen Equivalents						
Site Name:		Building 65 Plume Area TA-65B (DP-2)		RETURN TO COVER PAGE		
NOTE: Open cells are user input.						
1. Treatment Zone Physical Dimensions		Values	Range	Units		
Width (Perpendicular to predominant groundwater flow direction)		20	1-10,000	feet		
Length (Parallel to predominant groundwater flow)		75	1-1,000	feet		
Saturated Thickness		10	1-100	feet		
Treatment Zone Cross Sectional Area		200	--	ft ²		
Treatment Zone Volume		15,000	--	ft ³		
Treatment Zone Effective Pore Volume (total volume x effective porosity)		28,058	--	gallons		
Design Period of Performance		0.8	.5 to 5	year		
2. Treatment Zone Hydrogeologic Properties						
Total Porosity		0.35	.05-50			
Effective Porosity		0.25	.05-50			
Average Aquifer Hydraulic Conductivity		125.2	.01-1000	ft/day		
Average Hydraulic Gradient		0.002	0.1-0.0001	ft/ft		
Average Groundwater Seepage Velocity through the Treatment Zone		1.00	--	ft/day		
Average Groundwater Seepage Velocity through the Treatment Zone		365.6	--	ft/yr		
Average Groundwater Flux through the Treatment Zone		136,765	--	gallons/year		
Soil Bulk Density		1.65	1.4-2.0	gm/cm ³		
Soil Fraction Organic Carbon (foc)		0.0028	0.0001-0.1			
3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)						
A. Aqueous-Phase Native Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	0.1	0.03	7.94	0.00	4	
Nitrate (denitrification)	0.0	0.01	12.30	0.00	5	
Sulfate	0.5	0.12	11.91	0.01	8	
Carbon Dioxide (estimated as the amount of methane produced)	10.0	2.34	1.99	1.18	8	
Soluble Competing Electron Acceptor Demand (lb.)				1.19		
B. Solid-Phase Native Electron Acceptors						
(Based on manganese and iron produced)						
Manganese (IV) (estimated as the amount of Mn (II) produced)	0.8	0.89	27.25	0.03	2	
Iron (III) (estimated as the amount of Fe (II) produced)	0.9	1.02	55.41	0.02	1	
Solid-Phase Competing Electron Acceptor Demand (lb.)				0.05		
C. Soluble Contaminant Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.130	0.03	20.57	0.00	8	
Trichloroethene (TCE)	0.110	0.03	21.73	0.00	6	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.051	0.01	24.05	0.00	4	
Vinyl Chloride (VC)	0.005	0.00	31.00	0.00	2	
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8	
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6	
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4	
Chloromethane	0.000	0.00	25.04	0.00	2	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.003	0.00	24.55	0.00	4	
Chloroethane	0.000	0.00	32.00	0.00	2	
Perchlorate	0.000	0.00	12.33	0.00	6	
Total Soluble Contaminant Electron Acceptor Demand (lb.)				0.00		
D. Sorbed Contaminant Electron Acceptors						
(Soil Concentration = Koc x foc x Cgw)						
	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.10	0.15	20.57	0.01	8
Trichloroethene (TCE)	107	0.03	0.05	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.01	0.01	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)				0.01		

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents						
4. Treatment Cell Electron-Acceptor Flux (per year)						
A. Soluble Native Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen		0.1	0.15	7.94	0.02	4
Nitrate (denitrification)		0.0	0.04	10.25	0.00	5
Sulfate		0.5	0.57	11.91	0.05	8
Carbon Dioxide (estimated as the amount of Methane produced)		10	11.41	1.99	5.73	8
Total Competing Electron Acceptor Demand Flux (lb/yr)					5.8	
B. Soluble Contaminant Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)		0.130	0.15	20.57	0.01	8
Trichloroethene (TCE)		0.110	0.13	21.73	0.01	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)		0.051	0.06	24.05	0.00	4
Vinyl Chloride (VC)		0.005	0.01	31.00	0.00	2
Carbon Tetrachloride (CT)		0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)		0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)		0.000	0.00	21.06	0.00	4
Chloromethane		0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)		0.003	0.00	24.55	0.00	4
Chloroethane		0.000	0.00	32.00	0.00	2
Perchlorate		0.000	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)					0.02	
Initial Hydrogen Requirement First Year (lb)					7.1	
Total Life-Cycle Hydrogen Requirement (lb)					5.6	
5. Design Factors						
Microbial Efficiency Uncertainty Factor				2X - 4X		
Methane and Solid-Phase Electron Acceptor Uncertainty				2X - 4X		
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)				1X - 3X		
				Design Factor	10.0	
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)					56.2	
6. Acronyms and Abbreviations						
°C = degrees celsius		meq/100 g = milliequivalents per 100 grams				
µs/cm = microsiemens per centimeter		mg/kg = milligrams per kilogram				
cm/day = centimeters per day		mg/L = milligrams per liter				
cm/sec = centimeters per second		m/m = meters per meters				
ft ² = square feet		mV = millivolts				
ft/day = feet per day		m/yr = meters per year				
ft/ft = foot per foot		su = standard pH units				
ft/yr = feet per year		wt/wt H ₂ = concentration molecular hydrogen, weight per weight				
gm/cm ³ = grams per cubic centimeter						
kg of CaCO ₃ per mg = kilograms of calcium carbonate per milligram						
lb = pounds						

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

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Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H ₂ /Mole Substrate
Lactic Acid	C ₃ H ₆ O ₃	90.1	2	0.0448	2 to 3
Molasses (assuming 100% sucrose)	C ₁₂ H ₂₂ O ₁₁	342	8	0.0471	8 to 11
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	C ₆ H ₁₂ O ₆	180	4	0.0448	4 to 6
Ethanol	C ₂ H ₆ O	46.1	2	0.0875	2 to 6
Whey (assuming 100% lactose)	C ₁₂ H ₂₂ O ₁₁	342	11	0.0648	11
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	C ₃₉ H ₅₆ O ₃₉	956	28	0.0590	28
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	C ₁₈ H ₃₂ O ₂	281	16	0.1150	16

Table S.4
Estimated Substrate Requirements for
Hydrogen Demand in Table S.3

Design Life (years): 0.75

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	10.0	1,256	1,256	5.70E+08	1,152
Sodium Lactate Product (60 percent solution)	10.0	1,256	2,606	5.70E+08	1,152
Molasses (assuming 60 percent solution)	10.0	1,193	1,989	5.41E+08	1,094
HFCS (assuming 40% fructose and 40% glucose by weight)	10.0	1,256	1,570	5.70E+08	1,152
Ethanol Product (assuming 80% ethanol by weight)	10.0	642	803	2.91E+08	589
Whey (assuming 100% lactose)	10.0	867	1,239	3.93E+08	795
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	10.0	952	952	4.32E+08	699
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	10.0	489	489	2.22E+08	448
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	10.0	489	815	2.22E+08	448

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH₃-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid (C₃H₆O₃) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H₂O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC[®] weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents**Site Name:****Building 65 Plume Area TA-65B (DP-2)**[RETURN TO COVER PAGE](#)**1. Treatment Zone Physical Dimensions**

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	20	feet	6	meters
Length (parallel to groundwater flow)	75	feet	22.9	meters
Saturated Thickness	10	feet	3.0	meters
Design Period of Performance	0.75	years	0.75	years

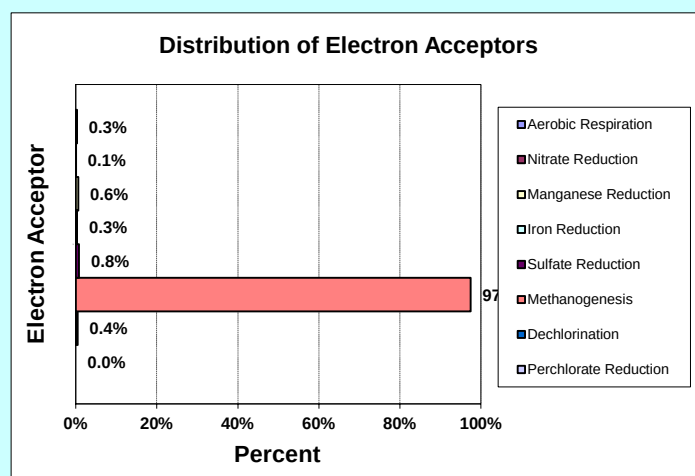
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	125.2	ft/day	4.4E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	1.00	ft/day	3.1E+01	cm/day
Average Groundwater Seepage Velocity	366	ft/yr	111.4	m/yr
Effective Treatment Zone Pore Volume	28,058	gallons	106,206	liters
Groundwater Flux (per year)	136,765	gallons/year	517,697	liters/year
Total Groundwater Volume Treated (over entire design period)	130,631	gallons total	494,479	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.3%	0.018
Nitrate Reduction	0.1%	0.004
Sulfate Reduction	0.8%	0.046
Manganese Reduction	0.6%	0.033
Iron Reduction	0.3%	0.018
Methanogenesis	97.4%	5.478
Dechlorination	0.4%	0.025
Perchlorate Reduction	0.0%	0.000
Totals:	100.00%	5.62

Hydrogen demand in pounds/gallon:	4.30E-05
Hydrogen demand in grams per liter:	5.16E-03

**4. Substrate Equivalents: Design Factor =****10.0**

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	2,606	237	1,152	as lactic acid
2. Molasses Product	1,989	166	1,094	as sucrose
3. Fructose Product	1,570	140	1,152	as fructose
4. Ethanol Product	803	116	589	as ethanol
5. Sweet Dry Whey (lactose)	1,239	sold by pound	795	as lactose
6. HRC®	952	sold by pound	699	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	489	63	448	as soybean oil
8. Emulsified Vegetable Oil	815	104	448	as soybean oil

Notes:

- Quantity assumes product is 60% sodium lactate by weight.
- Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
- Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
- Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
- Quantity assumes product is 70% lactose by weight.
- Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
- Quantity of neat soybean oil, corn oil, or canola oil.
- Quantity assumes commercial product is 60% soybean oil by weight.

B.3 Treatment Area TA-65C

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Building 65 Plume Area TA-65C (DP-3)

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.				
	Values	Range	Units	User Notes
1. Treatment Zone Physical Dimensions				
Width (Perpendicular to predominant groundwater flow direction)	20	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	100	1-1,000	feet	
Saturated Thickness	10	1-100	feet	13.8 to 23.8
Treatment Zone Cross Sectional Area	200	--	ft ²	
Treatment Zone Volume	20,000	--	ft ³	
Treatment Zone Total Pore Volume (total volume x total porosity)	52,374	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	37,410	--	gallons	
Design Period of Performance	0.8	.5 to 5	year	0.75 years
Design Factor (times the electron acceptor hydrogen demand)	10.0	2 to 20	unitless	microbial 4X, electron acceptor, 2X substrate loss 2X
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	35%	.05-50	percent	Eastover Data
Effective Porosity	25%	.05-50	percent	Eastover Data
Average Aquifer Hydraulic Conductivity	125.2	.01-1000	ft/day	AECOM PT Bldg 66 Area
Average Hydraulic Gradient	2.00E-03	0.0001-0.1	ft/ft	Area hydraulic gradient (2024)
Average Groundwater Seepage Velocity through the Treatment Zone	1.00	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	365.6	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	136,765	--	gallons/year	
Soil Bulk Density	1.65	1.4-2.0	gm/cm ³	Eastover Data
Soil Fraction Organic Carbon (foc)	0.28%	0.01-10	percent	Eastover Data
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	1.3	0.01 to 10	mg/L	MWANP-1
Nitrate	0.05	0.1 to- 20	mg/L	MWANP-1 (not detected)
Sulfate	8	10 to 5,000	mg/L	MWANP-1
Carbon Dioxide (estimated as the amount of Methane produced)	5.0	0.1 to 20	mg/L	Estimate based on previous EISB injections and area
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)	0	0.1 to 20	mg/L	MWANP-1
Iron (III) (estimated as the amount of Fe (II) produced)	0	0.1 to 20	mg/L	MWANP-1
4. Contaminant Electron Acceptors				
Tetrachloroethene (PCE)	0.038	--	mg/L	DP-3
Trichloroethene (TCE)	0.016	--	mg/L	DP-3
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.013	--	mg/L	DP-3
Vinyl Chloride (VC)	0.001	--	mg/L	DP-3
Carbon Tetrachloride (CT)	0.000	--	mg/L	Not detected
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	Not detected
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	Not detected
Chloromethane	0.000	--	mg/L	Not detected
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	Not detected
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	Not detected
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	MWANP-1
Chloroethane	0.000	--	mg/L	Not detected
Perchlorate	0.000	--	mg/L	No data
5. Aquifer Geochemistry (Optional Screening Parameters)				
A. Aqueous Geochemistry				
Oxidation-Reduction Potential (ORP)	344	-400 to +500	mV	MWANP-1
Temperature	21	5.0 to 30	°C	MWANP-1
pH	4.4	4.0 to 10.0	su	MWANP-1
Alkalinity	32	10 to 1,000	mg/L	MWANP-1
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	Estimated
Specific Conductivity	95	100 to 10,000	µs/cm	DP-2
Chloride	20	10 to 10,000	mg/L	DP-2
Sulfide - Pre injection	0.1	0.1 to 100	mg/L	Estimated
Sulfide - Post injection	2.0	0.1 to 100	mg/L	Estimated
B. Aquifer Matrix				
Total Iron	11145	200 to 20,000	mg/kg	CSM 2006 Mean of Subsurface Soil
Cation Exchange Capacity	1	1.0 to 10	meq/100 g	Estimated based on soil data
Neutralization Potential	1.0%	1.0 to 100	Percent as CaCO ₃	Estimated based on soil data

NOTES:

Gravity Feed Design includes DP-3

Table S.2 Substrate Calculations in Hydrogen Equivalents						
Site Name:		Building 65 Plume Area TA-65C (DP-3)		RETURN TO COVER PAGE		
NOTE: Open cells are user input.						
1. Treatment Zone Physical Dimensions		Values	Range	Units		
Width (Perpendicular to predominant groundwater flow direction)		20	1-10,000	feet		
Length (Parallel to predominant groundwater flow)		100	1-1,000	feet		
Saturated Thickness		10	1-100	feet		
Treatment Zone Cross Sectional Area		200	--	ft ²		
Treatment Zone Volume		20,000	--	ft ³		
Treatment Zone Effective Pore Volume (total volume x effective porosity)		37,410	--	gallons		
Design Period of Performance		0.8	.5 to 5	year		
2. Treatment Zone Hydrogeologic Properties						
Total Porosity		0.35	.05-50			
Effective Porosity		0.25	.05-50			
Average Aquifer Hydraulic Conductivity		125.2	.01-1000	ft/day		
Average Hydraulic Gradient		0.002	0.1-0.0001	ft/ft		
Average Groundwater Seepage Velocity through the Treatment Zone		1.00	--	ft/day		
Average Groundwater Seepage Velocity through the Treatment Zone		365.6	--	ft/yr		
Average Groundwater Flux through the Treatment Zone		136,765	--	gallons/year		
Soil Bulk Density		1.65	1.4-2.0	gm/cm ³		
Soil Fraction Organic Carbon (foc)		0.0028	0.0001-0.1			
3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)						
A. Aqueous-Phase Native Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	1.3	0.40	7.94	0.05	4	
Nitrate (denitrification)	0.1	0.02	12.30	0.00	5	
Sulfate	8.3	2.59	11.91	0.22	8	
Carbon Dioxide (estimated as the amount of methane produced)	5.0	1.56	1.99	0.78	8	
Soluble Competing Electron Acceptor Demand (lb.)				1.05		
B. Solid-Phase Native Electron Acceptors						
(Based on manganese and iron produced)						
Manganese (IV) (estimated as the amount of Mn (II) produced)	0.0	0.00	27.25	0.00	2	
Iron (III) (estimated as the amount of Fe (II) produced)	0.0	0.01	55.41	0.00	1	
Solid-Phase Competing Electron Acceptor Demand (lb.)				0.00		
C. Soluble Contaminant Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.038	0.01	20.57	0.00	8	
Trichloroethene (TCE)	0.016	0.00	21.73	0.00	6	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.013	0.00	24.05	0.00	4	
Vinyl Chloride (VC)	0.001	0.00	31.00	0.00	2	
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8	
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6	
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4	
Chloromethane	0.000	0.00	25.04	0.00	2	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4	
Chloroethane	0.000	0.00	32.00	0.00	2	
Perchlorate	0.000	0.00	12.33	0.00	6	
Total Soluble Contaminant Electron Acceptor Demand (lb.)				0.00		
D. Sorbed Contaminant Electron Acceptors						
(Soil Concentration = Koc x foc x Cgw)						
	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.03	0.06	20.57	0.00	8
Trichloroethene (TCE)	107	0.00	0.01	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.00	0.00	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)				0.00		

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents						
4. Treatment Cell Electron-Acceptor Flux (per year)						
A. Soluble Native Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen		1.3	1.47	7.94	0.19	4
Nitrate (denitrification)		0.1	0.06	10.25	0.01	5
Sulfate		8.3	9.47	11.91	0.80	8
Carbon Dioxide (estimated as the amount of Methane produced)		5	5.71	1.99	2.87	8
Total Competing Electron Acceptor Demand Flux (lb/yr)					3.9	
B. Soluble Contaminant Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)		0.038	0.04	20.57	0.00	8
Trichloroethene (TCE)		0.016	0.02	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)		0.013	0.01	24.05	0.00	4
Vinyl Chloride (VC)		0.001	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)		0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)		0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)		0.000	0.00	21.06	0.00	4
Chloromethane		0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)		0.000	0.00	24.55	0.00	4
Chloroethane		0.000	0.00	32.00	0.00	2
Perchlorate		0.000	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)					0.00	
Initial Hydrogen Requirement First Year (lb)					4.9	
Total Life-Cycle Hydrogen Requirement (lb)					4.0	
5. Design Factors						
Microbial Efficiency Uncertainty Factor				2X - 4X		
Methane and Solid-Phase Electron Acceptor Uncertainty				2X - 4X		
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)				1X - 3X		
				Design Factor	10.0	
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)					39.5	
6. Acronyms and Abbreviations						
°C = degrees celsius		meq/100 g = milliequivalents per 100 grams				
µs/cm = microsiemens per centimeter		mg/kg = milligrams per kilogram				
cm/day = centimeters per day		mg/L = milligrams per liter				
cm/sec = centimeters per second		m/m = meters per meters				
ft ² = square feet		mV = millivolts				
ft/day = feet per day		m/yr = meters per year				
ft/ft = foot per foot		su = standard pH units				
ft/yr = feet per year		wt/wt H ₂ = concentration molecular hydrogen, weight per weight				
gm/cm ³ = grams per cubic centimeter						
kg of CaCO ₃ per mg = kilograms of calcium carbonate per milligram						
lb = pounds						

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

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Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H ₂ /Mole Substrate
Lactic Acid	C ₃ H ₆ O ₃	90.1	2	0.0448	2 to 3
Molasses (assuming 100% sucrose)	C ₁₂ H ₂₂ O ₁₁	342	8	0.0471	8 to 11
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	C ₆ H ₁₂ O ₆	180	4	0.0448	4 to 6
Ethanol	C ₂ H ₆ O	46.1	2	0.0875	2 to 6
Whey (assuming 100% lactose)	C ₁₂ H ₂₂ O ₁₁	342	11	0.0648	11
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	C ₃₉ H ₅₆ O ₃₉	956	28	0.0590	28
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	C ₁₈ H ₃₂ O ₂	281	16	0.1150	16

Table S.4
Estimated Substrate Requirements for
Hydrogen Demand in Table S.3

Design Life (years): 0.75

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	10.0	883	883	4.00E+08	756
Sodium Lactate Product (60 percent solution)	10.0	883	1,832	4.00E+08	756
Molasses (assuming 60 percent solution)	10.0	839	1,398	3.80E+08	718
HFCS (assuming 40% fructose and 40% glucose by weight)	10.0	883	1,104	4.01E+08	756
Ethanol Product (assuming 80% ethanol by weight)	10.0	452	564	2.05E+08	387
Whey (assuming 100% lactose)	10.0	609	871	2.76E+08	522
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	10.0	669	669	3.04E+08	458
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	10.0	344	344	1.56E+08	294
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	10.0	344	573	1.56E+08	294

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH₃-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid (C₃H₆O₃) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H₂O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC[®] weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents**Site Name:****Building 65 Plume Area TA-65C (DP-3)**[RETURN TO COVER PAGE](#)**1. Treatment Zone Physical Dimensions**

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	20	feet	6	meters
Length (parallel to groundwater flow)	100	feet	30.5	meters
Saturated Thickness	10	feet	3.0	meters
Design Period of Performance	0.75	years	0.75	years

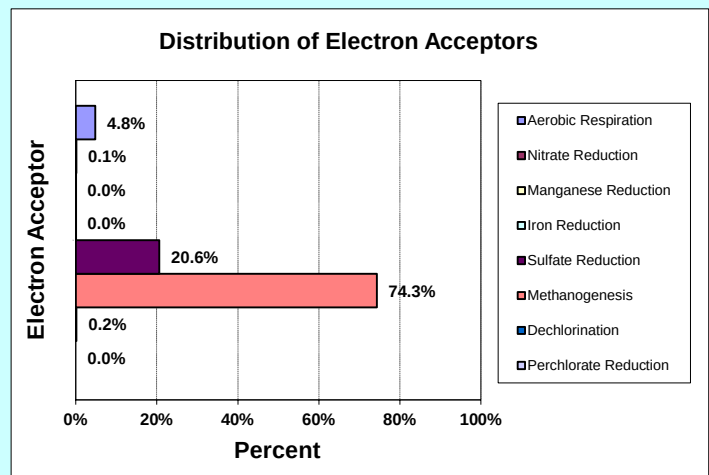
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	125.2	ft/day	4.4E-02	cm/sec
Average Hydraulic Gradient	0.002	ft/ft	0.002	m/m
Average Groundwater Seepage Velocity	1.00	ft/day	3.1E+01	cm/day
Average Groundwater Seepage Velocity	366	ft/yr	111.4	m/yr
Effective Treatment Zone Pore Volume	37,410	gallons	141,608	liters
Groundwater Flux (per year)	136,765	gallons/year	517,697	liters/year
Total Groundwater Volume Treated (over entire design period)	139,984	gallons total	529,881	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	4.8%	0.190
Nitrate Reduction	0.1%	0.005
Sulfate Reduction	20.6%	0.814
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.000
Methanogenesis	74.3%	2.935
Dechlorination	0.2%	0.007
Perchlorate Reduction	0.0%	0.000
Totals:	100.00%	3.95

Hydrogen demand in pounds/gallon:	2.82E-05
Hydrogen demand in grams per liter:	3.38E-03

**4. Substrate Equivalents: Design Factor =****10.0**

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	1,832	167	756	as lactic acid
2. Molasses Product	1,398	116	718	as sucrose
3. Fructose Product	1,104	99	756	as fructose
4. Ethanol Product	564	82	387	as ethanol
5. Sweet Dry Whey (lactose)	871	sold by pound	522	as lactose
6. HRC®	669	sold by pound	458	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	344	44	294	as soybean oil
8. Emulsified Vegetable Oil	573	73	294	as soybean oil

Notes:

- Quantity assumes product is 60% sodium lactate by weight.
- Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
- Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
- Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
- Quantity assumes product is 70% lactose by weight.
- Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
- Quantity of neat soybean oil, corn oil, or canola oil.
- Quantity assumes commercial product is 60% soybean oil by weight.

B.4 Treatment Area TA-66A

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents**Site Name:** Building 66 Plume Area TA-66A

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NOTE: Unshaded boxes are user input.				
	Values	Range	Units	User Notes
1. Treatment Zone Physical Dimensions				
Width (Perpendicular to predominant groundwater flow direction)	140	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	150	1-1,000	feet	
Saturated Thickness	10	1-100	feet	13.8 to 23.8
Treatment Zone Cross Sectional Area	1400	--	ft ²	
Treatment Zone Volume	210,000	--	ft ³	
Treatment Zone Total Pore Volume (total volume x total porosity)	549,927	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	392,805	--	gallons	
Design Period of Performance	1.0	.5 to 5	year	0.75 years
Design Factor (times the electron acceptor hydrogen demand)	10.0	2 to 20	unitless	
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	35%	.05-50	percent	Eastover Data
Effective Porosity	25%	.05-50	percent	Eastover Data
Average Aquifer Hydraulic Conductivity	125.2	.01-1000	ft/day	AECOM PT Bldg 66 Area
Average Hydraulic Gradient	1.50E-03	0.0001-0.1	ft/ft	2024 OU 8 Annual Report
Average Groundwater Seepage Velocity through the Treatment Zone	0.75	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	274.2	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	718,016	--	gallons/year	
Soil Bulk Density	1.65	1.4-2.0	gm/cm ³	Eastover Data
Soil Fraction Organic Carbon (foc)	0.28%	0.01-10	percent	Eastover Data
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.6	0.01 to 10	mg/L	Average of MWANP-3, OS72-MW1, and MW-92
Nitrate	0.59	0.1 to 20	mg/L	Average of MWANP-3, OS72-MW1, and MW-92
Sulfate	2	10 to 5,000	mg/L	Average of MWANP-3, OS72-MW1, and MW-92
Carbon Dioxide (estimated as the amount of Methane produced)	5.0	0.1 to 20	mg/L	Estimate based on previous EISB injections and area
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)	0	0.1 to 20	mg/L	Estimated based on Mn data
Iron (III) (estimated as the amount of Fe (II) produced)	0	0.1 to 20	mg/L	Average of MWANP-3, OS72-MW1, and MW-92
4. Contaminant Electron Acceptors				
Tetrachloroethene (PCE)	0.061	--	mg/L	Maximum at MWANP-3
Trichloroethene (TCE)	0.010	--	mg/L	Maximum at MWANP-3
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.054	--	mg/L	Maximum at MW-92
Vinyl Chloride (VC)	0.001	--	mg/L	Not detected
Carbon Tetrachloride (CT)	0.000	--	mg/L	Not detected
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	Not detected
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	Not detected
Chloromethane	0.000	--	mg/L	Not detected
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	Not detected
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	Not detected
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	Not detected
Chloroethane	0.000	--	mg/L	Not detected
Perchlorate	0.000	--	mg/L	No data
5. Aquifer Geochemistry (Optional Screening Parameters)				
A. Aqueous Geochemistry				
Oxidation-Reduction Potential (ORP)	200	-400 to +500	mV	Average of MWANP-3, OS72-MW1, and MW-92
Temperature	20	5.0 to 30	°C	Average of MWANP-3, OS72-MW1, and MW-92
pH	5.4	4.0 to 10.0	su	Average of MWANP-3, OS72-MW1, and MW-92
Alkalinity	31	10 to 1,000	mg/L	Average of MWANP-3, OS72-MW1, and MW-92
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	Estimated
Specific Conductivity	99	100 to 10,000	µs/cm	Average of MWANP-3, OS72-MW1, and MW-92
Chloride	8	10 to 10,000	mg/L	Average of MWANP-3, OS72-MW1, and MW-92
Sulfide - Pre injection	0.1	0.1 to 100	mg/L	Estimated
Sulfide - Post injection	2.0	0.1 to 100	mg/L	Estimated
B. Aquifer Matrix				
Total Iron	11145	200 to 20,000	mg/kg	CSM 2006 Mean of Subsurface Soil
Cation Exchange Capacity	1	1.0 to 10	meq/100 g	Estimated based on soil data
Neutralization Potential	1.0%	1.0 to 100	Percent as CaCO ₃	Estimated based on soil data

NOTES:

Gravity Feed Design includes MWANP-3, MW-92, and OS72-MW1

Table S.2 Substrate Calculations in Hydrogen Equivalents						
Site Name:		Building 66 Plume Area TA-66A		RETURN TO COVER PAGE		
NOTE: Open cells are user input.						
1. Treatment Zone Physical Dimensions		Values	Range	Units		
Width (Perpendicular to predominant groundwater flow direction)		140	1-10,000	feet		
Length (Parallel to predominant groundwater flow)		150	1-1,000	feet		
Saturated Thickness		10	1-100	feet		
Treatment Zone Cross Sectional Area		1400	--	ft ²		
Treatment Zone Volume		210,000	--	ft ³		
Treatment Zone Effective Pore Volume (total volume x effective porosity)		392,805	--	gallons		
Design Period of Performance		1.0	.5 to 5	year		
2. Treatment Zone Hydrogeologic Properties						
Total Porosity		0.35	.05-50			
Effective Porosity		0.25	.05-50			
Average Aquifer Hydraulic Conductivity		125.2	.01-1000	ft/day		
Average Hydraulic Gradient		0.0015	0.1-0.0001	ft/ft		
Average Groundwater Seepage Velocity through the Treatment Zone		0.75	--	ft/day		
Average Groundwater Seepage Velocity through the Treatment Zone		274.2	--	ft/yr		
Average Groundwater Flux through the Treatment Zone		718,016	--	gallons/year		
Soil Bulk Density		1.65	1.4-2.0	gm/cm ³		
Soil Fraction Organic Carbon (foc)		0.0028	0.0001-0.1			
3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)						
A. Aqueous-Phase Native Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	0.6	1.86	7.94	0.23	4	
Nitrate (denitrification)	0.6	1.93	12.30	0.16	5	
Sulfate	2.43	7.96	11.91	0.67	8	
Carbon Dioxide (estimated as the amount of methane produced)	5.0	16.39	1.99	8.24	8	
Soluble Competing Electron Acceptor Demand (lb.)				9.30		
B. Solid-Phase Native Electron Acceptors						
(Based on manganese and iron produced)						
Manganese (IV) (estimated as the amount of Mn (II) produced)	0.0	0.00	27.25	0.00	2	
Iron (III) (estimated as the amount of Fe (II) produced)	0.1	0.65	55.41	0.01	1	
Solid-Phase Competing Electron Acceptor Demand (lb.)				0.01		
C. Soluble Contaminant Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.061	0.20	20.57	0.01	8	
Trichloroethene (TCE)	0.010	0.03	21.73	0.00	6	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.054	0.18	24.05	0.01	4	
Vinyl Chloride (VC)	0.001	0.00	31.00	0.00	2	
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8	
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6	
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4	
Chloromethane	0.000	0.00	25.04	0.00	2	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4	
Chloroethane	0.000	0.00	32.00	0.00	2	
Perchlorate	0.000	0.00	12.33	0.00	6	
Total Soluble Contaminant Electron Acceptor Demand (lb.)				0.02		
D. Sorbed Contaminant Electron Acceptors						
(Soil Concentration = Koc x foc x Cgw)						
	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.04	0.97	20.57	0.05	8
Trichloroethene (TCE)	107	0.00	0.06	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.01	0.15	24.05	0.01	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)				0.06		

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents						
4. Treatment Cell Electron-Acceptor Flux (per year)						
A. Soluble Native Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen		0.6	3.39	7.94	0.43	4
Nitrate (denitrification)		0.6	3.53	10.25	0.34	5
Sulfate		2.43	14.56	11.91	1.22	8
Carbon Dioxide (estimated as the amount of Methane produced)		5	29.96	1.99	15.05	8
Total Competing Electron Acceptor Demand Flux (lb/yr)					17.0	
B. Soluble Contaminant Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)		0.061	0.37	20.57	0.02	8
Trichloroethene (TCE)		0.010	0.06	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)		0.054	0.32	24.05	0.01	4
Vinyl Chloride (VC)		0.001	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)		0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)		0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)		0.000	0.00	21.06	0.00	4
Chloromethane		0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)		0.000	0.00	24.55	0.00	4
Chloroethane		0.000	0.00	32.00	0.00	2
Perchlorate		0.000	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)					0.03	
Initial Hydrogen Requirement First Year (lb)					26.5	
Total Life-Cycle Hydrogen Requirement (lb)					26.5	
5. Design Factors						
Microbial Efficiency Uncertainty Factor				2X - 4X		
Methane and Solid-Phase Electron Acceptor Uncertainty				2X - 4X		
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)				1X - 3X		
				Design Factor	10.0	
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)					264.6	
6. Acronyms and Abbreviations						
°C = degrees celsius		meq/100 g = milliequivalents per 100 grams				
µs/cm = microsiemens per centimeter		mg/kg = milligrams per kilogram				
cm/day = centimeters per day		mg/L = milligrams per liter				
cm/sec = centimeters per second		m/m = meters per meters				
ft ² = square feet		mV = millivolts				
ft/day = feet per day		m/yr = meters per year				
ft/ft = foot per foot		su = standard pH units				
ft/yr = feet per year		wt/wt H ₂ = concentration molecular hydrogen, weight per weight				
gm/cm ³ = grams per cubic centimeter						
kg of CaCO ₃ per mg = kilograms of calcium carbonate per milligram						
lb = pounds						

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

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Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H ₂ /Mole Substrate
Lactic Acid	C ₃ H ₆ O ₃	90.1	2	0.0448	2 to 3
Molasses (assuming 100% sucrose)	C ₁₂ H ₂₂ O ₁₁	342	8	0.0471	8 to 11
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	C ₆ H ₁₂ O ₆	180	4	0.0448	4 to 6
Ethanol	C ₂ H ₆ O	46.1	2	0.0875	2 to 6
Whey (assuming 100% lactose)	C ₁₂ H ₂₂ O ₁₁	342	11	0.0648	11
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	C ₃₉ H ₅₆ O ₃₉	956	28	0.0590	28
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	C ₁₈ H ₃₂ O ₂	281	16	0.1150	16

Table S.4
Estimated Substrate Requirements for
Hydrogen Demand in Table S.3

Design Life (years): 1

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	10.0	5,913	5,913	2.68E+09	638
Sodium Lactate Product (60 percent solution)	10.0	5,913	12,267	2.68E+09	638
Molasses (assuming 60)	10.0	5,617	9,361	2.55E+09	606
HFCS (assuming 40% fructose and 40% glucose by weight)	10.0	5,914	7,392	2.68E+09	638
Ethanol Product (assuming 80% ethanol by weight)	10.0	3,024	3,780	1.37E+09	326
Whey (assuming 100% lactose)	10.0	4,081	5,831	1.85E+09	440
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	10.0	4,482	4,482	2.03E+09	387
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	10.0	2,301	2,301	1.04E+09	248
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	10.0	2,301	3,836	1.04E+09	248

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH₃-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid (C₃H₆O₃) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H₂O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC[®] weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents**Site Name:****Building 66 Plume Area TA-66A**[RETURN TO COVER PAGE](#)**1. Treatment Zone Physical Dimensions**

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	140	feet	43	meters
Length (parallel to groundwater flow)	150	feet	45.7	meters
Saturated Thickness	10	feet	3.0	meters
Design Period of Performance	1	years	1	years

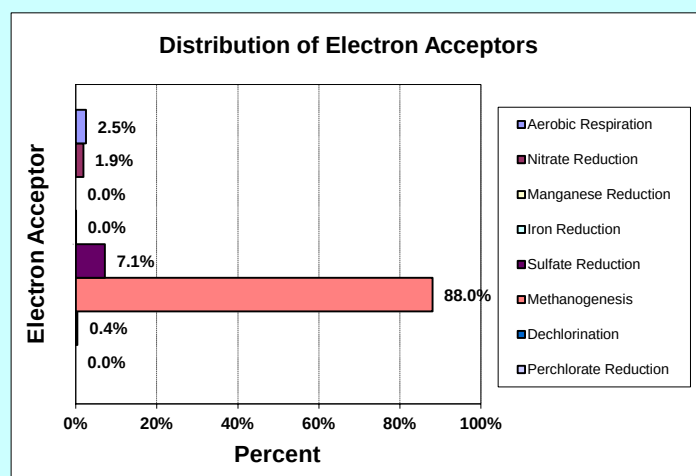
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	125.2	ft/day	4.4E-02	cm/sec
Average Hydraulic Gradient	0.0015	ft/ft	0.0015	m/m
Average Groundwater Seepage Velocity	0.75	ft/day	2.3E+01	cm/day
Average Groundwater Seepage Velocity	274	ft/yr	83.6	m/yr
Effective Treatment Zone Pore Volume	392,805	gallons	1,486,887	liters
Groundwater Flux (per year)	718,016	gallons/year	2,717,911	liters/year
Total Groundwater Volume Treated (over entire design period)	1,110,821	gallons total	4,204,798	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	2.5%	0.661
Nitrate Reduction	1.9%	0.502
Sulfate Reduction	7.1%	1.891
Manganese Reduction	0.0%	0.000
Iron Reduction	0.0%	0.012
Methanogenesis	88.0%	23.290
Dechlorination	0.4%	0.109
Perchlorate Reduction	0.0%	0.000
Totals:	100.00%	26.46

Hydrogen demand in pounds/gallon:	2.38E-05
Hydrogen demand in grams per liter:	2.85E-03

**4. Substrate Equivalents: Design Factor =****10.0**

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	12,267	1,115	638	as lactic acid
2. Molasses Product	9,361	780	606	as sucrose
3. Fructose Product	7,392	660	638	as fructose
4. Ethanol Product	3,780	548	326	as ethanol
5. Sweet Dry Whey (lactose)	5,831	sold by pound	440	as lactose
6. HRC®	4,482	sold by pound	387	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	2,301	295	248	as soybean oil
8. Emulsified Vegetable Oil	3,836	492	248	as soybean oil

Notes:

- Quantity assumes product is 60% sodium lactate by weight.
- Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
- Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
- Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
- Quantity assumes product is 70% lactose by weight.
- Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
- Quantity of neat soybean oil, corn oil, or canola oil.
- Quantity assumes commercial product is 60% soybean oil by weight.

B.5 Treatment Area TA-66B

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: Building 66 Plume Area TA-66B

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NOTE: Unshaded boxes are user input.				
	Values	Range	Units	User Notes
1. Treatment Zone Physical Dimensions				
Width (Perpendicular to predominant groundwater flow direction)	50	1-10,000	feet	
Length (Parallel to predominant groundwater flow)	100	1-1,000	feet	
Saturated Thickness	10	1-100	feet	13.8 to 23.8
Treatment Zone Cross Sectional Area	500	--	ft ²	
Treatment Zone Volume	50,000	--	ft ³	
Treatment Zone Total Pore Volume (total volume x total porosity)	130,935	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	93,525	--	gallons	
Design Period of Performance	0.8	.5 to 5	year	0.75 years
Design Factor (times the electron acceptor hydrogen demand)	10.0	2 to 20	unitless	microbial 4X, electron acceptor, 2X substrate loss 2X
2. Treatment Zone Hydrogeologic Properties				
Total Porosity	35%	.05-50	percent	Eastover Data
Effective Porosity	25%	.05-50	percent	Eastover Data
Average Aquifer Hydraulic Conductivity	125.2	.01-1000	ft/day	AECOM PT Bldg 66 Area
Average Hydraulic Gradient	1.50E-03	0.0001-0.1	ft/ft	Area hydraulic gradient (2024)
Average Groundwater Seepage Velocity through the Treatment Zone	0.75	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	274.2	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	256,434	--	gallons/year	
Soil Bulk Density	1.65	1.4-2.0	gm/cm ³	Eastover Data
Soil Fraction Organic Carbon (foc)	0.28%	0.01-10	percent	Eastover Data
3. Native Electron Acceptors				
A. Aqueous-Phase Native Electron Acceptors				
Oxygen	0.1	0.01 to 10	mg/L	MWANP-26
Nitrate	3.10	0.1 to- 20	mg/L	MWANP-26
Sulfate	1	10 to 5,000	mg/L	MWANP-26 - Not detected
Carbon Dioxide (estimated as the amount of Methane produced)	5.0	0.1 to 20	mg/L	Estimate based on previous EISB injections and area
B. Solid-Phase Native Electron Acceptors				
Manganese (IV) (estimated as the amount of Mn (II) produced)	0	0.1 to 20	mg/L	MWANP-26
Iron (III) (estimated as the amount of Fe (II) produced)	6	0.1 to 20	mg/L	MWANP-26
4. Contaminant Electron Acceptors				
Tetrachloroethene (PCE)	0.010	--	mg/L	MWANP-26
Trichloroethene (TCE)	0.049	--	mg/L	MWANP-26
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.075	--	mg/L	MWANP-26
Vinyl Chloride (VC)	0.002	--	mg/L	MWANP-26
Carbon Tetrachloride (CT)	0.000	--	mg/L	Not detected
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	Not detected
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	Not detected
Chloromethane	0.000	--	mg/L	Not detected
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	Not detected
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	Not detected
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	Not detected
Chloroethane	0.000	--	mg/L	Not detected
Perchlorate	0.000	--	mg/L	No data
5. Aquifer Geochemistry (Optional Screening Parameters)				
A. Aqueous Geochemistry				
Oxidation-Reduction Potential (ORP)	361	-400 to +500	mV	MWANP-26
Temperature	20	5.0 to 30	°C	MWANP-26
pH	5.1	4.0 to 10.0	su	MWANP-26
Alkalinity	22	10 to 1,000	mg/L	MWANP-26
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	Estimated
Specific Conductivity	85	100 to 10,000	µs/cm	MWANP-26
Chloride	7	10 to 10,000	mg/L	MWANP-26
Sulfide - Pre injection	0.1	0.1 to 100	mg/L	Estimated
Sulfide - Post injection	2.0	0.1 to 100	mg/L	Estimated
B. Aquifer Matrix				
Total Iron	11145	200 to 20,000	mg/kg	CSM 2006 Mean of Subsurface Soil
Cation Exchange Capacity	1	1.0 to 10	meq/100 g	Estimated based on soil data
Neutralization Potential	1.0%	1.0 to 100	Percent as CaCO ₃	Estimated based on soil data

NOTES:

Gravity Feed Design includes MWANP-26

Table S.2 Substrate Calculations in Hydrogen Equivalents						
Site Name:		Building 66 Plume Area TA-66B		RETURN TO COVER PAGE		
NOTE: Open cells are user input.						
1. Treatment Zone Physical Dimensions		Values	Range	Units		
Width (Perpendicular to predominant groundwater flow direction)		50	1-10,000	feet		
Length (Parallel to predominant groundwater flow)		100	1-1,000	feet		
Saturated Thickness		10	1-100	feet		
Treatment Zone Cross Sectional Area		500	--	ft ²		
Treatment Zone Volume		50,000	--	ft ³		
Treatment Zone Effective Pore Volume (total volume x effective porosity)		93,525	--	gallons		
Design Period of Performance		0.8	.5 to 5	year		
2. Treatment Zone Hydrogeologic Properties						
Total Porosity		0.35	.05-50			
Effective Porosity		0.25	.05-50			
Average Aquifer Hydraulic Conductivity		125.2	.01-1000	ft/day		
Average Hydraulic Gradient		0.0015	0.1-0.0001	ft/ft		
Average Groundwater Seepage Velocity through the Treatment Zone		0.75	--	ft/day		
Average Groundwater Seepage Velocity through the Treatment Zone		274.2	--	ft/yr		
Average Groundwater Flux through the Treatment Zone		256,434	--	gallons/year		
Soil Bulk Density		1.65	1.4-2.0	gm/cm ³		
Soil Fraction Organic Carbon (foc)		0.0028	0.0001-0.1			
3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)						
A. Aqueous-Phase Native Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Oxygen	0.1	0.07	7.94	0.01	4	
Nitrate (denitrification)	3.1	2.42	12.30	0.20	5	
Sulfate	0.5	0.39	11.91	0.03	8	
Carbon Dioxide (estimated as the amount of methane produced)	5.0	3.90	1.99	1.96	8	
Soluble Competing Electron Acceptor Demand (lb.)				2.20		
B. Solid-Phase Native Electron Acceptors						
(Based on manganese and iron produced)						
Manganese (IV) (estimated as the amount of Mn (II) produced)	0.2	0.36	27.25	0.01	2	
Iron (III) (estimated as the amount of Fe (II) produced)	5.9	14.12	55.41	0.25	1	
Solid-Phase Competing Electron Acceptor Demand (lb.)				0.27		
C. Soluble Contaminant Electron Acceptors						
	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole	
Tetrachloroethene (PCE)	0.010	0.01	20.57	0.00	8	
Trichloroethene (TCE)	0.049	0.04	21.73	0.00	6	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.075	0.06	24.05	0.00	4	
Vinyl Chloride (VC)	0.002	0.00	31.00	0.00	2	
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8	
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6	
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4	
Chloromethane	0.000	0.00	25.04	0.00	2	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4	
Chloroethane	0.000	0.00	32.00	0.00	2	
Perchlorate	0.000	0.00	12.33	0.00	6	
Total Soluble Contaminant Electron Acceptor Demand (lb.)				0.00		
D. Sorbed Contaminant Electron Acceptors						
(Soil Concentration = Koc x foc x Cgw)						
	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.01	0.04	20.57	0.00	8
Trichloroethene (TCE)	107	0.01	0.08	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.01	0.05	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)				0.01		

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents						
4. Treatment Cell Electron-Acceptor Flux (per year)						
A. Soluble Native Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen		0.1	0.19	7.94	0.02	4
Nitrate (denitrification)		3.1	6.63	10.25	0.65	5
Sulfate		0.5	1.07	11.91	0.09	8
Carbon Dioxide (estimated as the amount of Methane produced)		5	10.70	1.99	5.38	8
Total Competing Electron Acceptor Demand Flux (lb/yr)					6.1	
B. Soluble Contaminant Electron Acceptors		Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt H ₂)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)		0.010	0.02	20.57	0.00	8
Trichloroethene (TCE)		0.049	0.10	21.73	0.00	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)		0.075	0.16	24.05	0.01	4
Vinyl Chloride (VC)		0.002	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)		0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)		0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)		0.000	0.00	21.06	0.00	4
Chloromethane		0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)		0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)		0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)		0.000	0.00	24.55	0.00	4
Chloroethane		0.000	0.00	32.00	0.00	2
Perchlorate		0.000	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)					0.01	
Initial Hydrogen Requirement First Year (lb)					8.6	
Total Life-Cycle Hydrogen Requirement (lb)					7.1	
5. Design Factors						
Microbial Efficiency Uncertainty Factor				2X - 4X		
Methane and Solid-Phase Electron Acceptor Uncertainty				2X - 4X		
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)				1X - 3X		
				Design Factor	10.0	
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)					70.9	
6. Acronyms and Abbreviations						
°C = degrees celsius		meq/100 g = milliequivalents per 100 grams				
µs/cm = microsiemens per centimeter		mg/kg = milligrams per kilogram				
cm/day = centimeters per day		mg/L = milligrams per liter				
cm/sec = centimeters per second		m/m = meters per meters				
ft ² = square feet		mV = millivolts				
ft/day = feet per day		m/yr = meters per year				
ft/ft = foot per foot		su = standard pH units				
ft/yr = feet per year		wt/wt H ₂ = concentration molecular hydrogen, weight per weight				
gm/cm ³ = grams per cubic centimeter						
kg of CaCO ₃ per mg = kilograms of calcium carbonate per milligram						
lb = pounds						

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

[RETURN TO COVER PAGE](#)

Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H ₂ /Mole Substrate
Lactic Acid	C ₃ H ₆ O ₃	90.1	2	0.0448	2 to 3
Molasses (assuming 100% sucrose)	C ₁₂ H ₂₂ O ₁₁	342	8	0.0471	8 to 11
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	C ₆ H ₁₂ O ₆	180	4	0.0448	4 to 6
Ethanol	C ₂ H ₆ O	46.1	2	0.0875	2 to 6
Whey (assuming 100% lactose)	C ₁₂ H ₂₂ O ₁₁	342	11	0.0648	11
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	C ₃₉ H ₅₆ O ₃₉	956	28	0.0590	28
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	C ₁₈ H ₃₂ O ₂	281	16	0.1150	16

Table S.4
Estimated Substrate Requirements for
Hydrogen Demand in Table S.3

Design Life (years): 0.75

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	10.0	1,584	1,584	7.19E+08	664
Sodium Lactate Product (60 percent solution)	10.0	1,584	3,287	7.19E+08	664
Molasses (assuming 60)	10.0	1,505	2,509	6.83E+08	631
HFCS (assuming 40% fructose and 40% glucose by weight)	10.0	1,585	1,981	7.19E+08	664
Ethanol Product (assuming 80% ethanol by weight)	10.0	810	1,013	3.68E+08	340
Whey (assuming 100% lactose)	10.0	1,094	1,562	4.96E+08	458
HRC [®] (assumes 40% lactic acid and 40% glycerol by weight)	10.0	1,201	1,201	5.45E+08	403
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	10.0	617	617	2.80E+08	259
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	10.0	617	1,028	2.80E+08	259

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH₃-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid (C₃H₆O₃) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H₂O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC[®] weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents**Site Name:****Building 66 Plume Area TA-66B**[RETURN TO COVER PAGE](#)**1. Treatment Zone Physical Dimensions**

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	50	feet	15	meters
Length (parallel to groundwater flow)	100	feet	30.5	meters
Saturated Thickness	10	feet	3.0	meters
Design Period of Performance	0.75	years	0.75	years

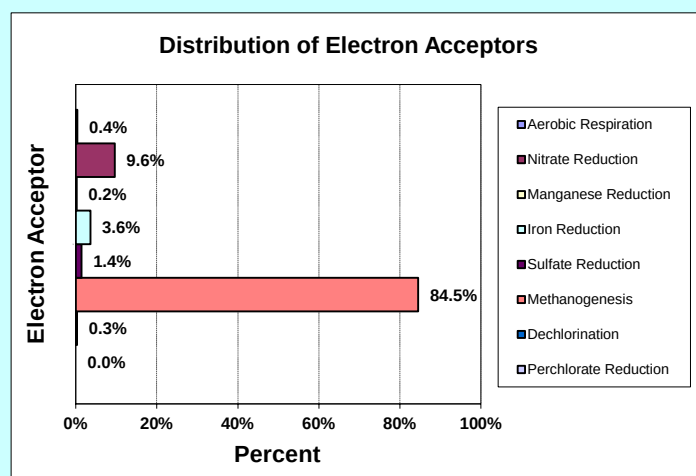
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.25	percent	0.25	percent
Average Aquifer Hydraulic Conductivity	125.2	ft/day	4.4E-02	cm/sec
Average Hydraulic Gradient	0.0015	ft/ft	0.0015	m/m
Average Groundwater Seepage Velocity	0.75	ft/day	2.3E+01	cm/day
Average Groundwater Seepage Velocity	274	ft/yr	83.6	m/yr
Effective Treatment Zone Pore Volume	93,525	gallons	354,021	liters
Groundwater Flux (per year)	256,434	gallons/year	970,682	liters/year
Total Groundwater Volume Treated (over entire design period)	285,851	gallons total	1,082,033	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.4%	0.027
Nitrate Reduction	9.6%	0.682
Sulfate Reduction	1.4%	0.100
Manganese Reduction	0.2%	0.013
Iron Reduction	3.6%	0.255
Methanogenesis	84.5%	5.993
Dechlorination	0.3%	0.021
Perchlorate Reduction	0.0%	0.000
Totals:	100.00%	7.09

Hydrogen demand in pounds/gallon:	2.48E-05
Hydrogen demand in grams per liter:	2.97E-03

**4. Substrate Equivalents: Design Factor =****10.0**

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	3,287	299	664	as lactic acid
2. Molasses Product	2,509	209	631	as sucrose
3. Fructose Product	1,981	177	664	as fructose
4. Ethanol Product	1,013	147	340	as ethanol
5. Sweet Dry Whey (lactose)	1,562	sold by pound	458	as lactose
6. HRC®	1,201	sold by pound	403	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	617	79	259	as soybean oil
8. Emulsified Vegetable Oil	1,028	132	259	as soybean oil

Notes:

- Quantity assumes product is 60% sodium lactate by weight.
- Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
- Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
- Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
- Quantity assumes product is 70% lactose by weight.
- Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
- Quantity of neat soybean oil, corn oil, or canola oil.
- Quantity assumes commercial product is 60% soybean oil by weight.

Appendix C Regulatory Correspondence



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Wheeling Field Office
1060 Chapline Street
Wheeling, West Virginia 26003

March 7, 2013

Ms. Susan Trussell
U.S. Army Corps of Engineers, Tulsa District
CESWT-EC-EE
1645 S. 101st E. Avenue
Tulsa, Oklahoma 74128-4609

Re: Defense Supply Center Richmond
Operable Unit 7
Richmond, Chesterfield County, VA

Dear Ms. Trussell:

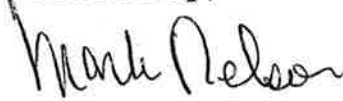
We have received correspondence from your consultant, AECOM Technical Services, dated February 28, 2013 describing ground water remediation efforts at the above referenced facility. We understand that you intend to utilize enhanced in-situ bioremediation processes, involving shallow injection wells, to reduce volatile organic compound (VOC) contamination. **The subsurface emplacement of fluids through injection wells as part of an aquifer cleanup project is subject to the ground water protection requirements of the Underground Injection Control (UIC) program.** The UIC program is administered by the Environmental Protection Agency (EPA) in the Commonwealth of Virginia.

Based upon our understanding of aquifer remediation of contaminated soil and ground water in general, and the proposed subsurface emplacement of nutrients to facilitate biodegradation specifically, we believe that the injection wells pose minimal potential to adversely impact ground water. For these reasons you may proceed with plans to construct and operate aquifer remediation related injection wells and you will not be required to obtain an Underground Injection Control (UIC) program permit.

The above referenced facility has been added to our inventory of shallow injection wells. The UIC program prohibits the subsurface emplacement of fluids which have the potential to adversely impact underground sources of drinking water.

EPA approval or "rule authorization" of the injection wells is contingent upon operator compliance with all applicable requirements. We appreciate your cooperation in these matters and the opportunity to address these issues with you. Please contact me at (304) 234-0286 if you have any questions.

Sincerely,

A handwritten signature in dark ink, appearing to read "Mark Nelson", written in a cursive style.

Mark A. Nelson, Hydrologist
Water Protection Division

/ Cc: Manish M. Joshi, AECOM



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
Four Penn Center
1600 John F. Kennedy Boulevard
Philadelphia, Pennsylvania 19103-2852

EPA Comments on *Draft Remedial Action Work Plan Addendum – Building 65 Injections Technical Memorandum*, dated December 1, 2022

January 17, 2023

Comment from USEPA Hydrogeologist, Ryan Bower

Overall, the planned injection approach appears sufficient and the performance monitoring adequate. My only suggestion would be to collect a Microbial Assay at a downgradient location from either the Quarterly or Semi-Annual Monitoring Well Network(s) depicted on **Figure 7**. While the VOC data will ultimately demonstrate the effectiveness of the injection, it would be beneficial to assess whether any downgradient DHC communities are present.