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Shakespeare Composite Structures Site, Newberry, SC

PDF Copies of Three Previous Shakespeare Reports

PDF copies of the following previous reports are included on a DVD in Attachment D of the hard copy of this FS Report:

- AECOM, 2023a. Site-Wide Groundwater Monitoring Report. AECOM, May 2023.
- AECOM, 2023b. Pilot Study Report. AECOM, May 2023.
- AECOM, 2024. Feasibility Study Technical Memorandum. AECOM, February 2024.

AECOM

Site Wide Groundwater Monitoring Report

Former Shakespeare Composite Structures Site

19845 US Highway 76

Newberry, SC

RP-VCC-14-6271-RP

Site ID # 51025

Prepared for:

Signify North America Corporation

May 2023

Quality information

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List of Acronyms

AECOM	AECOM Technical Services, Inc.
AFCEE	Air Force Center for Engineering and the Environment
BRA	Baseline Risk Assessment
bgs	below ground surface
BSTS	bench-scale treatability study
BTEX	benzene, toluene, ethylbenzene, and xylenes
cells/mL	cells per milliliter
cis-1,2-DCE	cis-1,2 – dichloroethane
COCs	chemical of concerns
CVOCs	chlorinated volatile organic compounds
DHB	*Dehalobacter spp.*
DHC	*Dehalococcoides*
DO	dissolved oxygen
DPT	direct push technology
ERD	enhanced reductive dichlorination
EVS	Earth Volumetric Studio
FS	feasibility study
ft	feet or foot
ft/ft	feet per foot
ft/day	feet per day
ft/yr	feet per year
IDW	investigation derived waste
ISB	in situ bioremediation
ISCR	in situ chemical reduction
ISCO	in situ chemical oxidation
K	hydraulic conductivity
$KMnO_4$	potassium permanganate
LDPE	low-density polyethylene
µg/L	micrograms per liter
MCL	maximum contaminant level
mg/L	milligrams per liter
ml	milliliter
msl	mean sea level
mV	millivolts
ORP	oxidation reduction potential
Pace	Pace Analytical Services, Inc.
PCE	tetrachloroethene
PDB	passive diffusion bag
PENAC	Philips Electronics North America Corporation

List of Acronyms (cont'd.)

PS	Pilot Study
QAPP	Quality Assurance Project Plan
redox	oxygen reduction
RI	Remedial Investigation
ROI	radius of influence
RPD	relative percent difference
RP-VCC	responsible party-voluntary cleanup contract
SC	specific conductance
SCDHEC	South Carolina Department of Health and Environmental Control
Signify	Signify North America, Inc.
S.U.	standard units (for pH)
TCE	trichloroethene
TCL	target compound list
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
VC	vinyl chloride

Professional Geologist Certification

"I certify that I am a qualified groundwater scientist who has received a baccalaureate degree in geology and have sufficient training and experience in groundwater hydrology and related fields, as demonstrated by South Carolina registration and completion of accredited university courses that enable me to make sound professional judgments regarding groundwater monitoring and contaminant fate and transport. I further certify that I have technically reviewed this report."

By:

Scott E. Ross, PG
Project Manager
South Carolina P.G. No.: 2201

Date: May 31, 2023

1. Introduction

The Valmont Composite Structures Site (the "Site"), located in Newberry, South Carolina is participating in a voluntary cleanup program with the South Carolina Department of Health and Environmental Control (SCDHEC). The Site is currently listed as responsible party – voluntary cleanup contract (RP-VCC) number RP-VCC-14-6271-RP. As part of the RP-VCC process, the Site has undergone a Remedial Investigation (RI) and Baseline Risk Assessment (BRA), which were completed in November 2018. The RI efforts delineated a plume of dissolved phase chlorinated volatile organic compounds (CVOCs) in Site groundwater. Based on the results of the RI, it is anticipated that an active groundwater treatment remedy will be required for at least a portion of Site groundwater. The RP for the Site [Signify North America, Inc. – (Signify)] has been conducting several activities that will be incorporated into a Feasibility Study (FS) for potential remedial alternatives to treat CVOC-impacted groundwater.

1.1 Site Description

The Site is located at 19845 US Highway 76, approximately 1 mile northwest of Newberry, South Carolina **(Figure 1-1)**. The Site is centered on the Valmont Composite Structures facility (the “facility”, formerly known as Shakespeare Composite Structures), and includes several surrounding properties (**Figure 1-2**). The facility was originally opened to produce fiberglass products, and it has continued to be used for this manufacturing process. Operations at the facility include the design and manufacture of large fiberglass utility poles and cross arms and a variety of other fiberglass outdoor products such as posts, signs, sheet piling, and signposts. Manufacturing is conducted inside two separate buildings – the Main Building and the Pole Winder Building.

General land use surrounding the facility consists of agricultural, residential, undeveloped, and commercial/light industrial properties (**AECOM Technical Services, Inc. [AECOM], 2018**). The topography of the Site is generally flat or slightly sloping on the Facility property. Land surface elevations generally decrease to the southwest, west, and north moving away from the Facility property. Surface elevations range from approximately 562 feet (ft) mean sea level (msl) on the east side of the Facility to less than 520 ft msl along an unnamed intermittent stream located to the north of the Facility.

More detailed descriptions of the facility’s description, historical operation, and site topographic setting information are included in the RI Report (**AECOM, 2018**).

1.2 Surrounding Properties

In addition to the Shakespeare property, the Site includes several surrounding properties (**Figure 1-2**). General land use surrounding the facility consists of agricultural, residential, undeveloped and commercial/light industrial properties. Uses of adjacent properties are as follows:

North: The Shakespeare property is bordered immediately to the north by a CSX rail line and undeveloped land planted with pine trees. The property bounding the facility to the north of the CSX rail line is owned by Mr. J.L. Dickert.

East: The Shakespeare property is bordered immediately to the east by a residential parcel (owned by Mr. Jesse Stephens), beyond which is vacant land (pine trees) and vacant buildings formerly occupied by the Dickert Lumber Company. The property immediately east of the private residence up to Lumber Road is also owned by J.L. Dickert.

South: The Shakespeare property is bordered to the south by U.S. Highway 76 and properties owned by the Newberry County Airport, Mr. Walter Shealy, and Ms. Yvonne Fisher. The property owned by Mr. Shealy is primarily farmland with a few small residences (rental homes) located sporadically across more than 60 acres.

West: There are three properties located immediately to the west of the Shakespeare property. The property that immediately bounds the facility to the west is owned by Ms. Harriet Boazman. The properties to the west of the Boazman property are owned by Ms. Edna Ringer and Ms. Kimberly Chapman.

Northwest: Property located to the north-northwest of the Ringer property and west of the Dickert property is owned by Ms. Merri Folk.

Some of these off-site properties have private water located on those parcels.

1.3 Previous and Ongoing Investigations

Several phases of investigative efforts have been performed at the Site. This includes multiple investigative efforts prior to execution of the VCC. The pre-VCC investigative efforts that were conducted include:

- Phase II Environmental Site Assessment – Collection of initial soil and groundwater samples from the Shakespeare facility (February through April 2014);
- Site Investigation – Collection of additional soil and groundwater samples from the Shakespeare facility along with several groundwater samples from surrounding private parcels (May 2014 through August 2014); and
- Expanded Investigation - Collection of additional shallow groundwater samples and evaluation of shallow bedrock for impacted groundwater on surrounding properties (August through September 2014).

An RP-VCC between the SCDHEC and Philips Electronics North America Corporation (PENAC) was executed in September 2014. Once this VCC was executed, additional investigative efforts were performed as part of the RI process. PENAC is the former name of Signify.

The RI was implemented in two phases, beginning in 2014 after execution of the VCC. The RI was conducted to further evaluate the vertical and/or horizontal extent of previously identified CVOCs in soil and groundwater; assess additional potential areas of interest for secondary sources of VOCs that could be contributing to soil and/or groundwater impacts; evaluate potential vapor intrusion pathways; determine risk to potential human and ecological receptors; and provide additional data needed to develop a remedial strategy for the Site.

RI efforts determined that the source areas for CVOCs present in groundwater originated from historical operational practices that impacted groundwater beneath the western portions of the Main and Pole Winder Buildings located on the Facility property. CVOCs subsequently migrated both horizontally and vertically within groundwater away from the identified source areas and impacted multiple aquifer depth intervals (shallow, intermediate, and bedrock) beyond the Facility property.

In general, the water table at the Site is encountered in the fine sands and silts and clays of the residuum. Groundwater is encountered at depths ranging from approximately two ft below ground surface (bgs) near the northern end of the Site and on the Dickert property to as deep as approximately 18 ft bgs on the former Shakespeare Composite Structures facility. Groundwater beneath the Site is mainly encountered under unconfined conditions.

As a result, the direction of groundwater flow beneath the Site, particularly in the shallow (water table) zone follows topography, with flow components to the west and northwest. CVOCs have migrated within the water table and saprolite zones primarily through natural dispersion. Vertical migration downgradient of the source areas within the saprolite and into underlying granitic bedrock was influenced primarily by numerous privately-operated water supply wells located to the west and southwest of the Facility.

The RI defined the extent of CVOC-impacted groundwater at multiple aquifer depth intervals. Analytical results were screened against United States Environmental Protection Agency (USEPA) maximum contaminant levels (MCLs) to identify compounds of interest in groundwater beneath the Site. Concentrations of tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2 dichloroethene (cis-1,2-DCE), and vinyl chloride (VC) exceeded their respective MCLs in several groundwater samples collected from the Site. Of these, TCE was the most frequently detected chemical in groundwater samples collected at the Site. The elevated concentrations of CVOCs are most widespread in shallow zone groundwater (upper portion of the water table aquifer). TCE and cis-1,2-DCE also exceeded their respective MCLs in one or more samples collected in the intermediate (saprolite) zone.

A more detailed discussion of the results of the investigative efforts conducted at the Site to date is included in the RI Report (**AECOM, 2018**).

Following approval of the RI Report, SCDHEC requested that Signify develop an FS Work Plan for the Site. The purpose of the FS Work Plan was to outline the proposed information that would be included in the Site FS. The cover letter for the FS Work Plan also proposed that a BSTS and subsequent pilot study should be completed prior to development of the FS. The FS Work Plan was submitted to SCDHEC on May 15, 2019 (**AECOM, 2019**). SCDHEC approved the FS Work Plan in correspondenc dated June 4, 2019.

Previously completed groundwater treatability activities include a BSTS that was conducted between September 2019 and January 2020 (**AECOM, 2020a**). A field-scale, groundwater treatability pilot study was initiated in August 2021, and the final performance monitoring event was completed in December 2022. A site wide groundwater monitoring event, which is the subject of this report, was conducted in February 2022.

1.4 Purpose of This Report

The purpose of this report is to present the field and laboratory analytical data for the site wide groundwater monitoring event conducted in February 2022. It was stated in Section 2.3.5 of the Pilot Study Work Plan (**AECOM, 2020b**) that the baseline groundwater sampling event would be performed for both the site wide and for the pilot study wells. The report does include limited comparisons between the 2022 data and groundwater data collected during previous investigative efforts. This report also includes a comparison of the conventional groundwater sampling techniques along with passive diffusion bag (PDB) sampling performed at selective wells during the 2022 site wide monitoring event. Also, groundwater remediation pilot test data generated to date in 2021 and 2022 are briefly discussed in this document. Plume volumetrics, calculated using data from the 2022 monitoring event, are summarized, and conclusions regarding this information also are provided in this report.

1.5 Organization of This Report

This report is organized into four additional sections.

- Section 2 briefly summarizes the sampling and analysis procedures performed at the Site.
- Section 3 contains a discussion of the site wide groundwater monitoring results of February and March 2022, including a comparison of conventional sampling techniques with PDB sampling.
- Section 4 presents a discussion of the groundwater plume volumetrics.

- Section 5 contains a summary and conclusions that may be drawn from the 2022 sitewide monitoring event.

2. Sampling and Analysis Procedures

The site wide groundwater monitoring event was conducted in February and March 2022. Groundwater samples were collected from February 21 to March 8, 2022. The monitoring event included sampling of 65 monitoring wells located at the Site. This includes 39 shallow wells, 12 intermediate wells, and 14 bedrock wells. The sampling plan for the 2022 event is summarized in **Table 2-1.**

Figures 2-1, 2-2, and 2-3 show the locations of all the monitoring wells located at the Site. Each of the shallow wells are screened within the severely weathered residuum (at or just below the water table). The intermediate wells are screened within saprolite zone, above the bedrock zone interface. The majority of the bedrock wells are constructed as “open hole” borings, allowing monitoring of isolated fracture zones within the granitic bedrock underlying the site. **Table 2-2** lists the monitoring wells at the site, describes the portions of the site at which the wells are located, and denotes the well screened intervals.

Sampling and analysis procedures are discussed below. All groundwater samples collected during the site wide monitoring event were analysed for Target Compound List-Volatile Organic Compounds (TCL-VOCs) using SW-846 Method 8260D. As part of the site wide monitoring event, a subset of wells was also sampled for a several biogeochemical parameters. Results from these analyses, as well as those from the Pilot Study (PS) performed at the site, will be evaluated to determine if conditions within the groundwater beneath the site are suitable for in-situ treatment efforts. Section 2.2 below lists the analytical parameters for the 2022 site wide monitoring event. **Table 2-1** also summarizes the analyses performed on samples collected from each well during the 2022 site wide monitoring event.

In addition to the site wide event sampling of selected monitoring wells related to the groundwater PS was conducted between August 2021 and December 2022. Eight wells were included in the PS monitoring and the analysis program. The PS performance monitoring has included a baseline sampling event and four post injection monitoring events to date. In accordance with the approved Pilot Study Work Plan (**AECOM, 2020b**), VOC samples were collected from the in situ chemical oxidation (ISCO) study area wells and from the in situ enhanced reductive dichlorination (ISERD) study area wells. Samples from wells located within the ISCO PS area also were analyzed for chloride and total dissolved solids (TDS). Groundwater samples collected from the ISERD study area were analyzed for electron acceptors, electron donors, total organic carbon (TOC), alkalinity, dissolved gases, and biological parameters. Results of the pilot study sampling program are briefly discussed in this report. A more detailed discussion of the groundwater treatability study and pilot test results is included in the pilot study report (**AECOM, 2023**).

2.1 Sampling Procedures

Groundwater sampling was conducted in accordance with procedures described in the Phase II RI Work Plan for this Site (**AECOM, 2017**). Prior to well purging, depth to water readings were recorded for all wells. Each monitoring well was sampled using the low-flow sampling method. The purging efforts included use of a peristaltic or submersible pump to evacuate groundwater from a well along with periodic monitoring of groundwater quality parameters during the purging process. The groundwater quality parameters measured during well purging included pH, specific conductance (SC), temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), and turbidity. Information obtained during well purging efforts was documented on Site-specific groundwater sampling forms. Once purging efforts were completed, sample containers provided by the contract laboratory were filled using the peristaltic or submersible pump. Copies of these forms and the depth to water readings for the 2022 monitoring event are included in **Appendix A**.

In addition to sampling via the low-flow sampling method,15 monitoring wells were also sampled for VOCs using PDBs. Nine shallow zone, four intermediate zone, and two deep zone wells were selected for PDB deployment and sampling. The wells designated for PDB sampling included upgradient, side gradient of treatment zones, and downgradient locations (**Table 2-2**).

PDB deployment included installation of a 500 milliliter (mL) semi-permeable low-density polyethylene (LDPE) bag filled with organic free water surrounded by a protective LDPE mesh sleeve. The PDBs were deployed in a well, being situated within 1-2 ft of the bottom of each well and allowed to remain in place (stabilize) for at least two weeks.

At the end of the stabilization period, all PDBs were removed from the wells. Approximately 150 mL of water from the PDB was used to measure the water quality parameters listed above. The remaining volume was poured into appropriate sample containers used for VOC analysis provided by the contract laboratory. Each of the wells used for PDB deployment were then purged and sampled using low flow sampling procedures as discussed above. The VOC analytical results from the PDBs and the low-flow sampling methods are compared and discussed later in this report.

2.2 Sample Analyses

Groundwater samples collected for this site wide monitoring event includes sampling from 39 shallow wells, 12 intermediate wells, and 14 bedrock wells during the February and March 2022 event, and they were analyzed for TCL VOCs.

In addition to the analysis for VOCs, samples from the following 15 wells were also analyzed for a list of specific biogeochemical parameters:

- Shallow: MW-5, -6, -7, -8, -9, -22 and TMW-21, -22, and -24
- Intermediate: MW-5I, 6I, 7I, 9I, and 20I
- Bedrock: MW-6D

Samples from each of these wells were analyzed for VOCs as well as the following parameters:

- Total Organic Carbon;
- Alkalinity;
- Nitrate and Nitrite;
- Electron acceptors – ferric iron (calculation), total manganese, and sulfate, plus total iron;
- Degradation indicators – ferrous iron, dissolved manganese, sulfide, and chloride;
- Degradation end compounds – carbon dioxide, methane, ethane, and ethene;
- Biological indicators (via QuantArray-Chlor testing method) – expanded list of bacteria and functional genes to determine if groundwater conditions can support either or both aerobic and anaerobic degradation of chlorinated solvents including TCE.

As indicated above, some of the monitoring wells sampled for these parameters were also part of the ISERD or the ISCO pilot study. **Table 2-1** lists the monitoring wells sampled during this sitewide event and the analytical parameters for which each sample was analyzed. **Table 2-2** notes the wells included in the PS performance monitoring effort.

Each of the groundwater quality parameters as measured during well purging, VOC concentrations, and other indicator parameters are evaluated to determine if site conditions continue to be conducive for anaerobic biodegradation.

Pace Analytical Services, Inc. (Pace) performed analysis for all parameters except for the biological parameters. Microbial Insights, Inc performed the analysis for the biological parameters.

Analytical results were reviewed by AECOM personnel upon delivery. VOC data were evaluated and validated in accordance with guidance referenced in the RI Work Plan (**AECOM, 2017**). Validation reports for groundwater samples are included in **Appendix B**. Copies of analytical reports for VOCs and other parameters are shown in **Appendix C**. The laboratory analytical report for biogeochemical parameters is contained in **Appendix D**.

2.3 Investigation-Derived Waste

Purged water investigation-derived waste (IDW) from sampling of groundwater wells during the site wide monitoring event was contained in 55-gallon steel drums and staged at the on-Site designated staging area. The laboratory analytical reports containing those data is included in **Appendix C**. Those data, along with groundwater sampling data from October 2021 through December 2022 from the pilot study area, were used to indicate that the remedial action derived waste was not a hazardous waste. Therefore, there was no maximum holding time for the waste containers.

In January 2023, AECOM subcontracted Green Rock Strategies to mobilize to the Site, load and transport drums of remedial action derived waste, and dispose of the non-hazardous wastes through A&D Environmental Services. **Appendix E** contains a copy of the bill of lading / material manifest for eight drums of liquid, three drums of solids, and two empty used drums of IDW, from the installation and development of temporary pilot study monitoring wells, the sitewide sampling event, and the pilot study performance monitoring events. The wastes were picked up on January 10 and January 24, 2023 and transported to the A&D Environmental Services facility in Archdale, North Carolina for treatment and subsequent disposal.

3. Discussion of Site Wide Monitoring Results

Information collected during the 2022 site wide monitoring event, including hydrogeologic data, groundwater geochemical data, and biogeochemical data, are discussed in this section of the report. The following subsections describe the hydrogeology within the study areas, groundwater monitoring results, design, and implementation procedures.

This section also includes comparisons of the 2022 sitewide results with the data collected during the RI. The comparisons were performed to help evaluate whether the changes have occurred as a result of natural attenuation processes or as a result of the pilot study injections to date. Copies of sample analytical reports are included in **Appendix C and Appendix D.**

3.1 Site Hydrogeology

This section briefly discusses the site-specific hydrogeology summarized following the RI efforts, updated with 2022 groundwater elevation data.

3.1.1 Hydraulic Conductivity

During Phase II of the RI, hydraulic conductivity tests (slug tests) were performed on select shallow and intermediate monitoring wells. Data collected from the slug tests were used to calculate hydraulic conductivity (K), which is a two-dimensional measure of the ability of a square unit of the aquifer to allow the flow of water. The hydraulic conductivity is also used with the groundwater gradient to determine the rate of groundwater flow. The procedures for conducting slug tests are discussed in Section 3.3.7 of the RI Report (**AECOM, 2018**).

Slug tests were performed on seven paired shallow and intermediate wells:

- MW-2 and MW-2I
- MW-3 and MW-3I
- MW-5 and MW-5I
- MW-6 and MW-6I
- MW10 and MW10I
- MW-20 and MW-20I
- MW-21 and MW-21I

Data generated during the slug tests were evaluated using Aqtesolv, a commonly used, commercially available, computer software package. Aqtesolv allows a choice of published methods to evaluate slug test data. Two methods were used to calculate K values: the Bouwer and Rice method (1976 and 1989) and the Hvorslev method (1951). Initial values as calculated using the Bouwer and Rice method were confirmed by also analyzing the data by the Hvorslev method. Both methods provided similar values for hydraulic conductivity, so only the K values calculated using the Bouwer and Rice method was used to determine groundwater flow velocity beneath the Site.

The results of the slug tests for the six shallow wells showed that the K values ranged from 0.13 to 2.19 feet per day (ft/day) with an average K of 0.80 ft/day. K values in the intermediate zone wells ranged from 0.055 to 1.65 ft/day for an average of 0.72 ft/day. The results of the analysis of the slug test data for the shallow wells are included in Appendix E of the RI Report, along with the copies of the raw water level data and graphs generated using Aqtesolv software.

3.1.2 Groundwater Hydraulic Gradients

Depth to groundwater data from the February 2022 sitewide groundwater monitoring event were used to calculate groundwater elevations and to prepare groundwater elevation contour maps for each zone. **Figures 2-1 through 2-3** contain groundwater elevation contour maps for the shallow, intermediate and bedrock zones, respectively. As shown in each of the contour maps, the general direction of groundwater flow appears to be to the west-northwest. In the shallow zone, the groundwater flow is to the northwest with a southwest flow component, likely the result of topographic low in that direction (**Figure 2-1**). Groundwater flow in the shallow zone can be interpreted to being in the direction of several small unnamed tributaries that lie to the west of the Site. The groundwater flow direction in the intermediate zone is also to the west (**Figure 2-2**).

Based on elevations determined for the bedrock wells, the direction of flow within bedrock appears to be to the west. There are several private water supply wells located to the west and southwest of the Site. Historic use of these wells has likely directed flow within the bedrock fracture system to the southwest (**Figure 2-3**).

The groundwater elevations and flow maps were used to calculate average horizontal and vertical groundwater gradients across the site. The triangulation method was used to calculate horizontal gradients for each zone. This method uses groundwater elevations from upgradient wells on the east side of the Site, side gradient wells, and down gradient wells located west of the Site. Based on the groundwater elevations determined during the February 2022 sitewide measurement event, the average hydraulic gradients for each zone are as follows:

- Shallow zone – 0.016 feet per foot (ft/ft), the same as that calculated in June 2018, to the west-northwest
- Intermediate zone – 0.015 ft/ft, which is almost identical to that calculated in June 2018, to the west-northwest
- Bedrock zone – 0.02 ft/ft, compared with 0.013 ft/ft in June 2018, also to the west

Horizontal hydraulic gradients were calculated using the February 2022 data provided in **Table 3-1**.

Determination of the vertical gradients provides a basic indication of whether contaminants have the potential to migrate vertically from shallower groundwater zones to deeper zones. Vertical hydraulic gradients were also calculated using the February 2022 data from paired shallow and intermediate well clusters across the Site. The following formula was used to calculate vertical hydraulic gradients at each well cluster:

$$\frac{(GWSW-GWDW)}{(SW-DW)} = Vertical\ Gradient \text{ (ft/ft)}$$

Where:

GW SW - groundwater elevation of shallow well (ft)
GW DW - groundwater elevation of intermediate zone well (ft)
SW - elevation of top of mid-point of shallow well screen (ft)
DW - elevation of top of mid-point of intermediate well screen (ft)

The vertical gradient calculations for the February 2022 monitoring event are shown in **Table 3-2**.

Based on the calculated hydraulic gradients, it appears that there is a general downward gradient between the shallow and intermediate zones across the site during this event. The average vertical gradient between the shallow and intermediate zones for this event was determined to be -0.044 ft/ft in the downward direction. The vertical gradient on Site ranged from -0.46 ft/ft at well pair MW-19 to +0.20 ft/ft at MW-21 well pair.

3.1.3 Groundwater Flow Rates

The hydrogeologic data (hydraulic conductivity and gradient) collected at the Site during the RI and updated with the February 2022 groundwater elevation data were used to calculate groundwater flow rates for the shallow zone using Darcy's Law as follows:

$$V = \frac{K \times i}{n}$$

Where:

V = Average Groundwater Flow Velocity
K = Hydraulic Conductivity
i = Groundwater Gradient
n = Porosity

Groundwater flow rates for the unconsolidated formation (water table/shallow zone and intermediate zone) beneath the Site are summarized in the table below.

Hydraulic Property Summary Table
Shakespeare Composite Structures Site

	Hydraulic Gradient (from February 2022 Monitoring Data) (ft/ft)	Assumed Effective Porosity	Average Hydraulic Conductivity (from RI Data)	Calculated Groundwater Velocity (ft/day)	Calculated Groundwater Velocity (ft/yr)
Shallow	0.016	0.25	0.81	0.051	18.9
Intermediate	0.015	0.3	0.72	0.036	13.14
Bedrock	0.020	NA*	NA*	NA*	NA*

* Not determined based on variability within screened fracture zones.

3.2 Summary of Field Parameter Measurements

DO, ORP, and pH values measured during the sitewide monitoring well purging efforts were evaluated as initial indicators to determine if reducing (anaerobic) conditions are present on site. Special field parameter evaluations were conducted within the pilot study treatment areas. The range of values for these parameters were assembled for areas not included in the pilot study treatment zone. Field parameter measurements obtained from the limited number of wells included in that program are discussed in the Pilot Study Report (**AECOM, 2023**).

Field parameter measurements obtained at the time of sample collection during the February 2022 sitewide monitoring event are included on field sampling logs in **Appendix A**. The recorded values for each field parameter are included in **Tables 3-3, 3-4, and 3-5** for the shallow, intermediate, and deep groundwater zones, respectively.

DO is the most preferred terminal electron acceptor relative to others (nitrate, ferric iron, sulfate) that can be used by microorganisms for the biodegradation of organic carbon. Organic carbon includes naturally occurring and anthropogenic sources. If DO is present in groundwater at concentrations above 0.5 milligrams per liter (mg/L), aerobic biodegradation is the predominant microbial process. During this process, microorganisms naturally present in groundwater couple the oxidation of an electron donor (usually organic carbon) with the reduction of an electron acceptor (**Air Force Center for Engineering and the Environment [AFCEE] et al., 2004**).

Reductive dechlorination is the primary process by which chlorinated solvents such as TCE are biologically degraded. This is an anaerobic process. Anaerobic bacteria generally cannot function at DO concentrations greater than 0.5 mg/L. After depletion of DO, anaerobic microorganisms will use nitrate as an electron acceptor, followed by ferric iron, sulfate, and carbon dioxide (methanogenesis). Each sequential reaction drives the ORP of the groundwater further downward and into the range within which reductive dechlorination can occur.

For wells not including the pilot study areas, the range of DO values observed in groundwater monitoring wells during the February 2022 sampling event was as follows:

- 0.24 to 8.30 mg/L in the shallow zone, with ten of the 36 samples having a DO of <0.5 mg/L;
- 0.21 to 3.67 mg/L in the intermediate zone, with four of the eleven samples having a DO of <0.5 mg/L;
- 0.16 to 7.71 mg/L in the bedrock zone, with six of the thirteen samples having a DO of <0.5 mg/L; five of these six wells are off Site private water wells.

ORP is a measure of the oxidation-reduction (redox) state of the aquifer, and it is an indicator of the relative tendency of the groundwater to accept or transfer electrons. ORP values in groundwater can vary from as low as -400 millivolts (mV) to 800 mV or higher. As terminal electron acceptors and nutrients are depleted, the ORP of the groundwater decreases (i.e., becomes more negative). Reductive dechlorination is possible at less than 50 mV.

For wells not including the pilot study areas, the range of ORP values observed in groundwater monitoring wells during the February 2022 sampling event was as follows:

- -1.0 to +869 mv in the shallow zone, with only one of the 36 samples having a negative ORP, and that sample was from an off Site water well;
- +13.0 to +498 mv in the intermediate zone, with all 11 values being positive;
- -146 to +225 mv in the bedrock zone, with six out of the 13 samples having a negative ORP (not the same wells as for DO. Two of the off Site water wells had a negative ORP.

The pH of groundwater influences the presence and activity of the microbial population in groundwater. Historical investigations and current groundwater monitoring conducted at the Site generally confirm that a lowered pH and oxidative conditions dominate the shallow and intermediate zone aquifers. Microorganisms capable of degrading TCE and its daughter products generally prefer pH values between 6 and 8 standard units (S.U.). A pH below 5.5 is generally considered inhibitory to CVOC degradation by *Dehalococcoides (DHC)* bacteria. The pH can be an issue in ERD applications when the targeted ambient aquifer pH is either above or below this preferred range. As a result, neutralization agents have been injected concurrently with the organic carbon source during all three phases of in situ treatment.

For wells not including the pilot study areas, the range of pH values observed in groundwater monitoring wells during the February 2022 sampling event was as follows:

- 4.20 to 6.22 S.U. in the shallow zone, with 29 of the 36 samples having a pH below 5.5;
- 4.77 to 6.47 S.U. in the intermediate zone, with four of the eleven samples having a pH below 5.5.
- 5.52 to 12.11 S.U. in the bedrock zone, with five of the thirteen samples having a pH between 8.0 and 12.2. Sometimes an elevated pH is due to grout from well installation, and one of those five high pH values was from an off Site private water well.

DO, ORP, and pH field parameter results are further evaluated in Section 3.3 below.

3.3 Sitewide Biogeochemical Parameter Evaluation

Microbial analysis groundwater samples were collected from monitoring wells MW-5, MW-6, MW-7, MW-8, MW-9, MW-22, TMW-21, TMW-22, TMW-24, MW-5I, MW-6I, MW-7I, MW-20I, and MW-6D, between February 24, 2022, and March 4, 2022. The samples were submitted to the Microbial Insights laboratory in Knoxville, Tennessee for analysis via the QuantArray®-Chlor Study process. The analytical results include cell count concentrations for bacteria and functional genes associated with anaerobic halorespiring bacteria capable of reductive dichlorination of TCE and PCE, and aerobic bacteria capable of co-oxidizing TCE, cis-1,2-dichloroethylene (cis-1,2-DCE), and VC. The laboratory analytical report is included in **Attachment D**. The laboratory results are also shown in **Tables 3-3, 3-4, and 3-5** for the shallow, intermediate, and deep groundwater zones, respectively.

Except for MW-22, all wells sampled are within the boundaries of the Site TCE plume, with concentrations ranging from 15 micrograms per liter (µg/L) in MW-6I to 850 µg/L in MW-9I during February and March 2022. MW-22 is an upgradient shallow monitoring well. The following sections include a discussion of the microbial results with respect to the potential for natural biological attenuation of TCE, cis-1,2-DCE, and VC in Site groundwater. Although the results and conclusions discussed can likely be applied to the Site as a whole, the discussion is limited to the aforementioned set of microbial analysis wells.

3.3.1 Background and Geochemical Conditions

In general, natural geochemical conditions in Site groundwater are not considered favorable to biological reductive dichlorination. As shown in the data contained in **Appendix D**,

- Total organic carbon concentrations are relatively low across the Site (<3 mg/L). A natural or anthropogenic carbon source is necessary to drive reductive dechlorination. Without a degradable carbon source, or when the source becomes exhausted, reductive dechlorination will not occur.

- At this Site, ORP values are relatively high (positive values) across all shallow and intermediate zone monitoring wells. ORP values less than 0.0 mV (negative values) would indicate that an environment conducive to reductive dechlorination has been achieved.
- The pH in the microbial analysis wells ranged from approximately 4.5 to 5.5 for the shallow zone wells and approximately 5 to 6 in the intermediate zone wells. The pH in deep well MW-6D was 10.67 in March 2022. Neutral pH conditions (i.e., 6 to 8) are more favorable for bacteria capable of reductive dichlorination.
- Methane is characteristic of highly reduced groundwater conditions and is usually present when reductive dechlorination is occurring. Methane concentrations in the microbial wells were generally minimal (< 500 µg/L).

Limited evidence of more favorable conditions was noted in some monitoring wells, including a negative ORP in MW-6D (-91.3) and a moderately high methane concentration in MW-6 (790 µg/L) in March 2022. However, the geochemical results are predominately unfavorable for biological reductive dichlorination without some type of enhancement. Despite these conditions, many of the microbial analysis wells exhibit concentrations of TCE degradation by products cis-1,2-DCE (i.e., MW-6, MW-7, MW-8, MW-7I, MW-9I, TMW-21, and TMW-22) and VC (MW-6, MW-7, MW-8, TMW-21, and TMW-22). Although low concentrations of these by-products can be generated via abiotic mineral process, the concentrations observed are high enough to suggest biological degradation. As discussed below, the QuantArray®-Chlor Study (**Appendix D**) results provide some insight into bacteria that may contribute to the TCE degradation observed.

3.3.2 QuantArray®-Chlor Study Results Discussion

Anaerobic Study Results

Three anaerobic bacteria capable of utilizing TCE as a growth-supporting electron acceptor were detected at low to mid-range concentrations: *Dehalobacter spp.(DHB), Desulfitobacterium, and Desulfuromonas*. *DHB* was detected in groundwater from wells MW-6, MW-22, TMW-21, MW-5I, MW-6I, and MW-20I, with the highest cell count identified at TMW-21 (9.64×10^3 cells per milliliter [cells/mL]). *Desulfitobacterium* was detected in MW-5, MW-6, MW-9, MW-22, TMW-21, MW-6I, MW-20I, and MW-6D with the highest cell counts identified at TMW-21 (1.14×10^4 cells/mL) and MW-20I (1.19×10^4 cells/mL). *Desulfuromonas* was detected in TMW-21, TMW-24, MW-20I, and MW-6D with the highest cell count identified at MW-6D (8.04×10^1 cells/mL). The presence of these bacteria may partially explain the degradation of TCE to cis-1,2-DCE at the Site. However, these bacteria are not capable of complete reductive dechlorination to ethene.

DHC are the only known bacterial group capable of complete reductive dechlorination of TCE to ethene. Cell counts for *DHC* and associated functional genes were generally low in the samples analyzed, with trace detections in monitoring wells MW-5, MW-6, TMW-22, MW-5I, MW-6I, MW-7I, and MW-20I. These low results are consistent with results for samples collected in 2014 and 2017 from wells MW-1, MW-6, MW-7, MW-8, MW-10, MW-7I, MW-9I, MW-10I, MW-20I, and MW-6D and are not surprising given the aforementioned geochemical conditions in Site groundwater.

Aerobic Study Results

The functional genes Soluble Methane Monooxygenase, Toluene Dioxygenase, Phenol Hydroxylase, Toluene Monooxygenase, Ethene Monooxygenase, or Epoxyalkane Transferase were detected at trace concentrations in MW-5 and MW-7 and at low to mid-range concentrations in wells MW-6, MW-9, MW-22, TMW-21, TMW-22, MW-5I, MW-6I, MW-7I, MW-20I, and MW-6D. These functional genes indicate the presence of bacteria capable of co-metabolizing TCE, cis-1,2-DCE, and VC under aerobic conditions. The co-metabolism process is generally a result of monooxygenase enzymes that allow the bacteria to oxidize a primary growth supporting substrate (e.g., methane or benzene, toluene, ethylbenzene, and xylenes [BTEX]) and co-oxidize the chlorinated compounds.

The aforementioned unfavorable Site geochemical conditions for biological reductive dechlorination (e.g., high ORP) may be more favorable for these aerobic processes. Trace BTEX concentrations have been detected in wells MW-5, MW-6, MW-22, and MW-7I, and methane was detected at 790 µg/L in MW-6 in March 2022. However, concentrations of potential primary growth supporting compounds are relatively minimal in Site groundwater. Nevertheless, it is possible that the presence of bacteria capable of co-oxidation of chlorinated ethenes may allow for complete degradation of TCE, or further degradation of cis-1,2-DCE and VC generated via anaerobic degradation, under aerobic conditions.

3.3.3 Summary of Biogeochemical Evaluation

The QuantArray®-Chlor Study results demonstrate the presence of anaerobic bacteria capable of partial degradation of TCE and aerobic bacteria capable of degradation of TCE, cis-1,2-DCE, and VC. Natural attenuation of TCE at the Site will also continue to occur due to physical processes (e.g., diffusion and dispersion) and chemical processes (i.e., abiotic mineral processes). However, the relatively low cell counts for TCE-degrading bacteria at the Site suggest that natural biological attenuation rates will be limited without additional in-situ enhancement.

3.4 Laboratory Analytical Results

3.4.1 VOC Analytical Results – February 2022

Groundwater data have been collected during multiple phases of work beginning with the Phase II ESA and continuing through the Site Investigation, Expanded Investigation, RI Phase I, RI Phase II, and Pilot Study. This includes sampling from temporary well borings, permanent monitoring wells, and private water supply wells. **Tables 3-3** through **3-5** list the results for the groundwater samples collected from the monitoring well network in 2022. **Appendix F** contains historical data tables (**Tables F-1** through **F-3**) that include analytical results for groundwater samples collected from the Site since 2014. This section briefly summarizes the results of the historic and RI related groundwater investigative efforts. Maps depicting pre-RI and RI data have not been included in this report. This section of the report focuses primarily on the most recent data of the 2022 site wide monitoring event. See the RI Report (**AECOM, 2018**) for more information regarding previous analytical results.

All of the groundwater samples collected from the Site in 2022 were analyzed for TCL VOCs. A limited number of samples were also analyzed for both TCL VOCs and/or specific biogeochemical parameters used to evaluate natural attenuation potential. The biogeochemical parameter results are discussed in **Section 3.2.** This section presents VOC analytical results in groundwater from the shallow, intermediate, and bedrock zones.

<u>Shallow Zone</u>

During the site wide monitoring event, each of the 39 previously installed shallow wells were sampled for TCL VOCs. The results for the shallow zone samples are summarized in **Table 3-3**.

A number of VOCs were detected in at least one groundwater sample collected from the shallow wells during the 2022 monitoring event. The only compounds reported above their respective MCLs, in the shallow well samples collected during the side wide monitoring event, were the CVOCs TCE, PCE, cis-1,2-DCE, and VC.

TCE was detected above its MCL of 5 µg/L in 21 of the 39 shallow well samples collected during the site wide event. Exceedances of the MCL ranged from 8.6 µg/L in well MW-17 to 590 µg/L in well MW-10 (and 600 µg/L in the MW-8 sample collected from the PDB). This is compared to the elevated TCE concentrations exceeding the MCL reported during RFI Phase II in shallow well samples, which ranged from 7.3 µg/L in MW-18 to 1400 µg/L in TMW-31 in June 2017. The TCE concentration at TMW-31 had decreased to 480 µg/L in March 2022, likely due to the ISCO pilot study being performed in that area (see **Section 3.3.2**).

Shallow zone TCE concentrations in 2022 in groundwater at several other wells exhibited notable increases or decreases, in comparison with the 2017 RI Phase II concentrations, including the following:

- MW-5: increase in 2022 to 240 µg/L, compared with 71 and 11 µg/L in 2015 and 2017, respectively;
- MW-6: increase in 2022 to 330 µg/L, compared with 27 to 64 µg/L in 2014-2017;
- TMW-24: decrease in 2022 to 70 µg/L, compared with 1200 and 320 µg/L in 2015 and 2017, respectively;
- TMW-33: decrease in 2022 to 20 µg/L, compared with 240 and 120 µg/L in 2015 and 2017, respectively.

The CVOC degradation product cis-1,2-DCE was detected in several shallow zone samples collected during the 2022 monitoring event. However, cis-1,2-DCE was detected above its MCL (70 µg/L) in only a limited number of samples: MW-6 (220 µg/L), MW-8 (76 µg/L), and TMW-21 (130 µg/L). During the 2017 RI Phase II, the only samples where cis-1,2-DCE exceeded the MCL was at MW-6 (430 µg/L) and MW-8 (74 µg/L).

The CVOC degradation compound VC was detected in several groundwater samples collected during the 2022 monitoring event, but no concentrations exceeding its MCL of 2 µg/L were reported. The highest detected concentration in 2022 occurred at well MW-6 (2.0 µg/L, which is equal to the MCL).

The CVOC PCE was the only other CVOC detected above its MCL (5 µg/L) during historic groundwater sampling events, but there were no PCE MCL exceedances in 2017 or 2022. There have been two wells with exceedances of the PCE MCL of 5 µg/L prior to 2017 and 2022. At well MW-8, the PCE concentrations were 5.7 and 8.4 µg/L in 2014 and 2015, respectively, but less than the MCL in 2017 and 2022. At well TMW-21, the PCE concentration was 7.2 µg/L in 2015, but less than the MCL in all other sampling events.

One non-CVOC exceeded its MCL in 2022. Styrene at well TMW-29 (120 µg/L) exceeded its MCL of 100 µg/L in the March 2022 sample. There have been no styrene exceedances in groundwater from any other wells prior to 2022. Well TMW-29 is located inside the east end of the main building and in the ISCO pilot study area. It is not known whether or not this analytical result was anomalous.

It should be noted that well TMW-31, which is inside the ISCO pilot study area and near to TMW-29, had 929 µg/L TCE in August 2021 before the pilot study. The TCE concentration was reduced to 480 µg/L in March 2022, likely due to chemical oxidation from the permanganate injectant, but the concentration increased to 3,600 µg/L in December 2022. There may be a continuing TCE source beneath that part of the building that needs to be evaluated. See Section 3.3.2.1 below for additional evaluation.

Intermediate Zone

During the site wide monitoring event, the 12 intermediate zone wells were sampled for TCL VOCs. The results for the intermediate zone samples are summarized in **Table 3-4**.

A number of VOCs were detected in at least one intermediate zone permanent monitoring well sample collected during the 2022 monitoring event. The VOCs cis-1,2-DCE and TCE were the only compounds detected above their respective MCLs in these samples. TCE was detected above its MCL of 5 µg/L in eight intermediate zone samples ranging from 15 µg/L in MW-6I to 850 µg/L in MW-9I. In the 2017 RI Phase II event, there were also eight wells in which the TCE MCL was exceeded, with a maximum of 1,000 µg/L at MW-10I. The MW-10I TCE concentration in 2022 was only 50 µg/L, a concentration reduction likely due to the impact from substrate injections during the ISERD pilot study.

The CVOC degradation compound cis-1,2-DCE was detected above its MCL of 70 µg/L in the sample from MW-7I at 84 µg/L conventional sampling and 100 µg/L with the PDB. The 2017 result during the RI Phase II was 140 µg/L.

Deep Zone

During the site wide monitoring event, the 14 bedrock zone wells were sampled for TCL VOCs. The results for the deep zone samples are summarized in **Table 3-5**.

A small number of VOCs were detected in the samples collected from the bedrock intervals. However, the only compound detected above its MCL in bedrock zone samples during the 2022 sampling event was TCE. The CVOC TCE was detected above its MCL of 5 µg/L in six of the 14 shallow well samples collected during site wide event. TCE concentrations exceeding the MCL ranged from 10 µg/L in the downgradient, off-site well RDW-1 (on the Ringer Property) to 160 µg/L in MW-6D located on the north side of the Main building.

Groundwater Summary for the 2022 Site Wide Monitoring Event

As previously indicated, multiple temporary, permanent, and water well sampling events have been performed at the Site. For the 2022 site wide monitoring event, TCE continued to be the most widespread of the CVOCs detected in the groundwater zones. TCE isoconcentration maps were developed for the shallow, intermediate, and bedrock zones using the 2022 groundwater data. The site wide monitoring event isoconcentrations are shown for the shallow, intermediate, and deep zones in **Figures 3-1**, **3-2**, and **3-3**, respectively.

The highest TCE concentrations found in shallow wells in 2022 are beneath the Main building: MW-8 at 530 µg/L (600 µg/L from the PDB); and TMW-31 at 480 µg/L (down from 1,400 µg/L in 2017 and at the location of the ISCO pilot study). The highest concentration is also found outside and hydraulically downgradient of the Pole Winder building: (MW-10 at 590 µg/L, which is the location of the shallow zone ISERD pilot study). These concentrations are shown in **Figure 3-1**. The area of TCE impacted groundwater in the shallow zone extends radially from the Main building to the west and from the Pole Winder building to the north-northwest. This distribution of TCE in the shallow zone appears to be consistent with groundwater flow direction which is generally to the northwest or north-northwest.

As shown in **Figure 3-2**, the distribution of TCE in the intermediate zone is similar to that depicted beneath the facility property. The extent of TCE impacts to west-southwest is slightly more widespread than in the shallow zone, but less than that to the northwest. The highest TCE concentrations in the intermediate zone in 2022 occurred at wells MW-9I (850 µg/L), located west of the main building, and MW-5I (610 µg/L), located on the north side of the Pole Winder building. The previously high concentration at MW-10I in 2017 (1000 µg/L) was reduced to 50 µg/L in 2022, as a result of the ISERD pilot study initiated in fall 2021.

TCE impacts in the bedrock zone extends farther to the southwest than either the shallow or intermediate zones, as shown in **Figure 3-3**. This is thought to be due to the historic use of private water supply wells, screened in the bedrock, located to the south and west of the facility. The highest TCE concentration in the bedrock during the 2022 site wide monitoring event occurred at well MW-6D (160 µg/L), located on the north side of the main building. The second highest concentrations occurred at off-site well MW-12D (53 µg/L and 70 µg/L in the PDB sample); MW-12D is located on the tract of land (Dickert property) to the north of the Pole Winder building and railroad tracks.

Isoconcentration maps were not developed in this report for cis-1,2-DCE or any other VOC, since there were very few additional MCL exceedances other than for TCE. As previously mentioned above, cis-1,2-DCE was detected above its MCL (70 µg/L) in only three samples of the 2022 site wide monitoring event: MW-6 (220 µg/L), MW-8 (76 µg/L), and TMW-21 (130 µg/L). The area of cis-1,2-DCE impacted groundwater generally mimics the TCE plume but is much less widespread. The highest cis-1,2-DCE concentrations are also found in wells located on the Facility property near the Main building and towards the northwest corner of the Facility property.

3.4.2 Summary of Pilot Study Analytical Results to Date

In September 2021, Signify and AECOM implemented a pilot study (PS) designed to evaluate multiple groundwater remediation technologies at the Site. The PS has included an evaluation of ISCO and ISERD for groundwater at specific locations on the Site. Pilot study locations are shown in **Figures 3-4, 3-5, and 3-6**. The "Pilot Study Update Summary" (**AECOM, 2022**) was transmitted to SCDHEC in December 2022. Then, the "Pilot Study Report" was transmitted to SCDHEC in May 2023. The following overall conclusions of the PS were included in the PS Report:

<u>ISCO Pilot Study:</u> Review of field observations and measurements along with analytical results from the ISCO study area monitoring wells indicate the following ISCO PS conclusions:

- Treatment using $KMnO_4$ oxidant was effective in decreasing the TCE concentrations to non-detect levels in the area where obstructions did not limit access to the DPT injection equipment.
- The December 2022 TCE concentration of 3,600 µg/L in groundwater at "hot spot" well TMW-31 indicates that a TCE source still exists in groundwater underneath and potentially immediately next to the building in that area. A decrease in TCE concentration was observed March 2022 when a light purple color was observed in the sample, which indicated that some chemical oxidant remained in the vicinity of the well. Following the March 2022 sampling event, the concentration of TCE continued to increase, and the presence of the chemical oxidant was no longer observed. Matrix back diffusion of TCE from shallow aquifer materials in this area likely contributed to the increasing TCE concentrations in that well.
- Because of overhead obstructions inside the eastern end of the building, another approach to accessing appropriate injection locations in the TMW-31 CVOC groundwater source area may need to be identified.
- A radius of influence (ROI) of at most 10 ft was confirmed during the pilot study.

<u>ISERD Pilot Study</u>: Review of field observations and measurements along with analytical results from the ISERD study area monitoring wells indicate the following PS conclusions:

- CVOC and the biogeochemical concentrations indicate that overall conditions, with enhancement, in the treatment areas remain favorable for continued degradation to occur in the vicinity of MW-10, MW-10I, and ERD-OBSW-1I. The distance of ERD-OBSW-1S from the injection locations prevented treatment at this well due to the tight lithology associated with the shallow zone groundwater aquifer.

- An increase in other parameters such as dissolved iron, TOC, and methane also support the conclusion that conditions still could be favorable for continued degradation of CVOCs.
- The ERD technology worked favorably for the intermediate zone, as evidenced by the decline in TCE concentrations and increase in cis-1,2-DCE. The pH may have been a limiting factor for success in the shallow zone.
- The bioaugmentation injection event conducted in December 2021 did not result in a significant increase in *DHC* and associated reductase enzymes, which indicates limited effectiveness of this procedure.
- If ISERD is conducted in the future, buffering to increase the targeted groundwater pH will need to be closely controlled in order to avoid increasing the pH to above 8 S.U., which is outside the favorable range for reductive dechlorination to occur.
- An ROI of at most 10 ft was confirmed during the pilot study.

3.5 Chemicals of Concern

As discussed in Section 3.3, the following CVOCs exceeded their MCLs in at least one groundwater sample during the 2014 to 2017 period: TCE, cis-1,2-DCE, VC, and PCE. These constituents were determined to be chemicals of concern (COCs) in the RI Report. Only two of these constituents, TCE and cis-1,2-DCE, exhibited exceedances of the MCL in the 2022 samples. One non-CVOC, styrene, had one MCL exceedance in one well, occurring only in March 2022. As a result, no new COCs were identified during the 2022 sitewide monitoring event.

3.6 Data Validation

Data validation was performed on the analytical laboratory deliverables for the sitewide groundwater monitoring event. The general and complete validation process was performed in accordance with the USEPA Region 4's *Data Validation Standard Operating Procedures for Contract Laboratory Program Routine Analytical Services* in association with the USEPA's *Contract Laboratory Program, National Functional Guidelines for Organic Data Review* (**USEPA, 1999**), Contract *Laboratory Program, National Functional Guidelines for Inorganic Data Review* (**USEPA, 2002**), and the approved Quality Assurance Project Plan (QAPP) for the project. The USEPA data validation protocols were used in conjunction with the SW-846 analytical methodologies to determine if data should be accepted without qualification, rejected, or qualified.

Data flags were added to some of the acetone and styrene results from some of the sample batches, due to those constituents being detected in either the trip blank or the field blank. Data flags, as applied, were consistent with the USEPA validation guidelines cited above. However, the QC excursions encountered during the validation of this data set did not result in the rejection of any data. Therefore, the data associated with this laboratory batch should be considered compliant and adequate for the intended use. Copies of the data validation reports are contained in **Appendix B**.

3.7 Comparison of Conventional Sampling Techniques vs. Passive Diffusion Bags

As part of the sitewide groundwater monitoring event, sampling was performed in order to make a comparison of conventions low-flow groundwater sampling techniques with passive diffusion bags (PDBs). The purpose of this comparison was to determine if results generated by samples collected using low-flow sampling methods are comparable to results obtained using PDBs, to evaluate if PDBs could be used instead of conventional techniques for some of the future groundwater sampling for VOC analysis. Use of PDBs would result in a decrease in the volume of purge water generated during sampling.

During the sitewide monitoring event, PDBs were inserted in the following monitoring wells in February 2022:

- Nine Shallow wells: MW-1, MW-7, MW-8, MW-9, MW-11, MW-12, MW-14, MW-20, and MW-25;
- Four Intermediate wells: MW-2I, MW-5I, MW-7I, and MW-20I;
- Two Bedrock Wells: MW-12D and RDW-1.

Tables 3-6A, 3-6B, and 3-6C contain comparisons of the laboratory analytical results for samples collected using conventional low-flow groundwater sampling techniques versus samples collected using PDBs, for shallow, intermediate, and bedrock zones, respectively. **Table 3-7** contains calculations for the relative percent difference (RPD) in TCE, cis-1,2-DCE, and VC concentrations between the two techniques. The results of the RPD comparison are shown on **Table 3-7**.

A summary of the RPD comparisons for TCE, cis-1,2 DCE, and VC results is also included on **Table 3-7**. A brief description is of each comparison is as follows:

- TCE: Of the 15 wells in which both techniques were utilized, four of those wells had non-detect concentrations for TCE. Samples from six wells had RPDs of less than 15%, three sample sets had an RPD of less than 30%, and one sample had an RPD of greater than 10%. Most of the larger RPDs for TCE were for concentrations that were less than 50 µg/L.

- Cis-1,2 DCE: 10 of the 15 wells selected had non-detect concentrations for cis-1,2 DCE (0% RPD). Two sets of results had an RPD of 15%, two sets had an RPD of less than 30%, and one set had an RPD of greater than 30%. Six wells had RPDs between 0.1 and 15%. Three wells had RPDs between 15 and 30%. One well had an RPD greater than 30%. The larger RPDs for the cis-1,2 DCE concentrations were for samples with concentrations that were also less than 50 µg/L.

- VC: VC was not detected in either sample collected from 14 of the 15 wells in which both sampling techniques were utilized during the 2022 monitoring event (0% RPD). The one sample set in which VC was detected had an RPD of just over 30% (**Table 3-7**). The concentrations in the two samples from this set were less than the MCL of 2 µg/L.

<u>Conclusion and Request:</u> Comparison of the PDB and low-flow sampling results indicates that the majority of the variations were less than 15%. The largest variations were seen within well sample data sets with concentrations of less than 50 µg/L. Based on the limited number of substantial variations, Signify would like to incorporate the use of PDBs for future groundwater sampling events. Where it is critical that other groundwater natural attenuation or remediation parameters besides VOCs need to be sampled, it is recommended that low-flow groundwater sampling continue to be performed.

4. Plume Volumetrics

Following completion of the previous monitoring efforts, the Earth Volumetric Studio (EVS) software (C Tech Development Corporation, Las Vegas, Nevada) was utilized to develop an additional line of evidence regarding the current extent of groundwater impact beneath the Site. The EVS process generated an updated three-dimensional (3-D) visualization of the TCE plume and estimated plume volumetrics for this parameter. The data generated and modeled during this event can be compared to information collected from the site in the future, particularly once remedial efforts have been implemented, to visually depict changes to plume dimensions over time.

4.1 Plume Dimensions

The EVS system has been used to depict the TCE plume dimensions and boundaries based on the analytical data obtained during the 2022 monitoring event. The visualizations show each well sampled during the 2022 event, highlights each well's screen interval, and the distribution of TCE concentrations.

A snapshot of the plume visualization from various angles has been included in **Appendix G**. A copy of the complete 3-D visualization is also included on the compact disc contained in **Appendix G**. Instructions for accessing the visualization and a link enabling access to the visualization are also included in **Appendix G**.

- **Figure G-1** is a snapshot depicting the extent of TCE detected at the site. This is a planar view depicting the horizontal extent in all depth intervals.
- **Figure G-2** depicts the extent of TCE looking north, through the plume.
- **Figure G-3** depicts the extent of TCE looking south through the plume.

4.2 Bulk Mass Calculations

The EVS process was also used to estimate the total mass[1] volume of TCE in groundwater. **Table 4-1** summarizes the calculated chemical mass (207 kilograms) and average concentration (43.5 µg/L) for this compound based on the 2022 groundwater data. The volume and mass values are based on concentrations above 1.0 µg/L.

[1] The molar mass creates a normalized concentration unit for the COC, which will allow for a better visualization of overall changes in mass loss not only for TCE but other compounds if incorporated into the model.

5. Conclusions, Recommendations, and Next Step Actions

The February 2022 sitewide groundwater monitoring event was performed to determine the status of groundwater quality beneath the Site. The monitoring event included sampling of 65 monitoring wells located at the Site. Sampling was conducted at 39 shallow zone wells, 12 intermediate zone wells, and 14 bedrock zone wells. Groundwater samples collected from all of these wells were analyzed for TCL-VOCs. Some of the wells were sampled for biogeochemical and biological parameters. All of the monitoring wells and piezometers were sampled using low flow-low volume purging methods. Nine shallow zone wells, four intermediate zone wells, and two bedrock wells were also sampled using PDBs, for comparison of laboratory analytical results with the low flow-low volume purging method.

The following conclusions are based on the data collected during this sitewide monitoring event:

- Groundwater Hydrogeology: The groundwater elevations, flow directions, and calculated flow velocities are similar to those determined during the RI.

- Field Parameter and Biogeochemical Data Evaluation: Field parameters from 2022 and earlier events, and biogeochemical data from 2022, indicate the presence of anaerobic bacteria capable of partial degradation of TCE and aerobic bacteria capable of degradation of TCE, cis-1,2-DCE, and VC. Natural attenuation of TCE at the Site will also continue to occur due to physical processes (e.g., diffusion and dispersion) and chemical processes (i.e., abiotic mineral processes). However, the relatively low cell counts for TCE-degrading bacteria at the Site suggest that natural biological attenuation rates will be limited.

- Shallow Zone Groundwater Analytical Results Outside of the Pilot Study Areas: TCE was detected above its MCL of 5 µg/L in 21 of the 39 shallow well samples collected during the site wide event, with the highest detection of 590 µg/L in well MW-10. Cis-1,2-DCE was detected above its MCL of 70 µg/L in only three of the 39 shallow zone samples, with the highest detection of 220 µg/L at well MW-6. VC was not detected at a concentration exceeding its MCL in any of the 39 samples.

- Intermediate Zone Groundwater Analytical Results Outside of the Pilot Study Areas: TCE was detected above its MCL of 5 µg/L in eight intermediate zone samples ranging from 15 µg/L in MW-6I to 850 µg/L in MW-9I. The CVOC degradation compound cis-1,2-DCE was detected above its MCL of 70 µg/L in only one well: MW-7I at 84 µg/L conventional sampling and 100 µg/L with the PDB. There were no exceedances of the VC MCL during the 2022 monitoring event.

- Deep Zone Groundwater Analytical Results: TCE, the only constituent exceeding its MCL during the sitewide monitoring event, was detected above its MCL of 5 µg/L in six of the 14 deep well samples collected during the site wide event. TCE concentrations exceeding the MCL ranged from 10 µg/L in the downgradient, off-site well RDW-1 (on the Ringer Property) to 160 µg/L in MW-6D located on the north side of the Main building.

- ISCO Pilot Study: Review of field observations and measurements along with analytical results from the ISCO study area monitoring wells indicate the following ISCO PS conclusions:
  - Treatment using potassium permanganate ($KMnO_4$) oxidant was effective in decreasing the TCE concentrations to non-detection levels in the area where

obstructions did not limit access to the injection direct push technology (DPT) equipment.
  - The December 2022 TCE concentration of 3,600 µg/L in groundwater at source area well TMW-31 indicated that a significant TCE source still exists in groundwater under the building in that area.
  - Because of overhead obstructions inside the eastern end of the building, another approach to accessing appropriate injection locations in the TMW-31 CVOC groundwater source area may need to be identified.

- ISERD Pilot Study: Review of field observations and measurements along with analytical results from the ISERD study area monitoring wells indicate the following PS conclusions:
  - CVOC and the biogeochemical concentrations indicate that overall conditions, with enhancement, in the treatment areas remain favorable for continued degradation to occur in the vicinity of MW-10, MW-10I, and ERD-OBSW-1I. The distance of ERD-OBSW-1S from the injection locations prevented treatment at this well due to the tight lithology associated with the shallow zone groundwater aquifer.
  - An increase in other parameters such as dissolved iron, TOC, and methane also support the conclusion that conditions still could be favorable for continued degradation of CVOCs.
  - The ERD technology worked favorably for the intermediate zone, as evidenced by the decline in TCE concentrations and increase in cis-1,2-DCE. The pH may have been a limiting factor for success in the shallow zone.
  - The bioaugmentation injection event conducted in December 2021 did not result in a significant increase in *DHC* and associated reductase enzymes, which indicates limited effectiveness of this procedure.
  - If ISERD is conducted in the future, buffering to increase the targeted groundwater pH will need to be closely controlled in order to avoid increasing the pH to above 8 S.U., which is outside the favorable range for reductive dechlorination to occur.
  - A ROI of at most 10 ft was confirmed during the pilot study.

- Low-flow Purging Compared with PDB Sampling Collection: Comparison of the PDB and low-flow sampling results indicates that the majority of the variations were less than 15%. The largest variations were seen within well sample data sets with concentrations of less than 50 µg/L. Based on the limited number of substantial variations, Signify would like to incorporate the use of PDBs for future groundwater sampling events.

- Plume Volumetrics: The EVS software was used to develop a 3-D model depicting the extent of TCE impact in groundwater beneath the site. This software was also used to estimate the volume of TCE in groundwater beneath the site. The calculated TCE chemical mass was 207 kilograms and the average TCE concentration was 43.5 µg/L based on the 2022 groundwater data.

Recommendations/requests and next step actions are listed below:

- Groundwater Pilot Study: Both in situ chemical oxidation (ISCO) and in situ enhanced reductive dechlorination (ISERD) should be retained as potential treatment technologies and for remedial alternatives development in the upcoming feasibility study (FS).

- Chemicals of Concern (COCs): The COCs which are being carried through from the remedial investigation (RI), through the sitewide groundwater monitoring event, and into the FS are TCE, cis-1,2-dichloroethene (DCE), and vinyl chloride (VC).

- Low-flow Purging Compared with PDB Sample Collection: Signify would like to incorporate the use of PDBs for future groundwater sampling events. Where it is critical that other groundwater natural attenuation or remediation parameters besides VOCs need to be sampled, it is recommended that low-flow groundwater sampling continue to be performed.

- Plume Volumetrics: Updating of the EVS model as remedial efforts are implemented can be used to depict changes in plume dimensions.

- Initiation of Feasibility Study Phase: Based on the sitewide groundwater monitoring event data and the pilot study results, Signify recommends proceeding with the feasibility study phase. Signify anticipates that the FS will be completed by the end of 2023.

6. References

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FIGURES