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May 28, 2020

Ms. Kim Kuhn
Bureau of Land and Waste Management
SC Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201

Regarding: Bench Scale Treatability Study Report
Shakespeare Composite Structures Site
Newberry, South Carolina
SCDHEC VCC Number 14-6271-RP

Dear Ms. Kuhn:

Please find attached one hard copy and one electronic copy (on compact disc) of the Bench Scale Treatability Study (BSTS) Report for the Shakespeare Composite Structures Site (the Site) located in Newberry, South Carolina. This report details the field and laboratory related activities performed in accordance with the BSTS Work Plan approved by the South Carolina Department of Health and Environmental Control (SCDHEC) in August 2019.

Should you have any questions regarding the report, please feel free to contact me at your convenience.

Sincerely,
AECOM Technical Services, Inc.

Scott E. Ross, P.G.
Project Manager
803-201-9662
scott.ross@aecom.com

cc: Mr. Dean Weeks – Signify North America

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SITE ASSESSMENT,
REMEDIATION, &
REVITALIZATION

Bench Scale Treatability Study Report Shakespeare Composite Structures Site

RP-VCC-146271-RP
Signify North America

May 2020

Project # 60534283

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Bench-Scale Treatability Study Report

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Tables

List of Acronyms

AECOM	AECOM Technical Services, Inc.
bgs	below ground surface
BSTS	bench-scale treatability study
cis-1,2-DCE	cis-1,2 – dichloroethene
CVOCs	chlorinated volatile organic compounds
DHG	dissolved hydrocarbon gases
DOT	Department of Transportation
EVO	emulsified vegetable oil
FS	feasibility study
g/kg	grams per kilogram
IDW	investigation derived waste
ISCO	in situ chemical oxidation
ISEB	in situ enhanced bioremediation
$KMnO_4$	potassium permanganate
MCL	maximum contaminant level
mg/L	milligrams per liter
MNA	monitored natural attenuation
mL	milliliter
msl	mean sea level
mZVI	micro-scale ZVI
OD	outside diameter
PENAC	Philips Electronics North America Corporation
PS	pilot study
RI	remedial investigation
RP-VCC	responsible party-voluntary cleanup contract
SCDHEC	South Carolina Department of Health and Environmental Control
SiREM	SiREM Laboratories
s.u.	standard unit
TCE	trichloroethene
TOD	total oxidant demand
USEPA	United States Environmental Protection Agency
VC	vinyl chloride

VCC	voluntary cleanup contract
VOCs	volatile organic compounds

Section 1. Introduction

The Shakespeare 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-146271-RP. As part of the RP-VCC process the Site has undergone a Remedial Investigation (RI), which was 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 this Site [Signify North America – (Signify)] is conducting several activities that will be incorporated into the completion of a Feasibility Study (FS) for potential remedial efforts for CVOC-impacted groundwater. These activities include a bench-scale treatability study (BSTS) that was implemented for the Site in September 2019. This document serves as the BSTS Report, summarizing the results of the laboratory-based evaluation of multiple in-situ remediation options.

1.1 Facility and Site Setting

The Site is located on 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 has continued to be used for this 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.

In addition to the Facility 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 (AECOM Technical Services, Inc. [AECOM], 2018).

Topography of the Site is generally flat 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 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.

A more detailed description of the facility's operation, surrounding property usage, and site topographic setting information is included in the RI Report (AECOM, 2018).

1.2 Previous Investigations

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

- 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 – 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, investigative efforts were performed as part of the RI process.

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 either 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 beyond the Facility property.

Groundwater beneath the site is generally encountered under unconfined conditions. As a result, the direction of groundwater flow beneath this 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 by numerous privately operated water supply wells located to the west and southwest of the Facility.

The investigative efforts have defined the extent of CVOC-impacted groundwater at multiple aquifer depth intervals. Analytical results were screened against United States Environmental Protection Agency maximum contaminant levels (MCLs) to identify compounds of interest in groundwater beneath the Site. Concentrations of 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 has been the most frequently detected in groundwater samples from the Site. The elevated concentrations of CVOCs are most widespread in the shallow zone (upper portion of the water table aquifer).

TCE and cis-1,2-DCE have also exceeded their respective MCLs in one or more samples collected in the intermediate (saprolite) zone. Of these, TCE was also detected most frequently above its MCL in groundwater samples collected from several private water supply wells screened in the underlying granitic bedrock and in monitoring wells installed in the bedrock.

Because TCE was detected most frequently and at the highest concentrations at the Site, the results for this compound have been used to represent the extent of impact in each groundwater zone beneath the Site. **Figures 1-3** through **1-5** depict the extent of TCE in groundwater beneath the Site based on data from the last site wide monitoring event completed in 2017.

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

1.3 Feasibility Study Work Plan

The RI Report for the Site was submitted to the SCDHEC in November 2018 and approved on February 4, 2019. 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 FS Work Plan was submitted to SCDHEC on May 15, 2019. SCDHEC approved the FS Work Plan on June 4, 2019.

In their June 4, 2019 approval letter, SCDHEC requested that Signify submit a BSTS Work Plan by July 31, 2019. The BSTS Work Plan was approved by SCDHEC on August 23, 2019. The BSTS was implemented in September 2019.

1.4 Purpose

It is anticipated that an active groundwater treatment remedy will be required for at least a portion of the CVOC-impacted Site groundwater. In order to develop a more definitive groundwater remedial plan and prior to developing an FS, two potential in-situ remediation processes – in-situ chemical oxidation (ISCO) and in situ enhanced bioremediation (ISEB) were evaluated in the BSTS as possible treatment options for the CVOCs detected in Site groundwater. The BSTS results will be used to develop a pilot study (PS) work plan that proposes methods to be used for a field evaluation of the most promising remedial approach, as determined by the BSTS, for the treatment of CVOCs in Site groundwater

Section 2. Field Sample Collection Activities

Based on the most recent TCE concentrations and ease of access for drilling and sampling efforts, soil and groundwater samples were collected from an area between monitoring wells MW-10 and MW-10I, located just north of the Facility property on the Dickert property (**Figure 2-1**). AECOM contracted the environmental drilling contractor Elite Techniques, Inc. to assist with soil sample collection efforts. AECOM personnel collected groundwater samples from the two monitoring wells.

2.1 Soil Sample Collection

Soil samples were collected from the Site on September 19, 2019. The soil sampling efforts included advancement of multiple soil borings at locations between MW-10 and MW-10I to allow collection of soil samples from depth intervals equivalent to the screen intervals for MW-10 and MW-10I. The soil borings were advanced at locations approximately mid-way between MW-10 and MW-10I (**Figure 2-1**).

Soil borings were advanced using a Geoprobe™ direct push drill rig. Borings were advanced via a dual tube soil coring system utilizing a four-foot long, 2.25 outside diameter (OD) stainless steel core barrel fitted with a disposable acetate liner and a slightly larger (3-inch OD) over-ride casing. The soil core barrel was advanced into the subsurface followed by the override casing. Once the over-ride casing was advanced to the bottom of the sample interval, the core barrel was retrieved from the borehole, allowing removal of the disposable acetate liner containing a soil core. This process was repeated until soil cores were retrieved from the targeted depth intervals equivalent to the center depths of the monitoring well screen intervals for MW-10 (23 to 27 feet below ground surface [bgs]) and MW-10I (34 to 38 feet bgs). Once the soil cores were retrieved from the desired depth intervals the core liners were cut in half, sealed at both ends using a flexible cap wrapped with tape, and prepared for shipment to the laboratories performing the BSTS. The soil cores collected for the BSTS were identified as MC-01S, and MC-02S (collected from the shallow groundwater zone) and MC-01I and MC-02I (collected from the intermediate groundwater zone).

2.2 Groundwater Sample Collection

In addition to the soil core collection, approximately 7 liters of groundwater (3.5 liters per well) were collected from MW-10 and MW-10I for use in the BSTS. Each of these monitoring wells were purged and sampled in accordance with the procedures described in the Phase II RI Work Plan (AECOM, 2017).

2.3 Sample Shipment

In accordance with the Phase II RI Work Plan (AECOM, 2017) all samples were packaged, placed on ice for preservation immediately after collection and shipped to the designated laboratories with chain of custody forms the same day of collection.

One set of soil cores (MC-01S and MC-01I) and 3 liters of water from each monitoring well were shipped to SiREM Laboratories (SiREM) in Ontario, Canada for evaluation of ISEB methods.

The other set of soil cores (MC-02S and MC-02I) and 500 milliliters (mL) of water from each of the two monitoring wells were sent to Redox-Tech, LLC in Cary, North Carolina for ISCO total oxidant demand (TOD) testing.

2.4 IDW Management

A limited amount of investigative derived waste (IDW) was generated during the field efforts. Soil core liner and soil cores not utilized for sample collection were containerized in a 55 gallon drum staged on site. Well purge water generated during sampling of the two monitoring wells was also containerized in a 55 gallon drum that is staged on site.

The small volume of IDW generated during this field effort will be disposed of with IDW generated during Pilot Study efforts proposed for later this year.

Section 3. Bench-Scale Treatability Study Activities

The bench-scale testing efforts were performed to evaluate two potential in-situ treatment processes using the soil and groundwater samples collected from an area at the Site with elevated TCE levels. The laboratory based BSTS activities are briefly described below.

3.1 ISCO Testing

As indicated in Section 2, a subset of soil and groundwater samples collected from the Site was sent to Redox Tech, LLC and evaluated to determine if site conditions were amenable to treatment by ISCO. This process included a colorimetric evaluation that provided a determination of the TOD for a mixture of Site soil and groundwater.

The ISCO testing entailed the creation of four microcosms of Site soil and groundwater (two for each soil sample depth interval), and two control microcosms. Two of the microcosms and one control sample were dosed with 5 grams per kilogram (g/kg) of the oxidant potassium permanganate ($KMnO_4$), and two microcosms and the remaining control sample were dosed with 10 g/kg of $KMnO_4$. The microcosms were then allowed to incubate for 48 hours. After the incubation period, the color of the microcosm solution was measured using a spectrometer. The measured color in the microcosm solution was used to determine the associated TOD in each of the microcosm set ups. The results of the ISCO testing are summarized in Section 4, and a copy of the Redox Tech, LLC TOD sample analysis report is included in **Appendix A**.

3.2 ISEB Testing

The ISEB testing was conducted to determine if variations of electron donor reagents and bacterial amendments could enhance degradation of Site-related CVOCs. SiREM Laboratory (SiREM) conducted the ISEB testing. The results of the ISEB testing are summarized in Section 4, and a copy of SiREM's Laboratory Biotreatability Study to Evaluate In-Situ Bioremediation of Chlorinated VOCs in Groundwater report is included in **Appendix B**.

3.2.1 Buffering Evaluation

Prior to the beginning of the ISEB treatability study, a 6-day buffering study using a mixture of Site soil and groundwater was performed to determine if amendments were required to be added to the treatment groups to maintain an optimal pH (approximately 7 standard units) for biological activity to occur during the testing period. The buffering evaluation determined that materials from the site are generally acidic requiring the anaerobic treatment groups to be amended with a buffering solution to raise the pH in each group to be within the optimal treatment range. A detailed discussion of the activities completed for the buffering evaluation is included in **Appendix B**.

3.2.2 Treatment Group Development

After completion of the buffering evaluation site soil and groundwater were also used to develop several treatment groups. Each treatment group included three microcosms, and each microcosm consisted of 200 mL of Site groundwater and 60 grams of Site soil. **Table 1** lists the ISEB treatment microcosms and briefly describes how each group was amended.

Table 1 ISEB Microcosms and Treatment Descriptions

Microcosm -No.	Treatment/Control Group Name	Description of Treatment
1-3	Anaerobic Sterile Control	Autoclaved and amended with mercuric chloride and sodium azide
4-6	Intrinsic Control	No treatment
7-9	MicroEVO® ISCR Amended	Amended with MicroEVO™ ISCR, optional pH buffered on Day 60EDS-ER™ and bioaugmented with KB-1® Plus
10-12	MicroEVO® ISCR Amended, pH buffered, KB-1® Plus bioaugmented,	Amended with MicroEVO™ ISCR pH buffered to neutral on Day 0 and Day 23, bioaugmented with KB-1® Plus on Day 42
13-15	EDS-ER® Amended, pH buffered, KB-1® Plus bioaugmented,	Amended with EDS-ER™, pH buffered to neutral on Day 0 and Day 23, bioaugmented with KB-1® Plus

Microcosms were initially constructed on October 2, 2019. The groundwater for the sterile control microcosms (Nos. 1-3) was amended with mercuric chloride and sodium azide and the soil portions of these microcosms were then autoclaved to inhibit microbial activity. The anaerobic intrinsic control microcosms (Nos. 4-6) were used to measure intrinsic biodegradation activity and did not receive electron donor amendments or pH buffering. One replicate of each microcosm control and microcosm treatment group were also amended with resazurin to monitor redox conditions. Resazurin turn from pink to clear in the absence of oxygen and is used to indicate the onset of reducing conditions.

On October 4, 2019, each treatment microcosm was initially amended with a TCE stock solution to achieve a target concentration of 1 milligram per liter (mg/L) prior to the start of testing.

On October 7, 2019 (Day 0), treatment microcosms (Nos. 7-9 and 10-12) were amended with EDS-ER™ (Tersus Environmental [Tersus], Wake Forest, NC), an emulsified vegetable oil (EVO) product and MicroEVO™ ISCR (Tersus). MicroEVO™ ISCR was amended as three separate products: ISR-CL (a solution of suspended ferrous sulfide), a solution of micro-scale zero valent iron (mZVI) suspended in glycerol, and EDS-ER™. Treatment microcosms Nos. 13-15 were amended with EDS-ER™ and Nutriments®. The concentrations of the amendments were based on supplier (Tersus) recommendations and in consultation with AECOM.

The optimum pH for reductive dechlorination to occur is 6.8 to 7.5 (Middledorp et al., 1999). Because Site groundwater pH (approximately 5.4 s.u.) is below the optimum levels, one of the MicroEVO™ ISCR amended treatments (Nos. 10-12) and one of the EDS-ER™ amended treatments (Nos. 13-15) were also buffered using sodium bicarbonate to raise the pH of these microcosms to 7.0±0.2 s.u. The amount of buffer used was based on the results of the initial buffering assay mentioned in Section 3.2.1.

On October 30, 2019, (Day 23), the pH in the buffered microcosms was observed to have decreased to below the target pH range of 7.0 ±0.2 s.u. As a result, these microcosms were buffered for a second time with a sodium bicarbonate solution.

Bioaugmentation can improve the rate of TCE dechlorination. On November 18, 2019 (Day 42 after electron donor addition), after reducing conditions were achieved, the previously mentioned buffered treatment microcosms were amended with a dehalorespiring microbial consortium (KB- 1® Plus) to assess the ability of this culture to promote or accelerate complete reductive dechlorination of TCE in site groundwater. KB-1® Plus is a natural microbial consortium containing *Dehalococcoides* (*Dhc*) bacteria that dechlorinate chlorinated ethenes to ethene. The KB-1® Plus culture is formulated to degrade TCE to ethene at pH conditions of between 5.75 to 6 s.u. and was selected for this BSTS due to the naturally low pH of Site groundwater. Even though the bioaugmentation microcosms were buffered to a neutral pH, there was the potential for the pH to return to starting pH conditions once the KB-1® Plus was added.

On December 6, 2019, microcosm treatment Nos. 7-9 were buffered to a pH range of 7.0 ±0.2 s.u. This was done in attempt to stimulate further reduction of TCE that had stalled after the initial 30 days of treatment.

3.2.3 ISEB Microcosm Analysis

Once the microcosms were established, each was monitored periodically for approximately four months. Aqueous samples collected from the microcosms were analyzed for chlorinated VOCs (TCE, cis-,1,2-DCE, and VC) and dissolved hydrocarbon gases (DHGs, acetylene, ethane, and methane). In addition, the anaerobic treatment microcosms were periodically sample to determine concentrations of volatile fatty acids (VFAs - e.g., lactate, acetate, and propionate) to permit evaluation of electron donor fermentation and longevity. Analysis for anions (i.e., sulfate, nitrate, nitrite, chloride, and phosphate) and oxidation-reduction potential was also conducted during the BSTS to assess the onset of reducing conditions. The pH of the various microcosms was measured for the duration of the BSTS. A summary of the results for the various analyses is presented in the report in **Appendix B**.

Section 4. ISCO and ISEB Testing Results and Conclusions

The results of the evaluations of the in-situ methods are briefly summarized in this section.

4.1 ISCO Testing Results

The TOD evaluation was conducted to determine if native Site groundwater and saturated soil would be amenable to ISCO treatment. Targeted aquifer materials with high natural organic carbon, high naturally reduced inorganic minerals such as iron, and elevated CVOC concentrations require higher concentrations of oxidant to effectively treat the targeted contaminants. TOD values determined in the four microcosms used for testing indicated a limited oxidant demand exerted by Site groundwater and saturated soil. TOD values for the microcosms ranged from less than 0.3 g/kg to 2.8 g/kg, which fall within the typical range for saprolitic soils found in the piedmont region of South Carolina. Based on these results and a subsequent discussion with Redox Tech LLC, a TOD value of 1 to 2 g/kg would be adequate for design purposes. Because this value is low, these results indicate that treatment via ISCO may be a suitable remedial option to treat impacted Site groundwater. However, a field-based pilot study would be necessary in order to determine the effectiveness, implementability, and cost associated with full-scale implementation of this remedial option. A copy of the Redox Tech, LLC TOD Sample Analysis report is included in **Appendix A**.

4.2 ISEB Testing

The ISEB BSTS evaluated the effectiveness of multiple treatment amendments for TCE-impacted Site media including EDS-ER™ , MicroEVO™ ISCR,and KB- 1® Plus. One of the EDS-ER™ amended treatments and one of the MicroEVO™ ISCR amended treatment microcosms were also buffered using $NaHCO_3$ to maintain the pH within the optimal range for reductive dechlorination to occur.

Review of the laboratory BSTS suggest the following conclusions:

- Site groundwater pH is below the ideal range for reductive dechlorination to occur; therefore, buffering will be required to increase pH values in potential treatment areas.
- MicroEVO™ ISCR (treatment microcosm Nos. 7-9) was able to rapidly (14 days) induce the reduction in the concentration of TCE in half. However, minimal reduction was seen after that, and buffering of the solution to pH of 7.0 did not promote further reduction. This indicates that in the microcosm setting, the ZVI may have been used up and was no longer available to promote reductive reactions. Also, the low concentrations of cis-1,2-DCE that were detected, and the lack of VC detected indicate that the intrinsic bacterial populations in this portion of the site may not be suitable for facilitating complete dechlorination of TCE to ethene. As a result, bioaugmentation may be required.
- EDS-ERTM with KB-1 Plus bioaugmentation (treatment microcosm Nos. 13-15) was able to completely degrade TCE to ethene.

- MicroEVO™ ISCR with KB- 1® Plus bioaugmentation (treatment microcosms Nos. 10-12) achieved dechlorination of TCE to VC, but complete degradation of VC to ethene was slow. This is likely due to the high sulfate concentrations that were detected in these microcosms as a result of the addition of ISR-CL (a solution of suspended ferrous sulfide). High sulfate concentrations (greater than 20 mg/L) are known to be inhibitory to reductive dechlorination (United States Environmental Protection Agency [USEPA], 1998).
- The high sulfate concentrations may also have been inhibitory to the intrinsic bacterial populations present in the MicroEVO™ ISCR microcosms (treatment microcosms Nos. 10-12) and the reason for the lack of TCE degradation via biological means.

A copy of SiREM's Laboratory Biotreatability Study to Evaluate In-Situ Bioremediation of Chlorinated VOCs in Groundwater report is included in **Appendix B**.

4.3 Field-Scale Pilot Testing

Based on the results of the BSTS, both ISCO and ISEB are potentially applicable remediation technologies that can be used to address CVOC contamination in Site groundwater. As such, Signify and AECOM recommend that a field-scale pilot study (PS) be developed to evaluate the most promising technology. As a next step, a PS Work Plan will be developed. The PS Work Plan will include the remedial technology to be pilot tested, the location for the PS, the product(s) and estimated volumes to be used, the proposed plan for product injection including preparation of an Underground Injection Control Permit, and details regarding a PS performance monitoring program.

Section 5 References

AECOM, 2017. Phase II Remedial Investigation Work Plan - Shakespeare Composite Structures, Newberry, South Carolina. August 2017.

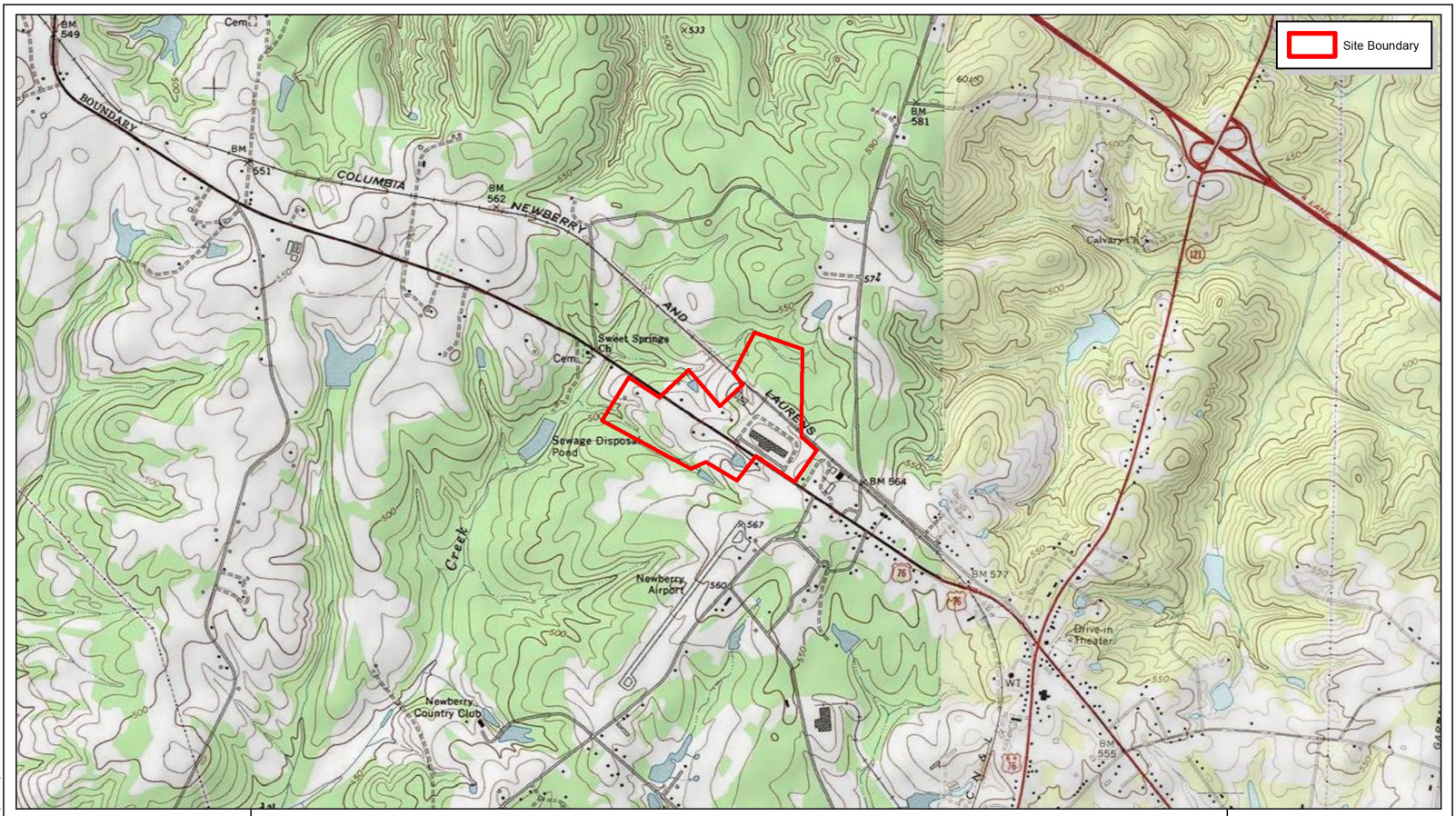
AECOM, 2018. Remedial Investigation Report, Shakespeare Composite Structures, Newberry, South Carolina. November 2018.

AECOM, 2019. Feasibility Study Work Plan, Shakespeare Composite Structures, Newberry, South Carolina. May 2019

Middledorp, P.J.M. et al., 1999. Anaerobic Microbial Reductive Dechlorination of Chlorinated Ethenes. Bioremediation Journal. 3:151-169.

USEPA, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water, EPA/600/R-98/128, Office of Research and Development, Washington DC. September 1998.

FIGURES



AECOM

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Figure 1-1: Site Location Map

Shakespeare Composition Structures
Newberry, South Carolina

Project No.: 60534283; Prepared by: JG; Date: 5/10/2018.

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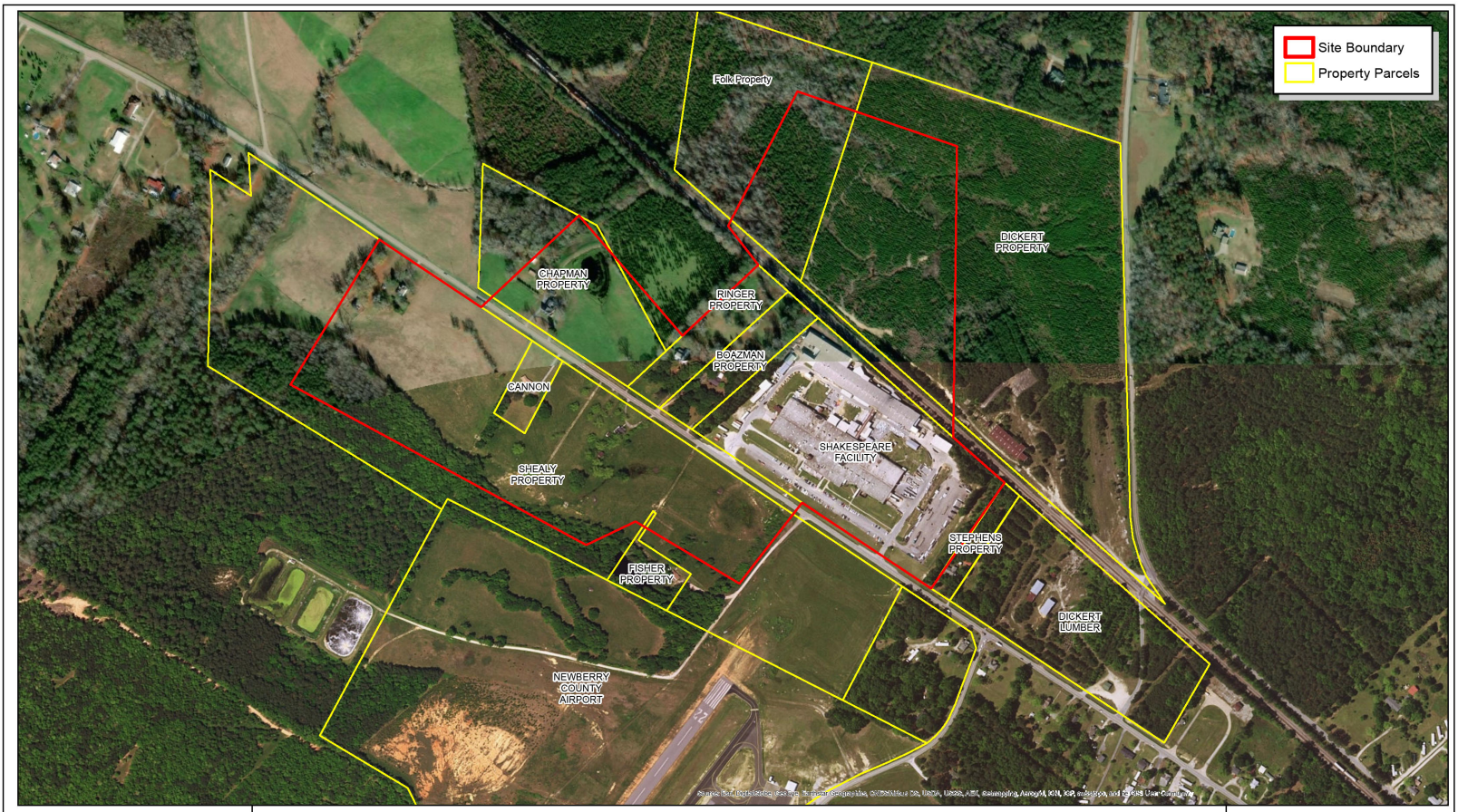

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Figure 1-2: Site Plan

Shakespeare Composition Structures
Newberry, South Carolina

Project No.: 60534283; Prepared by: JG; Date: 5/10/2018.

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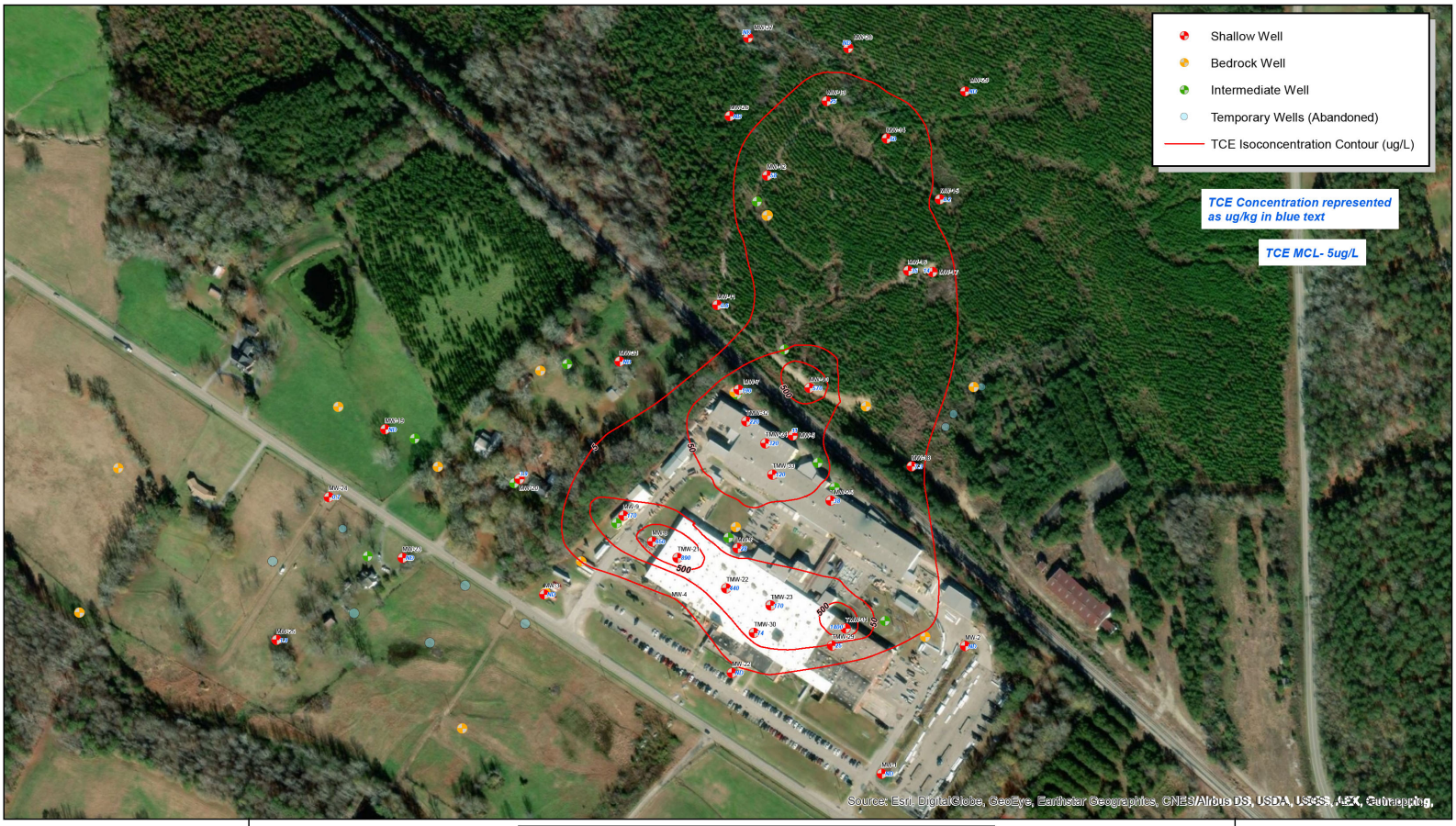

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Figure 1-3: TCE Concentration in Shallow Zone

Shakespeare Composition Structures
Newberry, South Carolina

Project No.: 60534283; Prepared by: JG; Date: 6/11/2018.

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Figure 1-4: TCE Concentration in Intermediate Zone

Shakespeare Composition Structures
Newberry, South Carolina

Project No.: 60534283; Prepared by: JG; Date: 6/11/2018.

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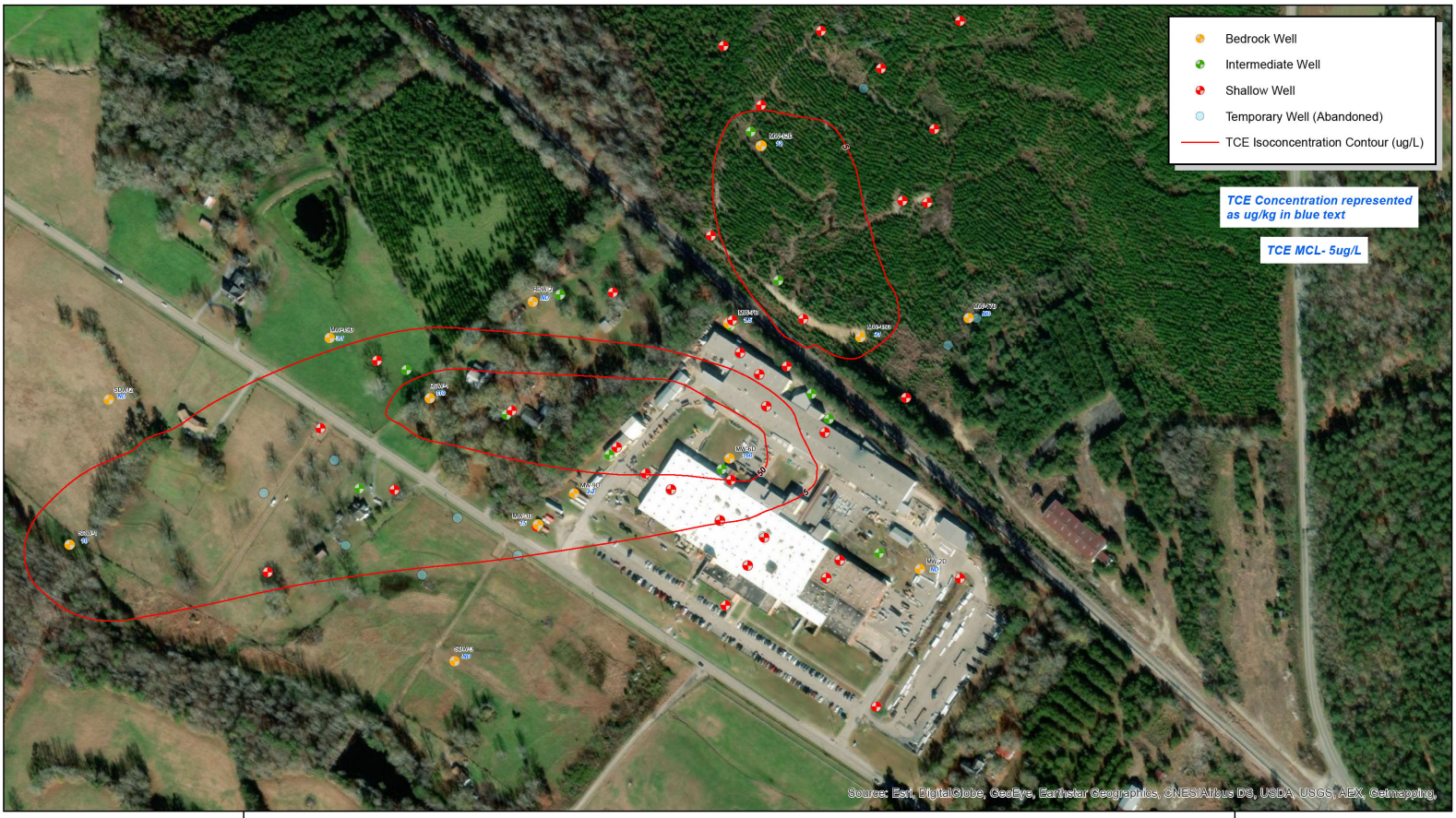

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Figure 1-5 : TCE Concentration in Bedrock

Shakespeare Composition Structures
Newberry, South Carolina

Project No.: 60534283; Prepared by: JG; Date: 6/11/2018.

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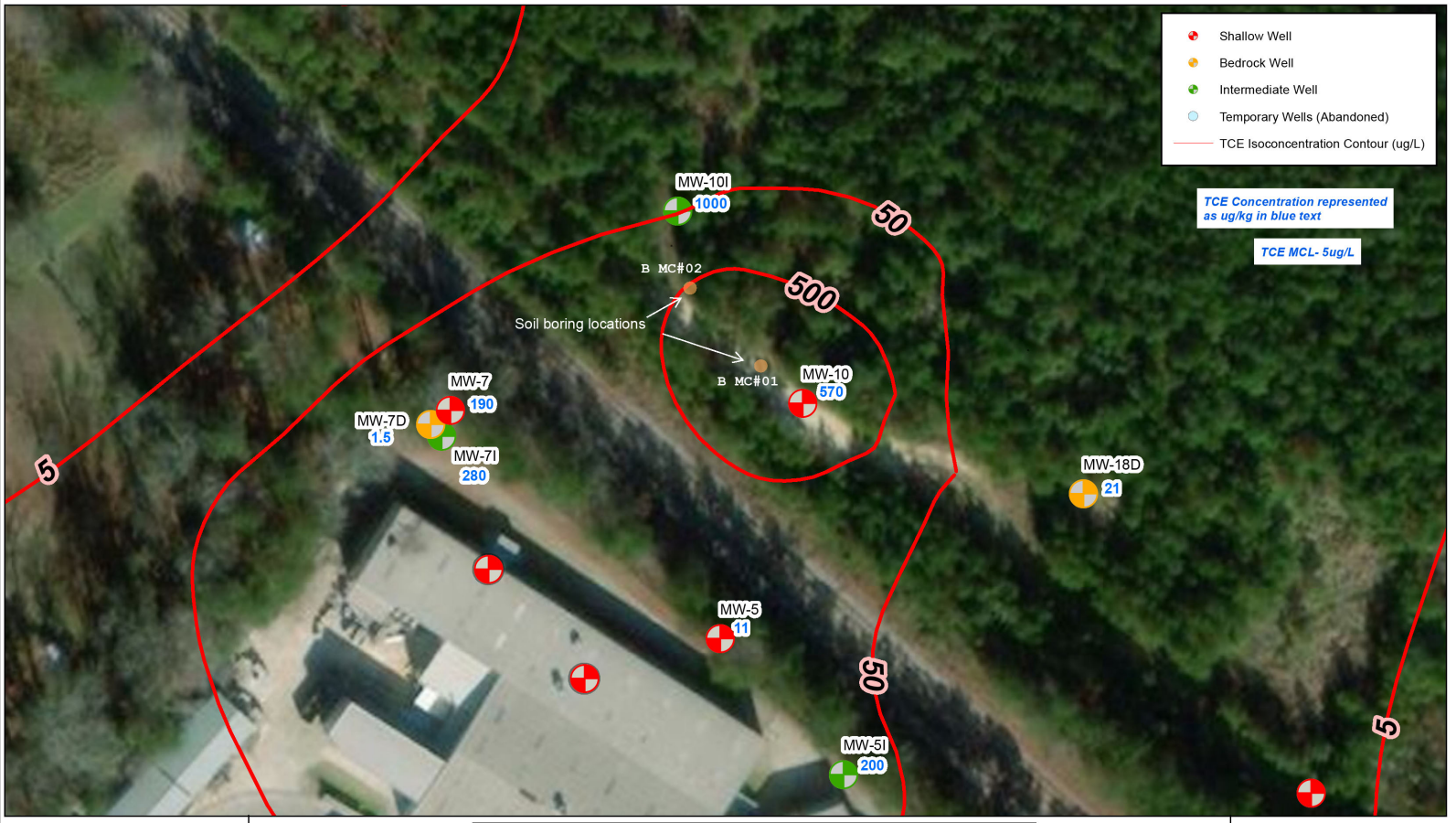

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Figure 2-1 BSTS Sample Locations

Shakespeare Composition Structures
Newberry, South Carolina

Project No.: 60534283; Prepared by: JG; Date:

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Appendix A

Results of TOD Testing

Redox Tech, LLC

REDOX TECH, LLC

"Providing Innovative In Situ Soil and Groundwater Treatment"

TOTAL OXIDANT DEMAND (TOD) SAMPLE ANALYSIS

Company: AECOM
Project: Newberry, SC

Samples prepared: September 19, 2019
Samples titrated: September 23, 2019
Oxidant: Potassium Permanganate

Sample	Dose (g/Kg)	Total Oxidant Demand (g/kg Soil)
MC-02S (25-27')	5	< 0.3
MC-02S (25-27')	10	2.8
MC-02I (36-38')	5	< 0.3
MC-02I (36-38')	10	2.1
Control	5 g/L	5.3 g/L*
Control	10 g/L	9.2 g/L*

*Measured control

TOD is reported in grams of oxidant per kilogram of groundwater sample. TOD testing for potassium permanganate completed per Haselow *et al., 2003.* Estimating the Total Oxidant Demand for In Situ Chemical Oxidation Design, Remediation, Autumn, 2003. Soil samples were paired with provided groundwater as follows, MC-02S with MW-10 and MC-02I with MW-10I.

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Appendix B

Bench Scale Treatability Study Report – SiREM Laboratories

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FINAL

Laboratory Biotreatability Study to Evaluate In-Situ Bioremediation of Chlorinated VOCs in Groundwater

Newberry, South Carolina

Prepared by:

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SiREM Ref: TL0337

12 March 2020

siremlab.com

SiREM

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%	percent
°C	degrees Celsius
°C/min	degrees Celsius per minute
µg/L	micrograms per liter
µL	microliter
*c*DCE	*cis*-1,2-dichloroethene
CO_2	carbon dioxide
cVOC	chlorinated volatile organic compound
Dhb	*Dehalobacter*
Dhc	*Dehalococcoides*
DHG	dissolved hydrocarbon gases
DI	deionized
ERD	enhanced reductive dechlorination
FID	flame ionization detector
g	grams
GC	gas chromatograph
IC	ion chromatograph
mg/L	milligrams per liter
min	minutes
mL	milliliters
mL/min	milliliters per minute
mM	millimolar
mmol/bottle	millimoles per bottle
mV	millivolts
mZVI	microscale zero valent iron
ORP	oxidation reduction potential
psi	pounds per square inch
QL	quantitation limit
RPM	revolutions per minute
SiREM	SiREM Laboratory
SRB	sulfate-reducing bacteria
TCE	trichloroethene
VC	vinyl chloride
VFA	volatile fatty acid
VOC	volatile organic compound
ZVI	zero valent iron

1 INTRODUCTION

AECOM retained SiREM Laboratory (SiREM) to perform a laboratory biotreatability study to assess the potential for in situ bioremediation of chlorinated volatile organic compounds (cVOCs) in groundwater at the Newberry, South Carolina site (the Site). The purpose of the study was to evaluate anaerobic biodegradation of the target compounds, namely chlorinated ethenes (trichloroethene [TCE], cis-1,2-dichloroethene [cDCE], and vinyl chloride [VC]) in groundwater.

The geologic materials labelled MC-01I and MC-01-23-27 and groundwater labelled MW-10I and MW-10 were collected by AECOM personnel on 18 September 2019. All materials were received by SiREM on 20 September 2019 in good condition at a temperature of 7 degrees Celsius (°C). Refer to Appendix A for the chain of custody documentation received with the materials.

Prior to the beginning of the biotreatability study, a buffering capacity test was completed starting on 24 September 2019 and finishing on 30 September 2019. The buffering capacity test was completed to inform the buffering amendment concentrations for the biotreatability study. The results of the buffering capacity test are presented in Appendix B.

The remainder of this report contains a summary of key degradation processes (Section 1.1), the experimental materials and methods (Section 2), the results and discussion of the microcosm study (Section 3), conclusions (Section 4) and report references (Section 5).

1.1 Summary of Degradation Processes

Biological degradation products of TCE include cDCE, VC and the fully dechlorinated end product ethene as shown Figure 1.

Natural attenuation processes can occur in situ and are often mediated by indigenous microbial populations present at contaminated sites. Enhanced reductive dechlorination (ERD), can in certain cases, be achieved by stimulating the indigenous microbial populations through the addition of electron donors. Bioaugmentation is the process in which a microbial population known to promote ERD or other biodegradation processes is introduced to groundwater to enhance the rate or extent of biodegradation.

KB-1® Plus is a custom formulated natural microbial consortium containing microorganisms (*Dehalococcoides* [*Dhc*] and *Dehalobacter* [*Dhb*]). *Dhc* are known to be responsible for mediating the complete dechlorination of TCE, cDCE, and VC to ethene (Major et al., 2002; Duhamel et al., 2002). The KB-1® Plus formulation used in this study was pre-conditioned at approximately pH 5.75 and that has been demonstrated complete reductive dechlorination of TCE at pH 5.75 to 6.0.

Zero valent iron (ZVI) and sulfidated ZVI (ZVI with a layer of ferrous sulfide over the particles) are also known to facilitate the dechlorination of chlorinated ethenes to acetylene, ethene or ethane. Two dominant pathways for the degradation of chlorinated ethene compounds by ZVI include hydrogenolysis and reductive β-elimination (Gillham et al., 2010). In the hydrogenolysis reaction, a chlorine atom is replaced by a hydrogen atom, accompanied by the addition of two electrons (from the iron). Reductive β-elimination involves release of two chlorine atoms and the formation

of an additional carbon-carbon bond. Both pathways are thought to occur simultaneously (Arnold and Roberts, 2000) and are presented in Figure 2.

Often ERD is paired with the application of ZVI to stimulate the onset of immediate reducing conditions, followed by sustained biological ERD. However, there have been studies which suggest that nanoscale ZVI (nZVI) may be inhibitory to biological dechlorination (Barnes et al. 2010), while microscale ZVI (mZVI) does not demonstrate this inhibitory effect. This may need to be taken into consideration when applying combination technologies, such as ERD and ZVI for the remediation of chlorinated ethenes. In this study, MicroEVO™ ISCR (Tersus Environmental, Wake Forest, NC) was tested to observe the effects of a combined ZVI, sulfidated ZVI and ERD amendment in the Site materials.

2 MATERIALS AND METHODS

The following sections describe the materials and methods used for microcosm construction and incubation (Section 2.1), and microcosm sampling and analysis (Section 2.2).

2.1 Microcosm Construction and Incubation

2.1.1 Microcosm Construction

Biotreatability microcosms were constructed in a disposable anaerobic glove bag containing the Site groundwater, geologic material, and all the materials required to construct the treatment and control microcosms. The glove bag was purged with nitrogen gas to create an anaerobic environment and to protect any microorganisms present in the Site materials from oxygen exposure. Prior to microcosm construction the Site geologic materials were homogenized by passing materials from the cores through a ½ inch sieve and mixing by hand.

Microcosms were constructed on 2 October 2019 (Day -5) by filling sterile 250 milliliter (mL) (nominal volume) screw cap Boston round clear glass bottles (Systems Plus, New Hamburg, ON) with 60 grams (g) of homogenized geologic material and 200 mL of Site groundwater. The bottles were capped with Mininert™ closures to allow repetitive sampling with minimal cVOC loss and to allow nutrient amendment, as needed, throughout the incubation period. Control and treatment microcosms were constructed in triplicate. Table 1 summarizes the details of microcosm construction and the amendments used for the treatment and control microcosms.

Anaerobic sterile control microcosms were constructed to quantify potential abiotic and experimental chlorinated volatile organic compound losses from the microcosms. The sterile controls were constructed by autoclaving the Site geologic materials at 121 °C and 15 pounds per square inch (psi) pressure for 45 to 60 minutes (min). After autoclaving the sterile control microcosms were returned to the anaerobic chamber, filled with 200 mL of Site groundwater, and amended with mercuric chloride and sodium azide as described in Tables 1 and 2.

2.1.2 Microcosm Amendments and Incubation

All microcosms were sampled and incubated in an anaerobic chamber (Coy Laboratory Products, Grass Lake, MI) filled with an atmosphere of approximately 80 percent (%) nitrogen, 10% carbon dioxide (CO_2) and 10% hydrogen (Linde Gases, Guelph, ON). Hydrogen in the anaerobic chamber functions to scavenge trace oxygen via a palladium catalyst. Anaerobic conditions in the anaerobic chamber were verified using an indicator containing resazurin (Sigma, St. Louis, MO) in a mineral medium, which turns pink in the presence of oxygen. During quiescent incubation, all microcosms were covered to minimize photodegradation, and stored horizontally to minimize volatile organic compound (VOC) losses via the (submerged) Mininert™ closure. Microcosms were incubated for a period of 101 days at approximately 22 °C (room temperature).

On 3 October 2019 (Day -4) three randomly selected microcosms were sampled for cVOC analysis. The results indicated that the aqueous TCE concentration was approximately 0.3 milligrams per liter (mg/L). In consultation with AECOM, it was decided that the TCE concentration was below the target Site concentration, and therefore the microcosms were amended with 130 microliters (µL) of a saturated TCE stock solution to achieve a target concentration of 1 mg/L.

Treatment microcosms were amended with electron donor on 7 October 2019 (Day 0). MicroEVO™ ISCR and EDS-ER™ with Nutrimens® (Tersus Environmental, Wake Forest, NC) were the selected electron donors evaluated in this study. MicroEVO™ ISCR was amended as three separate products: ISR-CL (a solution of suspended ferrous sulfide), a solution of mZVI suspended in glycerol, and EDS-ER™. The first microcosm of each treatment and control was amended with resazurin (Sigma, St. Louis, MO) to monitor redox conditions. Resazurin turns from pink to clear in the absence of oxygen and can be used to indicate the on-set of reducing conditions. Details of electron donor addition and resazurin amendment are provided in Tables 1 and 2.

The optimum pH for reductive dechlorination is 6.8 to 7.5 (Middledorp et al., 1999) with dechlorination occurring at reasonable rates in the 6.0 to 8.5 pH range (SiREM, unpublished data). At some sites, buffering may be necessary to ensure the pH is suitable for bioremediation. The pH in the received Site groundwater was below the range required for optimal dechlorination (approximately 5.4). Therefore, a buffering capacity test was conducted before set-up of the treatability microcosms to determine the amount of buffering required to maintain a neutral pH in the microcosms as described in Appendix B. On 7 October 2019 (Day 0), bottles from the MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented treatment and EDS-ER™ Amended/KB-1® Plus Bioaugmented treatment were buffered up to a pH of 7.0 ± 0.2 using a saturated sodium bicarbonate solution. On 30 October 2019 (Day 23), the pH in both treatments was observed to have decreased below the target pH range (7.0 ±0.2) and so were buffered a second time with a saturated sodium bicarbonate solution. On 6 December 2019 (Day 60), in consultation with AECOM, bottles from the MicroEVO™ ISCR Amended treatment were also buffered up to a pH of 7.0 ± 0.2 using a saturated sodium bicarbonate solution. Buffering details are presented in Tables 1, 2, and 5.

Bioaugmentation may improve the extent and rate of TCE dechlorination. Microcosms are typically bioaugmented after reducing conditions required by the KB-1® Plus culture are achieved. Suitable reducing conditions are typically achieved after electron donor addition and are assessed by changes in the resazurin indicator colour (from pink to clear), the onset of sulfate reduction, and a decrease in oxidation-reduction potential (ORP) to below -75 millivolts (mV). The ORP of the treatment microcosms were measured on 4 November 2019 (Day 28) and were found to be -167 mV, -185 mV, and -85 mV in the MicroEVO™ ISCR Amended treatment, MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented treatment, and EDS-ER™ Amended/KB-1® Plus Bioaugmented treatment respectively, indicating suitable conditions for bioaugmentation. Sulfate reduction was also observed on 4 November 2019 (Day 28) in all treatments. The MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented treatment and EDS-ER™ Amended/KB-1® Plus Bioaugmented treatments were bioaugmented with KB-1® Plus culture on 18 November 2019 (Day 41). The KB-1® Plus culture formulated to degrade TCE to ethene at pH conditions of 5.75 to 6 was selected for this study due to the pH of the Site material being approximately 5.4 upon receipt. Even though the bioaugmentation microcosms had been buffered to a neutral pH there was the potential for the pH to return to the starting pH conditions, so the KB-1® Plus low pH formulation was selected to allow for uninhibited degradation of the chlorinated ethenes if the pH decreased in the buffered microcosms. Details of bioaugmentation and electron donor additions are presented in Tables 1 and 2.

2.2 Microcosm Sampling and Analysis

2.2.1 Microcosm Sampling Schedules

The frequency at which aqueous samples were collected from the control and treatment microcosms for analysis of cVOCs, dissolved hydrocarbon gases (DHGs – ethene, ethane, and methane) and pH varied from 7 days to 28 days based on the rate of dechlorination. Aqueous samples were also collected less frequently for analysis of volatile fatty acids (VFAs – lactate, acetate, propionate, formate, butyrate and pyruvate) and anions (sulfate, nitrate, nitrite, chloride, and phosphate).

The microcosms were sampled using gas-tight 1 mL Hamilton glass syringes. Separate sets of syringes were used for the bioaugmented and non-bioaugmented treatments to minimize the potential for transfer of KB-1® Plus microorganisms from bioaugmented to non-bioaugmented treatments. Syringes were cleaned with acidified water (pH ~2) and rinsed 10 times with deionized (DI) water between samples to ensure that VOCs and microorganisms were not transferred between different samples or treatments.

2.2.2 Analysis of cVOCs and Dissolved Hydrocarbon Gases

This section describes the methods used to quantify the VOCs and DHGs. The quantitation limits (QL) for the VOCs and DHGs are 10 micrograms per liter (µg/L) in the microcosms based on the sample dilution factor used and the lowest concentration standards that are included in the linear calibration trend.

Aqueous VOC and DHG concentrations in the microcosms are measured using an Agilent 7890 gas chromatograph (GC) equipped with an Agilent G1888 headspace autosampler programmed to heat each sample vial to 75 °C for 45 min prior to headspace injection into a GSQ Plot column (0.53 millimeters x 30 meters, J&W) with a flame ionization detector (FID). Sample vials are heated to ensure that all VOCs in the aqueous sample partition into the headspace. The injector temperature was 200 °C, and the detector temperature was 250 °C. The oven temperature was programmed as follows: 35 °C for 2 min, increased to 100 °C at 50 degrees Celsius per minute (°C/min), then increased to 185 °C at 25 °C/min and held at 185 °C for 6.80 min. The helium carrier gas was set to flow at a rate of 11 milliliters per minute (mL/min).

After withdrawing a sample (as described in Section 2.2.1) from the microcosms, the sample was injected into a 10 mL auto sampler vial containing acidified DI water (pH ~2). The sample volume was added to the vial containing acidified DI water to bring the total volume up to 6 mL. The water was acidified to inhibit microbial activity between microcosm sampling and GC analysis. The vial was sealed with an inert Teflon™-lined septum and aluminum crimp cap for automated injection of 3 mL of headspace onto the GC. One VOC standard was analyzed with each set of samples to verify the instrument five-point calibration curve using methanolic stock solutions containing known concentrations of the target analytes. Calibration was performed using external standards purchased as standard solutions (Sigma, St Louis, Missouri), where known volumes of standard solutions were added to acidified water in auto sampler vials and analyzed as described above for microcosm samples. Data were integrated using ChemStation Software (Agilent Technologies, Santa Clara, California).

2.2.3 Analysis of Anions and Total Volatile Fatty Acids

Anions and total VFA analysis were performed on a Thermo-Fisher ICS-2100 ion chromatograph (IC) equipped with a Thermo-Fisher AS-DV autosampler and an AS18 column. An isocratic separation was performed using 33 millimolar (mM) reagent grade sodium hydroxide eluent generator cartridge (Thermo Scientific, Burlington, ON) eluent for 13 min and a flow rate of 0.25 mL/min. One standard was analysed with each set of samples tested in order to verify the seven-point calibration using external standards of known concentrations. External standards were prepared gravimetrically using chemicals of the highest purity available (Sigma St Louis, MO or Bioshop, Burlington, ON). Data were integrated using Chromeleon 7® Chromatography software (Thermo-Fisher, Burlington, ON). The QLs were as follows: 0.07 mg/L total VFA, 0.07 mg/L chloride, 0.09 mg/L nitrite, 0.09 mg/L nitrate, 0.07 mg/L sulfate, 0.07 mg/L phosphate and 0.08 mg/L bromide. The total VFA value was initially calibrated as lactate, but includes lactate, formate, acetate, propionate, pyruvate and butyrate (valerate has not been confirmed). The VFA method described below (Section 2.2.4) is used to quantify individual VFAs.

A 0.5 mL sample was collected (as described in section 2.2.1), after which the sample was placed in a 1.5 mL micro-centrifuge tube. Samples were centrifuged for five minutes at 13,000 revolutions per minute (RPM) to remove solids. The supernatant was removed, diluted 50-fold in DI water and placed in a Thermo-Fisher autosampler vial with a cap that filters the sample during automated injection onto the IC through a 25 µL sample loop.

2.2.4 Analysis of Volatile Fatty Acids

Individual VFA (lactate, acetate, propionate, formate, butyrate and pyruvate) analysis was performed on a Thermo-Fisher ICS-2100 IC equipped with a Thermo-Fisher AS-DV autosampler and an AS11-HC column. A gradient separation was performed using the following eluent profile; 1.0 mM sodium hydroxide for 8.0 min to 15 mM at 18.0 min and proceeding to 30 mM at 28.0 min with a flow rate of 0.25 mL/min. Calibration was performed using external standards of known concentrations. One standard was analysed with each set of samples to verify the instrument's seven-point calibration curve produced using external standards of known concentrations. External standards were prepared gravimetrically using chemicals of the highest purity available (Sigma St Louis, MO or Bioshop, Burlington, ON). Data were integrated using Chromeleon 7® Chromatography software (Thermo-Fisher, Burlington, ON). The QLs were as follows: lactate 0.40 mg/L, acetate 0.54 mg/L, propionate 0.31 mg/L, formate 0.23 mg/L, butyrate 0.41 mg/L and pyruvate 0.69 mg/L.

A 0.5 mL sample was withdrawn (as described in section 2.2.1), after which the sample was placed in a 1.5 mL micro-centrifuge tube. Samples were centrifuged for five minutes at 13,000 RPM in a micro-centrifuge to remove solids. The supernatant was removed, diluted 50-fold in DI water and placed in a Thermo-Fisher autosampler vial with a cap that filters the sample during automated injection onto the IC through a 25 µL sample loop.

2.2.5 Analysis of pH

The pH measurements were performed using an Oakton pH spear with a combination pH electrode (Oakton, Vernon Hills, IL). A 0.5 mL sample was collected (as described in section 2.2.1) in a 1.5 mL micro-centrifuge tube. The vial was removed from the glove box and the pH was measured on the lab bench. The pH spear was calibrated at each sampling event according to the manufacturer's instructions using pH 4.0, 7.0 and 10 standards.

2.2.6 Analysis of ORP

The ORP measurements were performed using an YSI Multilab IDS Meter with YSI 4210 ORP glass electrode (Mandel Scientific, Guelph, ON). A 1.0 mL sample was collected (as described in Section 2.2.1) and taken out of the glove box. The sample was transferred to a 5 mL Thermo-Fisher vial and the ORP measured on the lab bench. The ORP probe was tested weekly according to the manufacturer's instructions using Zobell's solution.

3 RESULTS AND DISCUSSION

The following sections present and discuss the results of the biotreatability study:

- Redox processes (Section 3.1),
- Volatile Fatty Acids (Section 3.2),
- pH (Section 3.3)

- Chlorinated ethenes biodegradation results (Section 3.4)

Tables 2, 3, 4, and 5 provide cVOC, ethene, ethane, methane, anion, VFA, and pH data from the control and treatment microcosms over the incubation period for the study. All cVOC, ethene, ethane, and methane concentrations are presented in units of mg/L and millimoles per microcosm bottle (mmol/bottle) to demonstrate mass balances on a molar basis. Concentrations were converted from mg/L to mmol/bottle using Henry's Law as demonstrated in Appendix C. All anion and VFA concentrations are reported in mg/L and ORP values were reported in mV.

Figures 3 through 7 present trends in the concentrations of chlorinated ethenes and ethene in the control and treatment microcosms over the incubation period for the study.

3.1 Redox Processes

The addition of electron donor typically results in microbial activity that promotes changes in the redox conditions in groundwater. Aerobic or mildly reducing redox conditions will be reduced, resulting in more strongly reducing conditions required to support anaerobic degradation of cVOCs.

The sequence of redox reactions in groundwater is well known (Appelo and Postma, 1994). Oxygen is first consumed, followed by nitrate (denitrification), manganese and iron, then sulfate reduction. The final step is CO_2 reduction producing methane (methanogenesis). The consumption of each species in sequence indicates that conditions are becoming increasingly reducing. Dechlorination of chlorinated solvents typically occurs in the range of sulfate reducing to methanogenic conditions.

In the sterile and active control microcosms, nitrate and sulfate were present and remained relatively stable throughout the incubation period (Table 3). Methane concentrations increased slightly in the active control microcosms from Day 14 to Day 42 (Table 2), perhaps due to some intrinsic methanogens; however, methane concentrations then decreased to non-detectable from Day 70 onwards. This suggests that reducing conditions were not established in the sterile or active control microcosms. These observations are consistent with low levels of microbial activity expected in control microcosms.

Sulfate reduction was observed in the MicroEVO™ ISCR and EDS-ER™ Amended treatments by Day 28 (Table 3). Methane concentrations began increasing by Day 28 in the MicroEVO™ ISCR amended and EDS-ER™ Amended treatments (Table 2). Methane concentrations later decreased to non-detectable levels in the non-bioaugmented MicroEVO™ ISCR Amended microcosms, while methane concentrations continued to increase throughout the incubation periods for both the MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented and EDS-ER™ Amended/KB-1® Plus Bioaugmented treatments. These results suggest that both electron donors can support the necessary reducing conditions needed for ERD of chlorinated ethenes to occur.

3.2 Volatile Fatty Acids

MicroEVO™ ISCR and EDS-ER™ contain long chain fatty acids, which provide fermentable electron donor sources to promote microbial activity. The fermentation of long chain fatty acids results in the production of VFAs and hydrogen, which is the ultimate electron donor used by dechlorinators. The presence of the intermediate VFA fermentation products can indicate if the production of hydrogen is occurring and if there is electron donor present for reductive dechlorination to occur.

The concentrations of lactate, formate, butyrate, and pyruvate in the MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented treatment were below the detection limit at Day 49 (Table 4), while the concentrations of acetate and propionate were 869 and 203 mg/L respectively. By Day 101, the concentration of acetate had increased to 977 mg/L and the concentration of propionate increased to 249 mg/L, while all other VFA concentrations remained near detection limits. For the EDS-ER™ Amended/KB-1® Plus Bioaugmented treatment, the concentrations of lactate, formate, butyrate, and pyruvate were below the detection limits on Day 49, while acetate and propionate concentrations were 43 and 2.4 mg/L respectively. By Day 105, the concentration of acetate increased to 104 mg/L and the concentration of propionate decreased to 2.0 mg/L, while all other VFA concentrations remained near detection limits.

These results suggest that the fermentable portions of the MicroEVO™ ISCR and EDS-ER™ were being actively consumed and fermented to produce VFAs and ultimately hydrogen. The VFA concentrations were higher in MicroEVO™ ISCR amended microcosms than EDS-ER™ amended microcosms due to the higher sulfate concentrations present in MicroEVO™ ISCR, which provides more substrate for microbes to ferment. Over the duration of the study the VFA concentrations continued to increase, which also suggests that sufficient electron donor was amended to the microcosms to maintain reducing conditions suitable for reductive dechlorination.

3.3 pH

Prior to the beginning of the biotreatability study a buffering capacity test was completed to determine the amount of buffer that would be required to adjust the pH of the Site material to neutral (pH 7.0 ± 0.2). The results of the 6-day buffering capacity test indicated that buffering the Site materials in the microcosms would require 0.067 g of sodium bicarbonate amended to each test microcosm. The buffering capacity test results are presented in Appendix B.

The initial pH in the control microcosms was approximately 5.7. Throughout the incubation period, the pH of the control microcosms ranged between 5.60 and 5.80 (Table 5). The initial pH in the MicroEVO™ ISCR Amended, MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented, and EDS-ER™ Amended/KB-1® Plus Bioaugmented microcosms was 7.48, 8.10, and 6.83 respectively, after being buffered with the requisite amount of sodium bicarbonate as determined in the buffering capacity test (Table 1 and Appendix B). In the MicroEVO™ ISCR Amended treatment, the pH decreased to approximately 6.3 by Day 56, was adjusted to a pH of 7.0±0.2 on Day 60 and remained stable at approximately 7.0 for the remainder of the study. For the MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented treatment, the pH decreased to 6.09 by Day 14, was adjusted to 7.0±0.2 on Day 23 and remained stable around 7.0 for the remainder of the study. In

the EDS-ER™ Amended/KB-1® Plus Bioaugmented treatment, the pH decreased to 6.57 by Day 14, was adjusted to a pH of 7.0 on Day 23, and gradually decreased to 6.50 by Day 101.

The optimal pH for reductive dechlorination is 6.8 to 7.5 (Middledorp et al., 1999) with dechlorination occurring at reasonable rates in the 6.0 to 8.5 pH range (SiREM, unpublished data). The KB-1® Plus culture used in this study has been acclimated under acidic conditions to facilitate the complete reductive dechlorination of TCE to ethene at a pH between 5.75 and 6.0. Reductive dechlorination and fermentation of long chain fatty acids produces acid which can lower the pH, as observed in the EDS-ER™ amended treatment.

These results suggest that a buffering agent is required to maintain the pH in the optimal range to support reductive dechlorination. The use of the low pH KB-1® Plus culture may help to lower the amount of buffer required at the Site as this culture can promote complete dechlorination to ethene at pH levels down to 5.75.

3.4 Chlorinated Ethene Biodegradation Results

3.4.1 Degradation Half-Lives for Chlorinated Ethenes

Laboratory half-lives were calculated based on the average dechlorination observed in the treatment microcosms as indicated in Table 6. First order reaction kinetics was assumed for all calculations as described in Newell et al, 2002. The half-lives were calculated using the following relationship:

$$Half - life = \frac{\ln(2)}{\left[\frac{\ln\left(\frac{C_2}{C_1}\right)}{t_2 - t_1}\right]}$$

where,

C_1 is the concentration at early time (t_1 days)

C_2 is the concentration at later time (t_2 days)

Based on the data collected, the calculated dechlorination half-lives for TCE, cDCE, and VC were determined (Table 6). Half-lives were not determined for compounds in some treatments where the concentration remained stable or increased throughout the study period.

3.4.2 Anaerobic Sterile and Active Control Microcosms

All cVOC concentrations in the sterile and active control microcosms remained relatively stable over the incubation period with no increases in degradation products (Table 2 and Figures 3 and 4). The half-lives for the chlorinated ethene compounds were incalculable, as the concentrations remained stable (Table 6). These results are consistent with the limited microbial activity

suggested by the lack of observed sulfate reduction and methanogenesis measured in the active controls (Tables 2 and 3).

3.4.3 MicroEVO™ ISCR Amended Microcosms

In the MicroEVO™ ISCR amended microcosms, TCE and cDCE concentrations initially decreased likely due to abiotic degradation by ZVI, as evidenced by the increase in ethene and acetylene concentrations (Table 2 and Figure 5). ZVI can facilitate the abiotic degradation of TCE and cDCE to ethene or acetylene, as demonstrated in Figure 2.

By Day 28, TCE, cDCE, ethene and acetylene concentrations stabilized. VC concentrations were non-detect throughout the duration of the study. In an attempt to stimulate degradation via Site microbes, the MicroEVO™ ISCR amended microcosms were buffered to a pH of 7.0 ± 0.2 on 6 December 2019 (Day 60). After buffering, TCE and cDCE concentrations still remained relatively stable. The half-lives for TCE and cDCE were calculated to be 78 and 30 days respectively (Table 6).

These results suggest that the addition of MicroEVO™ ISCR may have stimulated partial abiotic degradation of TCE and cDCE to ethene and acetylene, but complete degradation of the chlorinated ethenes may not be possible with the addition of MicroEVO™ ISCR alone.

3.4.4 MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented Microcosms

Prior to bioaugmentation on Day 42, the MicroEVO™ ISCR amended/KB-1® Plus bioaugmented microcosms performed similarly to the non-bioaugmented MicroEVO™ ISCR treatment (Table 2 and Figures 5 and 6). The TCE and cDCE concentrations initially decreased by Day 28 with a corresponding increase in ethene and acetylene concentrations. After the initial degradation, TCE and cDCE concentrations remained relatively stable until bioaugmentation on Day 42. After bioaugmentation, dechlorination of TCE with a corresponding increase in cDCE and VC was observed by Day 49, followed by decreases in cDCE and VC with a corresponding increase in ethene. By Day 56 TCE and cDCE concentrations were below detection limits, while VC concentrations decreased more slowly from 0.15 mg/L on Day 56 to 0.11 mg/L by Day 101. Ethene concentrations increased from Day 56 to Day 101, suggesting that VC dechlorination to ethene was occurring. Half-lives for TCE, cDCE, and VC were calculated to be 2.9, 15, and 106 days, respectively, after the addition of KB-1® Plus (Table 6). The relatively slow degradation of VC was likely the result of the high sulfate concentrations from the sulfidated ZVI component of the MicroEVO™ ISCR. The presence of high sulfate concentrations can stimulate populations of sulfate-reducing bacteria (SRB), which can compete for the same electron donor source (hydrogen) as *Dhc*, limiting access to the electron donor for *Dhc* and reducing the overall rate of chlorinated ethene degradation (Panagiotakis et al. 2014).

These results suggest that degradation of TCE to VC and potentially to ethene in the Site material is possible when using MicroEVO™ ISCR combined with KB-1® Plus bioaugmentation, but the presence of high sulfate concentrations from the MicroEVO™ ISCR amendment may slow the overall rate of chlorinated ethenes degradation.

3.4.5 EDS-ER™ Amended/KB-1® Plus Bioaugmented Microcosms

In the EDS-ER™ amended/KB-1® Plus bioaugmented microcosms, TCE remained stable prior to bioaugmentation on Day 42 (Table 2 and Figure 7). After bioaugmentation, dechlorination of TCE with corresponding increases in cDCE and VC was observed by Day 49, followed by decreases in cDCE and VC to below detection limits with a corresponding increase in ethene by Day 56. Half-lives for TCE, cDCE and VC were calculated to be 1.0, 1.6, and 1.4 days after the addition of KB-1® Plus (Table 6).

These results suggest that complete dechlorination of TCE to ethene in the Site material is possible when using EDS-ER™ as electron donor combined with KB-1® Plus bioaugmentation.

4 CONCLUSIONS

The laboratory biotreatability study results suggest the following conclusions:

1. The intrinsic bacterial populations at the Site may not be suitable for facilitating complete dechlorination of TCE to ethene.

2. MicroEVO™ ISCR and EDS-ER™ amendments can promote the appropriate geochemical conditions for reductive dechlorination of chlorinated ethenes.

3. Complete dechlorination of TCE to ethene occurred with EDS-ER™ amendment combined with KB-1® Plus bioaugmentation.

4. Dechlorination of TCE to VC occurred with MicroEVO™ ISCR amendment combined with KB-1® Plus bioaugmentation, but complete degradation of VC to ethene was slow due to the high sulfate concentrations.

5. The Site pH is below the range suitable for reductive dechlorination to occur and a buffering agent may be required to increase the pH to the dechlorination range. The low pH KB-1® Plus culture can be used at the Site to lower the buffering requirements from the optimal range of 6.8 – 7.5 to pH levels in the 5.75 - 6.0 range.

The results of this study indicate that ERD using KB-1® Plus bioaugmentation combined with either MicroEVO™ ISCR or EDS-ER™ as an electron donor has the potential to be an effective remedial approach for the Site.

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TABLES

TABLE 1: SUMMARY OF MICROCOSM CONTROLS, TREATMENTS AND AMENDMENTS
Newberry, SC

SiREM

Treatment/Control	Assigned Microcosm Number	Number of Microcosms	Geological Material (g)	Groundwater (mL)	Headspace (mL)	Sodium Azide	Mercuric Chloride	VOCs	Resazurin	Buffering	ISR-CL	mZVI	EDS-ER™	Nutrimens®	KB-1® Plus
Anaerobic Sterile Control	1 to 3	3	60	200	20	Amended with 0.5 mL of a 5 % sodium azide solution on Day -5.	Amended with 2.8 mL of a 2.7 % mecuric chloride solution on Day -5.	Spiked with 0.13 mL of a saturated TCE solution to target 1 g/L on Day -3.	Amended first replicate with 100 µL of a 1 g/L resazurin solution on Day -5.	--	--	--	--	--	--
Anaerobic Activec Control	4 to 6	3	60	200	20	--	--			--	--	--	--	--	--
MicroEVO™ ISCR Amended	7 to 9	3	60	200	20	--	--			Amended with 1.0, 1.5, or 1.7 mL of a saturated sodium bicarbonate solution to target a pH of 7.0 ± 0.2 on Day 60.	Amended with 3.1 mL of a 1,270 g/L glycerol based solution of ISR-CL to target 20 g/L FeS on Day 0.	Amended with 0.59 mL of a 1,360 g/L glycerol based mZVI solution to target 4 g/L on Day 0.	Amended with 0.43 mL of a 925 g/L EDS-ER™ solution to target 2 g/L as EVO on Day 0.	--	--
MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented	10 to 12	3	60	200	20	--	--			Amended with 0.45 mL of a saturated sodium bicarbonate solution on Day 0 and with 1.5, 1.7, or 2.1 mL to target a pH of 7.0 ± 0.2 on Day 23.	Amended with 3.1 mL of a 1,270 g/L glycerol based solution of ISR-CL to target 20 g/L FeS on Day 0.	Amended with 0.59 mL of a 1,360 g/L glycerol based mZVI solution to target 4 g/L on Day 0.	Amended with 0.43 mL of a 925 g/L EDS-ER™ solution to target 2 g/L as EVO on Day 0.	--	Amended with 0.5 mL of KB-1® Plus on Day 42.
EDS-ER™ Amended/KB-1® Plus Bioaugmented	13 to 15	3	60	200	20	--	--			Amended with 0.45 mL of a saturated sodium bicarbonate solution on Day 0 and with 0.15 mL to target a pH of 7.0 ± 0.2 on Day 23.	--	--	Amended with 0.43 mL of a 925 g/L EDS-ER™ solution to target 2 g/L as EVO on Day 0.	Amended with 0.018 mL of a 1,100 g/L Nutrimens solution to target of 0.1 g/L on Day 0.	Amended with 0.5 mL of KB-1® Plus on Day 42.

Notes:
-- - not applicable
% - percent
µL - microliter
EVO - emulsified vegetable oil
FeS - ferrous sulfate
g - grams
g/L - grams per liter
mL - milliliters
mZVI - microscale zero valent iron
TCE - trichloroethene
VOCs - volatile organic compounds

TABLE 2: SUMMARY OF MICROCOSM cVOC AND DHG RESULTS
Newberry, SC

SIREM

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene					DHGs			Comments
				TCE	cDCE	VC	Ethene	Total Ethenes	Acetylene	Ethane	Methane	
				mg/L	mg/L	mg/L	mg/L	mmol/bottle	mg/L	mg/L	mg/L	
Anaerobic Sterile Control	02-Oct-19	-5										Amended first replicate with resazurin.
												Anended with mercuric chloride and sodium azide.
	04-Oct-19	-3										Spiked with a saturated TCE solution to a target concentration of 1 mg/L.
	07-Oct-19	0	ANSC-1	1.5	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			ANSC-2	1.7	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			ANSC-3	1.9	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			Average Concentration (mg/L)	1.7	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	3.1E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0027**	**ND**	**ND**	**ND**	**2.7E-03**	**ND**	**ND**	**ND**	
	21-Oct-19	14	ANSC-1	1.2	0.032	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANSC-2	1.7	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANSC-3	1.8	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			Average Concentration (mg/L)	1.6	0.011	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	5.3E-04	3.9E-05	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0025**	**0.000023**	**ND**	**ND**	**2.5E-03**	**ND**	**ND**	**ND**	
	04-Nov-19	28	ANSC-1	1.5	<0.010	<0.010	<0.010	--	<0.0010	0.081	0.11	
			ANSC-2	1.8	<0.010	<0.010	<0.010	--	<0.0010	0.081	0.11	
			ANSC-3	2.0	<0.010	<0.010	<0.010	--	<0.0010	0.081	0.11	
			Average Concentration (mg/L)	1.8	ND	ND	ND	--	ND	0.081	0.11	
			Standard Deviation (mmoles)	4.5E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	5.2E-06	1.2E-05	
			Average Total mmoles	**0.0029**	**ND**	**ND**	**ND**	**2.9E-03**	**ND**	**0.0016**	**0.005**	
	18-Nov-19	42	ANSC-1	1.5	<0.010	<0.010	<0.010	--	<0.0010	0.030	0.10	
			ANSC-2	1.8	<0.010	<0.010	<0.010	--	<0.0010	0.029	0.10	
			ANSC-3	1.9	<0.010	<0.010	<0.010	--	<0.0010	<0.010	0.10	
			Average Concentration (mg/L)	1.7	ND	ND	ND	--	ND	0.020	0.10	
			Standard Deviation (mmoles)	3.4E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	3.4E-04	1.7E-05	
			Average Total mmoles	**0.0028**	**ND**	**ND**	**ND**	**2.8E-03**	**ND**	**0.00039**	**0.0047**	
	16-Dec-19	70	ANSC-1	1.5	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANSC-2	1.8	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANSC-3	1.9	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			Average Concentration (mg/L)	1.7	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	3.2E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0028**	**ND**	**ND**	**ND**	**2.8E-03**	**ND**	**ND**	**ND**	
	16-Jan-20	101	ANSC-1	1.6	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANSC-2	1.9	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANSC-3	2.0	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			Average Concentration (mg/L)	1.8	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	3.6E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0029**	**ND**	**ND**	**ND**	**2.9E-03**	**ND**	**ND**	**ND**	
Anaerobic Active Control	02-Oct-19	-5										Amended first replicate with resazurin.
	04-Oct-19	-3										Spiked with a saturated TCE solution to a target concentration of 1 mg/L.
	07-Oct-19	0	ANAC-1	1.2	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			ANAC-2	1.1	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			ANAC-3	1.2	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			Average Concentration (mg/L)	1.2	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	3.7E-05	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0019**	**ND**	**ND**	**ND**	**1.9E-03**	**ND**	**ND**	**ND**	
	21-Oct-19	14	ANAC-1	1.1	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANAC-2	1.1	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANAC-3	1.2	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			Average Concentration (mg/L)	1.1	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	9.4E-05	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0018**	**ND**	**ND**	**ND**	**1.8E-03**	**ND**	**ND**	**ND**	
	04-Nov-19	28	ANAC-1	1.0	<0.010	<0.010	<0.010	--	<0.0010	0.061	0.082	
			ANAC-2	1.1	<0.010	<0.010	<0.010	--	<0.0010	0.078	0.10	
			ANAC-3	1.2	<0.010	<0.010	<0.010	--	<0.0010	0.077	0.10	
			Average Concentration (mg/L)	1.1	ND	ND	ND	--	ND	0.072	0.096	
			Standard Deviation (mmoles)	1.8E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	1.9E-04	5.8E-04	
			Average Total mmoles	**0.0018**	**ND**	**ND**	**ND**	**1.8E-03**	**ND**	**0.0014**	**0.0045**	
	18-Nov-19	42	ANAC-1	1.1	<0.010	<0.010	<0.010	--	<0.0010	0.029	0.10	
			ANAC-2	0.95	<0.010	<0.010	<0.010	--	<0.0010	0.029	0.099	
			ANAC-3	1.1	<0.010	<0.010	<0.010	--	<0.0010	0.028	0.096	
			Average Concentration (mg/L)	1.1	ND	ND	ND	--	ND	0.029	0.098	
			Standard Deviation (mmoles)	1.5E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	1.7E-05	1.2E-04	
			Average Total mmoles	**0.0017**	**ND**	**ND**	**ND**	**1.7E-03**	**ND**	**0.00057**	**0.0046**	

TABLE 2: SUMMARY OF MICROCOSM cVOC AND DHG RESULTS
Newberry, SC

SIREM

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene					DHGs			Comments
				TCE	cDCE	VC	Ethene	Total Ethenes	Acetylene	Ethane	Methane	
				mg/L	mg/L	mg/L	mg/L	mmol/bottle	mg/L	mg/L	mg/L	
Anaerobic Active Control Continued	16-Dec-19	70	ANAC-1	1.1	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANAC-2	1.1	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANAC-3	1.1	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			Average Concentration (mg/L)	1.1	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	5.0E-05	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0018**	**ND**	**ND**	**ND**	**1.8E-03**	**ND**	**ND**	**ND**	
	16-Jan-20	101	ANAC-1	1.2	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANAC-2	1.2	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			ANAC-3	1.3	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			Average Concentration (mg/L)	1.2	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	8.8E-05	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0019**	**ND**	**ND**	**ND**	**1.9E-03**	**ND**	**ND**	**ND**	
MicroEVO™ ISCR Amended	02-Oct-19	-5										Amended first replicate with resazurin.
	04-Oct-19	-3										Spiked with a saturated TCE solution to a target concentration of 1 mg/L.
	07-Oct-19	0										Amended with glycerol-suspended mZVI, ISR-CL, and EDS-ER™ to target 4 g/L ZVI, 20 g/L FeS, and 2 g/L EVO, respectively.
			MEVO-ISCR-1	0.69	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			MEVO-ISCR-2	0.55	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			MEVO-ISCR-3	0.46	0.26	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			Average Concentration (mg/L)	0.57	0.085	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	1.9E-04	3.1E-04	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00091**	**0.00018**	**ND**	**ND**	**1.1E-03**	**ND**	**ND**	**ND**	
	21-Oct-19	14	MEVO-ISCR-1	0.34	0.010	<0.010	0.014	--	0.0083	<0.010	<0.050	
			MEVO-ISCR-2	0.23	<0.010	<0.010	<0.010	--	0.0035	<0.010	<0.050	
			MEVO-ISCR-3	0.30	<0.010	<0.010	0.013	--	0.0067	<0.010	<0.050	
			Average Concentration (mg/L)	0.29	0.0034	ND	0.0090	--	0.0062	ND	ND	
			Standard Deviation (mmoles)	8.6E-05	1.2E-05	0.0E+00	1.0E-04	--	2.2E-05	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00046**	**0.0000072**	**ND**	**0.00012**	**5.9E-04**	**0.000055**	**ND**	**ND**	
	04-Nov-19	28	MEVO-ISCR-1	0.26	0.013	<0.010	0.016	--	0.012	0.078	0.10	
			MEVO-ISCR-2	0.17	<0.010	<0.010	<0.010	--	0.0049	0.077	0.10	
			MEVO-ISCR-3	0.29	0.011	<0.010	0.012	--	0.0096	0.078	0.10	
			Average Concentration (mg/L)	0.25	0.0082	ND	0.0092	--	0.0089	0.078	0.10	
			Standard Deviation (mmoles)	1.1E-04	1.5E-05	0.0E+00	1.1E-04	--	3.3E-05	1.0E-05	2.9E-05	
			Average Total mmoles	**0.00040**	**0.000017**	**ND**	**0.00012**	**5.4E-04**	**0.000079**	**0.0015**	**0.0048**	
	18-Nov-19	42	MEVO-ISCR-1	0.28	0.012	<0.010	0.015	--	0.011	0.03	0.10	
			MEVO-ISCR-2	0.17	0.011	<0.010	<0.010	--	0.0058	0.03	0.10	
			MEVO-ISCR-3	0.29	0.010	<0.010	0.011	--	0.0099	<0.010	<0.050	
			Average Concentration (mg/L)	0.25	0.011	ND	0.0090	--	0.0090	0.02	0.068	
			Standard Deviation (mmoles)	1.0E-04	2.3E-06	0.0E+00	1.1E-04	--	2.5E-05	3.4E-04	2.7E-03	
			Average Total mmoles	**0.00040**	**0.000024**	**ND**	**0.00012**	**5.4E-04**	**0.000080**	**0.00039**	**0.0032**	
	02-Dec-19	56	MEVO-ISCR-1	0.29	0.027	<0.010	0.016	--	0.010	<0.010	<0.050	
			MEVO-ISCR-2	0.16	<0.010	<0.010	<0.010	--	0.0051	<0.010	<0.050	
			MEVO-ISCR-3	0.26	<0.010	<0.010	0.010	--	0.0079	<0.010	<0.050	
			Average Concentration (mg/L)	0.24	0.009	ND	0.0087	--	0.0076	ND	ND	
			Standard Deviation (mmoles)	1.1E-04	3.3E-05	0.0E+00	1.1E-04	--	2.2E-05	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00038**	**0.000019**	**ND**	**0.00011**	**5.1E-04**	**0.000068**	**ND**	**ND**	
	06-Dec-19	60										Amended with a saturated bicarbonate solution to target a pH of 7.0±0.2.
	16-Dec-19	70	MEVO-ISCR-1	0.27	0.014	<0.010	0.014	--	0.0099	<0.010	<0.050	
			MEVO-ISCR-2	0.16	0.011	<0.010	<0.010	--	0.0047	<0.010	<0.050	
			MEVO-ISCR-3	0.21	<0.010	<0.010	<0.010	--	0.0012	<0.010	<0.050	
			Average Concentration (mg/L)	0.21	0.0082	ND	0.0048	--	0.0053	ND	ND	
			Standard Deviation (mmoles)	8.3E-05	1.5E-05	0.0E+00	1.1E-04	--	3.9E-05	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00034**	**0.000017**	**ND**	**0.000063**	**4.2E-04**	**0.000047**	**ND**	**ND**	
	16-Jan-20	101	MEVO-ISCR-1	0.29	0.014	<0.010	0.014	--	0.0094	<0.010	<0.050	
			MEVO-ISCR-2	0.17	0.011	<0.010	<0.010	--	0.0038	<0.010	<0.050	
			MEVO-ISCR-3	0.23	<0.010	<0.010	<0.010	--	0.0012	<0.010	<0.050	
			Average Concentration (mg/L)	0.23	0.0083	ND	0.0048	--	0.0048	ND	ND	
			Standard Deviation (mmoles)	9.2E-05	1.5E-05	0.0E+00	1.1E-04	--	3.7E-05	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00037**	**0.000018**	**ND**	**0.000063**	**4.5E-04**	**0.000043**	**ND**	**ND**	
MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented	02-Oct-19	-5										Amended first replicate with resazurin.
	04-Oct-19	-3										Spiked with a saturated TCE solution to a target concentration of 1 mg/L.
	07-Oct-19	0										Amended with glycerol-suspended mZVI, ISR-CL, and EDS-ER™ to target 4 g/L ZVI, 20 g/L FeS, and 2 g/L EVO, respectively.
												Amended with a saturated bicarbonate solution to target a pH of 7.0±0.2.
			MEVO-ISCR/KB-1-1	0.55	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			MEVO-ISCR/KB-1-2	0.64	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			MEVO-ISCR/KB-1-3	0.58	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			Average Concentration (mg/L)	0.59	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	7.8E-05	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00094**	**ND**	**ND**	**ND**	**9.4E-04**	**ND**	**ND**	**ND**	

TABLE 2: SUMMARY OF MICROCOSM cVOC AND DHG RESULTS
Newberry, SC

SIREM

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene					DHGs			Comments
				TCE	cDCE	VC	Ethene	Total Ethenes	Acetylene	Ethane	Methane	
				mg/L	mg/L	mg/L	mg/L	mmol/bottle	mg/L	mg/L	mg/L	
MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented Continued	21-Oct-19	14	MEVO-ISCR/KB-1-1	0.098	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			MEVO-ISCR/KB-1-2	0.26	<0.010	<0.010	0.017	--	0.0070	<0.010	<0.050	
			MEVO-ISCR/KB-1-3	0.19	0.011	<0.010	<0.010	--	0.0024	<0.010	<0.050	
			Average Concentration (mg/L)	0.18	0.0038	ND	0.0057	--	0.0031	ND	ND	
			Standard Deviation (mmoles)	1.3E-04	1.4E-05	0.0E+00	1.3E-04	--	3.1E-05	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00030**	**0.0000081**	**ND**	**0.000075**	**3.8E-04**	**0.000028**	**ND**	**ND**	
	30-Oct-19	23										Amended with a saturated bicarbonate solution to target a pH of 7.0±0.2.
	04-Nov-19	28	MEVO-ISCR/KB-1-1	0.12	<0.010	<0.010	<0.010	--	0.0030	0.075	0.10	
			MEVO-ISCR/KB-1-2	0.21	0.013	<0.010	0.018	--	0.012	0.076	0.10	
			MEVO-ISCR/KB-1-3	0.13	0.017	<0.010	<0.010	--	0.0094	0.075	0.10	
			Average Concentration (mg/L)	0.15	0.010	ND	0.0059	--	0.0082	0.075	0.10	
			Standard Deviation (mmoles)	7.4E-05	1.9E-05	0.0E+00	1.3E-04	--	4.1E-05	1.5E-05	3.3E-05	
			Average Total mmoles	**0.00025**	**0.000021**	**ND**	**0.000078**	**3.5E-04**	**0.000073**	**0.0015**	**0.0047**	
	18-Nov-19	42										Bioaugmented with KB-1® Plus.
			MEVO-ISCR/KB-1-1	0.11	<0.010	<0.010	<0.010	--	0.0033	0.029	0.098	
			MEVO-ISCR/KB-1-2	0.19	0.013	<0.010	0.018	--	0.013	0.029	0.10	
			MEVO-ISCR/KB-1-3	0.11	0.015	<0.010	<0.010	--	0.0098	0.029	0.099	
			Average Concentration (mg/L)	0.14	0.0093	ND	0.006	--	0.0087	0.029	0.099	
			Standard Deviation (mmoles)	7.5E-05	1.7E-05	0.0E+00	1.4E-04	--	4.4E-05	7.1E-06	3.4E-05	
			Average Total mmoles	**0.00022**	**0.000020**	**ND**	**0.000079**	**3.2E-04**	**0.000077**	**0.00058**	**0.0046**	
	25-Nov-19	49	MEVO-ISCR/KB-1-1	<0.010	<0.010	0.099	<0.010	--	0.0033	<0.010	0.23	
			MEVO-ISCR/KB-1-2	0.086	0.019	0.12	0.019	--	0.012	<0.010	0.059	
			MEVO-ISCR/KB-1-3	0.039	<0.010	0.091	<0.010	--	0.0093	<0.010	0.060	
			Average Concentration (mg/L)	0.042	0.0062	0.10	0.0063	--	0.0083	ND	0.12	
			Standard Deviation (mmoles)	6.9E-05	2.3E-05	4.8E-05	1.4E-04	--	4.1E-05	0.0E+00	4.6E-03	
			Average Total mmoles	**0.000067**	**0.000013**	**0.00036**	**0.000083**	**5.2E-04**	**0.000074**	**ND**	**0.0054**	
	02-Dec-19	56	MEVO-ISCR/KB-1-1	<0.010	<0.010	0.083	<0.010	--	0.0025	<0.010	0.43	
			MEVO-ISCR/KB-1-2	<0.010	<0.010	0.21	0.017	--	0.011	<0.010	0.078	
			MEVO-ISCR/KB-1-3	<0.010	<0.010	0.14	<0.010	--	0.0085	<0.010	0.14	
			Average Concentration (mg/L)	ND	ND	0.15	0.0058	--	0.0072	ND	0.22	
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	2.3E-04	1.3E-04	--	3.8E-05	0.0E+00	8.7E-03	
			Average Total mmoles	**ND**	**ND**	**0.00051**	**0.000076**	**5.9E-04**	**0.000065**	**ND**	**0.010**	
	16-Dec-19	70	MEVO-ISCR/KB-1-1	<0.010	<0.010	0.064	<0.010	--	0.0022	<0.010	0.78	
			MEVO-ISCR/KB-1-2	<0.010	<0.010	0.21	0.021	--	0.010	<0.010	0.25	
			MEVO-ISCR/KB-1-3	<0.010	<0.010	0.12	0.011	--	0.0074	<0.010	0.60	
			Average Concentration (mg/L)	ND	ND	0.13	0.011	--	0.0066	ND	0.54	
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	2.7E-04	1.4E-04	--	3.6E-05	0.0E+00	1.3E-02	
			Average Total mmoles	**ND**	**ND**	**0.00047**	**0.00014**	**6.1E-04**	**0.000059**	**ND**	**0.025**	
	16-Jan-20	101	MEVO-ISCR/KB-1-1	<0.010	<0.010	0.016	0.011	--	0.0013	<0.010	2.8	
			MEVO-ISCR/KB-1-2	<0.010	<0.010	0.21	0.024	--	0.0087	<0.010	1.3	
			MEVO-ISCR/KB-1-3	<0.010	<0.010	0.10	0.014	--	0.0056	<0.010	5.2	
			Average Concentration (mg/L)	ND	ND	0.11	0.016	--	0.0052	ND	3.1	
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	3.4E-04	9.1E-05	--	3.3E-05	0.0E+00	9.2E-02	
			Average Total mmoles	**ND**	**ND**	**0.00038**	**0.00021**	**5.9E-04**	**0.000046**	**ND**	**0.14**	
EDS-ER™ Amended/KB-1® Plus Bioaugmented	02-Oct-19	-5										Amended first replicate with resazurin.
	04-Oct-19	-3										Spiked with a saturated TCE solution to a target concentration of 1 mg/L.
	07-Oct-19	0										Amended with a saturated bicarbonate solution to target a pH of 7.0±0.2.
												Amended with EDS-ER™and Nutrimens™ to target 2 g/L EVO and 0.1 g/L nutrients, respectively.
			EDS-ER/KB-1-1	0.72	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			EDS-ER/KB-1-2	0.58	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			EDS-ER/KB-1-3	0.64	<0.020	<0.020	<0.020	--	<0.0020	<0.020	<0.10	
			Average Concentration (mg/L)	0.65	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	1.1E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.0010**	**ND**	**ND**	**ND**	**1.0E-03**	**ND**	**ND**	**ND**	
	21-Oct-19	14	EDS-ER/KB-1-1	0.61	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			EDS-ER/KB-1-2	0.52	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			EDS-ER/KB-1-3	0.43	<0.010	<0.010	<0.010	--	<0.0010	<0.010	<0.050	
			Average Concentration (mg/L)	0.52	ND	ND	ND	--	ND	ND	ND	
			Standard Deviation (mmoles)	1.4E-04	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	0.0E+00	0.0E+00	
			Average Total mmoles	**0.00083**	**ND**	**ND**	**ND**	**8.3E-04**	**ND**	**ND**	**ND**	
	30-Oct-19	23										Amended with a saturated bicarbonate solution to target a pH of 7.0±0.2.
	04-Nov-19	28	EDS-ER/KB-1-1	0.61	<0.010	<0.010	<0.010	--	<0.0010	0.078	0.10	
			EDS-ER/KB-1-2	0.53	<0.010	<0.010	<0.010	--	<0.0010	0.077	0.10	
			EDS-ER/KB-1-3	0.56	<0.010	<0.010	<0.010	--	<0.0010	0.078	0.11	
			Average Concentration (mg/L)	0.57	ND	ND	ND	--	ND	0.078	0.10	
			Standard Deviation (mmoles)	6.8E-05	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	9.2E-06	6.9E-05	
			Average Total mmoles	**0.00091**	**ND**	**ND**	**ND**	**9.1E-04**	**ND**	**0.0015**	**0.0048**	

TABLE 2: SUMMARY OF MICROCOSM cVOC AND DHG RESULTS
Newberry, SC

Treatment	Date	Day	Replicate	Chlorinated Ethenes and Ethene					DHGs			Comments
				TCE	cDCE	VC	Ethene	Total Ethenes	Acetylene	Ethane	Methane	
				mg/L	mg/L	mg/L	mg/L	mmol/bottle	mg/L	mg/L	mg/L	
EDS-ER™ Amended/KB-1® Plus Bioaugmented Continued	18-Nov-19	42										Bioaugmented with KB-1® Plus
			EDS-ER/KB-1-1	0.56	<0.010	<0.010	<0.010	--	<0.0010	0.030	0.10	
			EDS-ER/KB-1-2	0.55	<0.010	<0.010	<0.010	--	<0.0010	0.030	0.11	
			EDS-ER/KB-1-3	0.54	<0.010	<0.010	<0.010	--	<0.0010	0.030	0.10	
			Average Concentration (mg/L)	0.55	ND	ND	ND	--	ND	0.030	0.10	
			Standard Deviation (mmoles)	1.5E-05	0.0E+00	0.0E+00	0.0E+00	--	0.0E+00	1.1E-06	1.1E-04	
			Average Total mmoles	**0.00089**	**ND**	**ND**	**ND**	**8.9E-04**	**ND**	**0.00059**	**0.0048**	
	25-Nov-19	49	EDS-ER/KB-1-1	<0.010	0.057	0.16	0.047	--	<0.0010	<0.010	0.10	
			EDS-ER/KB-1-2	<0.010	0.11	0.20	0.037	--	<0.0010	<0.010	<0.050	
			EDS-ER/KB-1-3	<0.010	0.11	0.18	0.049	--	<0.0010	<0.010	0.088	
			Average Concentration (mg/L)	ND	0.093	0.18	0.044	--	ND	ND	0.063	
			Standard Deviation (mmoles)	0.0E+00	6.6E-05	7.2E-05	8.5E-05	--	0.0E+00	0.0E+00	2.5E-03	
			Average Total mmoles	**ND**	**0.00020**	**0.00062**	**0.00058**	**1.4E-03**	**ND**	**ND**	**0.0029**	
	02-Dec-19	56	EDS-ER/KB-1-1	<0.010	<0.010	<0.010	0.057	--	<0.0010	<0.010	0.66	
			EDS-ER/KB-1-2	<0.010	<0.010	<0.010	0.055	--	<0.0010	<0.010	0.16	
			EDS-ER/KB-1-3	<0.010	<0.010	<0.010	0.069	--	<0.0010	<0.010	0.41	
			Average Concentration (mg/L)	ND	ND	ND	0.060	--	ND	ND	0.41	
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	0.0E+00	9.5E-05	--	0.0E+00	0.0E+00	1.2E-02	
			Average Total mmoles	**ND**	**ND**	**ND**	**0.00080**	**8.0E-04**	**ND**	**ND**	**0.019**	
	16-Dec-19	70	EDS-ER/KB-1-1	<0.010	<0.010	<0.010	0.053	--	<0.0010	<0.010	3.6	
			EDS-ER/KB-1-2	<0.010	<0.010	<0.010	0.051	--	<0.0010	<0.010	0.98	
			EDS-ER/KB-1-3	<0.010	<0.010	<0.010	0.066	--	<0.0010	<0.010	2.3	
			Average Concentration (mg/L)	ND	ND	ND	0.057	--	ND	ND	2.3	
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	0.0E+00	1.0E-04	--	0.0E+00	0.0E+00	6.0E-02	
			Average Total mmoles	**ND**	**ND**	**ND**	**0.00075**	**7.5E-04**	**ND**	**ND**	**0.11**	
	16-Jan-20	101	EDS-ER/KB-1-1	<0.010	<0.010	<0.010	0.048	--	<0.0010	<0.010	4.8	
			EDS-ER/KB-1-2	<0.010	<0.010	<0.010	0.052	--	<0.0010	<0.010	1.8	
			EDS-ER/KB-1-3	<0.010	<0.010	<0.010	0.065	--	<0.0010	<0.010	7.9	
			Average Concentration (mg/L)	ND	ND	ND	0.055	--	ND	ND	4.9	
			Standard Deviation (mmoles)	0.0E+00	0.0E+00	0.0E+00	1.2E-04	--	0.0E+00	0.0E+00	1.4E-01	
			Average Total mmoles	**ND**	**ND**	**ND**	**0.00072**	**7.2E-04**	**ND**	**ND**	**0.23**	

Notes:

- - not applicable
< - less than
ANAC - anaerobic active control
ANSC - anaerobic sterile control
cDCE- cis-1,2-dichloroethene
cVOC - chlorinated volatile organic compounds
DHG - dissolved hydrocarbon gases
EVO - emulsified vegetable oil
FeS - ferrous sulfide
g/L - grams per liter
MEVO - MicroEVO™
mg/L - milligrams per liter
mmoles/bottle - millimoles per bottle
mZVI - microscale zero valent iron
ND - non-detect
TCE - trichloroethene
VC - vinyl chloride
ZVI - zero valent iron

TABLE 3: SUMMARY OF MICROCOSM ANION RESULTS

Newberry, SC

SiREM

Treatment	Date	Day	Replicate	Total VFAs	Chloride	Nitrite-N	Nitrate-N	Sulfate	Phosphate
				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Anaerobic Sterile Control	7-Oct-19	0	ANSC-1	<0.07	84	<0.09	0.58	0.24	0.55
			ANSC-2	<0.07	80	<0.09	0.52	0.16	<0.07
			ANSC-3	<0.07	80	<0.09	0.54	0.61	0.15
			Average	**ND**	**81**	**ND**	**0.55**	**0.34**	**ND**
	4-Nov-19	28	ANSC-1	<0.07	83	<0.09	0.62	<0.07	<0.07
			ANSC-2	<0.07	83	<0.09	0.63	<0.07	<0.07
			ANSC-3	<0.07	86	<0.09	0.63	<0.07	<0.07
			Average	**ND**	**84**	**ND**	**0.63**	**ND**	**ND**
	16-Dec-19	70	ANSC-1	<0.07	75	<0.09	0.79	<0.07	<0.07
			ANSC-2	<0.07	71	<0.09	0.68	<0.07	<0.07
			ANSC-3	<0.07	77	<0.09	0.81	<0.07	<0.07
			Average	**ND**	**74**	**ND**	**0.76**	**ND**	**ND**
	16-Jan-20	101	ANSC-1	<0.07	83	<0.09	0.83	<0.07	<0.07
			ANSC-2	<0.07	84	<0.09	0.77	<0.07	<0.07
			ANSC-3	<0.07	82	<0.09	0.82	<0.07	<0.07
			Average	**ND**	**83**	**ND**	**0.80**	**ND**	**ND**
Anaerobic Active Control	7-Oct-19	0	ANAC-1	<0.07	56	<0.09	1.0	0.19	<0.07
			ANAC-2	<0.07	57	<0.09	0.83	0.09	<0.07
			ANAC-3	<0.07	56	<0.09	0.99	0.19	<0.07
			Average	**ND**	**57**	**ND**	**0.94**	**0.16**	**ND**
	4-Nov-19	28	ANAC-1	<0.07	56	<0.09	1.0	<0.07	<0.07
			ANAC-2	<0.07	62	<0.09	1.1	<0.07	<0.07
			ANAC-3	<0.07	57	<0.09	1.1	<0.07	<0.07
			Average	**ND**	**58**	**ND**	**1.07**	**ND**	**ND**
	16-Dec-19	70	ANAC-1	<0.07	54	<0.09	1.1	<0.07	<0.07
			ANAC-2	<0.07	55	<0.09	0.31	0.85	<0.07
			ANAC-3	<0.07	53	<0.09	1.0	<0.07	<0.07
			Average	**ND**	**54**	**ND**	**0.80**	**0.28**	**ND**
	16-Jan-20	101	ANAC-1	<0.07	57	<0.09	1.1	<0.07	<0.07
			ANAC-2	<0.07	58	<0.09	<0.09	<0.07	<0.07
			ANAC-3	<0.07	56	<0.09	1.0	<0.07	<0.07
			Average	**ND**	**57**	**ND**	**0.69**	**ND**	**ND**
MicroEVO™ ISCR Amended	7-Oct-19	0	MEVO-ISCR-1	5.8	80	<0.09	1.1	1,060	<0.07
			MEVO-ISCR-2	11	73	<0.09	0.94	1,078	<0.07
			MEVO-ISCR-3	7.2	71	<0.09	0.98	1,102	<0.07
			Average	**8.0**	**75**	**ND**	**1.0**	**1,080**	**ND**
	4-Nov-19	28	MEVO-ISCR-1	542	83	<0.09	<0.09	1,017	<0.07
			MEVO-ISCR-2	534	67	<0.09	<0.09	876	<0.07
			MEVO-ISCR-3	655	71	<0.09	<0.09	1,030	<0.07
			Average	**577**	**74**	**ND**	**ND**	**974**	**ND**

TABLE 3: SUMMARY OF MICROCOSM ANION RESULTS SiREM

Newberry, SC

Treatment	Date	Day	Replicate	Total VFAs	Chloride	Nitrite-N	Nitrate-N	Sulfate	Phosphate
				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
MicroEVO™ ISCR Amended Continued	16-Dec-19	70	MEVO-ISCR-1	711	68	<0.09	<0.09	450	<0.07
			MEVO-ISCR-2	709	74	<0.09	<0.09	349	<0.07
			MEVO-ISCR-3	686	67	<0.09	<0.09	468	<0.07
			Average	**702**	**70**	**ND**	**ND**	**422**	**ND**
	16-Jan-20	101	MEVO-ISCR-1	609	73	<0.09	<0.09	296	<0.07
			MEVO-ISCR-2	633	71	<0.09	<0.09	120	<0.07
			MEVO-ISCR-3	565	74	<0.09	<0.09	275	<0.07
			Average	**ND**	**73**	**ND**	**ND**	**230**	**ND**
MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented	7-Oct-19	0	MEVO-ISCR/KB-1-1	8.3	72	<0.09	1.1	1,117	<0.07
			MEVO-ISCR/KB-1-2	8.1	73	<0.09	0.99	1,056	<0.07
			MEVO-ISCR/KB-1-3	8.1	77	<0.09	1.0	1,059	<0.07
			Average	**8.2**	**74**	**ND**	**1.0**	**1,077**	**ND**
	4-Nov-19	28	MEVO-ISCR/KB-1-1	793	72	<0.09	<0.09	1,093	<0.07
			MEVO-ISCR/KB-1-2	675	70	<0.09	<0.09	841	<0.07
			MEVO-ISCR/KB-1-3	692	130	<0.09	<0.09	826	<0.07
			Average	**720**	**91**	**ND**	**ND**	**920**	**ND**
	25-Nov-19	49	MEVO-ISCR/KB-1-1	710	77	<0.09	<0.09	706	<0.07
			MEVO-ISCR/KB-1-2	656	75	<0.09	<0.09	541	<0.07
			MEVO-ISCR/KB-1-3	692	76	<0.09	<0.09	411	<0.07
			Average	**686**	**76**	**ND**	**ND**	**553**	**ND**
	16-Dec-19	70	MEVO-ISCR/KB-1-1	959	71	<0.09	<0.09	124	<0.07
			MEVO-ISCR/KB-1-2	932	70	<0.09	<0.09	8.4	<0.07
			MEVO-ISCR/KB-1-3	843	74	<0.09	<0.09	11.9	<0.07
			Average	**911**	**72**	**ND**	**ND**	**48**	**ND**
	16-Jan-20	101	MEVO-ISCR/KB-1-1	669	71	<0.09	<0.09	<0.07	<0.07
			MEVO-ISCR/KB-1-2	735	73	<0.09	<0.09	<0.07	<0.07
			MEVO-ISCR/KB-1-3	728	71	<0.09	<0.09	<0.07	<0.07
			Average	**711**	**72**	**ND**	**ND**	**ND**	**ND**
EDS-ER™ Amended/KB-1® Plus Bioaugmented	7-Oct-19	0	EDS-ER/KB-1-1	9.1	57	<0.09	0.96	0.35	<0.07
			EDS-ER/KB-1-2	12	60	<0.09	0.64	0.47	<0.07
			EDS-ER/KB-1-3	11	59	<0.09	0.96	0.54	<0.07
			Average	**11**	**58**	**ND**	**0.85**	**0.45**	**ND**
	4-Nov-19	28	EDS-ER/KB-1-1	16	56	<0.09	<0.09	<0.07	<0.07
			EDS-ER/KB-1-2	7.4	57	<0.09	<0.09	<0.07	<0.07
			EDS-ER/KB-1-3	8.5	57	<0.09	<0.09	<0.07	<0.07
			Average	**11**	**57**	**ND**	**ND**	**ND**	**ND**
	25-Nov-19	49	EDS-ER/KB-1-1	46	63	<0.09	<0.09	<0.07	<0.07
			EDS-ER/KB-1-2	32	57	<0.09	<0.09	<0.07	<0.07
			EDS-ER/KB-1-3	32	58	<0.09	<0.09	<0.07	<0.07
			Average	**37**	**59**	**ND**	**ND**	**ND**	**ND**

TABLE 3: SUMMARY OF MICROCOSM ANION RESULTS SiREM

Newberry, SC

Treatment	Date	Day	Replicate	Total VFAs	Chloride	Nitrite-N	Nitrate-N	Sulfate	Phosphate
				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
EDS-ER™ Amended/KB-1®	16-Dec-19	70	EDS-ER/KB-1-1	38	59	<0.09	<0.09	<0.07	<0.07
Plus Bioaugmented			EDS-ER/KB-1-2	113	59	<0.09	<0.09	<0.07	<0.07
Continued			EDS-ER/KB-1-3	99	58	<0.09	<0.09	<0.07	<0.07
			Average	**83**	**59**	**ND**	**ND**	**ND**	**ND**
	16-Jan-20	101	EDS-ER/KB-1-1	7.6	59	<0.09	<0.09	<0.07	<0.07
			EDS-ER/KB-1-2	204	64	<0.09	0.24	<0.07	<0.07
			EDS-ER/KB-1-3	11	62	<0.09	<0.09	<0.07	<0.07
			Average	**74**	**62**	**ND**	**0.08**	**ND**	**ND**

Notes:

< - compound not detected, the associated value is the detection limit
ANAC - anaerobic active control
ANSC - anaerobic sterile control
MEVO - MicroEVO™
mg/L - milligrams per liter
ND - not detected
VFAs - total volatile fatty acids, calibrated as lactate but may include other VFAs such as formate, acetate, propionate, pyruvate and butyrate

TABLE 4: SUMMARY OF MICROCOSM VFA RESULTS

SiREM

Newberry, SC

Treatment	Date	Day	Replicate	Lactate	Acetate	Propionate	Formate	Butyrate	Pyruvate
				mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
MicroEVO™ ISCR Amended	16-Dec-19	70	MEVO-ISCR-1	<0.39	864	143	<0.22	6.0	0.73
			MEVO-ISCR-2	27	770	165	<0.22	5.0	1.9
			MEVO-ISCR-3	148	757	65	<0.22	0.86	1.0
			Average	**58**	**797**	**125**	**ND**	**4.0**	**1.2**
	16-Jan-20	101	MEVO-ISCR-1	2.5	820	116	<0.22	1.0	<0.69
			MEVO-ISCR-2	2.2	899	164	<0.22	2.7	0.78
			MEVO-ISCR-3	1.6	831	114	<0.22	<0.41	<0.69
			Average	**2.1**	**850**	**131**	**ND**	**1.2**	**0.26**
MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented	25-Nov-19	49	MEVO-ISCR/KB-1-1	<0.39	945	182	<0.22	<0.41	<0.69
			MEVO-ISCR/KB-1-2	<0.39	793	201	<0.22	<0.41	<0.69
			MEVO-ISCR/KB-1-3	<0.39	870	227	<0.22	<0.41	<0.69
			Average	**ND**	**869**	**203**	**ND**	**ND**	**ND**
	16-Dec-19	70	MEVO-ISCR/KB-1-1	--	845	41	<0.22	<0.41	<0.69
			MEVO-ISCR/KB-1-2	--	799	94	<0.22	<0.41	<0.69
			MEVO-ISCR/KB-1-3	--	872	173	1.7	<0.41	<0.69
			Average	--	**839**	**102**	**0.57**	**ND**	**ND**
	16-Jan-20	101	MEVO-ISCR/KB-1-1	1.5	1,021	160	0.97	0.58	<0.69
			MEVO-ISCR/KB-1-2	<0.39	984	278	<0.22	1.8	<0.69
			MEVO-ISCR/KB-1-3	<0.39	928	309	<0.22	0.46	<0.69
			Average	**0.52**	**977**	**249**	**0.32**	**1.0**	**ND**
EDS-ER™ Amended/KB-1® Plus Bioaugmented	25-Nov-19	49	EDS-ER/KB-1-1	<0.39	51	1.0	<0.22	<0.41	<0.69
			EDS-ER/KB-1-2	<0.39	43	4.2	<0.22	<0.41	<0.69
			EDS-ER/KB-1-3	<0.39	34	2.0	<0.22	<0.41	<0.69
			Average	**ND**	**43**	**2.4**	**ND**	**ND**	**ND**
	16-Dec-19	70	EDS-ER/KB-1-1	<0.39	44	1.5	<0.22	10	<0.69
			EDS-ER/KB-1-2	<0.39	156	4.9	<0.22	7.4	<0.69
			EDS-ER/KB-1-3	<0.39	133	2.7	<0.22	11	<0.69
			Average	**ND**	**111**	**3.0**	**ND**	**9.5**	**ND**
	16-Jan-20	101	EDS-ER/KB-1-1	<0.39	<0.54	<0.31	<0.22	<0.41	<0.69
			EDS-ER/KB-1-2	<0.39	305	6.0	<0.22	12	<0.69
			EDS-ER/KB-1-3	<0.39	8.2	<0.31	<0.22	<0.41	<0.69
			Average	**ND**	**104**	**2.0**	**ND**	**3.9**	**ND**

Notes:

-- - data not available

< - compound not detected, the associated value is the detection limit

MEVO - MicroEVO™

mg/L - milligrams per liter

ND - not detected

VFA -volatile fatty acids

TABLE 5: SUMMARY OF MICROCOSM pH AND ORP RESULTS

Newberry, SC

SiREM

Treatment	Date	Day	Replicate	pH	ORP mV
Anaerobic Sterile Control	7-Oct-19	0	ANSC-1	5.78	--
			ANSC-2	5.72	--
			ANSC-3	5.70	--
			Average	**5.73**	--
	21-Oct-19	14	ANSC-1	5.68	--
			ANSC-2	5.65	--
			ANSC-3	5.62	--
			Average	**5.65**	--
	4-Nov-19	28	ANSC-1	5.63	374
			ANSC-2	5.66	388
			ANSC-3	5.62	395
			Average	**5.64**	**386**
	18-Nov-19	42	ANSC-1	5.63	348
			ANSC-2	5.69	378
			ANSC-3	5.69	385
			Average	**5.67**	**370**
	16-Dec-19	70	ANSC-1	5.56	--
			ANSC-2	5.66	--
			ANSC-3	5.59	--
			Average	**5.60**	--
	16-Jan-20	101	ANSC-1	5.60	--
			ANSC-2	5.66	--
			ANSC-3	5.60	--
			Average	**5.62**	--
Anaerobic Active Control	7-Oct-19	0	ANAC-1	5.68	--
			ANAC-2	5.76	--
			ANAC-3	5.70	--
			Average	**5.71**	--
	21-Oct-19	14	ANAC-1	5.74	--
			ANAC-2	5.75	--
			ANAC-3	5.70	--
			Average	**5.73**	--
	4-Nov-19	28	ANAC-1	5.75	319
			ANAC-2	5.79	316
			ANAC-3	5.66	315
			Average	**5.73**	**317**
	18-Nov-19	42	ANAC-1	5.75	325
			ANAC-2	5.81	323
			ANAC-3	5.72	321
			Average	**5.76**	**323**
	16-Dec-19	70	ANAC-1	5.64	--
			ANAC-2	5.77	--
			ANAC-3	5.62	--
			Average	**5.68**	--
	16-Jan-20	101	ANAC-1	5.67	--
			ANAC-2	5.73	--
			ANAC-3	5.64	--
			Average	**5.68**	--
MicroEVO™ ISCR Amended	7-Oct-19	0	MEVO-ISCR-1	7.57	--
			MEVO-ISCR-2	7.45	--
			MEVO-ISCR-3	7.42	--
			Average	**7.48**	--
	21-Oct-19	14	MEVO-ISCR-1	6.07	--
			MEVO-ISCR-2	6.05	--
			MEVO-ISCR-3	5.88	--
			Average	**6.00**	--
	4-Nov-19	28	MEVO-ISCR-1	6.23	-189
			MEVO-ISCR-2	5.95	-173
			MEVO-ISCR-3	5.70	-140
			Average	**5.96**	**-167**
	18-Nov-19	42	MEVO-ISCR-1	6.30	-209
			MEVO-ISCR-2	6.35	-202
			MEVO-ISCR-3	5.97	-153
			Average	**6.21**	**-188**
	2-Dec-19	56	MEVO-ISCR-1	6.27	--
			MEVO-ISCR-2	6.48	--
			MEVO-ISCR-3	6.10	--
			Average	**6.28**	--
	6-Dec-19	60	Buffered to pH 7.0 ± 0.2		
			MEVO-ISCR-1	6.96	--
			MEVO-ISCR-2	6.93	--
			MEVO-ISCR-3	6.98	--
			Average	**6.96**	--
	16-Dec-19	70	MEVO-ISCR-1	6.78	--
			MEVO-ISCR-2	6.84	--
			MEVO-ISCR-3	6.96	--
			Average	**6.86**	--
	16-Jan-20	101	MEVO-ISCR-1	6.97	--
			MEVO-ISCR-2	6.97	--
			MEVO-ISCR-3	7.12	--
			Average	**7.02**	--

TABLE 5: SUMMARY OF MICROCOSM pH AND ORP RESULTS
Newberry, SC

Treatment	Date	Day	Replicate	pH	ORP mV
MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented	7-Oct-19	0	Buffered to pH 7.0 ± 0.2		
			MEVO-ISCR/KB-1-1	8.25	--
			MEVO-ISCR/KB-1-2	7.86	--
			MEVO-ISCR/KB-1-3	8.19	--
			Average	**8.10**	--
	21-Oct-19	14	MEVO-ISCR/KB-1-1	6.21	--
			MEVO-ISCR/KB-1-2	5.95	--
			MEVO-ISCR/KB-1-3	6.10	--
			Average	**6.09**	--
	30-Oct-19	23	Buffered to pH 7.0 ± 0.2		
			MEVO-ISCR/KB-1-1	6.88	--
			MEVO-ISCR/KB-1-2	6.83	--
			MEVO-ISCR/KB-1-3	6.85	--
			Average	**6.85**	--
	4-Nov-19	28	MEVO-ISCR/KB-1-1	6.81	-143
			MEVO-ISCR/KB-1-2	6.77	-212
			MEVO-ISCR/KB-1-3	6.78	-201
			Average	**6.79**	**-185**
	18-Nov-19	42	Bioaugmented with KB-1® Plus.		
			MEVO-ISCR/KB-1-1	6.91	-235
			MEVO-ISCR/KB-1-2	6.97	-260
			MEVO-ISCR/KB-1-3	6.97	-265
			Average	**6.95**	**-253**
	25-Nov-19	49	MEVO-ISCR/KB-1-1	7.01	--
			MEVO-ISCR/KB-1-2	7.00	--
			MEVO-ISCR/KB-1-3	6.96	--
			Average	**6.99**	--
	2-Dec-19	56	MEVO-ISCR/KB-1-1	6.93	--
			MEVO-ISCR/KB-1-2	6.95	--
			MEVO-ISCR/KB-1-3	6.99	--
			Average	**6.96**	--
	16-Dec-19	70	MEVO-ISCR/KB-1-1	6.83	--
			MEVO-ISCR/KB-1-2	6.80	--
			MEVO-ISCR/KB-1-3	6.87	--
			Average	**6.83**	--
	16-Jan-20	101	MEVO-ISCR/KB-1-1	7.09	--
			MEVO-ISCR/KB-1-2	6.89	--
			MEVO-ISCR/KB-1-3	6.91	--
			Average	**6.96**	--
EDS-ER™ Amended/KB-1® Plus Bioaugmented	7-Oct-19	0	Buffered to pH 7.0 ± 0.2		
			EDS-ER/KB-1-1	6.86	--
			EDS-ER/KB-1-2	6.85	--
			EDS-ER/KB-1-3	6.77	--
			Average	**6.83**	--
	21-Oct-19	14	EDS-ER/KB-1-1	6.54	--
			EDS-ER/KB-1-2	6.60	--
			EDS-ER/KB-1-3	6.56	--
			Average	**6.57**	--
	30-Oct-19	23	Buffered to pH 7.0 ± 0.2		
			EDS-ER/KB-1-1	6.94	--
			EDS-ER/KB-1-2	6.93	--
			EDS-ER/KB-1-3	6.98	--
			Average	**6.95**	--
	4-Nov-19	28	EDS-ER/KB-1-1	6.87	-88
			EDS-ER/KB-1-2	6.78	-62
			EDS-ER/KB-1-3	6.74	-104
			Average	**6.80**	**-85**
	18-Nov-19	42	Bioaugmented with KB-1® Plus.		
			EDS-ER/KB-1-1	6.82	-138
			EDS-ER/KB-1-2	6.83	-120
			EDS-ER/KB-1-3	6.76	-124
			Average	**6.80**	**-127**
	25-Nov-19	49	EDS-ER/KB-1-1	6.81	--
			EDS-ER/KB-1-2	6.82	--
			EDS-ER/KB-1-3	6.83	--
			Average	**6.82**	--
	2-Dec-19	56	EDS-ER/KB-1-1	6.66	--
			EDS-ER/KB-1-2	6.67	--
			EDS-ER/KB-1-3	6.65	--
			Average	**6.66**	--
	16-Dec-19	70	EDS-ER/KB-1-1	6.65	--
			EDS-ER/KB-1-2	6.58	--
			EDS-ER/KB-1-3	6.52	--
			Average	**6.58**	--
	16-Jan-20	101	EDS-ER/KB-1-1	6.61	--
			EDS-ER/KB-1-2	6.33	--
			EDS-ER/KB-1-3	6.57	--
			Average	**6.50**	--

Notes:

- - not applicable
MEVO - MicroEVO™
mV - millivolts
ORP - oxidative-reduction potential

TABLE 6: HALF-LIVES (DAYS) OF CHLORINATED VOCs DETECTED IN MICROCOSMS
Newberry, SC

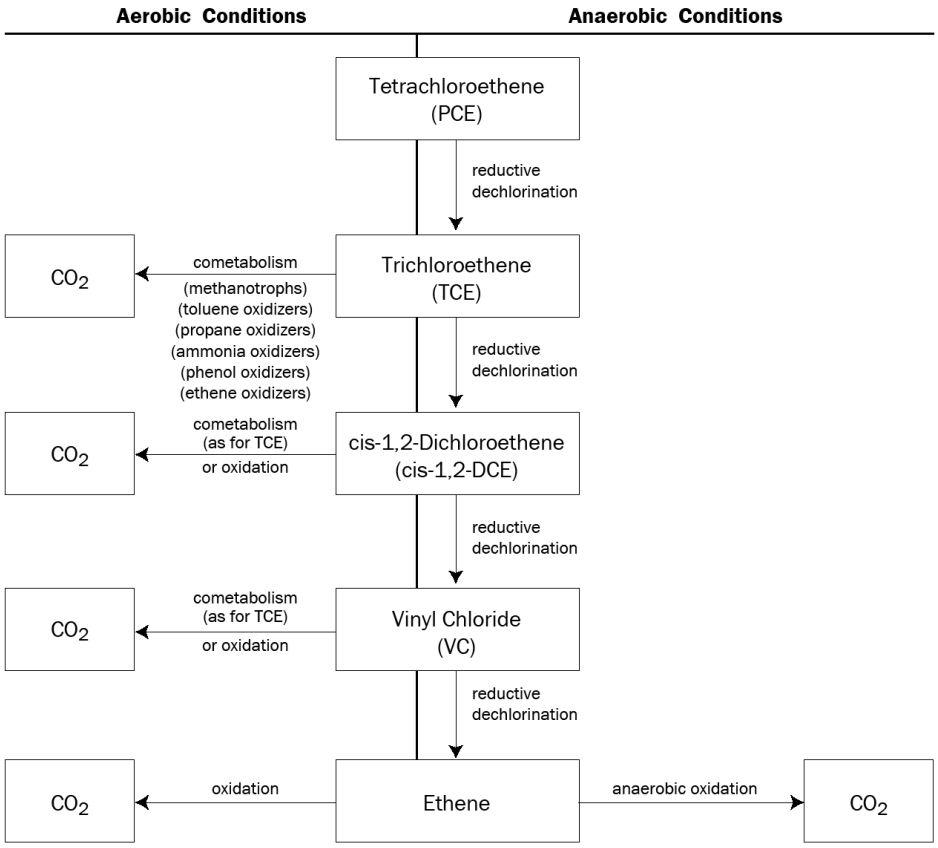
SIREM

Treatment/Control	TCE			cDCE			VC		
	Half Life (Days)	T_1 (Day)	T_2 (Days)	**Half Life (Days)**	T_1 (Day)	T_2 (Days)	**Half Life (Days)**	T_1 (Day)	T_2 (Days)
Anaerobic Sterile Control	~	0	101	~	0	101	~	0	101
Anaerobic Active Control	~	0	101	~	0	101	~	0	101
MicroEVO™ ISCR Amended	78	0	101	30	0	101	~	0	101
MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented	2.9*	42	56	15*	42	56	106*	56	101
EDS-ER™ Amended/KB-1® Plus Bioaugmented	1.0*	42	49	1.6*	49	56	1.4*	49	56

Notes:

* half lives determined after the addition of KB-1® Plus
~ - net degradation of compound was not detected over duration of study
cDCE - cis-1,2-dichloroethene
TCE - trichloroethene
VC - vinyl chloride
VOCs - volatile organic compounds

FIGURES



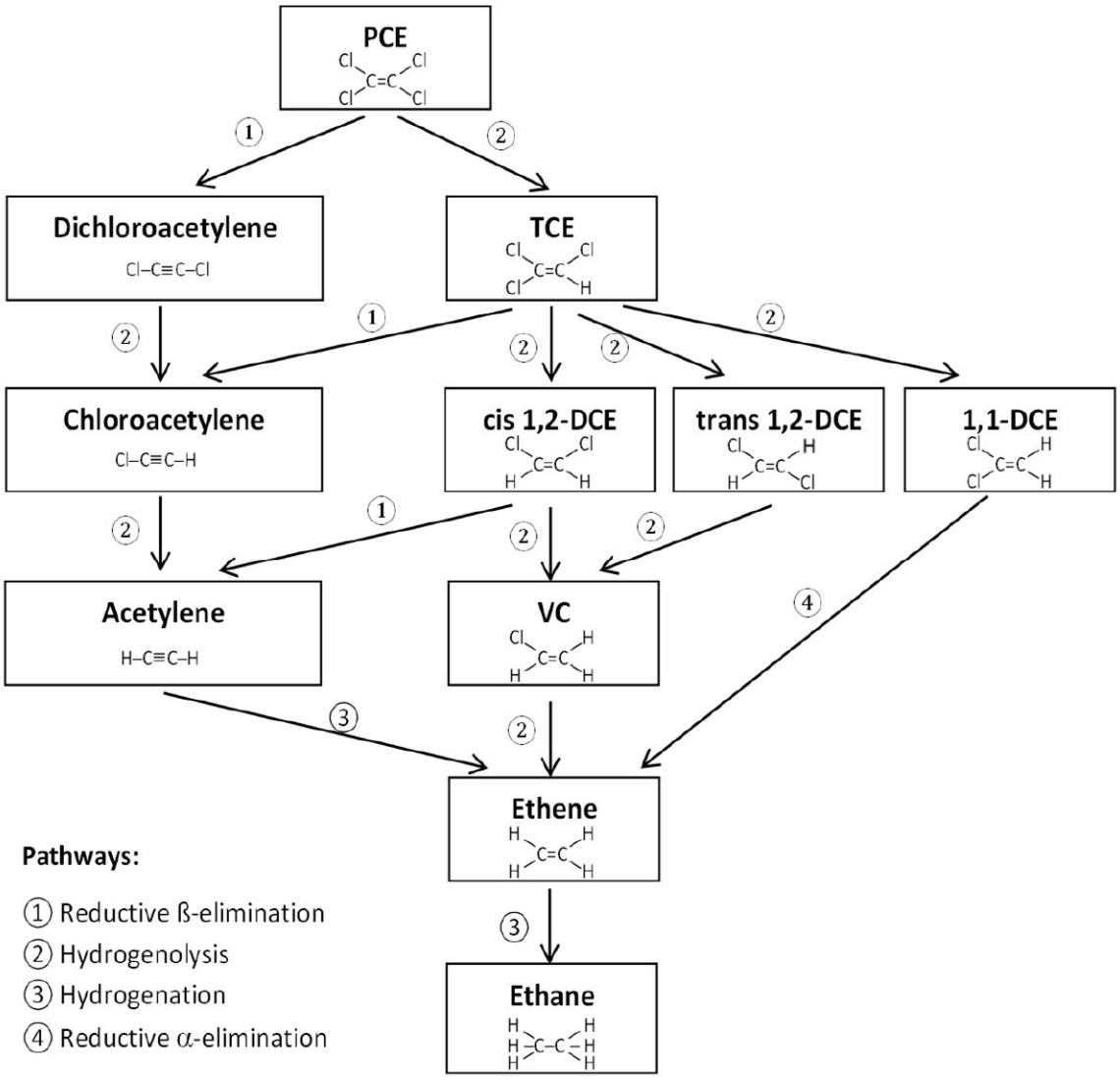
Pathways for the Degradation of Chlorinated Ethenes by Bioremediation

SiREM

October 2015

Figure: **1**

0001 pathways_chlorinated ethenes.ai



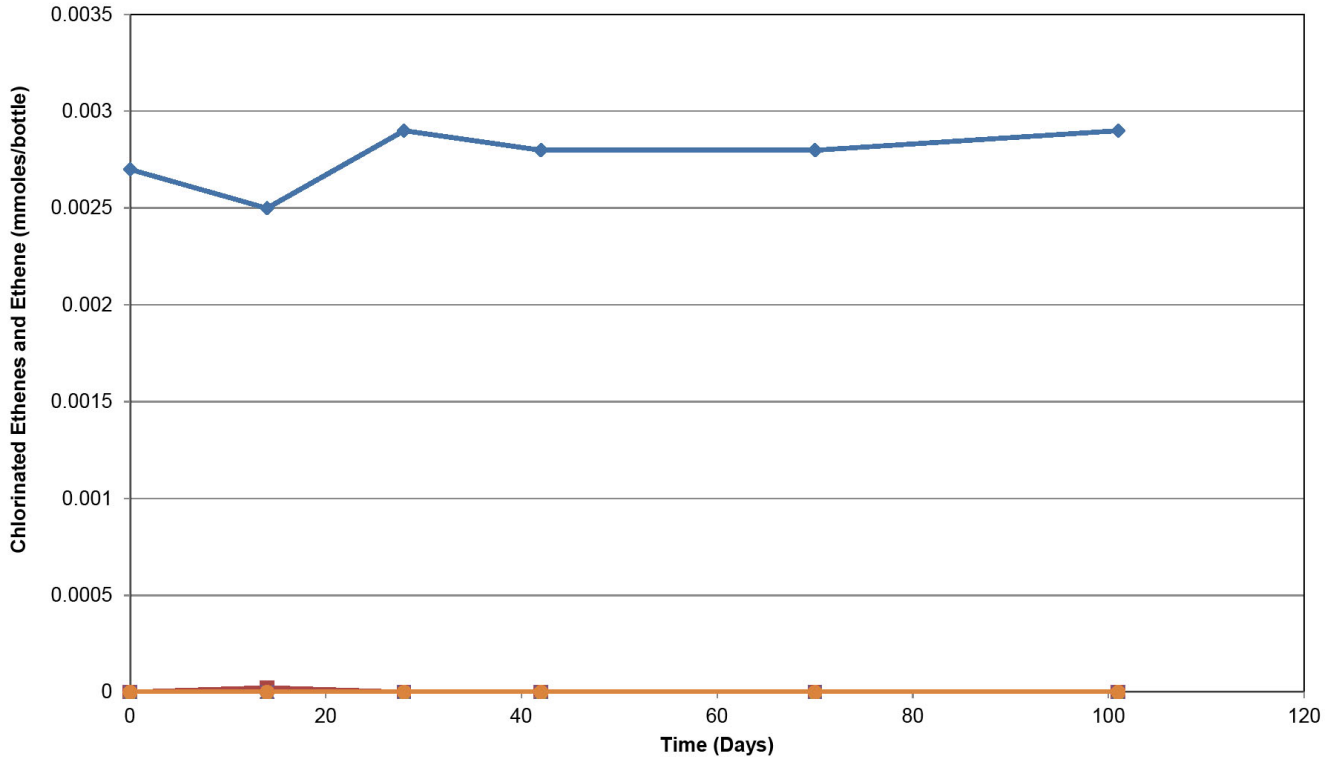
(modified from Arnold and Roberts, 2000)

Pathways for the Degradation of Chlorinated Ethenes by ZVI

SiREM

January 2018

Figure: 2



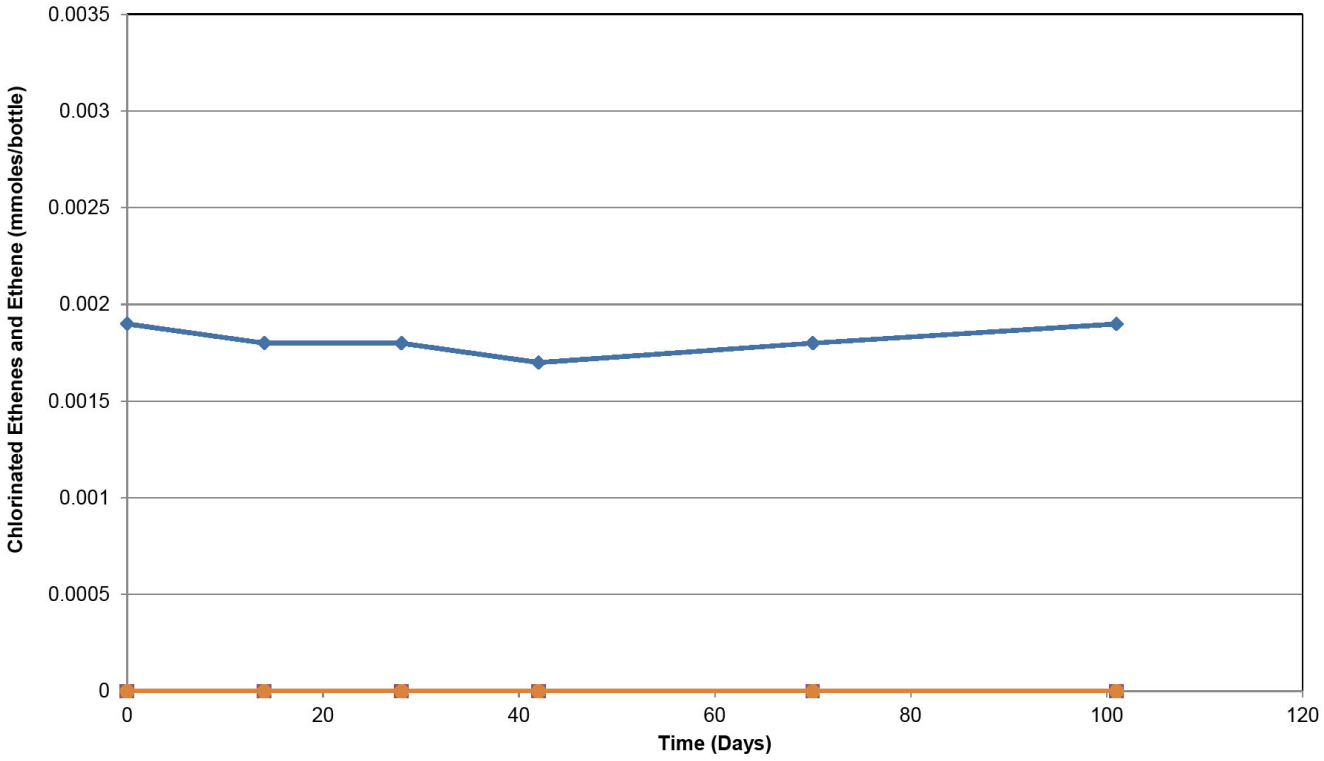
Chlorinated Ethenes and Ethene Concentration Trends in Anaerobic Sterile Control Microcosms

Newberry, SC

SiREM

February 2020

Figure: 3



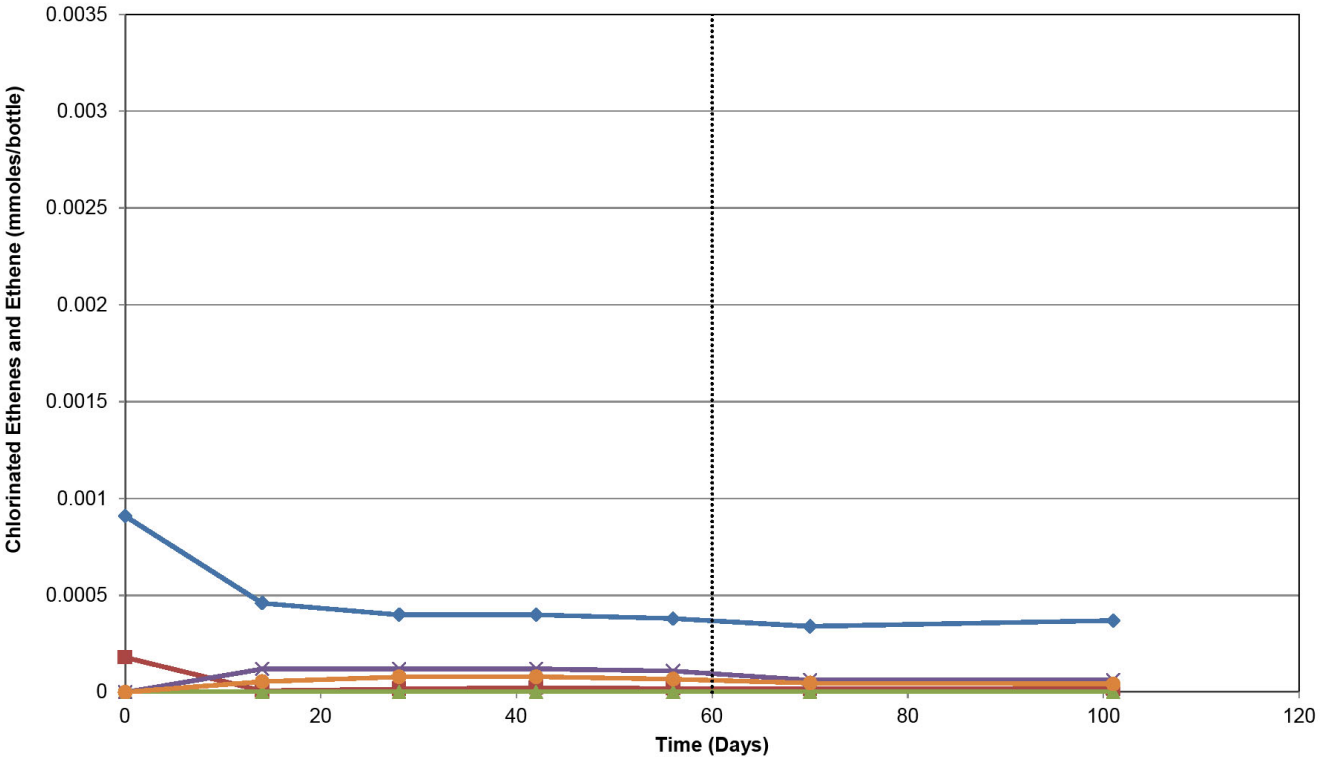
Chlorinated Ethenes and Ethene Concentration Trends in Anaerobic Active Control Microcosms

Newberry, SC

SiREM

February 2020

Figure: **4**



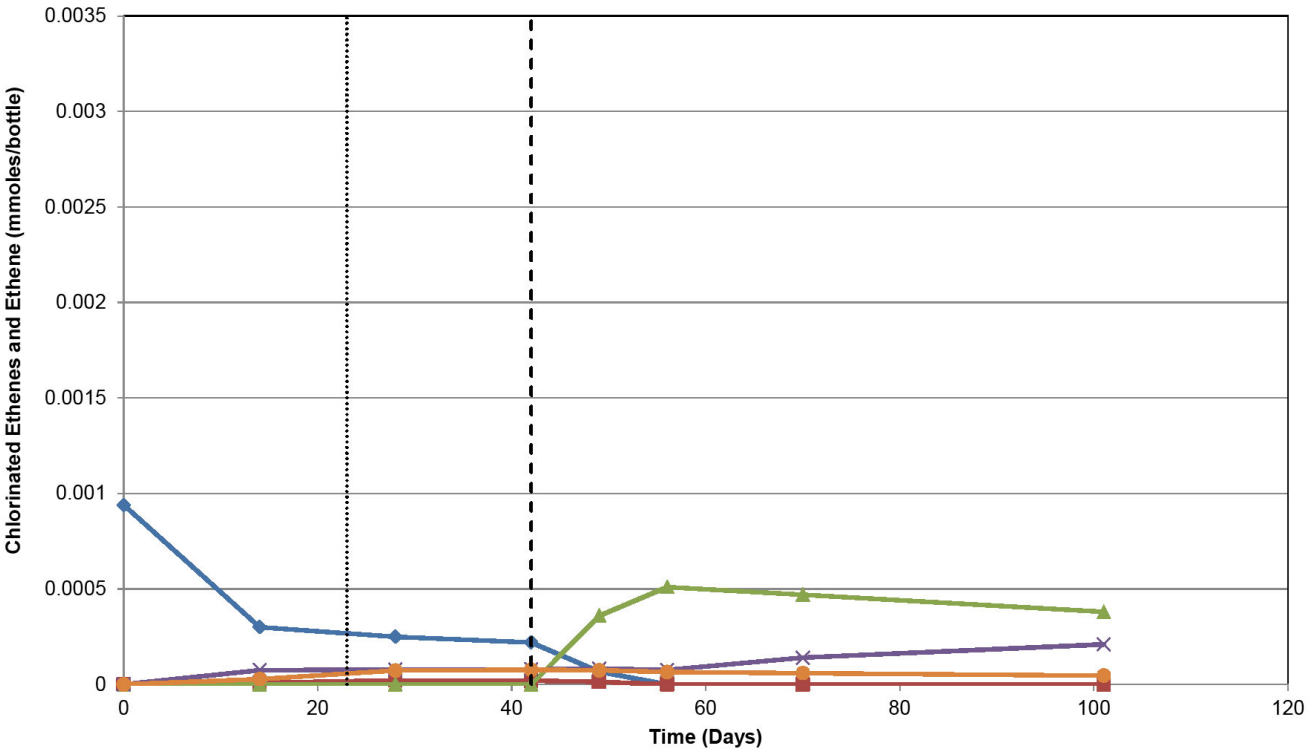
Chlorinated Ethenes and Ethene Concentration Trends in MicroEVO™ ISCR Amended Microcosms

Newberry, SC

SiREM

February 2020

Figure: **5**



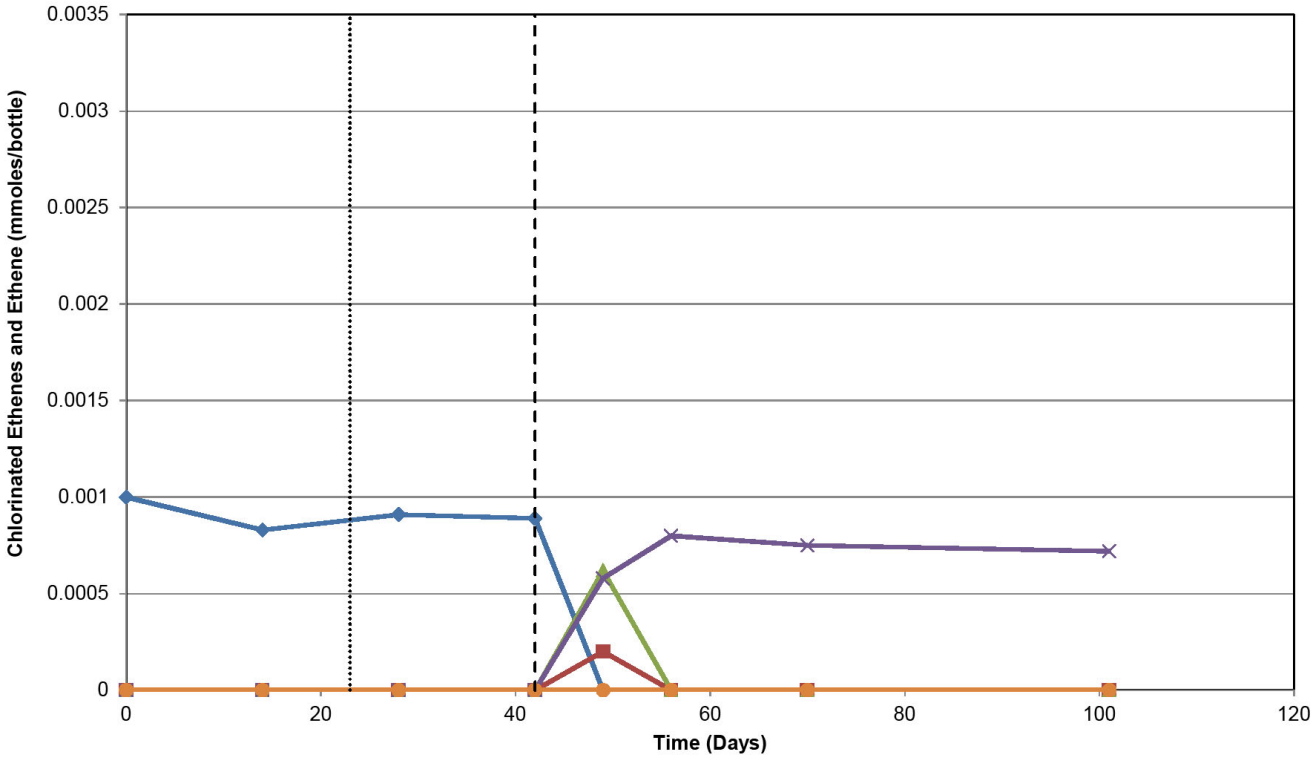
Chlorinated Ethenes and Ethene Concentration Trends in MicroEVO™ ISCR Amended/KB-1® Plus Bioaugmented Microcosms

Newberry, SC

SiREM

February 2020

Figure: 6



Chlorinated Ethenes and Ethene Concentration Trends in EDS-ER™ Amended/KB-1® Plus Bioaugmented Microcosms

Newberry, SC

SiREM

February 2020

Figure: 7

APPENDIX A: Chain of Custody Documentation

SiREM

Chain-of-Custody Form

siremlab.com

130 Stone Rd. W
Guelph, ON N1G 3Z2
(519) 822-2265

Lab # S-5508

P. 1 of 2

*Project Name: Shakespeare - Newbery	*Project #: 60534233
*Project Manager: Scott Ross	*Company: AECOM
*Email Address: Scott.ross@aecom.com	
Address (Street): 101 Research Drive	
City: Columbia	State/Province: SC
Country: US	
*Phone #: (803) 254-4400 x 2246	
*Sampler's Signature: Scott Ross	*Sampler's Printed Name: Scott E. Ross

	Client Sample ID	Sampling Date	Sampling Time	Matrix	# of Containers
1.	MC-01I	9/12/19	1320	Soil	3
2	MW-10I	9/12/19	1612	GW	1

Analysis

Gene-Trac DHC	Gene-Trac FGA (vcrA, bvcA, tceA)	Gene-Trac DHB	Gene-Trac DHG	Gene-Trac tceA	Volatile Fatty Acids	Dissolved hydrocarbon gases	Treatability Study				
							X				
							X				

Preservative Key

0. None
1. HCL
2. Other _____
3. Other _____
4. Other _____
5. Other _____
6. Other _____

Other Information

Billing Information	Turnaround Time Requested	For Lab Use Only	For Lab Use Only
P.O. #	Normal ☐	Cooler Condition: Good	
*Bill To:	Rush ☐	Cooler Temperature: 7°C	
		Custody Seals: Yes ☐ No ☒	Proposal #: _____

Relinquished By:	Received By:	Relinquished By:	Received By:	Relinquished By:	Received By:
Signature: Scott Ross	Signature: Taylor Aris	Signature:	Signature:	Signature:	Signature:
Printed Name: Scott Ross	Printed Name: Taylor Aris	Printed Name:	Printed Name:	Printed Name:	Printed Name:
Firm: AECOM	Firm: SiREM	Firm:	Firm:	Firm:	Firm:
Date/Time: 09/18/19 1700	Date/Time: Sep. 20/19 2:45 pm	Date/Time:	Date/Time:	Date/Time:	Date/Time:

Distribution: White - return to Originator; Yellow - Lab Copy; Pink - Retained by Client

* Mandatory Fields

SiREM

Chain-of-Custody Form

siremlab.com

130 Stone Rd. W
Guelph, ON N1G 3Z2
(519) 822-2265

Lab # S-5508

AECOM

P. 2 of 2

*Project Name: Shakespeare - Newberry	*Project #: 60534283 Task 13
*Project Manager: Scott Ross	*Company: AECOM
*Email Address: Scott.ross@aecom.com	
Address (Street): #101 Research Drive	
City: Columbia	State/Province: SC
Country: US	
*Phone #: (803) 201-9662	
*Sampler's Signature:	*Sampler's Printed Name: Scott E. Ross

	Client Sample ID	Sampling Date	Sampling Time	Matrix	# of Containers
3.	MC-01-23-27	9/13/19	1100	soil	3
4.	MW-10	11	1515	GW	1

Analysis

Gene-Trac DHC	Gene-Trac FGA (vcrA, bvcA, tceA)	Gene-Trac DHB	Gene-Trac DHG	Gene-Trac tceA	Volatile Fatty Acids	Dissolved hydrocarbon gases	Treatability Study				
							X				
							X				
							Y				

Preservative Key

0. None
1. HCL
2. Other
3. Other
4. Other
5. Other
6. Other

Other information

Billing Information	Turnaround Time Requested	For Lab Use Only	For Lab Use Only
P.O. #	Normal ☐	Cooler Condition: Good	
*Bill To:	Rush ☐	Cooler Temperature: 6°C	
		Custody Seals: Yes ☐ No ☒	Proposal #:

Relinquished By:	Received By:	Relinquished By:	Received By:	Relinquished By:	Received By:
Signature:	Signature: Taylor K	Signature:	Signature:	Signature:	Signature:
Printed Name: Scott E Ross	Printed Name: Taylor Ans	Printed Name:	Printed Name:	Printed Name:	Printed Name:
Firm: AECOM	Firm: SiREM	Firm:	Firm:	Firm:	Firm:
Date/Time: 9/13/19 1700	Date/Time: Sep. 20/19 2:45pm	Date/Time:	Date/Time:	Date/Time:	Date/Time:

Distribution: White - return to Originator; Yellow - Lab Copy; Pink - Retained by Client

* Mandatory Fields

APPENDIX B: Buffering Capacity Testing

Prepared for:

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Buffering Capacity Testing

Newberry, South Carolina

Prepared by:

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SiREM Ref: TL0337

9 March 2020

siremlab.com

INTRODUCTION

AECOM retained SiREM to perform a buffer capacity test using a saturated sodium bicarbonate ($NaHCO_3$) stock solution to obtain a target pH of 7.0 ± 0.2 in groundwater and geologic materials collected from the Newberry site in South Carolina (the Site). The geologic materials labelled MC-01I and MC-01-23-27 and groundwater labelled MW-10I and MW-10 were collected by AECOM personnel on 18 September 2019. All materials were received by SiREM on 20 September 2019 in good condition at a temperature of 7 degrees Celsius (°C). Refer to Appendix A for the chain of custody documentation received with the materials.

CASE NARRATIVE

On 24 September 2019, Site groundwater and geologic material were transferred into an anaerobic glove bag for reactor construction. The geologic materials from all cores were homogenized using a 1 centimeter (cm) x 1 cm stainless steel sieve to maximize reproducibility between replicates.

The reactors were constructed by combining 60 grams (g) of Site geologic material (wet weight) and 200 milliliters (mL) of Site groundwater in 250 mL (nominal volume) screw cap Boston round clear glass bottles (Systems Plus, New Hamburg, ON). The bottles were capped with Mininert™ closures to allow repetitive sampling. Control and treatment reactors were prepared in duplicate.

The control reactors did not receive $NaHCO_3$ amendments and were sampled for pH analysis at Time 0 and after 1, 2, 3 and 6 days of incubation. The treatment reactors were amended with $NaHCO_3$ incrementally to reach a target pH of 7.0 ± 0.2 and adjusted as necessary after 1, 2, 3 and 6 days of incubation. The pH of each reactor was measured with an Oakton waterproof pH spear (Oakton Instruments, Vernon Hills, IL). The pH meter was calibrated at each sampling event using pH standards (pH 4.0, 7.0 and 10).

All reactors were mixed thoroughly after $NaHCO_3$ additions. The reactors were then allowed to settle prior to pH measurement and sampled using a 1 mL glass syringe. Each titration was conducted by adding a series of saturated $NaHCO_3$ (96 gram per liter [g/L]) solution aliquots to the treatment reactors as required until the target pH was attained.

RESULTS

Table B1 provides a summary of the treatment reactor buffer demand. The buffer demand was calculated by converting the volume of $NaHCO_3$ added to the reactor to millimolar equivalents and dividing by the dry weight of the geological material in the reactors.

TABLE B1: SUMMARY OF BUFFERING ASSAY RESULTS
Newberry, SC

Groundwater and Geologic Material Treatment
Reactors 1 & 2

Average volume of groundwater (mL)	200
Average mass of dry soil (g)	60
Concentration of $NaHCO_3$ (g/L)	96
Molecular Weight of $NaHCO_3$ (g/mol)	84.01

Date	Day	pH	
		Reactor 1	Reactor 2
24-Sep-19	0	5.43	5.42
25-Sep-19	1	5.79	5.75
26-Sep-19	2	6.20	5.95
27-Sep-19	3	5.81	5.83
30-Sep-19	6	5.76	5.76

Groundwater and Geologic Material Buffered Treatment
Reactors 3 & 4

Average volume of groundwater (mL)	200
Average mass of dry soil (g)	60
Concentration of $NaHCO_3$ (g/L)	96
Molecular Weight of $NaHCO_3$ (g/mol)	84.01

Date	Day	pH		Volume of Buffer Solution Added (µL)	Cumulative Buffer Solution Added (µL)	Buffer Demand (g/reactor)	Buffer Demand (g/kg)	Buffer Demand (mmol/g)
		Reactor 3	Reactor 4					
24-Sep-19	0	5.43	5.43	0	0	--	--	--
		5.83	--	50	50	--	--	--
		6.02	--	50	100	--	--	--
		6.26	--	100	200	--	--	--
		6.44	6.57	100	300	--	--	--
		6.69	6.83	200	500	--	--	--
		--	7.08	100	600	0.036	--	--
		7.06	--	100	700	0.067	--	--
25-Sep-19	1	7.18	7.11	0	700	0.067	1.12	0.013
26-Sep-19	2	7.03	7.05	0	700	0.067	1.12	0.013
27-Sep-19	3	6.95	6.98	0	700	0.067	1.12	0.013
30-Sep-19	6	6.94	6.94	0	700	0.067	1.12	0.013
	Average initial pH		5.43					
	Average final pH		6.94					

Notes:

- -- not applicable
- µL - microliter
- g - grams
- g/kg - grams per kilogram
- g/L - grams per liter
- g/mol - grams per mole
- g/reactor - grams per reactor
- mL - milliliter
- mmol/g - millimoles per gram
- $NaHCO_3$ - sodium bicarbonate

APPENDIX C: Henry's Law Calculation

The following Henry's Law calculation was used to convert aqueous concentrations (Table 2) to total mmoles of each analyte per microcosm bottle (Figures 3 to 7):

$$Total\ mmoles = \frac{C_{liq} \cdot \left(V_{liq} + H \cdot V_{gas}\right)}{Molecular\ Weight\ (\frac{mg}{mmol})}$$

Where

C_{liq} = liquid concentration (mg/L)
V_{liq} = liquid volume (0.225 L) per bottle
V_{gas} = headspace volume (0.025 L) per bottle
H = Henry's Law constant (dimensionless)

The Henry's Law constants used are summarized in the table below.

Analyte	Henry's Law Constant [a] (dimensionless)
Trichloroethene	0.417
cis-1,2-Dichloroethene	0.184
Vinyl chloride	1.08
Acetylene	1.59
Ethene	8.78
Ethane	20.5
Methane	27.3

[a] Source: Montgomery, J.H. 2000. *Groundwater Chemicals Desk Reference, Third Edition.* CRC Press LLC, Boca Raton, FL.

About AECOM

AECOM is the world's premier infrastructure firm, delivering professional services throughout the project lifecycle – from planning, design and engineering to consulting and construction management. We partner with our clients in the public and private sectors to solve their most complex challenges and build legacies for generations to come. On projects spanning transportation, buildings, water, governments, energy and the environment, our teams are driven by a common purpose to deliver a better world. AECOM is a Fortune 500 firm with revenue of approximately $20.2 billion during fiscal year 2019. See how we deliver what others can only imagine at aecom.com and @AECOM.

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