APPENDIX I

Shallow Zone of Upper Surficial Aquifer – Groundwater Interim Corrective Measure Work Plan – *In situ* Chemical Oxidation

GEORGIA
DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION

Richard E. Dunn, Director

Land Protection Branch
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August 17, 2021

Sent via email and USPS

Mr. Tim Hassett
Project Manager
Hercules, LLC
500 Hercules Road
Wilmington, DE 19808-1599

Ms. Molly Matthews
Director of Operations
DRT America, Inc.
2801 Cook Street
Brunswick, Georgia 31520

RE: Interim Corrective Measure Work Plan
Shallow Zone of Upper Surficial Aquifer
Hercules/Pinova - Brunswick Facility
HW Facility Permit No. HW-52(D&S)
EPA ID# GAD004065520

Dear Mr. Hassett and Ms. Matthews:

The Georgia Environmental Protection Division (EPD) has reviewed the *Interim Corrective Measure Work Plan, Shallow Zone of Upper Surficial Aquifer, Stillhouse Control Room Area* dated August 2021. The revised plan adequately addresses the comments noted in our July 6, 2021, letter and the applicable general comments discussed regarding the Corrective Action Plan. No additional comments were noted; therefore, the Shallow Groundwater Interim Corrective Measure Work Plan is approved.

Please continue to keep us informed as to when the field work is scheduled. Should you have any questions, please contact Penny Gaynor at (470) 938 3364 or Penny.Gaynor@dnr.ga.gov.

Sincerely,

Jim McNamara
Digitally signed by Jim McNamara
Date: 2021.08.17 09:24:04 -04'00'

Jim McNamara
Program Manager
Hazardous Waste Corrective Action Program

File: Hercules, Brunswick 216-0060 (G)

Prepared for

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INTERIM CORRECTIVE MEASURE WORK PLAN

SHALLOW ZONE OF UPPER SURFICIAL AQUIFER
STILLHOUSE CONTROL ROOM AREA
HERCULES/PINOVA BRUNSWICK FACILITY
BRUNSWICK, GEORGIA

Prepared by

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1255 Roberts Boulevard, Suite 200
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Project Number GR6881K

August 2021

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1. INTRODUCTION

This Interim Corrective Measure Work Plan (the "Work Plan") has been prepared by Geosyntec Consultants ("Geosyntec") on behalf of Hercules LLC ("Hercules") for submission to the Georgia Department of Natural Resources, Environmental Protection Division ("EPD") in connection with environmental conditions at an industrial facility located at 2801 Cook Street in Brunswick, Glynn County, Georgia (referred to hereinafter as the "Brunswick facility" or the "Site"). The purpose of the interim corrective measure (the "ICM") described in the Work Plan is to reduce the mass of selected contaminants of potential concern ("COPCs") in groundwater in the shallow zone of the upper surficial aquifer underlying the southern production area of the Brunswick facility near a building designated as the Stillhouse Control Room. This area is shown on **Figure 1** along with the boundaries of the Brunswick facility. The ICM presented herein will utilize *in situ* chemical oxidation ("ISCO") to achieve mass reduction of COPCs in groundwater and is one of multiple ICMs for groundwater being implemented at the Brunswick facility as described in a document titled *Corrective Action Plan* that Hercules submitted to EPD on February 1, 2021 (Geosyntec, 2021). In addition to addressing groundwater conditions in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room using ISCO, the ICM will provide site-specific information about the effectiveness and implementability of ISCO for treating selected COPCs that are present in shallow groundwater in other areas of the Brunswick facility.

As discussed in more detail in later sections of this Work Plan, ISCO involves destruction of organic contaminants by injecting an oxidant into the groundwater treatment zone through injection wells or direct push injection probes. The oxidant then destroys organic contaminants through oxidizing those contaminants that come into contact with the oxidant. Effective use of ISCO in groundwater requires direct contact between organic contaminants and the oxidant for a complete oxidation reaction to occur. Oxidants that are commonly used for remediation of groundwater include permanganate, persulfate (often combined with activators), ozone, percarbonate, and peroxide (e.g., Fenton's reagent and calcium peroxide). Certain oxidants can also be combined for enhanced effects.

1.1 Site History

As described in detail in the Corrective Action Plan that Hercules submitted to EPD on February 1, 2021, the operational history of the Brunswick facility spans more than a century. Yaryan Rosin and Turpentine Company began operations at the Brunswick facility in 1911 on a 70-acre parcel. Hercules purchased the Brunswick facility in 1920. Over time, Hercules acquired additional parcels of land and significantly expanded the scope of the manufacturing operations at the Brunswick facility. After several recent transactions reduced the overall size of the Brunswick facility from its greatest extent, the total area of the Brunswick facility now encompasses approximately 321 acres of land. In January 2010, Hercules sold the southern portion of the Brunswick facility to Pinova, Inc. ("Pinova"), which continues to operate the manufacturing processes in that portion of the Brunswick facility for the production of wood rosins, resins, and terpene oils for a wide variety of end uses. Hercules continues to own the remaining portions of the Brunswick facility. No manufacturing operations are conducted on property currently owned by Hercules. The ICM described in this Work Plan is expected to take place in the portion of the Brunswick facility that Pinova owns.

1.2 Overview of Site Geology and Hydrogeology

While the ICM described in this Work Plan is expected to be performed in the shallow zone of the upper surficial aquifer, a broader description of the water-bearing zones and the characteristics of the hydrogeologic units beneath the Brunswick facility to a depth of approximately 200 feet below ground surface ("ft bgs") is provided below for reference. The geologic and hydrogeologic units that underlie the Brunswick facility to that depth include: the upper surficial aquifer (extending to approximately 100 ft bgs), a confining unit separating the upper surficial aquifer from the lower surficial aquifer, and the lower surficial aquifer (extending to approximately 200 ft bgs). The upper surficial aquifer is divided into three zones: shallow (~ 0–40 ft bgs), intermediate (~ 40–70 ft bgs), and deep (~70–100 ft bgs) as shown on **Figure 2**.

The aquifer zones are generally based on differences in geologic materials, hydraulic conductivities, and the vertical distribution of 40 C.F.R. Part 264, Appendix IX volatile organic compounds ("VOCs") in groundwater. The shallow zone of the upper surficial aquifer is generally composed of interbedded clays, silts, silty sands, clayey sands, and light brown/tan or gray fine to coarse sands. The vadose zone overlying the shallow zone of the upper surficial aquifer is generally very thin, with the seasonal high water table at a depth of only a few feet in many portions of the Brunswick facility. The intermediate zone of the upper surficial aquifer is primarily composed of gray fine to coarse sand, interbedded with varying amounts of clays, silts, silty sands, clayey sands, and gravel; cemented sands are also sometimes encountered in the intermediate zone. The deep zone of the upper surficial aquifer is composed of gray, fine to coarse sand, with relatively lesser amounts of clayey sands, silty sands, silts, and clays. Another characteristic of the deep zone of the upper surficial aquifer is the prevalence of coarse sand and sand with gravel intervals that may provide preferential groundwater flow pathways where they are linearly continuous. The lower surficial aquifer beneath the Brunswick facility is generally composed of olive green to gray fine sands, silty sands, clayey sands, and silts. The lower surficial aquifer is separated from the upper surficial aquifer by a confining unit consisting primarily of silts and clays.

Within the upper surficial aquifer underlying the Brunswick facility and adjacent areas, the prevailing direction of groundwater flow is toward the east-southeast, with local variations due to heterogeneities in the subsurface units. This groundwater flow direction is based on the interpreted potentiometric surface contour map that is presented as **Figure 3**. Well construction details for existing monitoring wells in the vicinity of the Stillhouse Control Room are provided in **Table 1**.

Based on observations obtained from previous soil borings, the geology beneath the area adjacent to the Stillhouse Control Room is characterized as grey to dark brown fine sand with trace silt. Groundwater is encountered approximately 2 ft bgs in the area of the Stillhouse Control Room. Based on the potentiometric surface map provided on **Figure 3,** a hydraulic mound is present in the area of the Stillhouse Control Room which would act to slightly steepen the downward vertical hydraulic gradient from the shallow zone to the deep zone of the upper surficial aquifer that has been observed in that area.

1.3 ICM Location and Contaminants of Potential Concern

The Work Plan focuses on corrective measures in the shallow zone of the upper surficial aquifer in the area of the Stillhouse Control Room. This portion of the Brunswick facility is located within the southern production area of the Brunswick facility and is shown on **Figure 4**. Hercules plans to proceed with an interim corrective measure for groundwater in the shallow zone of the upper surficial aquifer in this area because non-aqueous phase liquid ("NAPL") was observed to be present during the installation of temporary well point SGW-23 as part of investigation activities associated with assessing potential vapor intrusion into occupied buildings at the Brunswick facility and elevated concentrations of VOCs have been detected in shallow groundwater (specifically benzene, para-cymene, and toluene) in monitoring wells MW-21, MW-22, MW-23, and MW-24 in this area. In particular, benzene has been detected in the shallow zone of the upper surficial aquifer at concentrations ranging from 5,600 micrograms per liter ("ug/L") to 36,000 µg/L in monitoring wells MW-21 through MW-24. Benzene is the primary COPC in groundwater targeted for the interim corrective measure in this area.

2. DESIGN BASIS FOR INTERIM CORRECTIVE MEASURE

2.1 Corrective Measure Objectives

The interim corrective measure for groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room is intended to serve two purposes:

- To reduce the mass of COPCs in groundwater within the target treatment area which may contribute to the plume of VOCs in the deep zone of the upper surficial aquifer.

- To provide information regarding best practices for addressing targeted COPCs in groundwater in the shallow zone of the upper surficial aquifer which practices potentially can then be expanded to address COPCs in groundwater in other locations within the Brunswick facility as necessary.

Benzene is the primary COPC in groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room targeted for treatment using ISCO. The initial objective to determine the efficacy of the technology is to reduce the average concentration of benzene in groundwater in that area by 50%. This objective will be modified, as appropriate, based on updates and refinements to the conceptual site model (“CSM”) and appropriate fate and transport evaluations.

2.2 Basis for Selection of ISCO

As discussed in the Corrective Action Plan submitted to EPD on February 1, 2021, a combination of desktop, field, and laboratory evaluations were performed that led to the selection of ISCO as the remedial technology to be used for groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room. Several potential remedial technologies were considered for this ICM, with the main goal being to reduce the mass of benzene in shallow groundwater in the area of the Stillhouse Control Room. The remedial technologies that were screened included *in situ* chemical oxidation (i.e., ISCO), enhanced *in situ* bioremediation using aerobic bioremediation, enhanced *in situ* bioremediation using anaerobic bioremediation, air sparging coupled with soil vapor extraction, *in situ* stabilization, *in situ* thermal desorption, multi-phase extraction, and ozone sparging coupled with soil vapor extraction. The screening criteria included considerations such as implementability, effectiveness, efficiency (including relative costs and resource use), and the potential for disruption to Pinova’s manufacturing operations. As a result of the screening process, field pilot tests and bench scale studies were performed to further evaluate the following remedial technologies: multi-phase extraction, enhanced *in situ* bioremediation using aerobic bioremediation, enhanced *in situ* bioremediation using anaerobic bioremediation, and *in situ* chemical oxidation.

2.2.1 Physical Considerations Associated with the Targeted Groundwater Treatment Area

Constraints specific to the targeted groundwater treatment area near the Stillhouse Control Room that were considered as part of evaluating potential remedial technologies included the following:

- The area is classified as an electrical safety area designated as a Class I Division 2 area under criteria established by the National Fire Protection Association due to the potential presence of flammable gases and vapors. This classification significantly complicates the installation of systems requiring mechanical/electrical controls and necessitates using explosion-proof equipment.

- Groundwater in the area is very shallow (approximately 2 ft bgs). The shallow depth to groundwater and the limited vadose zone complicates remedial technologies that require injections under significant pressure (e.g., use of air sparging and soil vapor extraction).

- Underground and aboveground physical infrastructure and utilities are present in the area which must be protected in connection with any groundwater treatment process.

2.2.2 Field Pilot Tests

An *in situ* injection pilot test was performed in the area near the Stillhouse Control Room in 2020 to evaluate the physical injection characteristics of the subsurface and to gauge the feasibility of *in situ* injection of liquids into the shallow zone of the upper surficial aquifer for purposes of corrective measures. The results of the *in situ* injection pilot test indicate that *in situ* injection of liquids is feasible and can be implemented via gravity infiltration or using an applied low pressure dosing mechanism. The observed injection pressures, flow rates, and radius of influence ("ROI") achieved during this pilot test were used to estimate the design parameters for the ISCO treatment system described in Section 4.2 of this Work Plan.

In addition, a multi-phase extraction pilot test was performed to gauge the feasibility of using multi-phase extraction technology for future corrective measures. The results of the multi-phase extraction pilot test indicate that multi-phase extraction technology is capable of producing localized groundwater drawdown to expose additional portions of the vadose zone to facilitate extraction of soil vapors. However, this technology was not selected due to (i) the complexities and constraints associated with meeting the Class I Division 2 requirements for mechanical/electrical equipment needed for the extraction system and operation of aboveground treatment systems for recovered vapors and groundwater, and (ii) the associated ongoing operation and maintenance requirements for the extraction and treatment system for three different waste streams (i.e., extracted water, vapors/soil gas, and potentially NAPL).

2.2.3 Bench Scale Treatability Studies

As discussed in detail in the Corrective Action Plan that Hercules submitted to EPD on February 1, 2021, bench-scale treatability studies were performed to evaluate the viability of using either *in situ* aerobic bioremediation or enhanced *in situ* anaerobic bioremediation to remove benzene from groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room. While the treatability studies indicated that *in situ* aerobic bioremediation was potentially a viable option, Hercules decided not to use this approach because of the complications associated with using air sparging to deliver oxygen to shallow groundwater in the area of the Stillhouse Control Room.

In addition, Hercules performed a bench-scale treatability study for ISCO to evaluate the oxidant demand and pH amendment demand for soil and groundwater in the shallow zone of the upper surficial aquifer, as described in **Appendix A**. The ISCO bench-scale treatability study was conducted using soil from the area of the Stillhouse Control Room collected for the biotreatability studies described above and groundwater collected from monitoring well MW-21. The ISCO bench-scale treatability study evaluated base activated persulfate using sodium persulfate as an oxidant and sodium hydroxide as an activator. The treatability study also included base titration and soil oxidant demand testing. The treatability study showed that ISCO is effective in reducing concentrations of benzene in groundwater from an average initial starting concentration of 2.9 milligrams per liter ("mg/L") to an average final concentration of 0.133 mg/L in a reaction period of 17 days. These results represent a reduction in concentrations of benzene of more than 95% in a laboratory-controlled environment. The oxidant demand was estimated to be 33.3 grams per liter ("g/L") from the results of the treatability study.

The results of the ISCO bench-scale treatability study demonstrate that ISCO is feasible to use as a remedial technology for groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room. Multiple rounds of oxidant injections may be needed to reduce concentrations of benzene in groundwater to target levels. Multiple injections of oxidants are often necessary due to rebound in concentrations of COPCs in groundwater following initial treatment as COPCs desorb from the aquifer matrix into groundwater or are carried into the treatment zone from upgradient areas that may be impacted. While the ISCO bench-scale treatability study achieved reductions in the concentrations of benzene of over 95% in approximately two weeks, it is important to note that reaction times in ISCO field applications may not occur as rapidly as in a laboratory-controlled environment due to heterogenous conditions at the treatment location and desorption of COPCs from the soil matrix into the surrounding groundwater.

2.3 Proposed Interim Corrective Measure

Based on the results from the pilot tests and treatability studies described above and considering the various constraints that exist in the area to be addressed, Hercules has selected ISCO as the remedial technology to deploy to address COPCs in groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room. ISCO is an *in situ*, aggressive, and implementable remedial technology that can be deployed with readily available contractors and materials. ISCO can also be optimized to achieve varying levels of contaminant mass reduction. ISCO can produce rapid results under optimal conditions and avoids the significant challenges that are posed by attempting to deploy remedial technologies that rely on explosion-proof mechanical and/or electrical controls and systems that satisfy the requirements for an electric safety area designated as Class I Division 2.

ISCO will be implemented in the area of the Stillhouse Control Room by installing a series of injection wells and observation wells throughout a target treatment area that is approximately 40 feet by 70 feet in size. The injection wells will be used to deliver base activated persulfate to target groundwater in the shallow zone of the upper surficial aquifer from approximately 5 ft bgs to 20 ft bgs. The proposed locations and design of the injection wells are discussed further in Section 4.1 of this Work Plan, and oxidant selection is discussed further in Section 4.2 of this Work Plan.

3. PRE-IMPLEMENTATION ACTIVITIES AND SITE PREPARATION

Several planning and preparatory steps will be performed prior to mobilization to the area near the Stillhouse Control Room to implement ISCO in the shallow zone of the upper surficial aquifer including health and safety planning, permitting, contractor and amendment procurement, and utility clearances. These steps are discussed below.

3.1 Health and Safety Planning

The existing Health and Safety Plan ("HASP") for environmental work at the Brunswick facility will be amended to include the tasks, hazards, and hazard mitigation procedures related to implementation of ISCO. Pertinent elements of the amendments to the HASP will address hazard identification and mitigation, establishment of work zones, ingress/egress procedures, decontamination procedures, worker breathing space monitoring, chemical storage requirements, spill prevention procedures, and spill control procedures and countermeasures. Safety incident response supplies will also be specified in the HASP, such as first aid, eye wash, and fire suppression supplies. Preparation and handling of sodium hydroxide and sodium persulfate will be performed by or under the direct supervision of field personnel who have received project-specific health and safety training and instruction in the handling of the base and the oxidant that will be used.

Appropriate personal protective equipment ("PPE") will be worn during the duration of work activities associated with implementing ISCO, and additional PPE requirements will likely be necessary for activities involving (i) the handling and dilution of sodium hydroxide and (ii) the preparation of sodium persulfate batches.

The potential for worker exposure to possible hazards will be monitored and documented frequently using a calibrated four-gas meter. The four-gas meter will be used regularly to measure VOCs and the potential for combustible gases to be present at levels greater than the corresponding lower explosive limits ("LELs") as a matter of protecting worker health and safety related to chemicals other those used in implementing ISCO.

Field personnel will apply "good housekeeping" measures during injection events to prevent accidental slips, trips, or falls on injection system components. Spill containment protection (i.e., plastic sheeting) will be placed around the batch tank, underneath in-line mechanisms, and around the injection wells as they are being used. Neutralizing solution will be available in spray bottles, plastic jugs, and 3- to 5-gallon pump-type sprayers to address potential spills or leaks of oxidant.

3.2 Permitting

Injection of a fluid into the subsurface via an injection well in Georgia requires an underground injection control ("UIC") permit from EPD. A permit application will be prepared and submitted to EPD for approval to use Class V injection wells for delivery of the oxidant, specifically base activated sodium persulfate.

3.3 Contractor and Amendment Procurement

Procurement packages will be developed for use in communicating the scope of work to potential contractors and suppliers. Hercules anticipates procuring the following contractors and suppliers: a drilling contractor for installation of injection and observation wells, a subsurface utility location contractor, an injection contractor for injecting the base activated sodium persulfate into the subsurface, a sodium hydroxide supplier, and a sodium persulfate supplier.

There are also several elements of the proposed interim corrective measure that will require communication and coordination with Pinova regarding health and safety procedures and utility protection. Some of the items that will be coordinated with Pinova are the delivery procedures and storage locations for sodium persulfate and sodium hydroxide, batching operation locations, water sources, personal protective equipment requirements, and the health and safety monitoring program.

3.4 Utility Clearance

The locations of underground utilities in the area near the Stillhouse Control Room will be marked before initiating drilling operations. Documentation that nearby utilities have been marked on the ground and that the proposed drilling locations have been cleared will be kept in the project trailer/support vehicle and communicated to the drilling subcontractor. The utilities will be identified on a task hazard analysis and communicated to the support personnel.

4. DESIGN

4.1 Overview of the Oxidant Injection Plan

An oxidant injection program has been developed with the goal of reducing the mass of COPCs in shallow groundwater in the target treatment area near the Stillhouse Control Room while being protective of site utilities. Utilities are located around the perimeter of the target treatment area at depths of approximately five feet bgs. Hercules plans to inject oxidant in the treatment area in two phases or stages. Stage 1 will involve injecting oxidant in the center of the target treatment area (referred to as the Stage 1 treatment area). Stage 2 will involve injecting oxidant in locations working outward from the center of the target treatment area (referred to as the Stage 2 treatment area), based on the results obtained from injections completed during Stage 1. Performance of Stage 1 of the injection process will be further subdivided into two steps. Step 1 will involve injecting oxidant into injection wells screened from 15-20 ft bgs (i.e., at depths furthest away from the utilities that are present in the general area). Based on the results that are obtained during Step 1, oxidant will be injected into shallower injection wells (screened from 5-15 ft bgs) during Step 2 of the injection process within the Stage 1 treatment area. The Stage 1 treatment area is shown on **Figure 5**. The Stage 2 treatment area is shown on **Figure 6**. The locations for the injection wells that will be used during Stage 2 will be selected based on the Stage 1 results.

Baseline groundwater quality monitoring for VOCs, including benzene, will be performed in 14 observation wells spatially located in the target treatment area. As previously indicated, the goal of the ISCO treatment process is to reduce average concentrations of benzene in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room by 50%. Progress toward achieving the treatment goal will be measured by comparing post injection average benzene concentrations in the observation wells to baseline average benzene concentrations in the observation wells.

4.2 Amendment Selection and Dosage Calculations

Several oxidants are available for use in groundwater remediation involving ISCO, and they vary with respect to oxidizing potential, longevity in the subsurface, and the amount of heat and gas generated during oxidation reactions. Given the COPCs in shallow groundwater in the target treatment area, sodium persulfate was selected as the oxidant that was utilized in the ISCO bench-scale treatability study. Sodium persulfate has also been selected for use in full-scale implementation of ISCO in the target treatment area. A permanganate-based oxidant was considered for use, but such an oxidant is not strong enough to readily break the chemical bonds in benzene molecules. A peroxide-based oxidant was also considered for use, but this type of oxidant produces reactions that occur rapidly and that are exothermic. While peroxide-based oxidation is plausible for use at the Brunswick facility, the persulfate chemistry was selected over peroxide-based oxidants because persulfate will last longer in the subsurface and will provide a more controlled reaction that is less exothermic than the reaction produced from a peroxide-based oxidant.

Sodium persulfate ($Na_2S_2O_8$) is a highly reactive oxidant that can react with a variety of organic compounds; however, oxidation of some compounds can be kinetically slow or non-existent. By itself, the persulfate ion (S_2O_8) is capable of oxidizing a limited suite of contaminants (e.g., petroleum hydrocarbons and chlorobenzenes). However, when activated, sodium persulfate ($Na_2S_2O_8$) can destroy many organic compounds. When injected into water, persulfate salts dissociate to form persulfate anions that serve as a powerful oxidant. More notably, the addition of an activator dramatically increases the oxidative strength of persulfate through the formation of sulfate free radicals. Free radicals are molecular fragments that have an unpaired electron causing them to be highly reactive as strong oxidizing agents and are known to rapidly oxidize many compounds. The most economical and practical activation chemistries for persulfate are matrix activation (i.e., activation by naturally occurring minerals), activation using chelated iron, and activation from alkaline pH conditions. Other free radicals may also be formed depending on the activation approach that is employed.

Oxidant demand calculations were performed to estimate the total amounts of sodium persulfate and activator amendment (i.e., sodium hydroxide) required for the oxidation of COPCs in groundwater based on the results from the ISCO bench-scale treatability study. The oxidant demand and dosing design calculations are included in **Appendix B**.

4.3 Design Parameters

The results from the *in situ* injection pilot test and ISCO bench-scale treatability study described in Section 2.2 of this Work Plan were used as the basis for selecting design parameters for full-scale implementation of ISCO. The *in situ* injection pilot test was designed to mimic the most challenging injection conditions that are expected to be encountered in the target treatment area (i.e., injection at a shallow depth at the top of the well screen in an injection well). It can be assumed that injection wells that are screened at deeper intervals will be functional at higher injection pressures, allowing for injection of larger volumes of fluids and development of larger ROIs. The results from the *in situ* injection pilot test indicate that injection of liquid amendments via an injection well where the top of the well screen is located at 2 ft bgs is feasible under gravity feed conditions or using a very low dosing pressure (e.g., 0.5 pounds per square inch ("psi)). Injection under gravity flow conditions resulted in relatively little groundwater mounding (0.33 – 0.67 feet) throughout the pilot test area, and no daylighting of fluids was observed at the ground surface. Under pressurized injection conditions, daylighting of injectate was observed when injection pressures were increased to 1 psi in one of the test infiltration wells and 2 psi in the other test infiltration well. In addition to monitoring injection pressures and mounding, the ROIs that were produced at the test infiltration wells were evaluated by injecting bromide as a conservative tracer.

The following design parameters were used for the design of full-scale implementation of ISCO for the target treatment area near the Stillhouse Control Room.

- Injection well screens: Injection well screens located from 2 – 12 ft bgs were used successfully during the *in situ* pilot injection test. However, slightly deeper well screens are proposed for the injection wells to be used during full-scale implementation of ISCO because only very low infiltration pressures could be applied to the pilot test infiltration wells. The injection wells described in this Work Plan will utilize a screened interval with the top of the well screen located at a minimum of 5 ft bgs. This design includes some injection wells screened from 5 – 15 ft bgs and some injection wells screened from 15 – 20 ft bgs. The design for the injection wells is expected to provide flexibility to apply greater injection pressures than were feasible during the *in situ* pilot injection test.

- Design injection pressure: Pressurized injection can be helpful in distributing amendments (i.e., oxidants and activators) in the subsurface, but applying too much pressure can result in the amendments daylighting on the ground surface. The amount of injection pressure that can be applied is a function of the depth of the shallowest part of the well screen for an injection well. During the *in situ* injection pilot test that utilized injection wells with the tops of the well screens located at 2 ft bgs, the resulting acceptable design pressure was 0.5 to 1 psi. The use of slightly deeper screened intervals in the injection wells installed for full-scale implementation of ISCO will allow for higher injection pressures, as estimated by the injection pressure calculations provided in **Appendix B**. For injection wells that are installed with the top of their well screens at 5 ft bgs, the maximum theoretical injection pressure is 3.6 psi (or 2.7 psi after applying a 25% safety factor). For injection wells that are installed with the top of their well screens at 15 ft bgs, the maximum theoretical injection pressure is 10.9 psi (or 8.2 psi after applying a 25% safety factor). Injection pressures and mounding will be monitored during the injections and managed to maximize pressure while minimizing mounding.

- Design injection flowrate: The injection flowrate is a function of the local geology and how much pressure is applied at the well head of an injection well. During the *in situ* injection pilot test, the average flow rate that was achieved per well was 0.75 gallons per minute ("gpm") under gravity feed conditions (i.e., the average flow rates for test wells MPE-OW-01 and MPE-OW-02) and 1.5 gpm under low pressure conditions (0.5 - 1 psi). These were initial injection flow rates that were achieved, and injection flow rates can slow down over the course of a full-scale injection event. Based on the observations from the *in situ* injection pilot test, it is anticipated that the flow rate that can be achieved during full-scale implementation of ISCO will be an average of 1 gpm per injection well.

- Radius of Influence: The ROIs observed in the *in situ* injection pilot test were up to 22 feet in size based on the use of bromide as a conservative tracer. However, the oxidant that will be injected will be consumed by COPCs in groundwater and other organic matter likely leading to smaller ROIs for oxidant distribution than were observed with the conservative bromide tracer. An ROI of less than 22 feet is anticipated during full-scale implementation of ISCO. As a conservative metric for design purposes, the ROI for each injection well is likely to be in the range of 10 feet.

4.4 Well Layout

A network of wells has been designed for full-scale implementation of ISCO that includes injection wells for delivery of sodium persulfate and sodium hydroxide (i.e., remedial amendments) to the subsurface and observation wells to monitor the subsurface response to the injection of remedial amendments. As indicated above, the vertical placement of the well screens in the injection wells is based on the target treatment depth interval and the location of utilities surrounding the target treatment area. Injection wells used in Stage 1 of the ISCO treatment process will be screened at two different intervals: (i) five injection wells will be screened from 5-15 ft bgs and (ii) five injection wells will be screened from 15-20 ft bgs. Observation wells will also be screened at different intervals: (i) six observation wells will be screened from 5-10 ft bgs to assess potential movement of oxidant into areas where utilities are located; (ii) seven observation wells will be screened from 5-12 ft bgs, and (iii) seven observation wells will be screened from 13-20 ft bgs. The proposed well construction details are provided in **Table 2**, and a layout of the proposed well locations is provided in **Figure 5**. The purpose of each proposed well is shown in **Table 2**, and the wells are grouped into the following categories:

- Injection wells for Stage 1, Step 1 of the ISCO treatment process;
- Injection wells for Stage 1, Step 2 of the ISCO treatment process;
- Shallow utility observation wells (screened from 5-10 ft bgs) installed around the perimeter of the target treatment area for monitoring oxidant distribution from the target treatment area and oxidant encroachment toward the surrounding subsurface utilities; and
- Observation wells for monitoring concentrations of VOCs in groundwater. The observation wells will be screened at varied depth intervals of 5-12 ft bgs and 13-20 ft bgs in the target treatment zone for groundwater quality monitoring to evaluate the effectiveness of full-scale implementation of ISCO and to assess the distribution of oxidant in groundwater during the various stages of oxidant injections.

The grid of injection and observation wells is designed to allow for careful monitoring of the initial injection of oxidant in the target treatment area to better understand the spatial distribution and effectiveness of the oxidant, horizontally as well as vertically. As indicated previously, the oxidant injections will be performed in discrete steps with an observation period following each step, with the overall goal of delivering sufficient oxidant to the subsurface without compromising the integrity of the utility infrastructure. Installation procedures for injection and observation wells are further described in Section 5.1 of this Work Plan, and injection batching and sequencing details are provided in Section 5.4 of this Work Plan.

5. FIELD IMPLEMENTATION

Field implementation of the ISCO treatment process for groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room will include well installation and baseline sampling, storage and batching of sodium persulfate and sodium hydroxide, and injection of the prepared remedial amendments to the subsurface. Each of these tasks is described further below, as well as the monitoring that will be performed during the implementation of the ISCO treatment process for quality control and safety assurance purposes. Performance monitoring for the ISCO treatment process is described in Section 6 of this Work Plan.

5.1 Well Installation

The proposed well network for the target treatment area as initially configured includes a total of 30, 2-inch diameter wells to be constructed with Schedule 40 polyvinyl chloride ("PVC") riser pipes and 0.02-inch slotted screens. PVC is compatible with the selected oxidant. The 30 wells include 10 injection wells, 14 observation wells for groundwater quality monitoring and six utility observation wells. The network of 30 wells may be expanded to include additional injection wells depending on the results that are obtained from the initial ISCO injection events.

The wells will be installed using direct push technology, hollow stem auger, and/or sonic drilling techniques by a well driller licensed by the State of Georgia. Well locations will be staked in the field prior to installation and their locations will be recorded by a handheld global positioning system ("GPS") device. The well driller will use a hand auger or air knife to advance each boring to a minimum of five feet bgs prior to initiating drilling activities to complete the borings for the wells. Each borehole will be advanced to a depth sufficient to meet the targeted depth of the base of the intended screened interval listed in **Table 2**. The wells will be installed in the borings after the borings have reached the required depths.

Each well will be completed with a filter pack, a bentonite seal and grout to the ground surface. The wells will be completed with flush-mounted well heads. Clean, rounded to well-rounded quartz sand (20-40 mesh size) will be used as filter pack material. The filter pack material will be placed by pouring the material from the ground surface (gravity feed process) into the well annulus area between the drill casing and the PVC riser pipe assembly. The 20-40 mesh size sand has a typical size range of 0.017 to 0.033 inches. This filter pack material was selected because the gradation of the material covers the size range needed to keep the majority of filter pack particles outside the well screens, while providing a filter pack grain size that is small enough to filter out the formation fines and keep those fines from entering the wells. The top of the filter pack will be placed 2-3 feet above the top of the screened interval. Sodium bentonite pellets (uncoated) will be used as filter pack sealant material immediately above the filter pack. The remaining portion of the annular space will be filled with a bentonite cement grout slurry seal.

The surface completions for the wells will be constructed with flush-mount vaults measuring 12 inches in diameter with 12-inch minimum long "skirts" and water tight well caps. Injection wells will be equipped with the necessary fittings to receive the injection hose carrying the oxidant. Observation wells will be fitted with expandable plugs. Each flush-mount vault will be surrounded by a concrete pad at least three feet by three feet in size that is six inches thick.

Each new well will be developed using a "purge and surge" method with a submersible pump to promote communication between the well screen, filter pack, and the surrounding water-bearing zone. The wells will be surged vigorously along the entire length of screen using a surge block, and then purged with a submersible pump until free of visible fines. This process will be repeated a minimum of three times at each well or until surging no longer produces excessive silt or mud. Water quality readings should demonstrate declining turbidity values during the well development process. If NAPL is identified in any of the new wells, it will be recovered to the extent practicable prior to proceeding with the ISCO injections. NAPL recovery methods may include a combination of bailing, use of absorptive media, or high vacuum extraction. The groundwater quality observation wells will be surveyed for horizontal and vertical control.

Groundwater samples will be collected using low-flow purging methods from observation wells OW-1 through OW-14. The analytical results from these groundwater samples will serve as the baseline for performance monitoring associated with implementation of the ISCO treatment process. The groundwater samples will be sent to a laboratory for analysis of VOCs (including benzene) via EPA Method 8260 and chemical oxygen demand ("COD") via EPA Method 410.4. Additional details about the performance monitoring program are provided in Section 6 of this Work Plan.

5.2 Amendment Storage and Spill Prevention

The oxidant (sodium persulfate) and the activator base (sodium hydroxide) will be delivered to the Brunswick facility and stored in a cool and dry area. The storage locations will be selected prior to mobilization in consultation with Pinova. Sodium persulfate will arrive in a crystalline form and sodium hydroxide will arrive in a liquid form. The sodium persulfate storage area will be placarded to indicate that it is a "Class 1 Oxidizer" storage location. The bulk shipments of sodium hydroxide will be stored in a corrosive resistant container away from the sodium persulfate storage area. Chemically-compatible materials will be used for the storage, batching, and conveyance equipment, such as Type 304 and/or 316 stainless steel, polyvinyl chloride, polyethylene, poly(methyl methacrylate), Teflon®, chemical stoneware and glass (PeroxyChem, 2021a).

The batching tanks and the injection manifold will be placed inside spill containment structures, and spill response supplies will be kept in an easily accessible location in the work area. Spill response supplies will include chemically-compatible absorbent media, water for dilution, and mild alkali for neutralization of the oxidant. If neutralization of a spill of sodium persulfate is required, it will be performed incrementally with a mild alkali such as sodium bicarbonate (PeroxyChem, 2021b).

5.3 Equipment Staging and Water Tightness Testing

The staging and batching area for the ISCO treatment process will be established near the new injection wells. The staging and batching area will include provisions for chemical storage, setup of a batching tank, and space to store necessary equipment (such as an air compressor and injection trailer) during off hours. The anticipated location of the staging and batching area is shown in **Figure 7**. The location of the staging and batching area may be adjusted if needed based on consultation with Pinova or changes in site conditions.

The oxidant batching equipment will consist of the necessary tanks, pumps, hoses, and pipe/fixtures to prepare the injection amendments and deliver them to the injection wells. While anticipated to be located within the staging area, the batching equipment may be repositioned closer to the injection wells if deemed to be consistent with Pinova's site safety requirements.

Prior to using field-assembled equipment for batching or transfer of sodium persulfate or sodium hydroxide, the equipment will be tested with unamended water to confirm that the equipment and fittings are water-tight.

5.4 Injection Sequencing, Batching, and Process Monitoring

Sodium persulfate and sodium hydroxide will be batched separately and in small enough volumes that the batches can be used the same day that they are batched. The oxidant manufacturer recommends that aboveground contact between sodium persulfate and sodium hydroxide should be limited to prevent the initiation of the reaction (PeroxyChem, 2021c). This can be accomplished by mixing the amendments inline prior to injection or injecting the amendments separately in a serial manner so that sodium persulfate and sodium hydroxide mix in the subsurface to create sufficiently alkaline conditions to activate the persulfate. During the injection process, the injection wellhead pressures, and flow rates will be monitored and recorded.

The initial oxidant injections will focus on the five deepest injection wells (i.e., injection wells screened from 15-20 ft bgs) in Stage 1, Step 1 of the ISCO treatment process. The other five injection wells (i.e., injection wells screened from 5-15 ft bgs) will then be used for oxidant injections in Stage 1, Step 2. The well layout for the Stage 1 injection process is provided in **Figure 5**. There will be an observation period between Step 1 and Step 2 to monitor groundwater conditions in the target treatment area for oxidant distribution using field measurements of oxidation-reduction potential ("ORP"), pH, persulfate concentrations, and conductivity to confirm that the groundwater chemistry is not becoming unfavorable for the subsurface utilities that are adjacent to the target treatment area. The performance monitoring plan is described in further detail in Section 6 of this Work Plan.

Following the implementation of Stage 1 of the ISCO treatment process, the distribution of persulfate anions, ORP readings, pH levels, and the radius of influence around each injection well will be assessed to make selections about the Stage 2 application area, dosage, and volume. If the results from Stage 1 of the ISCO injection process are favorable, additional injection wells will be installed within the hatched area shown on the Stage 2 injection layout diagram, as shown in **Figure 6**.

5.5 Waste Management

Solid and liquid investigation derived waste ("IDW") will be containerized separately to the extent practical and staged in the Central Accumulation Area in the portion of the Brunswick facility that Hercules owns. Solid IDW (e.g., used absorbent material) and liquid IDW (e.g., decontamination fluids and well purge water) will be containerized in drums, which will be clearly labeled, as appropriate, indicating the name of the generator, contact information, generation date, and general contents. IDW will be characterized as soon as practical (generally within approximately 30 days) to allow adequate time for appropriate management and off-site disposal.

It is not anticipated that the field work will result in the need to dispose of sodium persulfate crystals, but should that occur, such waste material will be managed as hazardous waste.

6. PERFORMANCE MONITORING

Groundwater will be monitored in the target treatment area near the Stillhouse Control Room before, during, and after oxidant injections. Groundwater monitoring activities during oxidant injections will utilize field monitoring equipment for evaluating groundwater mounding and the radius of influence that is achieved around each injection well, as further described in Section 6.2 of this Work Plan. A primary purpose of the groundwater quality monitoring activities before and after the oxidant injections will be to assess changes in concentrations of VOCs (particularly benzene) in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room based on laboratory analysis. Other analyses of groundwater samples will also be performed as described in Section 6.2 of this Work Plan.

6.1 Groundwater Quality Performance Monitoring Plan

A groundwater performance monitoring program will be implemented to (i) evaluate the effectiveness of the ISCO treatment process in reducing concentrations of benzene; (ii) to document the concentrations of other VOCs in groundwater within the target treatment area; and (iii) to document the concentrations of the eight metals listed in 40 C.F.R. § 261.24 (relating to toxicity characteristics) promulgated pursuant to Resource Conservation and Recovery Act ("RCRA"). These eight metals are arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver, and are referred to hereinafter as RCRA metals. The temporary changes in ORP and pH that occur within an oxidant injection area can temporarily mobilize naturally occurring metals from soil to groundwater. However, the concentrations of metals in groundwater typically dissipate downgradient of the target treatment area where alterations in ORP and pH are not present. Within the target treatment area itself, concentrations of metals also typically return to pre-ISCO conditions after natural ORP and pH conditions in the target treatment area are restored (i.e., after the oxidant is spent).

The performance monitoring program that will be conducted in connection with the ISCO treatment process is summarized in **Table 3**, which provides a matrix that describes the specific well locations and frequency of evaluating field parameters, persulfate concentrations, and VOC concentrations. The table shows the wells, monitoring parameters and sampling frequencies for the following components of the performance monitoring program:

- Baseline monitoring;

- Post-injection monitoring following Stage 1, Step 1 of the ISCO treatment process;
- Post-injection monitoring following Stage 1, Step 2 of the ISCO treatment process; and
- Post-injection monitoring following Stage 2 of the ISCO treatment process.

As shown in **Table 3**, the observation wells will be monitored as part of establishing baseline conditions, one week after an injection event is completed, five weeks after the injection event is completed, and 10 weeks after the injection event is completed. **Table 3** describes in detail which observation wells will be monitored during these stages of the monitoring process. The monitoring of observation wells within the targeted injection area will include collection of groundwater samples for laboratory analysis of VOCs as part of the baseline and 10-week monitoring events, as detailed in **Table 3**. The monitoring frequency was selected to provide observations across the anticipated timeframe that the oxidant will remain viable in the subsurface. If additional groundwater monitoring is needed, the frequency and locations for such monitoring activities will be selected in consultation with EPD.

Field measurements of water quality parameters and persulfate field test kits (Klozur® field test kits – Method K, PeroxyChem 2021d) will be used to monitor the potential presence of oxidant within a well, as presented in **Table 3**. All of the observation wells will be monitored for water quality field parameters and persulfate. The utility observation wells will be monitored more frequently for water quality field parameters and persulfate to assess oxidant encroachment toward the utilities. Field equipment will be used to measure ORP, pH and specific conductance. Post injection field parameter measurements will be compared to baseline conditions. Colorimetric persulfate test kits will be used to assess the presence of persulfate in observation wells. The colorimetric persulfate test kits have an anticipated detection limit of 1 gram per liter. Discoloring in the groundwater, if present, may affect the persulfate detection limit. The concentrations of oxidant remaining in the injection wells will also be estimated using persulfate field test kits and field parameters ten weeks after each injection event to evaluate the longevity of the oxidant in groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room.

As indicated above, oxidants used for implementing ISCO may at times oxidize and mobilize select metals from the soil media. While metals may mobilize locally where

ISCO injections are occurring, they typically will not mobilize outside of the elevated ORP zone in the injection area. To monitor the potential mobilization of RCRA metals during the ISCO treatment process in shallow groundwater near the Stillhouse Control Room, additional groundwater samples will be collected from observation wells OW-04 and OW-05 and from monitoring wells MW-21, MW-23, and MW-49S. The groundwater samples will be analyzed for RCRA metals by EPA SW-846 Method 6010. These five wells were selected based on their locations within, adjacent to, and downgradient from the target treatment area. As shown in **Table 3**, these five wells will be monitored for RCRA metals and field parameters as part of the baseline monitoring event and 10 weeks after each oxidant injection event has been completed.

Baseline groundwater quality monitoring for VOCs will be performed using 14 observation wells (designated as wells OW-1 – OW-14) that are spatially distributed in the target treatment area. The initial goal of the ISCO treatment process is to reduce average concentrations of benzene in groundwater in the target treatment area by 50%. The treatment goal will be evaluated by comparing post injection average concentrations of benzene in the observation wells to baseline average concentrations of benzene. Observation wells OW-1 through OW-14 will sampled and analyzed for VOCs, including benzene, after the Stage 1, Step 1 injections are completed to evaluate performance of the initial injections with a focus on the analytical results from wells OW-1 through OW-6 located within the Stage 1 treatment zone. Observation wells OW-1 through OW-14 will also be sampled and analyzed for VOCs, including benzene, after the Stage 1, Step 2 and Stage 2 injections are completed. The spatial distribution of groundwater quality observation wells throughout the treatment area will allow for targeted supplemental oxidant injections, as deemed necessary, based on the groundwater quality results and treatment effectiveness.

6.2 Subsurface Monitoring During Injection Activities

As indicated above, water quality parameters and persulfate will be monitored in all of the wells prior to injection activities (i.e., baseline conditions) and then at specified intervals following injections as summarized on **Table 3**. During active injections, a subset of the observation wells that are located in close proximity to active injection wells will be monitored to measure water quality parameters, concentrations of persulfate, and water levels. Field water quality parameters will be measured in real time using a water quality meter (YSI-556 MPS or equivalent) to measure the following water quality parameters:

- Temperature (°C);
- pH;
- Specific conductance (in units of millisiemens per centimeter or mS/cm);
- Dissolved oxygen (mg/L); and
- ORP (in units of millivolts or mV).

The groundwater quality parameters will be monitored daily to assess the radius of influence that is established around each injection well. Depending on which injection wells oxidant is being injected into, the subset of wells may change on a daily basis but with the goal of monitoring field water quality parameters outward from each of the injection well to assess the injection radius of influence. Although the entire suite of water quality parameters listed above will be recorded, changes in ORP, pH, and specific conductance are typically the first indicators to be observed at observation wells in connection with the implementation of the ISCO treatment process.

Similarly, persulfate field test kits will be used to measure persulfate in groundwater at all wells prior to initiating injection activities (i.e., under baseline conditions) and then periodically (at least daily) during the injection process to monitor the radius of influence around each injection well and the distribution of remedial amendments (i.e., sodium persulfate and sodium hydroxide). It is presumed that the baseline concentrations of persulfate will be less than 1 g/L, and that a concentration of persulfate detected above that level at a particular observation well after injection activities begin will be indicative of oxidant reaching the location of that observation well. If a concentration of persulfate greater than 1 g/L is detected in the proposed utility observation wells that are screened from 5-10 ft bgs between the Stage 1 injection area and the underground utilities adjacent to the target treatment area, the injection activities will be temporarily suspended. The action level for persulfate of 1 g/L was selected because it is (i) the lower detection limit on the field test kits for persulfate and (ii) it is a concentration that is three orders of magnitude lower than the anticipated concentration of the batches of sodium persulfate that will be injected (i.e., 1,146 g/L of sodium persulfate). If an injection event is suspended, the concentrations of persulfate in the utility observation wells will be monitored weekly until those concentrations are less than 1 g/L. The decision of when to restart the injection process and which injection wells to use will be based upon the field parameter measurements that are obtained and the history of field observations of persulfate.

Water levels will be recorded using a water level meter from all observation wells a minimum of every four hours during an active injection event. If groundwater surfaces at the ground surface, injections will be temporarily suspended to allow groundwater levels in the target treatment area to recover to pre-injection levels.

7. REPORTING

An ISCO performance monitoring memorandum or report will be prepared following the monitoring period after each step in the ISCO treatment process (i.e., after Stage 1, Step 1; Stage 1, Step 2; and Stage 2). The memorandum or report will summarize the injection activities that were performed, the field measurements that were collected, the analytical data that were obtained, the interpreted ROIs for the oxidant injections, the average concentrations of benzene that were detected in observation wells in comparison with baseline conditions, and the analytical results that are obtained for VOCs other than benzene and RCRA metals. The first ISCO performance monitoring memorandum or report will also include documentation of the well installation activities that were completed and the results of the baseline sampling activities. In addition, each memorandum or report may include recommendations for future actions commensurate with the data and observations. Hercules will ensure that copies of such documents are provided to the UIC permitting office for EPD as necessary to fulfill substantive requirements of the UIC permitting program as applicable.

Following completion of the injection and monitoring activities, an interim corrective measure effectiveness report will be prepared for submittal to EPD. The results of the ISCO treatment process in groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room will be evaluated and considered as part of making recommendations for future corrective measures at the Brunswick facility consistent with the framework of the Corrective Action Plan that Hercules submitted to EPD on February 1, 2021.

8. SCHEDULE

As previously described, implementation of the ISCO treatment process in groundwater in the shallow zone of the upper surficial aquifer near the Stillhouse Control Room will occur in stages so that oxidant distribution and protection of surrounding utilities can be confirmed prior to proceeding to the next stage of the treatment process. The work is anticipated to progress in the following sequence of actions following receipt of written approval by EPD of this initial Work Plan. Estimated durations for each step in the process are provided. The duration of particular steps may be modified based on the progress of the injection process and the results that are obtained. EPD will be kept informed of the progress of the ISCO treatment process via regularly scheduled Triad meetings or other communications.

- Pre-mobilization planning, procurement, and permitting: 45 days;
- Initial well installation activities and baseline sampling: 45 days;
- Stage 1, Step 1 injections and monitoring: 90 days;
- Data evaluation and decision making for Stage 1, and preparation for Step 2: 45 days;
- Stage 1, Step 2 injections and monitoring: 90 days;
- Data evaluation, decision making, and preparation for Stage 2: 45 days;
- Stage 2 well installation activities, injections, and monitoring: 120 days; and
- Interim corrective measure effectiveness report: 60 days following receipt of final performance monitoring analytical data.

9. REFERENCES

Antea. 2016. Groundwater Technical Summary Report. Former Hercules Brunswick Facility, Brunswick, Georgia. EPA ID No. GAD004065520. September 6, 2016.

Geosyntec. 2021. Corrective Action Plan. Hercules/Pinova Brunswick Facility, Brunswick, Georgia. February 2021.

Integral. 2019. Refined Groundwater Conceptual Site Model. Hercules/Pinova Brunswick Facility, Brunswick, Georgia. March 15, 2019.

PeroxyChem, 2021a. Corrosion and Material Compatibility with Klozur® Persulfate. Klozur® Persulfate Technical Bulletin.

PeroxyChem, 2021b. Safe Handling, Use, and Storage of Klozur® Persulfate. Klozur® Persulfate Technical Bulletin.

PeroxyChem, 2021c. Alkaline Activated Klozur® Persulfate. Klozur® Persulfate Technical Bulletin.

PeroxyChem, 2021d. Klozur® Persulfate Field Test Kits. Klozur® Persulfate Technical Bulletin 04-01-ESD-15.

TABLES

Table 1
Well Construction Details for Existing Wells in the ISCO Treatment Area
Hercules/Pinova Facility, Brunswick, Georgia

Well ID	Easting	Northing	Top of Casing (ft MSL)	Ground Surface (ft MSL)	Boring Depth (ft bgs)	Well Depth (ft bgs)	Screened Interval (ft bgs)	Top of Well Screen Elevation (ft MSL)	Bottom of Well Screen Elevation (ft MSL)
MW-21	870454.1	424317.0	9.81	10.00	15.0	15.0	5.0-15.0	5.00	-5.00
MW-22	870491.1	424347.0	9.66	9.90	14.7	14.7	4.67-14.67	5.20	-4.77
MW-23	870474.3	424392.1	9.85	9.90	14.0	14.0	4.0-14.0	5.90	-4.10
MW-24	870415.9	424374.6	9.71	10.00	15.0	15.0	4.8-14.8	5.20	-4.80
MPE-01	870457.13	424368.64	9.56	9.71	10.3	10.3	2.0-10.0	7.71	-0.29
MPE-OW-01	870461.58	424368.92	9.51	9.78	17.3	17.3	2.0-17.0	7.78	-7.22
MPE-OW-02	870460.70	424359.36	9.50	9.78	17.3	17.3	2.0-15.0	7.78	-5.22
VP-01	870465.05	424364.22	9.42	9.82	5.3	5.3	2.0-5.0	7.82	4.82
VP-02	870456.94	424356.24	9.66	9.82	5.3	5.3	2.0-5.0	7.82	4.82
VP-03	870465.77	424380.89	9.67	9.85	5.3	5.3	2.0-5.0	7.85	4.85

Notes:

ft - feet

ft MSL - feet above mean sea level

ft bgs - feet below ground surface

ID - identification

ISCO - *in situ* chemical oxidation

Table 2
Well Construction Details for Proposed Observation and Injection Wells
Hercules/Pinova Facility, Brunswick, Georgia

Category of Proposed Wells	Well ID	Purpose	Well Diameter (in)	Well Material	Screen Diameter, Slot Size, and Material	Screened Interval (ft bgs)
Injection wells for Stage 1, Step 1	IW-01	Injection	2	PVC	2-inch, 0.020-inch, PVC	15 - 20
	IW-02	Injection	2	PVC	2-inch, 0.020-inch, PVC	15 - 20
	IW-03	Injection	2	PVC	2-inch, 0.020-inch, PVC	15 - 20
	IW-04	Injection	2	PVC	2-inch, 0.020-inch, PVC	15 - 20
	IW-05	Injection	2	PVC	2-inch, 0.020-inch, PVC	15 - 20
Injection wells for Stage 1, Step 2	IW-06	Injection	2	PVC	2-inch, 0.020-inch, PVC	5 - 15
	IW-07	Injection	2	PVC	2-inch, 0.020-inch, PVC	5 - 15
	IW-08	Injection	2	PVC	2-inch, 0.020-inch, PVC	5 - 15
	IW-09	Injection	2	PVC	2-inch, 0.020-inch, PVC	5 - 15
	IW-10	Injection	2	PVC	2-inch, 0.020-inch, PVC	5 - 15
Observation wells for monitoring groundwater quality	OW-01	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	13 - 20
	OW-02	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	5 - 12
	OW-03	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	13 - 20
	OW-04	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	5 - 12
	OW-05	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	13 - 20
	OW-06	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	5 - 12
	OW-07	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	13 - 20
	OW-08	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	5 - 12
	OW-09	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	13 - 20
	OW-10	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	5 - 12
	OW-11	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	13 - 20
	OW-12	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	5 - 12
	OW-13	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	13 - 20
	OW-14	Observation & Sampling	2	PVC	2-inch, 0.020-inch, PVC	5 - 12
Utility observation wells for monitoring oxidant encroachment from the injection area toward the subsurface utilities	UOW-01	Observation	2	PVC	2-inch, 0.020-inch, PVC	5 - 10
	UOW-02	Observation	2	PVC	2-inch, 0.020-inch, PVC	5 - 10
	UOW-03	Observation	2	PVC	2-inch, 0.020-inch, PVC	5 - 10
	UOW-04	Observation	2	PVC	2-inch, 0.020-inch, PVC	5 - 10
	UOW-05	Observation	2	PVC	2-inch, 0.020-inch, PVC	5 - 10
	UOW-06	Observation	2	PVC	2-inch, 0.020-inch, PVC	5 - 10

Notes:

ft - feet

ft bgs - feet below ground surface

ID - identification

PVC - polyvinyl chloride

Table 3
ISCO Treatment Performance Monitoring Plan
Hercules/Pinova Facility, Brunswick, Georgia

Purpose	**Timing**	**Observation Wells OW-01 through OW-06**			**Observation Wells OW-07 through OW-14**			**Utility Observation Wells UOW-01 through UOW-06**		**Injection Wells IW-01 through IW-10**	**Observation Wells OW-04/05 and Monitoring Wells MW-21, MW-23, MW-49S**	
		Field Parameters	**Persulfate**	**VOCs and COD**	**Field Parameters**	**Persulfate**	**VOCs and COD**	**Field Parameters**	**Persulfate**	**Persulfate and Field Parameters**	**Field Parameters**	**RCRA Metals**
Baseline	Before Stage 1, Step 1	X	X	X	X	X	X	X	X	X	X	X
Stage 1, Step 1	1 week after Stage 1, Step 1	X						X	X			
	5 weeks after Stage 1, Step 1	X						X	X			
	10 weeks after Stage 1, Step 1	X	X	X	X	X	X	X	X	X	X	X
Stage 1, Step 2	1 week after Stage 1, Step 2	X						X	X			
	5 weeks after Stage 1, Step 2	X						X	X			
	10 weeks after Stage 1, Step 2	X	X	X	X	X	X	X	X	X	X	X
Stage 2	1 week after Stage 2	X			X			X	X			
	5 weeks after Stage 2	X			X			X	X			
	10 weeks after Stage 2	X	X	X	X	X	X	X	X	X	X	X

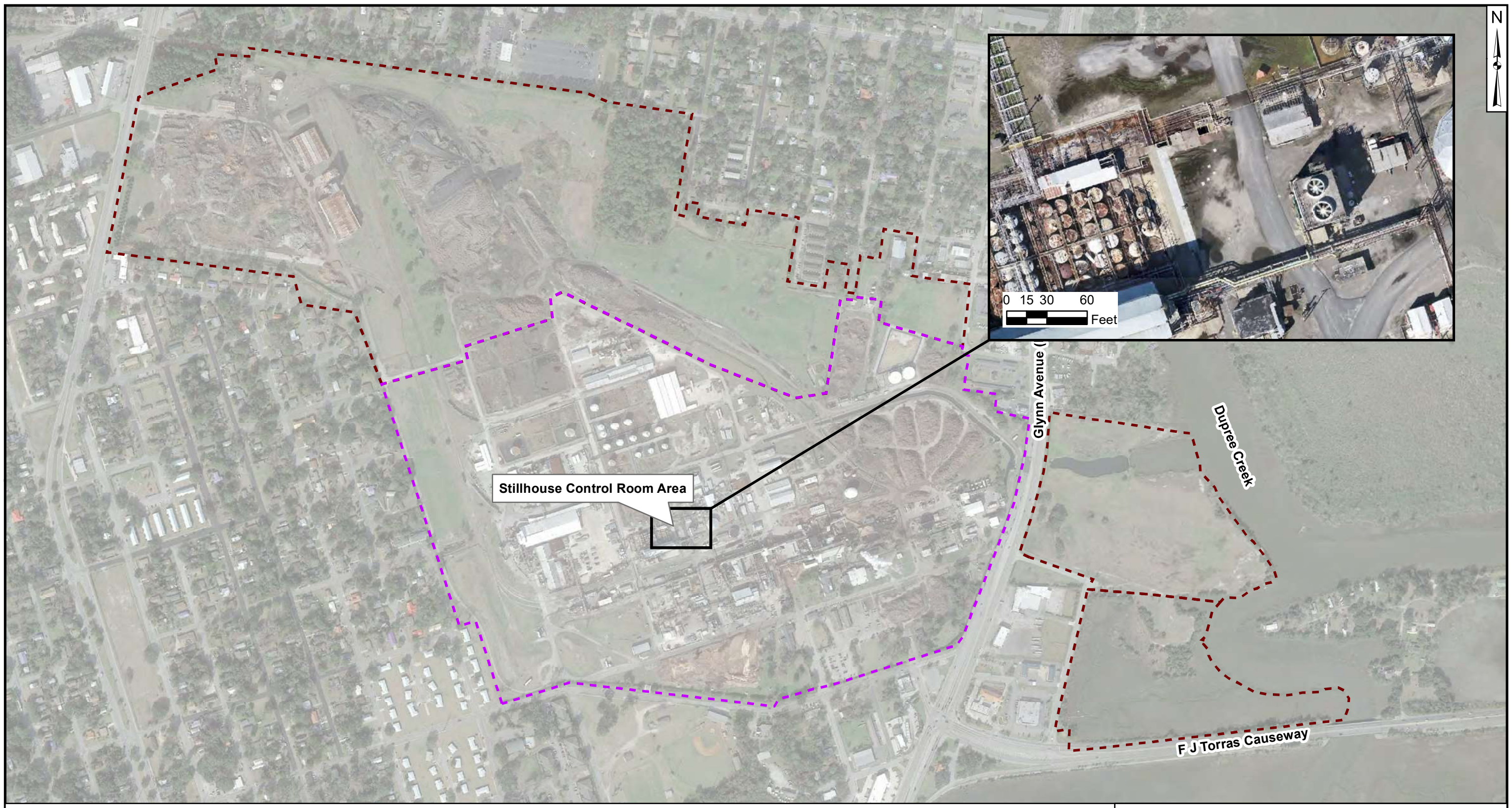
Notes:

1. VOCs, COD, and RCRA metals will be analyzed by a laboratory; all other parameters are field-measured.
2. VOCs will be analyzed by EPA Method 8260 and reported in micrograms per liter. COD will be analyzed by EPA Method 410.4 and reported in milligrams per liter. RCRA metals will be analyzed by EPA Method 6010D and reported in micrograms per liter.
3. Field parameters = water levels, temperature, pH, specific conductance, dissolved oxygen, and oxidation reduction potential.
4. Concentrations of persulfate will be measured using field test kits with a detection limit of 1 gram per liter.
5. The frequency of the monitoring for Stage 1, Step 2 and for Stage 2 may be adjusted based on the monitoring results from Stage 1, Step 1.

COD = chemical oxygen demand

VOCs = volatile organic compounds

FIGURES



Legend

🟪 Pinova Property

🟫 Hercules Property

Notes:
1. Aerial Photograph approximate date - January 2019. Source: Google Earth.

Stillhouse Control Room Treatment Area Location
Hercules/Pinova Facility
Brunswick, Georgia

Geosyntec consultants

Kennesaw, GA

April 2021

Figure

1

Path: \\Aro-01\prj1$\H\Hercules\Brunswick\GIS\MXD\ISCO ICM\Figure 1 Site Overview.mxd; BTickner; 3/10/2021

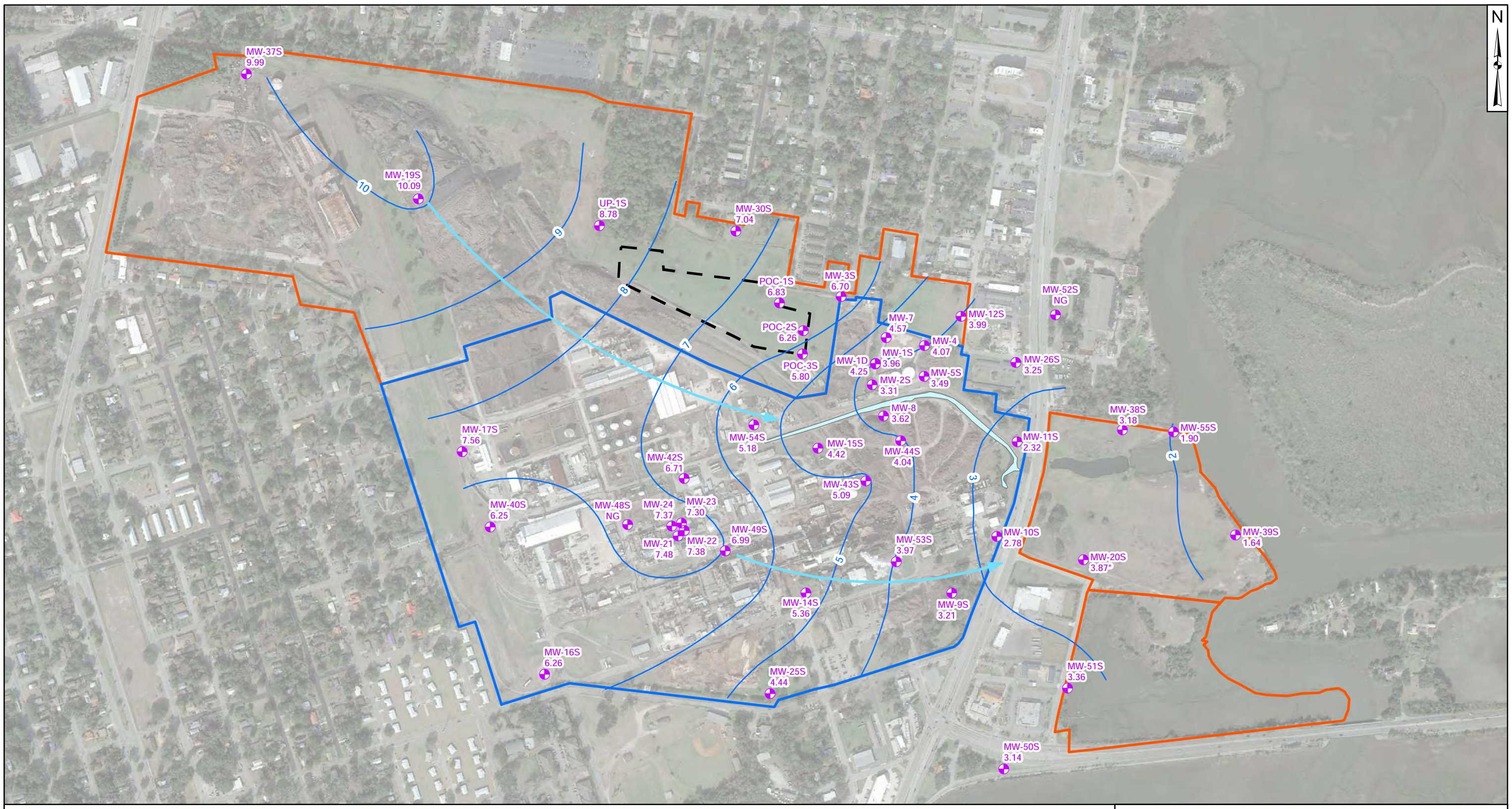
Geologic Epoch	Aquifer System	Aquifer and Confining Units	Approximate Aquifer or Confining Unit Depth (ft bgs)	Aquifer Zone	Approximate Zone Depth (ft bgs)
Post-Miocene	Surficial Aquifer System	Upper Surficial Aquifer	0 to 100	Shallow Zone	0 to 40
				Intermediate Zone	40 to 70
				Deep Zone	70 to 100
		Confining Unit (if present)	90 to 100 (if present)		
Miocene		Lower Surficial Aquifer	100 to 200		
	Brunswick Aquifer System	Confining Unit	200 to 280		
		Upper Brunswick Aquifer	280 to 355		
		Confining Unit	355 to 400		
		Lower Brunswick Aquifer	400 to 475		
	Floridian Aquifer System	Upper Floridian Confining Unit	475 to 500		
Oligocene to Eocene		Upper Floridian Aquifer	500 to 970		
		Lower Floridian Confining Unit	970 to 1000		
		Lower Floridian Aquifer	>1000+		

Notes:

1. Ft bgs = feet below ground surface.
2. Figure modified from Figure 1-3 in *Refined Conceptual Site Model, Hercules/Pinova Brunswick Facility, Brunswick, Georgia. March 15, 2019.* (Integral, 2019).
3. Geologic Epochs are approximate and estimated from Brunswick Pulp and Paper Co., Glynn County Cross section, found on Plate 2 in *Geology and Ground-water Resources of the Coastal Area of Georgia. Bulletin 113.* (Clarke, et al., 1990).
4. In general, aquifer/confining unit depths and zone depths are generalizations and should be considered as approximate depth intervals for the Brunswick facility. Depths are generally derived from Integral (2019) and from Brunswick Pulp and Paper Co., Glynn County Cross section, found on Plate 2 in Clarke, et al. (1990).
5. The confining unit depth separating the upper from the lower surficial aquifer is based on the boring log for monitoring well MW-52D.

Aquifers and Confining Units	Geosyntec consultants	Figure
Kennesaw, GA	April 2021	**2**

Source file: \\Aro-01\prj1$\H\Hercules\Brunswick\GIS\Figure 2 Aquifer and Confining Units.pptx



Legend

●	Monitoring Well for Shallow Zone of Upper Surficial Aquifer
—	Groundwater Elevation Iso-Contour (ft MSL)
➤	Approximate Groundwater Flow Direction - Shallow Zone of Upper Surficial Aquifer
[ ]	Closed Surface Impoundments
▭	Pinova Property
▭	Hercules Property
▭	N Street Ditch

0 275 550 1,100
Feet

Notes:
1. Water level measurements recorded on December 7, 2020.
Elevation provided in feet above mean sea level (ft MSL).
2. Groundwater elevation from monitoring well MW-20S was not used in contouring.
3. NG = Not gauged.
4.* indicates groundwater elevation not utilized for contouring.
5. Aerial photograph approximate date - January 2019. Source: Google Earth.

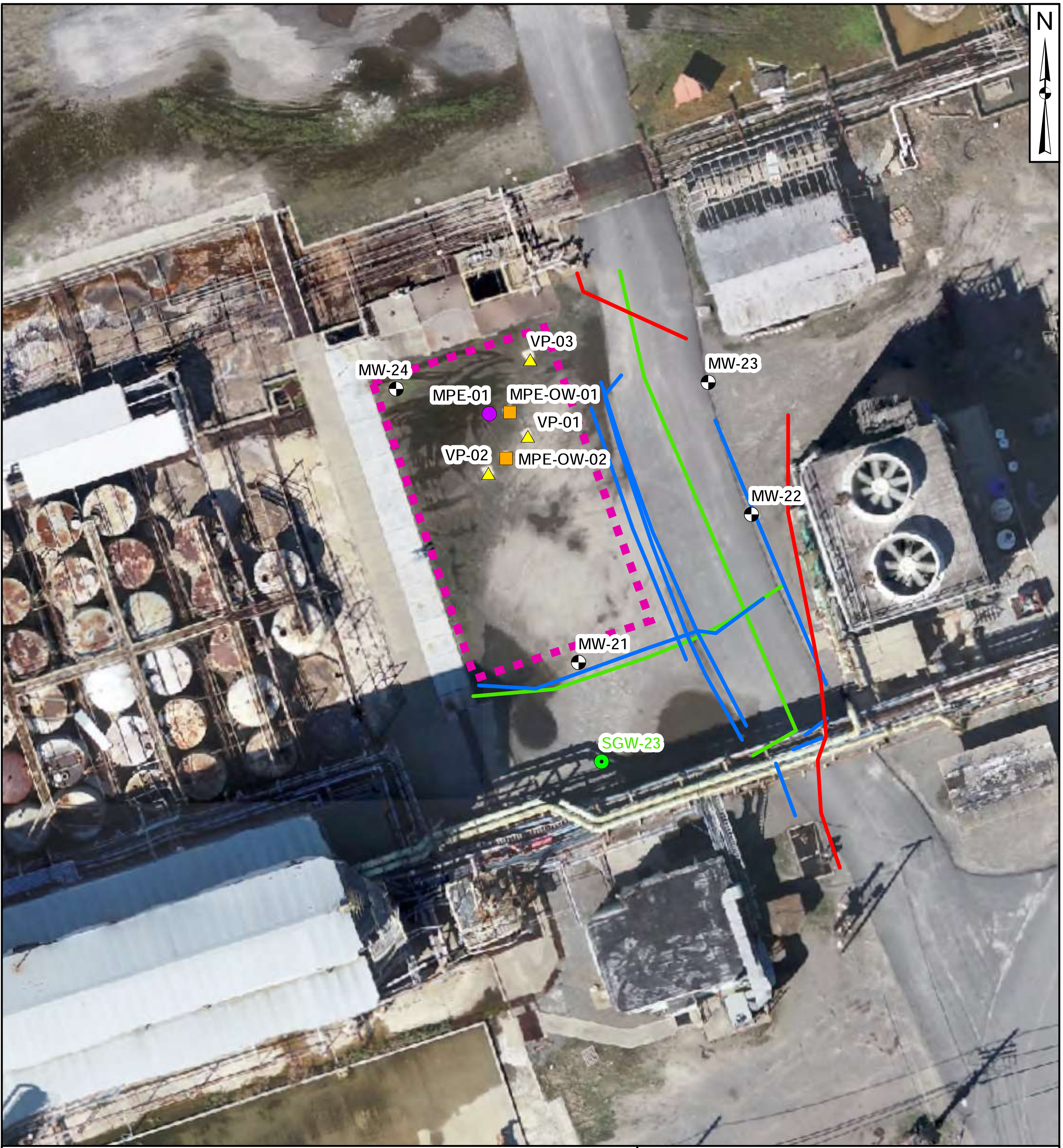
Potentiometric Map
Surficial Aquifer, Shallow Zone of Upper Unit
Hercules/Pinova Facility
Brunswick, Georgia

Geosyntec
consultants

Kennesaw, GA | April 2021

Figure
3

Path: \\Aro-01\prj1$\H\Hercules\Brunswick\GIS\MXD\ISCO ICM\Figure 3 - Potentiometric Map – Surficial Aquifer, Shallow Zone of Upper Unit.mxd



Legend

● Multi-Phase Extraction Well – Pilot Test

■ Multi-Phase Extraction Observation Well and *In Situ* Injection Pilot Test Well

△ Multi-Phase Extraction Vadose Zone Observation Point

◐ Existing Monitoring Well

⊙ Shallow Groundwater Sample Location (Temporary Well Point)

🟥 Electrical Line (Approximate Underground Location)

🟦 Fire Suppression Line (Approximate Underground Location)

🟩 Water Line (Approximate Underground Location)

▪ Target Treatment Area

0 15 30 60
Feet

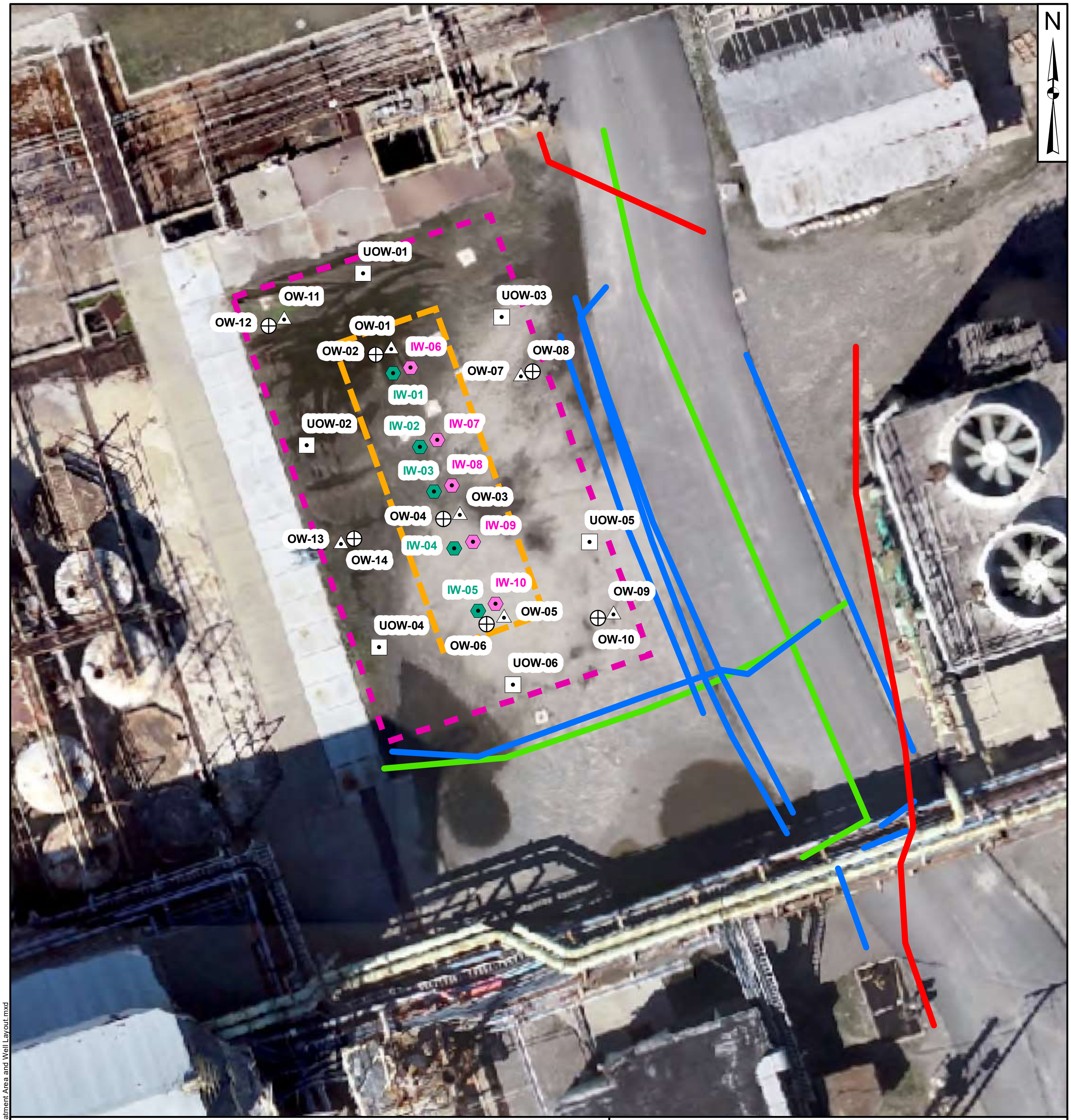
Stillhouse Control Room Area
Hercules/Pinova Facility
Brunswick, Georgia

Geosyntec
consultants

Kennesaw, GA | April 2021

Figure
4

Path: \\Aro-01\prj1$\H\Hercules\Brunswick\GIS\MXD\ISCO ICM\Figure 4 Stillhouse Control Room Area.mxd



Legend

⬢	Step 1 Injection Well (IW) Screened at 15-20 ft bgs
⬢	Step 2 Injection Well (IW) Screened at 5-15 ft bgs
⊕	Observation Well (OW) Screened at 5-12 ft bgs
△	Observation Well (OW) Screened at 13-20 ft bgs
⊡	Utility Observation Well (UOW) Screened at 5-10 ft bgs
━	Electrical Line (Approximate Underground Location)
━	Fire Suppression Line (Approximate Underground Location)
━	Water Line (Approximate Underground Location)
⬚	Treatment Area (Stage 1)
⬚	Target Treatment

Notes:

1. ft bgs - feet below ground surface; ISCO - *in situ* chemical oxidation.

0 10 20 40
Feet

ISCO Treatment for Shallow Groundwater
Stage 1 Treatment Area and Well Layout
Hercules/Pinova Facility
Brunswick, Georgia

Geosyntec
consultants

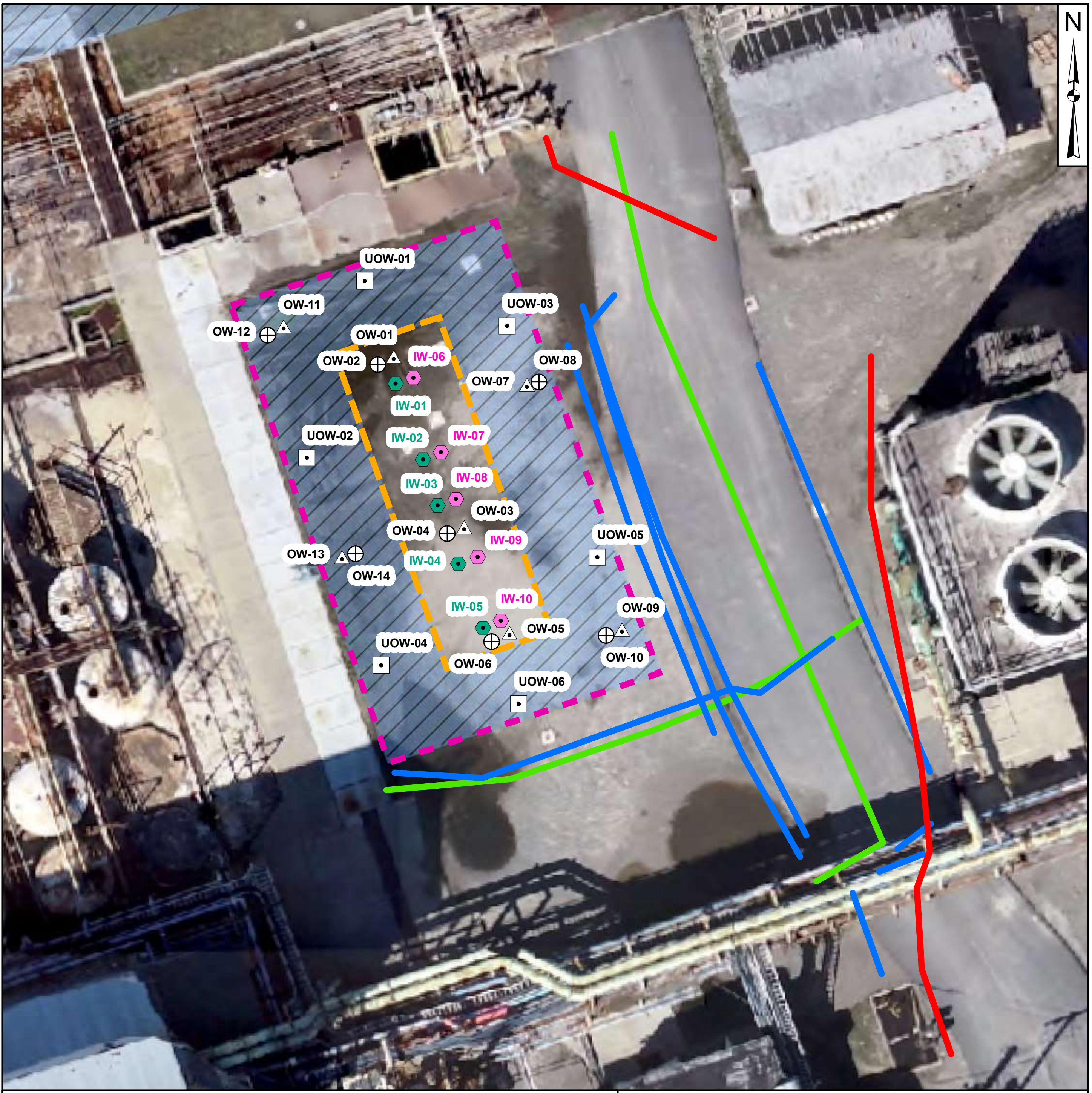
Kennesaw, GA

August 2021

Figure

5

Path: \\Aro-01\prj1$\H\Hercules\Brunswick\GIS\MXD\ISCO ICM\Figure 5 Stage 1 Treatment Area and Well Layout.mxd



Legend

⬢	Step 1 Injection Well (IW) Screened at 15-20 ft bgs	🟥	Electrical Line (Approximate Underground Location)
⬢	Step 2 Injection Well (IW) Screened at 5-15 ft bgs	🟦	Fire Suppression Line (Approximate Underground Location)
⊕	Observation Well (OW) Screened at 5-12 ft bgs	🟩	Water Line (Approximate Underground Location)
△	Observation Well (OW) Screened at 13-20 ft bgs	▭	Treatment Area (Stage
⊡	Utility Observation Well (UOW) Screened at 5-10 ft bgs	▨	Treatment Area (Stage
		▭	Target Treatment

Notes:
1. ft bgs - feet below ground surface; ISCO - *in situ* chemical oxidation.
2. Additional injection wells may be installed in the Stage 2 treatment area.
Stage 2 will be performed if Stage 1 can be performed safely and effectively.

0 10 20 40
Feet

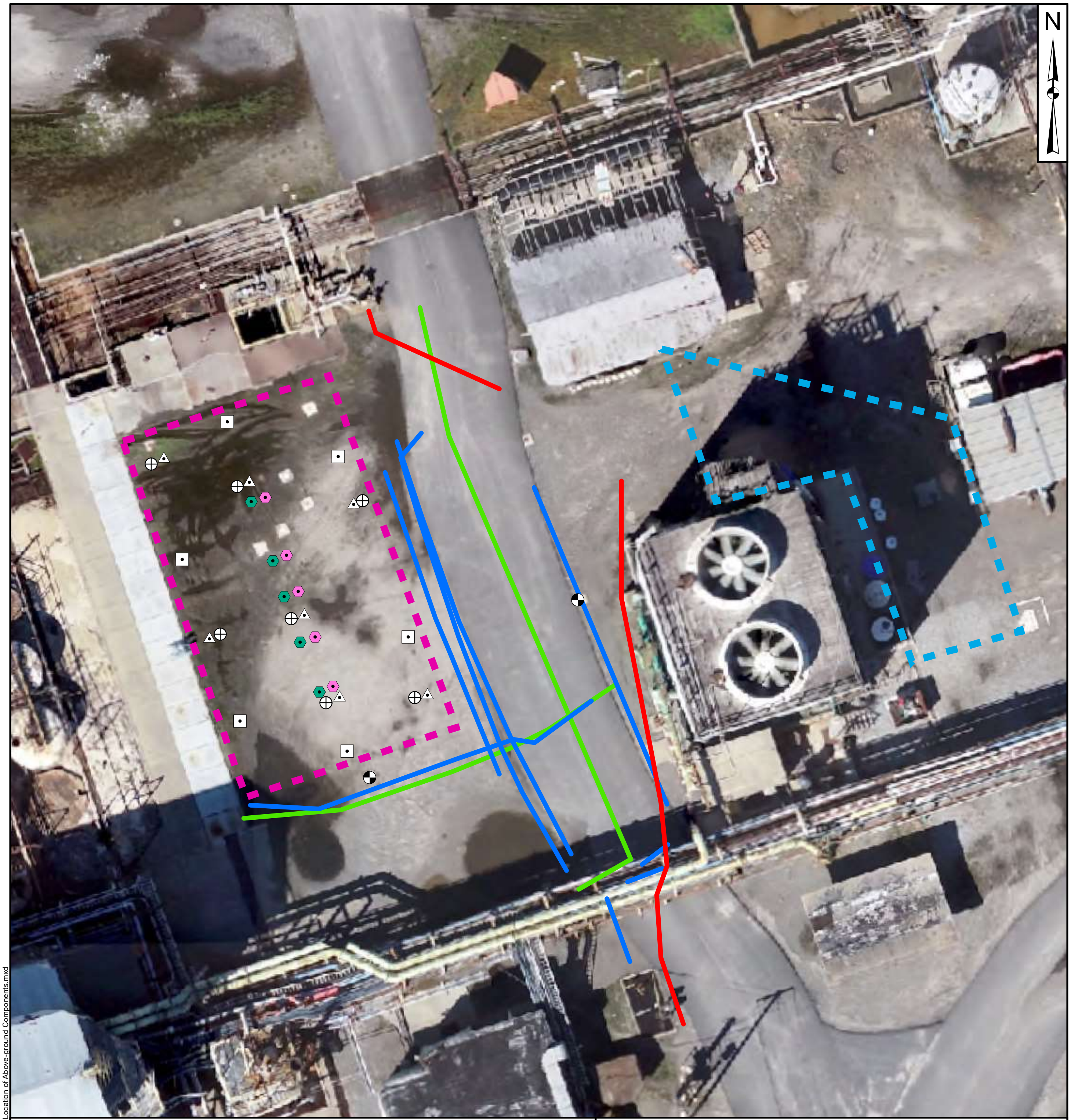
ISCO Treatment for Shallow Groundwater
Stage 2 Treatment Area
Hercules/Pinova Facility
Brunswick, Georgia

Geosyntec
consultants

Kennesaw, GA
August 2021

Figure
6

Path: \\Aro-01\prj1$\H\Hercules\Brunswick\GIS\MXD\ISCO ICM\Figure 6 Stage 2 Treatment Area.mxd



Legend

- ⬢ Step 1 Injection Well (IW) Screened at 15-20 ft bgs
- ⬢ Step 2 Injection Well (IW) Screened at 5-15 ft bgs
- ⊕ Observation Well (OW) Screened at 5-12 ft bgs
- △ Observation Well (OW) Screened at 13-20 ft bgs
- ⊡ Utility Observation Well (UOW) Screened at 5-10 ft bgs
- ◐ Existing Monitoring Well
- 🟥 Electrical Line (Approximate Underground Location)
- 🟦 Fire Suppression Line (Approximate Underground Location)
- 🟩 Water Line (Approximate Underground Location)
- ▨ Preliminary Location of Above-Ground Components for ISCO Treatment Process
- ▨ Target Treatment

Notes:
1. ft bgs - feet below ground surface; ISCO - *in situ* chemical oxidation.

0 12.5 25 50
Feet

Preliminary Location of Above-Ground Components for ISCO Treatment Process

Hercules/Pinova Facility
Brunswick, Georgia

Geosyntec consultants

Kennesaw, GA

August 2021

Figure

7

Path: \\Aro-01\prj1$\H\Hercules\Brunswick\GIS\MXD\ISCO ICM\Figure 7 Preliminary Location of Above-ground Components.mxd

APPENDIX A

ISCO Treatability Study Report

Prepared for:

Geosyntec Consultants, Inc.
1255 Roberts Boulevard, Suite 200
Kennesaw, Georgia 30144

Laboratory Treatability Study to Evaluate the Base Demand and Oxidant Demand of Geologic Materials and Groundwater

SGW-23 Area Near Stillhouse Control Room – Brunswick, GA

Prepared by:

SiREM

130 Stone Road W
Guelph, Ontario N1G 3Z2

SiREM Ref: GR6881C

27 January 2021

siremlab.com

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LIST OF ABBREVIATIONS

>	greater than
°C	degrees Celsius
°C/min	degrees Celsius per minute
µg/L	micrograms per liter
µL	microliters
µm	micrometer
BAP	base activated persulfate
DI	deionized water
FID	flame ionization detector
g	grams
g/kg	grams per kilogram
g/L	gram per liter
GC	gas chromatograph
Geosyntec	Geosyntec Consultants, Inc.
h	hours
H_2SO_4	sulfuric acid
IC	ion chromatograph
ISCO	in-situ chemical oxidation
M	molar
mg/L	milligrams per liter
min	minutes
mL	milliliters
mL/min	milliliters per minute
mM	millimolar
$Na_2S_2O_8$	sodium persulfate
NaOH	sodium hydroxide
nm	nanometers
QL	quantitation limit
RPM	revolutions per minute
S_2O_8	persulfate
SiREM	SiREM Laboratory
SOD	soil oxidant demand
UV/VIS	ultraviolet/visible
VOA	volatile organic analysis

1. INTRODUCTION

Geosyntec Consultants Inc. (Geosyntec) retained SiREM Laboratory (SiREM) to conduct a treatability study to assess the base demand and soil oxidant demand (SOD) for treatment of benzene and p-cymene in groundwater and geologic material samples from the SGW-23 area near Stillhouse Control Room at the Brunswick Site in Georgia (the Site).

The groundwater samples were collected from multi-phase extraction (MPE) pilot test well near Stillhouse Control Room on 20 February 2020 by Geosyntec personnel. The samples were received by SiREM on 24 February 2020 at a temperature of 4 degrees Celsius (°C). The geologic material was also collected from the boring of the MPE pilot test well from a depth between 2 to 10 feet bgs. (labelled on COC as Pinova MPE (2-5', 5-10', 6-8', 8-10')) on 18 February 2020 by Geosyntec personnel. The geologic material was received by SiREM on 21 February 2020 at a temperature of 3 °C. Additional water labelled "MW-21 Treatability" was collected on 15 October 2020 and was received by SiREM on 19 October 2020 at a temperature of 13 °C. Refer to Appendix A for the chain of custody documentation received with the materials.

The general scope of the bench scale tests included the following tasks:

Task 1: Base Titration Test

Task 2: SOD Test

The remainder of this report contains a summary of key *in-situ* chemical oxidation (ISCO) degradation processes (Section 1.1), the experimental materials and methods (Section 2), the results (Section 3), and the report references (Section 4).

1.1 Summary of ISCO Degradation Processes

Sodium persulfate ($Na_2S_2O_8$) is a highly reactive oxidant that can react with a variety of compounds; however, oxidation of some constituents can be kinetically slow or non-existent. By itself, the persulfate ion (S_2O_8) treats a limited suite of contaminants (e.g., petroleum hydrocarbons and chlorobenzenes), however when activated, $Na_2S_2O_8$ can destroy many organic compounds. When injected into water, persulfate salts dissociate to form persulfate anions that serve as the powerful oxidant. More notably, the addition of an activator dramatically increases the oxidative strength of the persulfate through the formation of sulfate free radicals as represented in Equations 1 through 4 below. Other free radicals may also be formed depending on the activation approach employed. Free radicals are molecular fragments that have an unpaired electron causing them to be highly reactive as strong oxidizing agents and are known to rapidly oxidize many compounds.

Sulfate Radical Generation and Reactions:

Initiation: $S_2O_8^{2-}$ + initiator $\rightarrow$ 2 $SO_4^{-}\bullet$ + ($SO_4^{-}\bullet$ or SO_4^{-2}) (1)

Propagation: $SO_4^{-}\bullet + H_2O \rightarrow OH^{-}\bullet + HSO_4^{-}$ (generation of hydroxyl radicals) (2)

Termination: $SO_4^{-}\bullet + RH \rightarrow R\bullet + HSO_4$ (3)

$$OH^{-}\bullet + RH \rightarrow R\bullet + H_2O \qquad (4)$$

Equations are not balanced. RH represents an organic compound; R• represents an oxidized organic compound. Soil oxidant demand and metals in the geologic materials may contribute to oxidant consumption and free radical chemistry is not necessarily stoichiometric or straightforward.

Mechanisms used for activation of persulfate include reactive metals (such as iron), other oxidants (such as permanganate or hydrogen peroxide), heat, and alkaline conditions. In this study, the persulfate was activated using an alkaline pH of greater than (>) 12 with the addition of sodium hydroxide (NaOH) to raise the pH. The reactive mechanisms that occurred are not clearly understood, as the activation chemistry can result in several different radical species (i.e., sulfate and hydroxide radicals) and alkaline hydrolysis side reactions may also play a key role in the degradation process.

2. MATERIALS AND METHODS

The following sections describe the construction and sampling schedule for the Base Titration Test (Section 2.1) and the SOD Test (Section 2.2); and the procedures used during the reactor sampling and analysis (Section 2.3).

The geologic materials from cores labelled Pinova MPE (2-5’, 5-10’, 6-8’, 8-10’) were previously homogenized on 27 February 2020 for the anaerobic biotreatability study. The previously homogenized soil was used to prepare the reactors for the base titration test and the SOD test. The Site groundwater collected on 20 February 2020 was used for the base titration test. However, due to the limited sample volume remaining after the set-up of the anaerobic and aerobic biotreatability studies (reported under separate covers), additional Site groundwater was required to set-up the SOD test. As a result, water collected on 15 October 2020 was used to construct the SOD reactors. All reactors were prepared in a chemical fume hood under ambient atmospheric conditions.

The following sections describe the construction and incubation conditions for each of the tests. The concentration of each oxidant and activator to be tested was selected based on recommendations of the manufacturer and in consultation with Geosyntec.

2.1 Base Titration Test

Two reactors were constructed to assess the base demand of the Site material. One reactor was prepared with Site groundwater and the second reactor was prepared with Site geologic material and deionized (DI) water. The site groundwater reactor was constructed in a 250 milliliter (mL) Boston round glass bottle (Systems Plus, Baden, ON) by adding 200 mL of Site groundwater on 14 October 2020 (Day 0). The Site geologic material reactor was constructed in a 250 mL Boston round glass bottle with 100 grams (g) of wet geological materials and 200 mL of DI water on 14 October 2020 (Day 0).

Both the Site groundwater and Site geologic material reactors were amended with NaOH (sodium hydroxide) (BioShop, Burlington, ON) stock solution to elevate the pH of the reactors to >12. Literature suggests the activation of persulfate occurs at a pH >10 (Block et., al, 2004). SiREM increased the pH to >12 as a safety factor for alkaline activation of persulfate. Due to an expected lower base demand in the groundwater, the Site groundwater reactor was amended with a 1 molar (M) NaOH solution while the Site geologic material reactor was amended with a 10 M NaOH solution.

All reactors were capped with Teflon™-lined caps (Systems Plus, New Hamburg, ON) and incubated in the dark at room temperature. Table 1-1 presents a summary of the reactor construction and amendments.

Samples were collected from control and treatment reactors for analysis of pH on Days 0 and 2 as well as after incremental amendments of NaOH.

2.2 SOD Test

On 23 October 2020 (Day 0), reactors were constructed by adding 150 g of homogenized geologic material (wet weight) and a mixture of Site groundwater, $Na_2S_2O_8$ solution, NaOH, and DI water to a total liquid volume of 150 mL to yield an approximate 1:1 ratio by weight. Reactors were constructed in 250 mL screw cap Boston round glass bottles capped with Mininert™ (VICI Valco, Brockville, ON) closures to allow repetitive sampling and amendment throughout the reaction period.

After construction, the unamended sterile control reactors were immediately poisoned with mercuric chloride and sodium azide to limit intrinsic biologic activity from occurring in the control reactors.

The base activated persulfate (BAP) reactors were amended with 10 mL of a 300 gram per liter (g/L) persulfate solution to a target concentration of 20 g/L as persulfate. The persulfate stock solution was prepared using $Na_2S_2O_8$ (PeroxyChem, Philadelphia, Pennsylvania). The reactors were then amended with 6 mL of 10 M NaOH solution (based on the results from the base titration test).

Control and treatment reactors were prepared in duplicate. A reagent control reactor was prepared in singlet in 250 mL Boston round bottle to a final volume of 140 mL using DI water and with 6.7 mL of the 300 g/L persulfate stock solution.

The initial benzene concentration in the reactors was not representative of Site conditions so on 23 October 2020, the reactors were spiked with a saturated benzene solution to target a benzene concentration of 5.0 milligrams per liter (mg/L) in the reactors. It was determined in consultation with Geosyntec that p-cymene would not be spiked into the reactors at the start of the study.

After observing decreases in the pH on Days 3, 5, 11, and 14, the BAP reactors were amended with additional 10 M NaOH solution to increase the pH to be >12. In total (including the initial amendment of NaOH on Day 0), the reactors were amended with 12 mL of 10 M NaOH solution over the course of the reaction period.

After observing a near-complete consumption of persulfate after 7 days, the BAP reactors were amended with additional $Na_2S_2O_8$ as a solid to target a concentration of 40 g/L as persulfate in the reactors. As a result, the BAP reactors were amended with an effective dose of 60 g/L as persulfate over the reaction period of the study.

Once prepared, reactors were stored in the dark at room temperature (approximately 22 °C) for 17 days. A summary of the reactor construction and amendments are presented in Table 2-1.

Reactors were sampled for analysis of benzene and persulfate on Days 0, 7, 10, 14 and 17. Reactors were additionally sampled for analysis of sulfate on Days 0, 7, 14 and 17. The pH of the reactors was monitored periodically throughout the study to ensure the BAP reactors had a pH that was >12. At the end of the incubation period, the reactors were sacrificially sampled and shipped to Pace Analytical in Indianapolis, IN for p-cymene analysis and confirmatory benzene analysis of the geologic material and groundwater from the control and treatment reactors.

2.3 Reactor Sampling and Analysis

2.3.1 Reactor Sampling

Aqueous samples for benzene were collected using gas-tight 1 mL Hamilton glass syringes. Syringes were cleaned with acidified water (pH ~2) and rinsed 10 times with DI water between samples to ensure that there was no cross contamination between different samples or treatments.

Reactors were sampled for pH, anions, and aqueous persulfate analysis using a 5 mL disposable syringe according the schedules presented in Sections 2.1, 2.2, and 2.3. Each oxidant sample was filtered through a 0.45 micrometer (µm) syringe filter into a clean 10 mL glass vial for analysis.

Aqueous samples for VOC analysis at an external laboratory were collected using 25 mL glass pipettes to transfer the liquid to 40 mL VOA vials.

2.3.2 Analysis of Benzene

This section describes the methods used to quantify aqueous benzene. The quantitation limits (QL) for the VOCs were typically 10 micrograms per liter (µg/L) in the reactors based on the dilution factors used and the lowest concentration standards that were included in the linear calibration trend.

Aqueous benzene concentrations in the reactors were measured using an Agilent 7890 gas chromatograph (GC) equipped with an Agilent G1888 headspace auto sampler programmed to heat each sample vial to 75°C for 45 minutes (min) prior to headspace injection into a GSQ Plot column (0.53 millimeters x 30 meters, J&W) with flame ionization detector (FID). Sample vials were heated to ensure that all VOCs in the aqueous sample would 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 carrier gas was helium at a flow rate of 11 milliliters per minute (mL/min).

After withdrawing a 0.5 mL sample from the reactors as described in Section 2.3.1, the sample was injected into a 10 mL auto sampler vial containing 4.3 mL of acidified DI water and 0.2 mL of ascorbic acid to quench the oxidant thus stopping the reaction of the oxidant and benzene (Ko et al. 2012). The vials were sealed with inert Teflon®-coated septa and aluminium crimp caps for automated injections of 3 mL of headspace onto the GC. One VOC standard was analysed with each set of samples to verify the instrument five-point calibration curve. Calibration was performed using external standard solutions (Sigma, St Louis, MO), where known volumes of standard solutions were added to acidified water in auto sampler vials and analysed as described above for microcosm samples. Data were integrated using Chemstation Software (Agilent Technologies, Santa Clara, CA).

2.3.3 Analysis of Sulfate

Sulfate analysis was performed by SIREM using 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 NaOH eluent generator cartridge (Thermo Scientific, Burlington, ON) eluent for 13 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 for sulfate was 0.07 mg/L.

A 0.5 mL sample was withdrawn (as described in section 2.3.1), 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 deionized 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 microliter (µL) sample loop.

2.3.4 Analysis of Persulfate

Persulfate was measured using the colorimetric method described by Huang et al. (2002). Persulfate samples were mixed with sulfuric acid (H_2SO_4) and ferrous ammonium sulfate to activate the persulfate. After an incubation period of 40 min, ammonium thiocyanate was added to oxidize the reaction and yield a coloured compound proportional to the amount of persulfate in solution. The light adsorption by the reaction mixture was measured with an ultraviolet/visible light (UV/VIS) spectrophotometer (Biochrom Ultraspec 1000) so that readings at 450 nanometers (nm) were less than 3.0 absorbance units. An eight-point calibration curve was prepared using known concentrations of a persulfate solution at each analysis event. The method QL was 50 mg/L.

2.3.5 Analysis of pH

pH measurements were performed using an Oakton pH spear with combination pH electrode (Oakton, Vernon Hills, Illinois). The pH spear was calibrated according to the manufacturer's instructions using pH 4.0, 7.0 and 10 standards.

2.3.6 Analysis of Benzene and p-Cymene at Pace Analytical

The reactors were sacrificially sampled at endpoint for analysis of benzene and p-cymene at Pace Analytical in Indianapolis, IN. Prior to collection of the aqueous phase of the reactors, the reactors were amended with 5 g of ascorbic acid to quench the oxidant reaction. The reactors were left to settle overnight to reduce the amount of silt particles collected in the aqueous sample. After 24 hours (h) of settling, A 25 mL glass pipette was used to transfer the aqueous phase of the reactor to triplicate 40 mL volatile organic analysis (VOA) vials containing hydrochloric acid as preservative. After collecting the aqueous phase samples, any remaining water was decanted from the reactors and a 5 g sample of the geologic material was collected from the reactors into a 40 mL VOA vial containing 10 mL of methanol to act as a preservative. The remaining geologic material from each reactor was collected into a 60 mL soil jar used to determine the moisture content of the sample. The samples were packed on ice in a cooler and shipped overnight from SiREM to Pace Analytical. The original laboratory report for Pace Analytical is presented in Appendix B.

3. RESULTS

Results are provided by task as follows:

Task 1) A summary of the measured base demands from the Base Titration Test in groundwater and geologic material are provided in Table 1-2.

Task 2) A summary of measured benzene and p-cymene concentrations from the SOD Test in geologic material and groundwater are presented in Table 2-2. The original laboratory report from Pace Analytical with the endpoint benzene and p-cymene results is presented in Appendix B. All aqueous benzene and p-cymene results are presented in units of mg/L and in millimoles and all geologic material results are presented in units of milligrams per kilogram (mg/kg) and millimoles. Concentrations were converted from mg/L or mg/kg to millimoles using Henry's Law as demonstrated in Appendix C. Table 2-3 presents a summary of the measured sulfate and persulfate concentrations and the calculated oxidant demands. Sulfate is presented in units of mg/L and persulfate is presented in units of g/L and grams per kilogram (g/kg). Table 2-4 presents the pH results from the SOD Test.

Figure 1 presents the aqueous benzene concentration trends in the SOD test reactors over the reaction period. Figure 2 presents the endpoint aqueous benzene and p-cymene concentrations from the unamended sterile controls and BAP amended reactors. Figure 3 presents the endpoint geologic material benzene and p-cymene concentrations from the unamended sterile controls and BAP amended reactors.

4. REFERENCES

Block, P.A., R.A. Brown, and D. Robinson. 2004. Novel Activation Technologies for Sodium Persulfate In-Situ Chemical Oxidation. Proceedings of the Fourth International Conference on the Remediation of Chlorinated and Recalcitrant Compounds.

Huang, K., R. Couttenye, and G. Hoag 2002. Kinetics of heat-assisted persulfate oxidation of methyl tert-butyl ether (MTBE). Chemosphere 49(2002): 413-420.

Ko, Saebom, S.G. Huling and B. Pivetz. 2012. Ground Water Sample Preservation at In-Situ Chemical Oxidation Sites – Recommended Guidelines. EPA/600/R-12/049 August 2012.

TABLES

TABLE 1-1: SUMMARY OF BASE TITRATION CONTROLS, TREATMENTS AND AMENDMENTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment/Control	Assigned Microcosm Number	Geological Material (g)	Site Groundwater (mL)	DI Water (mL)	Headspace (mL)	NaOH	Sampling Events (Days)
Site Groundwater	1	--	200	--	50	Amended with 1 M NaOH as required to maintain a pH >12.	0, 2
Site Geologic Material	2	100 g	--	200	5	Amended with 10 M NaOH as required to maintain a pH >12.	0, 2

Notes:

-- - not applicable
> - greater than
g - grams
M - molar
mL - milliliters
NaOH - sodium hydroxide
DI - deionized water

TABLE 1-2: SUMMARY OF BASE TITRATION RESULTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Site Groundwater - Buffered Treatment
Reactor 1

Average volume of site water (mL)	198
Concentration of NaOH (mol/L)	1
Molecular Weight of NaOH (g/mol)	40
Concentration of NaOH (g/L)	40

Date	Day	Time	pH	Volume of 1 M NaOH Solution Amended	Cumulative 1 M NaOH Solution Amended	Mass of NaOH Amended per Reactor	Base Demand	Base Demand
		hours		mL	mL	g/bottle	g/L	mmol/L
14-Oct-20	0	0	6.62	1.05	1.05	0.04	0.21	0.005
		1.0	9.94	1.25	2.30	0.09	0.46	0.012
		3.5	11.29	1.30	3.60	0.14	0.73	0.018
		5.5	11.70	2.90	6.50	0.26	1.31	0.033
		10	11.99	0.00	6.50	0.26	1.31	0.033
15-Oct-20	1	--	11.89	0.20	6.70	0.27	1.35	0.034
		--	12.10	0.00	6.70	0.27	1.35	0.034
16-Oct-20	2	--	12.05	0.00	6.70	0.27	1.35	0.034

Site Geologic Material and DI Water - Buffered Treatment
Reactor 2

Average Volume of DI Water (mL)	197
Concentration of NaOH (mol/L)	10
Molecular Weight of NaOH (g/mol)	40
Concentration of NaOH (g/L)	400
Average Mass of Geologic Material (g)	101

Date	Day	Time	pH	Volume of 1 M NaOH Solution Amended	Cumulative 1 M NaOH Solution Amended	Mass of NaOH Amended per Reactor	Base Demand	Base Demand
		hours		mL	mL	g/bottle	g/kg	mmol/g
14-Oct-20	0	0	6.32	0.10	0.10	0.04	0.40	0.010
		1.0	8.63	0.40	0.50	0.20	1.98	0.049
		3.5	10.22	0.60	1.10	0.44	4.35	0.109
		5.5	11.52	0.50	1.60	0.64	6.33	0.158
		10	11.98	0.00	1.60	0.64	6.33	0.158
15-Oct-20	1	--	12.04	0.00	1.60	0.64	6.33	0.158
16-Oct-20	2	--	11.89	0.00	1.60	0.64	6.33	0.158

Notes:

* wet weight basis
-- - not applicable
DI - deionized
g - grams
g/bottle - grams NaOH per bottle
g/kg - grams per kilogram
g/L - grams per liter
h - hours
M - molar
mL - milliliter
mmol/g - millimoles NaOH per gram of geologic material
mmol/L - millimoles NaOH per liter of groundwater
NaOH - sodium hydroxide

TABLE 2-1: SUMMARY OF SOD CONTROLS, TREATMENTS AND AMENDMENTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment/Control	Assigned Reactor Number	Number of Reactors	Geological Material (g)	Total Aqueous Volume (mL)	Groundwater (mL)	Headspace (mL)	Sodium Azide	Mercuric Chloride	Persulfate	NaOH	Benzene	DI Water (mL)
Persulfate Reagent Control	--	1	--	150	--	70	--	--	Amended with 10 mL of a 300 g/L persulfate stock solution to target a concentration of 20 g/L on Day 0.	--	--	
Unamended Sterile Control	1 to 2	2	150	150	134	25	Amended with 0.375 mL of a 5% solution on Day 0.	Amended with 2.1 mL of a 2.7% solution on Day 0.	--	--	Amended with 300 µL of a saturated benzene solution to target a concentration of 5 mg/L benzene on Day 0.	13.5
20 g/L + 40 g/L Base Activated Persulfate Treatment	3 to 4	2	150	150	134	25			Amended with 10 mL of a 300 g/L persulfate stock solution to target a concentration of 20 g/L on Day 0. Amended with 7.44 g of $Na_2S_2O_8$ to target a concentration of 40 g/L persulfate on Day 10.	Amended with a cumulative 12 mL of 10 M NaOH to target a pH >12 over the reaction period of the study.		--

Notes:

-- - not applicable
% - percent
> - greater than
DI - deionized water
g - grams
g/L - grams per liter
M - molar
mL - milliliters
$Na_2S_2O_8$ - sodium persulfate
NaOH - sodium hydroxide

TABLE 2-2: SUMMARY OF SOD REACTOR BENZENE AND p-CYMENE RESULTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment	Date	Day	Replicate	Aqueous Concentrations			Geologic Material Concentrations		Comments
				Benzene [SiREM]	Benzene [Pace]	p-Cymene [Pace]	Benzene [Pace]	p-Cymene [Pace]	
				mg/L	mg/L	mg/L	mg/kg	mg/kg	
Unamended Sterile Control	23-Oct-20	0							Amended with mecuric chloride and sodium azide.
									Spiked with benzene to a target concentration of 5 mg/L.
			SC-1	4.50	--	--	--	--	
			SC-2	4.64	--	--	--	--	
			Average Concentration	4.57	--	--	--	--	
			Standard Deviation (mmoles)	1.0E-01	--	--	--	--	
			Average Total mmoles	**0.0091**	**--**	**--**	**--**	**--**	
	30-Oct-20	7	SC-1	4.60	--	--	--	--	
			SC-2	4.23	--	--	--	--	
			Average Concentration	4.42	--	--	--	--	
			Standard Deviation (mmoles)	2.6E-01	--	--	--	--	
			Average Total mmoles	**0.0088**	**--**	**--**	**--**	**--**	
	02-Nov-20	10	SC-1	4.45	--	--	--	--	
			SC-2	4.10	--	--	--	--	
			Average Concentration	4.28	--	--	--	--	
			Standard Deviation (mmoles)	2.5E-01	--	--	--	--	
			Average Total mmoles	**0.0085**	**--**	**--**	**--**	**--**	
	06-Nov-20	14	SC-1	3.94	--	--	--	--	
			SC-2	4.11	--	--	--	--	
			Average Concentration	4.03	--	--	--	--	
			Standard Deviation (mmoles)	1.2E-01	--	--	--	--	
			Average Total mmoles	**0.0080**	**--**	**--**	**--**	**--**	
	09-Nov-20	17	SC-1	3.88	2.94	0.388	0.74	3.12	
			SC-2	3.78	2.77	0.378	0.51	1.67	
			Average Concentration	3.83	2.86	0.383	0.63	2.40	
			Standard Deviation (mmoles)	7.3E-02	1.2E-01	7.1E-03	1.6E-01	1.0E+00	
			Average Total mmoles	**0.0076**	**0.0057**	**0.00045**	**0.0012**	**0.00268**	
20 g/L + 40 g/L Base Activated Persulfate Treatment	23-Oct-20	0							Spiked with benzene to a target concentration of 5 mg/L.
									Amended with 10 mL of a 300 g/L persulfate solution to a target concentration of 20 g/L as persulfate.
	23-Oct-20	0.1	BAP-1	2.92	--	--	--	--	
			BAP-2	2.99	--	--	--	--	
			Average Concentration	2.95	--	--	--	--	
			Standard Deviation (mmoles)	4.9E-02	--	--	--	--	
			Average Total mmoles	**0.0059**	**--**	**--**	**--**	**--**	
	30-Oct-20	7	BAP-1	1.70	--	--	--	--	
			BAP-2	1.75	--	--	--	--	
			Average Concentration	1.72	--	--	--	--	
			Standard Deviation (mmoles)	3.8E-02	--	--	--	--	
			Average Total mmoles	**0.0034**	**--**	**--**	**--**	**--**	
	02-Nov-20	10	BAP-1	1.56	--	--	--	--	
			BAP-2	1.60	--	--	--	--	
			Average Concentration	1.58	--	--	--	--	
			Standard Deviation (mmoles)	2.8E-02	--	--	--	--	
			Average Total mmoles	**0.0031**	**--**	**--**	**--**	**--**	

TABLE 2-2: SUMMARY OF SOD REACTOR BENZENE AND p-CYMENE RESULTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment	Date	Day	Replicate	Aqueous Concentrations			Geologic Material Concentrations		Comments
				Benzene [SiREM]	**Benzene [Pace]**	**p-Cymene [Pace]**	**Benzene [Pace]**	**p-Cymene [Pace]**	
				mg/L	**mg/L**	**mg/L**	**mg/kg**	**mg/kg**	
20 g/L Base Activated Persulfate Treatment Continued	02-Nov-20	10	Amended with 7.44 g of persulfate to target 40 g/L.						Amended with 7.44 g of $Na_2S_2O_8$ to a target concentration of 40 g/L as persulfate.
			BAP-1	1.56	--	--	--	--	
			BAP-2	1.60	--	--	--	--	
			Average Concentration	1.58	--	--	--	--	
			Standard Deviation (mmoles)	2.8E-02	--	--	--	--	
			Average Total mmoles	**0.0031**	**--**	**--**	**--**	**--**	
	06-Nov-20	14	BAP-1	0.41	--	--	--	--	
			BAP-2	0.38	--	--	--	--	
			Average Concentration	0.39	--	--	--	--	
			Standard Deviation (mmoles)	2.0E-02	--	--	--	--	
			Average Total mmoles	**0.00079**	**--**	**--**	**--**	**--**	
	09-Nov-20	17	BAP-1	0.21	0.147	0.339	<0.17	2.15	
			BAP-2	0.18	0.118J	0.207	<0.17	1.43	
			Average Concentration	0.19	0.133	0.273	ND	1.79	
			Standard Deviation (mmoles)	2.5E-02	2.1E-02	9.3E-02	0.0E+00	5.1E-01	
			Average Total mmoles	**0.00039**	**0.00026**	**0.00032**	**ND**	**0.00200**	

Notes:

-- - not sampled
< - compound not detected, associated value is the method reporting limit
BAP - base activated persulfate
g/L - grams per liter
J - estimated concentration above the adjusted method detection limit and below the adjusted reporting limit
mg/kg - milligrams per kilogram
mg/L - milligrams per liter
mmoles - millimoles
$Na_2S_2O_8$ - sodium persulfate
ND - not detected
SC - sterile control

TABLE 2-3: SUMMARY OF SOD REACTOR SULFATE AND PERSULFATE RESULTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment	Date	Day	Replicate	Sulfate (Aqueous)	Persulfate (Aqueous)	Persulfate (Geologic Material)
				mg/L	g/L	g/kg
20 g/L Persulfate Reagent Control	23-Oct-20	0	Per-RC	--	19.2	--
	30-Oct-20	7	Per-RC	--	20.2	--
	02-Nov-20	10	Per-RC	--	19.5	--
	06-Nov-20	14	Per-RC	--	19.4	
Unamended Control	23-Oct-20	0	SC-1	145	--	--
			SC-2	137	--	--
			Average	**141**	**--**	**--**
	30-Oct-20	7	SC-1	145	--	--
			SC-2	170	--	--
			Average	**158**	**--**	**--**
	06-Nov-20	14	SC-1	155	--	--
			SC-2	169	--	--
			Average	**162**	**--**	**--**
	09-Nov-20	17	SC-1	121	--	--
			SC-2	138	--	--
			Average	**130**	**--**	**--**
20 g/L + 40 g/L Base Activated Persulfate Treatment	23-Oct-20	0	Amended with 10 mL of a 300 g/L persulfate solution to a target concentration of 20 g/L as persulfate.			
	23-Oct-20	0.1	BAP-1	<0.07	16.4	17.1
			BAP-2	<0.07	16.0	16.6
			Average	**ND**	**16.2**	**16.9**
	30-Oct-20	7	BAP-1	19,857	1.28	1.34
			BAP-2	15,685	1.28	1.33
			Average	**17,771**	**1.28**	**1.33**
	02-Nov-20	10	Amended with 7.44 g of $Na_2S_2O_8$ to a target concentration of 40 g/L as persulfate.			
			BAP-1	--	34.4	35.9
			BAP-2	--	33.2	34.4
			Average	**--**	**33.8**	**34.4**
	06-Nov-20	14	BAP-1	36,710	21.4	22.3
			BAP-2	31,190	21.9	22.7
			Average	**33,950**	**21.6**	**22.5**

TABLE 2-3: SUMMARY OF SOD REACTOR SULFATE AND PERSULFATE RESULTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment	Date	Day	Replicate	Sulfate (Aqueous)	Persulfate (Aqueous)	Persulfate (Geologic Material)
				mg/L	g/L	g/kg
20 g/L + 40 g/L Base Activated Persulfate Treatment	09-Nov-20	17	BAP-1	39,389	17.7	18.5
Continued			BAP-2	34,624	15.8	16.3
			Average	**37,006**	**16.7**	**17.4**
			Demand	***--***	***33.3***	***33.9***

Notes:

-- - not applicable
BAP - base activated persulfate
g - grams
g/kg - grams per kilogram
g/L - grams per liter
mg/L - milligrams per liter
mL - mililiters
$Na_2S_2O_8$ - sodium persulfate
Per-RC - persulfate reagent control
SC - sterile control
< - compound not detected, associated value is the method reporting limit

TABLE 2-4: SUMMARY OF SOD REACTOR pH RESULTS

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment	Date	Day	Reactor	Replicate	pH
Unamended Sterile Control	23-Oct-20	0	1	SC-1	5.73
			2	SC-2	5.81
				Average	**5.77**
	26-Oct-20	3	1	SC-1	5.61
			2	SC-2	5.60
				Average	**5.61**
	30-Oct-20	7	1	SC-1	5.74
			2	SC-2	5.78
				Average	**5.76**
	6-Nov-20	14	1	SC-1	5.67
			2	SC-2	5.73
				Average	**5.70**
	9-Nov-20	17	1	SC-1	5.93
			2	SC-2	5.84
				Average	**5.89**
20 g/L + 40 g/L Base Activated Persulfate Treatment	23-Oct-20	0	3	BAP-1	12.34
			4	BAP-2	12.35
				Average	**12.35**
	26-Oct-20	3	3	BAP-1	11.18
			4	BAP-2	11.03
				Average	**11.11**
			Amended with 0.5 mL of 10 M NaOH.		
			3	BAP-1	12.00
			4	BAP-2	12.02
				Average	**12.01**
	28-Oct-20	5	3	BAP-1	11.41
			4	BAP-2	11.52
				Average	**11.47**
			Amended with 0.5 mL of 10 M NaOH.		
			3	BAP-1	12.01
			4	BAP-2	12.02
				Average	**12.02**
	30-Oct-20	7	3	BAP-1	12.20
			4	BAP-2	12.12
				Average	**12.16**
	2-Nov-20	10	Amended with 7.44 g of $Na_2S_2O_8$ to a target concentration of 40 g/L as persulfate.		
			3	BAP-1	12.20
			4	BAP-2	12.12
				Average	**12.16**
	3-Nov-20	11	Amended with 1.5 mL of 10 M NaOH.		
			3	BAP-1	12.06
			4	BAP-2	12.03
				Average	**12.05**

TABLE 2-4: SUMMARY OF SOD REACTOR pH RESULTS

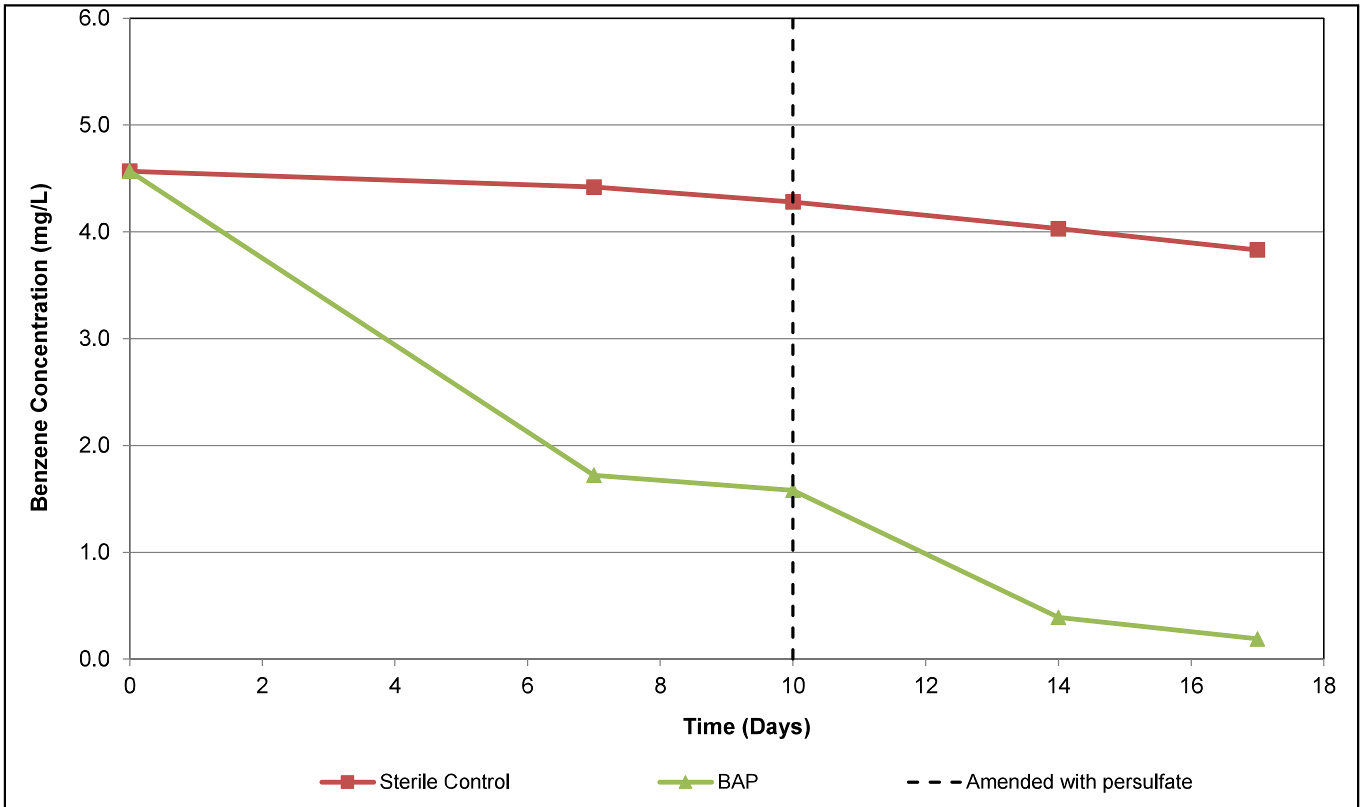
SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

Treatment	Date	Day	Reactor	Replicate	pH
20 g/L + 40 g/L Base Activated Persulfate Treatment Continued	6-Nov-20	14	3	BAP-1	9.04
			4	BAP-2	9.18
				Average	**9.11**
			Amended with 1.9 mL of 10 M NaOH.		
			3	BAP-1	12.04
			4	BAP-2	12.09
				Average	**12.07**
	9-Nov-20	17	3	BAP-1	10.32
			4	BAP-2	10.41
				Average	**10.37**

Notes:

BAP - base activated persulfate
g - grams
g/L - grams per liter
M - molar
$Na_2S_2O_8$ - sodium persulfate
NaOH - sodium hydroxide
SC - sterile control

FIGURES



Notes:

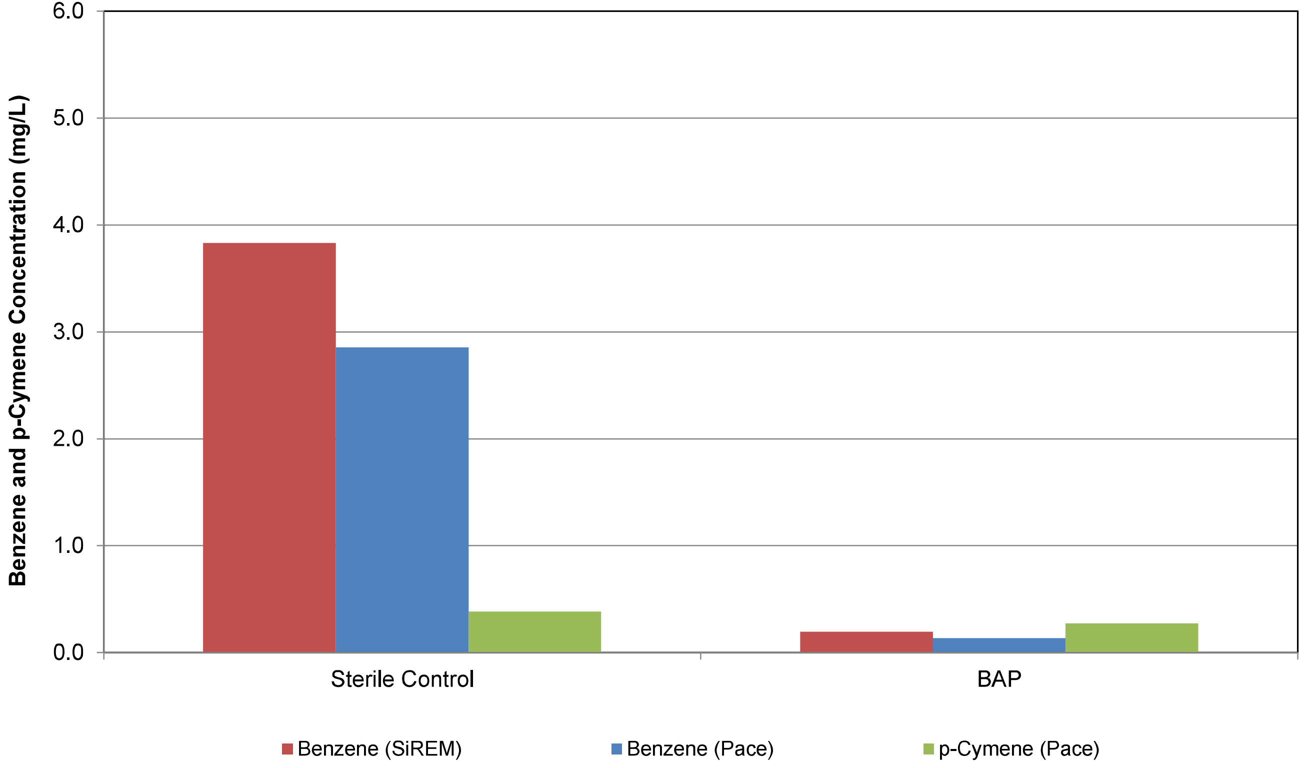
* Sterile control time zero benzene concentration used to represent the time zero concentrations in all reactors.
BAP - base activated persulfate
mg/L - milligrams per liter
SC - sterile control
SOD - soil oxidant demand

Benzene Concentration Trends in SOD Reactors
SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

SiREM

January 2021

Figure: **1**



Notes:

BAP - base activated persulfate
mg/L - milligrams per liter
SOD - soil oxidant demand

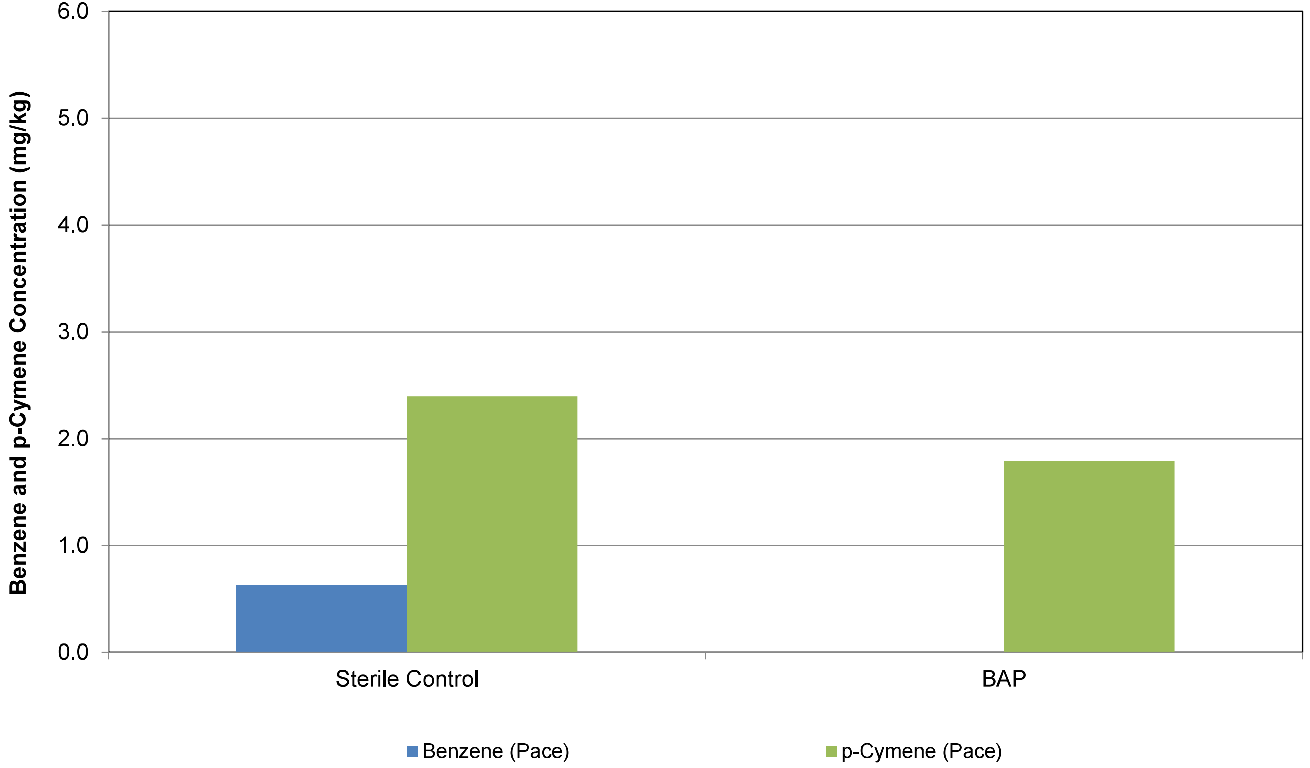
Endpoint Aqueous Benzene and p-Cymene Concentrations in SOD Reactors

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

SiREM

January 2021

Figure: **2**



Notes:

BAP - base activated persulfate
mg/kg - milligrams per kilogram
SOD - soil oxidant demand

Endpoint Geologic Material Benzene and p-Cymene Concentrations in SOD Reactors

SGW-23 Area Near Stillhouse Control Room - Brunswick, GA

SiREM

January 2021

Figure: **3**

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-5715

*Project Name: Hercules Brunswick
*Project #: GR6881C
*Project Manager: Adria Reimer
*Company: Geosyntec
*Email Address: areimer@geosyntec.com
Address (Street): 1255 Roberts Blvd.
City: Kennesaw
State/Province: GA
Country: USA
*Phone #: 678-202-9500
*Sampler's Signature:
*Sampler's Printed Name: Nardos Tilahun

Analysis

	Client Sample ID	Sampling Date	Sampling Time	Matrix	# of Containers	Gene-Trac DHC	Gene-Trac FGA (vcrA, bvcA, tceA)	Gene-Trac DHB	Gene-Trac DHG	Gene-Trac SRB	Volatile Fatty Acids	Dissolved hydrocarbon gases	Treatability Study				Other Information
1.	Pinova MPE (2-5')	2/18/20	1400	SO	1								X				Recovery = 12"
2.	Pinova MPE (5-10')	2/18/20	1400	SO	1								X				Recovery = 18"
3.	Pinova MPE (2-5')	2/18/20	1410	SO	1								X				Recovery = 2 ft.
4.	Pinova MPE (6-8')	2/18/20	1410	SO	1								X				Recovery = 4 ft (1 of 2)
5.	Pinova MPE (8-10')	2/18/20	1410	SO	1								X				Recovery = 4 ft (2 of 2)
6.	Pinova PZ-1 (2-5')	2/18/20	1420	SO	1								X				Recovery = 2 ft
7.	Pinova PZ-1 (5-10')	2/18/20	1420	SO	1								X				Recovery = 18"

2/19/2020

Preservative Key
0. None
1. HCL
2. Other ______
3. Other ______
4. Other ______
5. Other ______
6. Other ______

Billing Information
P.O. #:
*Bill To:

Turnaround Time Requested
Normal ☐
Rush ☐

For Lab Use Only
Cooler Condition: Good
Cooler Temperature: 3°C
Custody Seals: Yes ☐ No ☒

For Lab Use Only
Proposal #: ______

Relinquished By:	Received By:	Relinquished By:	Received By:	Relinquished By:	Received By:
Signature	Signature: Taylor R	Signature	Signature	Signature	Signature
Printed Name: Rich Murray	Printed Name	Printed Name	Printed Name	Printed Name	Printed Name
Firm: Geosyntec	Firm	Firm	Firm	Firm	Firm
Date/Time: 2/19/2020 1730	Date/Time	Date/Time	Date/Time	Date/Time	Date/Time

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

* Mandatory Fields

Chain-of-Custody Form

siremlab.com

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

Lab # S-5718

GB6881C

*Project Name Hercules Brunswick	*Project # ~~678-202-9500~~ RJ
*Project Manager Adria Reimer	*Company Geosyntec
*Email Address areimer@geosyntec.com	
Address (Street) ~~2155~~ 1255 Roberts Blvd.	
City Kennesaw	State/Province GA · Country 30144
*Phone # 678-202-9500	
*Sampler's Signature	*Sampler's Printed Name Rich Murray

Analysis

Client Sample ID	Sampling Date	Sampling Time	Matrix	# of Containers	Gene-Trac DHC	Gene-Trac FGA (vcrA, bvcA, tceA)	Gene-Trac DHB	Gene-Trac DHG	Gene-Trac SRB	Volatile Fatty Acids	Dissolved hydrocarbon gases	Treatability Study				Other Information
MPE Well	2/20/2020	1400	WG	4								X				4 x 2-L Bottles
~~MPE Well~~ RJ																

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

Billing Information

P.O. #

*Bill To:

Turnaround Time Requested

Normal ☐
Rush ☐

For Lab Use Only

Cooler Condition: Good.

Cooler Temperature: 4°C.

Custody Seals. Yes ☐ No ☒

For Lab Use Only

Proposal #:

	Relinquished By:	Received By:	Relinquished By:	Received By:	Relinquished By:	Received By:
Signature						
Printed Name	Rich Murray	D. Nespoli				
Firm	Geosyntec	SiREM.				
Date/Time	2/20/2020 . 1700	Feb 24 '20 1:30pm				

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

** Mandatory Fields*

SiREM

Chain-of-Custody Form

siremlab.com

130 Stone Road West
Guelph ON, Canada N1G 3Z2
(519) 822-2265

Lab # 5-6408

*Project Name: Brunswick	*Project #: GR6881C
*Project Manager: Adria Reimer	*Company: Geosyntec
*Email Address: areimer@geosyntec.com	
Address (Street): 1255 Roberts blvd ~~NW~~ NW ste 200	
City: Kennesaw	State/Province: Ga
Country: USA	
*Phone #: 470-361-7557	
*Sampler's Signature:	*Sampler's Printed Name: Ashley Ramsey

Analysis

Client Sample ID	Sampling Date	Sampling Time	Matrix	# of Containers	Gene-Trac DHC	Gene-Trac VC	Gene-Trac DHB	Gene-Trac DHG	Treatability Study							Other Information
MW-21 treatability	10/15/20	1303	GW	1					X							

Preservative Key

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

Billing Information

P.O. # GR6881C/100/100J

*Bill To:

Turnaround Time Requested

Normal ☒

Rush ☐

For Lab Use Only

Cooler Condition: Good

Cooler Temperature: 13°C

Custody Seals: Yes ☐ No ☑

For Lab Use Only

Proposal #: ________

Relinquished By:	Received By:	Relinquished By:	Received By:	Relinquished By:	Received By:
Signature	Signature	Signature	Signature	Signature	Signature
Printed Name: Ashley Ramsey	Printed Name: Rachel Hallman	Printed Name	Printed Name	Printed Name	Printed Name
Firm: Geosyntec	Firm: SiREM	Firm	Firm	Firm	Firm
Date/Time: 10/15/20	Date/Time: 19 Oct 20 4:15 pm	Date/Time	Date/Time	Date/Time	Date/Time

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

APPENDIX B: Pace Analytical Laboratory Report

Pace Analytical Services, LLC
7726 Moller Road
Indianapolis, IN 46268
(317)228-3100

November 17, 2020

Steve Sande
SiREM Lab
130 Stone Road W
Ontario, Canada,

RE: Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Dear Steve Sande:

Enclosed are the analytical results for sample(s) received by the laboratory on November 10, 2020. The results relate only to the samples included in this report. Results reported herein conform to the applicable TNI/NELAC Standards and the laboratory's Quality Manual, where applicable, unless otherwise noted in the body of the report.

The test results provided in this final report were generated by each of the following laboratories within the Pace Network:

- Pace Analytical Services - Indianapolis

If you have any questions concerning this report, please feel free to contact me.

Sincerely,

Kelly M Jones

Kelly Jones
kelly.jones@pacelabs.com
(317)228-3100
Project Manager

Enclosures

cc: Michael Healey, SiREM Lab
Jen Webb, SiREM

CERTIFICATIONS

Project:	SIREMGON-BENISOTOU
Pace Project No.:	50272776

Pace Analytical Services Indianapolis

7726 Moller Road, Indianapolis, IN 46268
Illinois Accreditation #: 200074
Indiana Drinking Water Laboratory #: C-49-06
Kansas/TNI Certification #: E-10177
Kentucky UST Agency Interest #: 80226
Kentucky WW Laboratory ID #: 98019
Michigan Drinking Water Laboratory #9050
Ohio VAP Certified Laboratory #: CL0065
Oklahoma Laboratory #: 9204
Texas Certification #: T104704355
West Virginia Certification #: 330
Wisconsin Laboratory #: 999788130
USDA Soil Permit #: P330-19-00257

SAMPLE SUMMARY

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Lab ID	Sample ID	Matrix	Date Collected	Date Received
50272776001	**Brunswick ISCO 1**	Solid	11/09/20 16:00	11/10/20 09:30
50272776002	**Brunswick ISCO 2**	Solid	11/09/20 16:00	11/10/20 09:30
50272776003	**Brunswick ISCO 3**	Solid	11/09/20 16:00	11/10/20 09:30
50272776004	**Brunswick ISCO 4**	Solid	11/09/20 16:00	11/10/20 09:30
50272776005	**Brunswick ISCO 1**	Water	11/09/20 16:00	11/10/20 09:30
50272776006	**Brunswick ISCO 2**	Water	11/09/20 16:00	11/10/20 09:30
50272776007	**Brunswick ISCO 3**	Water	11/09/20 16:00	11/10/20 09:30
50272776008	**Brunswick ISCO 4**	Water	11/09/20 16:00	11/10/20 09:30

SAMPLE ANALYTE COUNT

Project:	SIREMGON-BENISOTOU
Pace Project No.:	50272776

Lab ID	Sample ID	Method	Analysts	Analytes Reported	Laboratory
50272776001	**Brunswick ISCO 1**	EPA 8260	TMW	5	PASI-I
		SM 2540G	WZE	1	PASI-I
50272776002	**Brunswick ISCO 2**	EPA 8260	TMW	5	PASI-I
		SM 2540G	WZE	1	PASI-I
50272776003	**Brunswick ISCO 3**	EPA 8260	TMW	5	PASI-I
		SM 2540G	WZE	1	PASI-I
50272776004	**Brunswick ISCO 4**	EPA 8260	TMW	5	PASI-I
		SM 2540G	WZE	1	PASI-I
50272776005	**Brunswick ISCO 1**	EPA 8260	ZAH	5	PASI-I
50272776006	**Brunswick ISCO 2**	EPA 8260	ZAH	5	PASI-I
50272776007	**Brunswick ISCO 3**	EPA 8260	ZAH	5	PASI-I
50272776008	**Brunswick ISCO 4**	EPA 8260	ZAH	5	PASI-I

PASI-I = Pace Analytical Services - Indianapolis

SUMMARY OF DETECTION

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Lab Sample ID Method	Client Sample ID Parameters	Result	Units	Report Limit	Analyzed	Qualifiers
50272776001	**Brunswick ISCO 1**					
EPA 8260	Benzene	744	ug/kg	108	11/12/20 23:13	
EPA 8260	p-Isopropyltoluene	3120	ug/kg	108	11/12/20 23:13	
SM 2540G	Percent Moisture	25.9	%	0.10	11/12/20 11:52	N2
50272776002	**Brunswick ISCO 2**					
EPA 8260	Benzene	541	ug/kg	167	11/12/20 23:37	
EPA 8260	p-Isopropyltoluene	1670	ug/kg	167	11/12/20 23:37	
SM 2540G	Percent Moisture	23.5	%	0.10	11/12/20 11:53	N2
50272776003	**Brunswick ISCO 3**					
EPA 8260	p-Isopropyltoluene	2150	ug/kg	170	11/13/20 00:02	
SM 2540G	Percent Moisture	24.6	%	0.10	11/12/20 11:53	N2
50272776004	**Brunswick ISCO 4**					
EPA 8260	p-Isopropyltoluene	1430	ug/kg	165	11/13/20 09:25	
SM 2540G	Percent Moisture	25.4	%	0.10	11/12/20 11:53	N2
50272776005	**Brunswick ISCO 1**					
EPA 8260	Benzene	2940	ug/L	125	11/12/20 02:47	
EPA 8260	p-Isopropyltoluene	388	ug/L	125	11/12/20 02:47	
50272776006	**Brunswick ISCO 2**					
EPA 8260	Benzene	2770	ug/L	125	11/12/20 03:19	
EPA 8260	p-Isopropyltoluene	378	ug/L	125	11/12/20 03:19	
50272776007	**Brunswick ISCO 3**					
EPA 8260	Benzene	147	ug/L	125	11/12/20 03:51	
EPA 8260	p-Isopropyltoluene	339	ug/L	125	11/12/20 03:51	
50272776008	**Brunswick ISCO 4**					
EPA 8260	Benzene	118J	ug/L	125	11/12/20 04:23	
EPA 8260	p-Isopropyltoluene	207	ug/L	125	11/12/20 04:23	

ANALYTICAL RESULTS

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Sample: Brunswick ISCO 1 **Lab ID: 50272776001** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260 MSV 5035A VOA	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	**744**	ug/kg	108	50		11/12/20 23:13	71-43-2	
p-Isopropyltoluene	**3120**	ug/kg	108	50		11/12/20 23:13	99-87-6	
Surrogates								
Dibromofluoromethane (S)	89	%.	73-133	50		11/12/20 23:13	1868-53-7	
Toluene-d8 (S)	99	%.	73-130	50		11/12/20 23:13	2037-26-5	
4-Bromofluorobenzene (S)	104	%.	55-129	50		11/12/20 23:13	460-00-4	
Percent Moisture	Analytical Method: SM 2540G Pace Analytical Services - Indianapolis							
Percent Moisture	**25.9**	%	0.10	1		11/12/20 11:52		N2

ANALYTICAL RESULTS

Project:	SIREMGON-BENISOTOU
Pace Project No.:	50272776

Sample: Brunswick ISCO 2 **Lab ID: 50272776002** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260 MSV 5035A VOA	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	**541**	ug/kg	167	50		11/12/20 23:37	71-43-2	
p-Isopropyltoluene	**1670**	ug/kg	167	50		11/12/20 23:37	99-87-6	
Surrogates								
Dibromofluoromethane (S)	94	%.	73-133	50		11/12/20 23:37	1868-53-7	
Toluene-d8 (S)	94	%.	73-130	50		11/12/20 23:37	2037-26-5	
4-Bromofluorobenzene (S)	102	%.	55-129	50		11/12/20 23:37	460-00-4	
Percent Moisture	Analytical Method: SM 2540G Pace Analytical Services - Indianapolis							
Percent Moisture	**23.5**	%	0.10	1		11/12/20 11:53		N2

ANALYTICAL RESULTS

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Sample: Brunswick ISCO 3 **Lab ID: 50272776003** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260 MSV 5035A VOA	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	ND	ug/kg	170	50		11/13/20 00:02	71-43-2	
p-Isopropyltoluene	**2150**	ug/kg	170	50		11/13/20 00:02	99-87-6	
Surrogates								
Dibromofluoromethane (S)	95	%.	73-133	50		11/13/20 00:02	1868-53-7	
Toluene-d8 (S)	95	%.	73-130	50		11/13/20 00:02	2037-26-5	
4-Bromofluorobenzene (S)	98	%.	55-129	50		11/13/20 00:02	460-00-4	
Percent Moisture	Analytical Method: SM 2540G Pace Analytical Services - Indianapolis							
Percent Moisture	**24.6**	%	0.10	1		11/12/20 11:53		N2

ANALYTICAL RESULTS

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Sample: Brunswick ISCO 4 **Lab ID: 50272776004** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Solid

Results reported on a "dry weight" basis and are adjusted for percent moisture, sample size and any dilutions.

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260 MSV 5035A VOA	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	ND	ug/kg	165	50		11/13/20 09:25	71-43-2	
p-Isopropyltoluene	**1430**	ug/kg	165	50		11/13/20 09:25	99-87-6	
Surrogates								
Dibromofluoromethane (S)	92	%.	73-133	50		11/13/20 09:25	1868-53-7	
Toluene-d8 (S)	99	%.	73-130	50		11/13/20 09:25	2037-26-5	
4-Bromofluorobenzene (S)	97	%.	55-129	50		11/13/20 09:25	460-00-4	
Percent Moisture	Analytical Method: SM 2540G Pace Analytical Services - Indianapolis							
Percent Moisture	**25.4**	%	0.10	1		11/12/20 11:53		N2

ANALYTICAL RESULTS

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Sample: Brunswick ISCO 1 **Lab ID: 50272776005** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Water

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260/5030 MSV	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	**2940**	ug/L	125	25		11/12/20 02:47	71-43-2	
p-Isopropyltoluene	**388**	ug/L	125	25		11/12/20 02:47	99-87-6	
Surrogates								
Dibromofluoromethane (S)	100	%.	75-120	25		11/12/20 02:47	1868-53-7	D4
4-Bromofluorobenzene (S)	98	%.	85-116	25		11/12/20 02:47	460-00-4	
Toluene-d8 (S)	99	%.	83-111	25		11/12/20 02:47	2037-26-5	

ANALYTICAL RESULTS

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Sample: Brunswick ISCO 2 **Lab ID: 50272776006** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Water

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260/5030 MSV	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	**2770**	ug/L	125	25		11/12/20 03:19	71-43-2	
p-Isopropyltoluene	**378**	ug/L	125	25		11/12/20 03:19	99-87-6	
Surrogates								
Dibromofluoromethane (S)	98	%.	75-120	25		11/12/20 03:19	1868-53-7	D4
4-Bromofluorobenzene (S)	97	%.	85-116	25		11/12/20 03:19	460-00-4	
Toluene-d8 (S)	100	%.	83-111	25		11/12/20 03:19	2037-26-5	

ANALYTICAL RESULTS

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Sample: Brunswick ISCO 3 **Lab ID: 50272776007** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Water

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260/5030 MSV	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	**147**	ug/L	125	25		11/12/20 03:51	71-43-2	
p-Isopropyltoluene	**339**	ug/L	125	25		11/12/20 03:51	99-87-6	
Surrogates								
Dibromofluoromethane (S)	101	%.	75-120	25		11/12/20 03:51	1868-53-7	D4
4-Bromofluorobenzene (S)	100	%.	85-116	25		11/12/20 03:51	460-00-4	
Toluene-d8 (S)	99	%.	83-111	25		11/12/20 03:51	2037-26-5	

ANALYTICAL RESULTS

Project:	SIREMGON-BENISOTOU
Pace Project No.:	50272776

Sample: Brunswick ISCO 4 **Lab ID: 50272776008** Collected: 11/09/20 16:00 Received: 11/10/20 09:30 Matrix: Water

Parameters	Results	Units	Report Limit	DF	Prepared	Analyzed	CAS No.	Qual
8260/5030 MSV	Analytical Method: EPA 8260 Pace Analytical Services - Indianapolis							
Benzene	**118J**	ug/L	125	25		11/12/20 04:23	71-43-2	
p-Isopropyltoluene	**207**	ug/L	125	25		11/12/20 04:23	99-87-6	
Surrogates								
Dibromofluoromethane (S)	98	%.	75-120	25		11/12/20 04:23	1868-53-7	D4
4-Bromofluorobenzene (S)	98	%.	85-116	25		11/12/20 04:23	460-00-4	
Toluene-d8 (S)	100	%.	83-111	25		11/12/20 04:23	2037-26-5	

QUALITY CONTROL DATA

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

QC Batch: 592427
QC Batch Method: EPA 8260
Analysis Method: EPA 8260
Analysis Description: 8260 MSV
Laboratory: Pace Analytical Services - Indianapolis
Associated Lab Samples: 50272776005, 50272776006, 50272776007, 50272776008

METHOD BLANK: 2733330
Matrix: Water
Associated Lab Samples: 50272776005, 50272776006, 50272776007, 50272776008

Parameter	Units	Blank Result	Reporting Limit	Analyzed	Qualifiers
Benzene	ug/L	ND	5.0	11/12/20 00:38	
p-Isopropyltoluene	ug/L	ND	5.0	11/12/20 00:38	
4-Bromofluorobenzene (S)	%.	99	85-116	11/12/20 00:38	
Dibromofluoromethane (S)	%.	99	75-120	11/12/20 00:38	
Toluene-d8 (S)	%.	97	83-111	11/12/20 00:38	

LABORATORY CONTROL SAMPLE: 2733331

Parameter	Units	Spike Conc.	LCS Result	LCS % Rec	% Rec Limits	Qualifiers
Benzene	ug/L	50	51.4	103	75-118	
p-Isopropyltoluene	ug/L	50	52.8	106	82-119	
4-Bromofluorobenzene (S)	%.			98	85-116	
Dibromofluoromethane (S)	%.			96	75-120	
Toluene-d8 (S)	%.			101	83-111	

Results presented on this page are in the units indicated by the "Units" column except where an alternate unit is presented to the right of the result.

QUALITY CONTROL DATA

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

QC Batch: 592774
QC Batch Method: EPA 8260
Analysis Method: EPA 8260
Analysis Description: 8260 MSV 5035A Volatile Organics
Laboratory: Pace Analytical Services - Indianapolis
Associated Lab Samples: 50272776001, 50272776002, 50272776003

METHOD BLANK: 2735077 Matrix: Solid
Associated Lab Samples: 50272776001, 50272776002, 50272776003

Parameter	Units	Blank Result	Reporting Limit	Analyzed	Qualifiers
Benzene	ug/kg	ND	5.0	11/12/20 14:15	
p-Isopropyltoluene	ug/kg	ND	5.0	11/12/20 14:15	
4-Bromofluorobenzene (S)	%.	101	55-129	11/12/20 14:15	
Dibromofluoromethane (S)	%.	96	73-133	11/12/20 14:15	
Toluene-d8 (S)	%.	95	73-130	11/12/20 14:15	

LABORATORY CONTROL SAMPLE: 2735078

Parameter	Units	Spike Conc.	LCS Result	LCS % Rec	% Rec Limits	Qualifiers
Benzene	ug/kg	50	46.3	93	74-117	
p-Isopropyltoluene	ug/kg	50	43.2	86	60-118	
4-Bromofluorobenzene (S)	%.			108	55-129	
Dibromofluoromethane (S)	%.			106	73-133	
Toluene-d8 (S)	%.			95	73-130	

MATRIX SPIKE & MATRIX SPIKE DUPLICATE: 2735079 2735080

Parameter	Units	50272532011 Result	MS Spike Conc.	MSD Spike Conc.	MS Result	MSD Result	MS % Rec	MSD % Rec	% Rec Limits	RPD	Max RPD	Qual
Benzene	ug/kg	0.00099J mg/kg	59.4	59.1	63.2	58.5	105	97	23-146	8	20	
p-Isopropyltoluene	ug/kg	<0.00025 mg/kg	59.4	59.1	59.1	48.6	100	82	10-178	20	20	
4-Bromofluorobenzene (S)	%.						107	103	55-129			
Dibromofluoromethane (S)	%.						102	106	73-133			
Toluene-d8 (S)	%.						98	94	73-130			

Results presented on this page are in the units indicated by the "Units" column except where an alternate unit is presented to the right of the result.

QUALITY CONTROL DATA

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

QC Batch: 592783
QC Batch Method: EPA 8260
Analysis Method: EPA 8260
Analysis Description: 8260 MSV 5035A Volatile Organics
Laboratory: Pace Analytical Services - Indianapolis

Associated Lab Samples: 50272776004

METHOD BLANK: 2735115 Matrix: Solid

Associated Lab Samples: 50272776004

Parameter	Units	Blank Result	Reporting Limit	Analyzed	Qualifiers
Benzene	ug/kg	ND	5.0	11/13/20 08:36	
p-Isopropyltoluene	ug/kg	ND	5.0	11/13/20 08:36	
4-Bromofluorobenzene (S)	%.	103	55-129	11/13/20 08:36	
Dibromofluoromethane (S)	%.	107	73-133	11/13/20 08:36	
Toluene-d8 (S)	%.	92	73-130	11/13/20 08:36	

LABORATORY CONTROL SAMPLE: 2735116

Parameter	Units	Spike Conc.	LCS Result	LCS % Rec	% Rec Limits	Qualifiers
Benzene	ug/kg	50	44.5	89	74-117	
p-Isopropyltoluene	ug/kg	50	38.2	76	60-118	
4-Bromofluorobenzene (S)	%.			106	55-129	
Dibromofluoromethane (S)	%.			103	73-133	
Toluene-d8 (S)	%.			92	73-130	

Results presented on this page are in the units indicated by the "Units" column except where an alternate unit is presented to the right of the result.

QUALITY CONTROL DATA

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

QC Batch:	592652	Analysis Method:	SM 2540G
QC Batch Method:	SM 2540G	Analysis Description:	Dry Weight/Percent Moisture
		Laboratory:	Pace Analytical Services - Indianapolis

Associated Lab Samples: 50272776001, 50272776002, 50272776003, 50272776004

SAMPLE DUPLICATE: 2734314

Parameter	Units	50272776001 Result	Dup Result	RPD	Max RPD	Qualifiers
Percent Moisture	%	25.9	25.9	0	5	N2

SAMPLE DUPLICATE: 2734315

Parameter	Units	50272776004 Result	Dup Result	RPD	Max RPD	Qualifiers
Percent Moisture	%	25.4	27.4	8	5	N2,R1

Results presented on this page are in the units indicated by the "Units" column except where an alternate unit is presented to the right of the result.

QUALIFIERS

Project:	SIREMGON-BENISOTOU
Pace Project No.:	50272776

DEFINITIONS

DF - Dilution Factor, if reported, represents the factor applied to the reported data due to dilution of the sample aliquot.

ND - Not Detected at or above adjusted reporting limit.

TNTC - Too Numerous To Count

J - Estimated concentration above the adjusted method detection limit and below the adjusted reporting limit.

MDL - Adjusted Method Detection Limit.

PQL - Practical Quantitation Limit.

RL - Reporting Limit - The lowest concentration value that meets project requirements for quantitative data with known precision and bias for a specific analyte in a specific matrix.

S - Surrogate

1,2-Diphenylhydrazine decomposes to and cannot be separated from Azobenzene using Method 8270. The result for each analyte is a combined concentration.

Consistent with EPA guidelines, unrounded data are displayed and have been used to calculate % recovery and RPD values.

LCS(D) - Laboratory Control Sample (Duplicate)

MS(D) - Matrix Spike (Duplicate)

DUP - Sample Duplicate

RPD - Relative Percent Difference

NC - Not Calculable.

SG - Silica Gel - Clean-Up

U - Indicates the compound was analyzed for, but not detected.

N-Nitrosodiphenylamine decomposes and cannot be separated from Diphenylamine using Method 8270. The result reported for each analyte is a combined concentration.

Pace Analytical is TNI accredited. Contact your Pace PM for the current list of accredited analytes.

TNI - The NELAC Institute.

ANALYTE QUALIFIERS

D4	Sample was diluted due to the presence of high levels of target analytes.
N2	The lab does not hold NELAC/TNI accreditation for this parameter but other accreditations/certifications may apply. A complete list of accreditations/certifications is available upon request.
R1	RPD value was outside control limits.

QUALITY CONTROL DATA CROSS REFERENCE TABLE

Project: SIREMGON-BENISOTOU
Pace Project No.: 50272776

Lab ID	Sample ID	QC Batch Method	QC Batch	Analytical Method	Analytical Batch
50272776005	**Brunswick ISCO 1**	EPA 8260	592427		
50272776006	**Brunswick ISCO 2**	EPA 8260	592427		
50272776007	**Brunswick ISCO 3**	EPA 8260	592427		
50272776008	**Brunswick ISCO 4**	EPA 8260	592427		
50272776001	**Brunswick ISCO 1**	EPA 8260	592774		
50272776002	**Brunswick ISCO 2**	EPA 8260	592774		
50272776003	**Brunswick ISCO 3**	EPA 8260	592774		
50272776004	**Brunswick ISCO 4**	EPA 8260	592783		
50272776001	**Brunswick ISCO 1**	SM 2540G	592652		
50272776002	**Brunswick ISCO 2**	SM 2540G	592652		
50272776003	**Brunswick ISCO 3**	SM 2540G	592652		
50272776004	**Brunswick ISCO 4**	SM 2540G	592652		

SiREM - Ontario, Canada

130 Stone Rd W
Guelph Ontario N1G 3Z2, Canada

Billing Information:
Accounts Payable
130 Stone Rd W
Guelph Ontario N1G 3Z2, Canada

Pres Chk

Analysis / Container / Preservative

W0#:50272776
50272776

Chain of Custody Page 1 of 1

Pace Analytical®
National Center for Testing & Innovation

12065 Lebanon Rd
Mount Juliet, TN 37122
Phone: 615-758-5858
Phone: 800-767-5859
Fax: 615-758-5859

Report to: **Jen Webb**

Email To: jwebb@siremlab.com;mhealey@siremlab.com

Project Description:

City/State Collected:

Please Circle: PT MT CT ET

Phone: **519-822-2265**

Client Project #

Lab Project # **SIREMGON-BENISOTOU**

Collected by (print): Jen Webb

Site/Facility ID #

P.O. #

Collected by (signature): JWebb

Immediately Packed on Ice N____ Y X

Rush? (Lab MUST Be Notified)
___ Same Day ___ Five Day
___ Next Day ✓ 5 Day (Rad Only)
___ Two Day ___ 10 Day (Rad Only)
___ Three Day

Quote #

Date Results Needed

SDG #

Table #

Acctnum: **SIREMGON**
Template:**T177180**
Prelogin: **P807933**
PM: **844 - Christl M Wagner**
PB: 11-2-2020 Gem
Shipped Via: **FedEX Ground**

Sample ID	Comp/Grab	Matrix *	Depth	Date	Time	No. of Cntrs	TS 4ozClr-NoPres	V8260 40mlAmb-HCl	V8260 40mlAmb/MeOH10ml/Syr	Remarks	Sample # (lab only)
Brunswick ISCO 1	Grab	SS		9NOV20	4:00	2	X		X		001
Brunswick ISCO 2		SS				2	X		X		002
Brunswick ISCO 3		SS				2	X		X		003
Brunswick ISCO 4		SS				2	X		X		004
Brunswick ISCO 1		GW				3		X			005
Brunswick ISCO 2		GW				3		X			006
Brunswick ISCO 3		GW				3		X			007
Brunswick ISCO 4.	↓	GW		↓	↓	3		X			008

* Matrix:
SS - Soil **AIR** - Air **F** - Filter
GW - Groundwater **B** - Bioassay
WW - WasteWater
DW - Drinking Water
OT - Other________

Remarks:V8260 - Benzene and Isopropyl Toulene only.
benzene / isopropyltoluene between 0-5mg/L

pH ______ Temp ______
Flow ______ Other ______

Samples returned via:
__ UPS __ FedEx __ Courier __________

Tracking #

Sample Receipt Checklist
COC Seal Present/Intact: __NP ✓Y __N
COC Signed/Accurate: ✓Y __N
Bottles arrive intact: ✓Y __N
Correct bottles used: ✓Y __N
Sufficient volume sent: ✓Y __N
If Applicable
VOA Zero Headspace: ✓Y __N
Preservation Correct/Checked: ✓Y __N
RAD Screen <0.5 mR/hr: __Y __N

Relinquished by : (Signature) JWebb	Date: 9NOV20	Time: 4:00	Received by: (Signature) Fed Ex	Trip Blank Received: [✓ Yes] / No [✓ HCL] / MeOH TBR 6.9/5.8	
Relinquished by : (Signature) Fed Ex	Date:	Time:	Received by: (Signature) MP Pace 11/10/20 930	Temp: ↓ °C	Bottles Received:
Relinquished by : (Signature)	Date:	Time:	Received for lab by: (Signature)	Date:	Time:

If preservation required by Login: Date/Time

Hold:

Condition: NCF / OK

F-IN-Q-290-rev.19,23Jul2020

Pace Analytical

SAMPLE CONDITION UPON RECEIPT FORM

Date/Time and Initials of person examining contents: MRP 11/10/20 1450

Courier: [✓ Fed Ex] UPS Client Pace USPS Other ______

Custody Seal on Cooler/Box Present: [✓ Yes] No **(If yes)Seals Intact:** [✓ Yes] No **(leave blank if no seals were present)**

Packing Material: [✓ Bubble Wrap] [✓ Bubble Bags] None Other ______

Thermometer: 1 2 [✓ 3] 4 5 6 A B C D E F **Ice Type:** Wet [✓ Blue] None

Cooler Temperature: ______ **If temp. is over 6°C or under 0°C, was the PM notified?:** Yes No

Temp should be above freezing to 6°C **(Initial/Corrected)**

All discrepancies will be written out in the comments section below.

	Yes	No		Yes	No	N/A
Are samples from West Virginia? Document any containers out of temp.		✓	All containers needing acid/base pres. Have been CHECKED?: **exceptions: VOA, coliform, LLHg, O&G, and any container with a septum cap or preserved with HCl.** **Circle:** **HNO3 (<2) H2SO4 (<2) NaOH (>10) NaOH/ZnAc (>9)** Any non-conformance to pH recommendations will be noted on the container count form			✓
USDA Regulated Soils? (HI, ID, NY, WA, OR,CA, NM, TX, OK, AR, LA, TN, AL, MS, NC, SC, GA, FL, or Puerto Rico) Ontario, Canada	✓					
Short Hold Time Analysis (48 hours or less)? **Analysis:**		✓		Present	Absent	N/A
			Residual Chlorine Check (SVOC 625 Pest/PCB 608)			✓
Time 5035A TC placed in Freezer or Short Holds To Lab	Time:		Residual Chlorine Check (Total/Amenable/Free Cyanide)			✓
Rush TAT Requested (4 days or less):		✓	Headspace Wisconsin Sulfide?			✓
Custody Signatures Present?	✓		Headspace in VOA Vials (>6mm):		✓	
Containers Intact?:	✓		Trip Blank Present?	✓		
Sample Label (IDs/Dates/Times) Match COC?: Except TCs, which only require sample ID	✓		Trip Blank Custody Seals?:	✓		
Extra labels on Terracore Vials? (soils only)		✓				

COMMENTS: per J.Webb, do not analyze trip blank sample/ 111120kj

COC PAGE ____ of ____

Sample Container Count

SBS
DI
[✓ BK] - 1 MeOH vial
Kit

Sample Line Item	WGFU	R	DG9H [✓ VG9H]	VOA VIAL HS (>6mm)	VG9U	DG9U	DG9T	AG0U	AG1H	AG1U	AG3S	AG3C	BP1U	BP1N	BP2U	BP3U	BP3N	BP3F	BP3S	BP3B	BP3Z	CG3H	JGFU			Matrix	pH <2	pH >9	pH>10
1		1																					1			SL			
2		↓																					↓			↓			
3		↓																					↓			↓			
4		↓																					↓			↓			
5			3																							WT			
6			↓																							↓			
7			↓																							↓			
8			↓																							↓			
9			1																							↓			
10																													
11																													
12																													

Container Codes

Glass				Plastic / Misc.	
DG9B	40mL Na Bisulfate amber vial	AG0U	100mL unpres amber glass	BG3U	250mL Unpres Clear Glass
DG9H	40mL HCl amber voa vial	AG1H	1L HCl amber glass	BP1A	1L NaOH, Asc Acid plastic
DG9M	40mL MeOH clear vial	AG1S	1L H2SO4 amber glass	BP1N	1L HNO3 plastic
DG9P	40mL TSP amber vial	AG1T	1L Na Thiosulfate amber glass	BP1S	1L H2SO4 plastic
DG9S	40mL H2SO4 amber vial	AG1U	1liter unpres amber glass	BP1U	1L unpreserved plastic
DG9T	40mL Na Thio amber vial	AG2N	500mL HNO3 amber glass	BP1Z	1L NaOH, Zn, Ac
DG9U	40mL unpreserved **amber** vial	AG2S	500mL H2SO4 amber glass	BP2A	500mL NaOH, Asc Acid plastic
VG9H	40mL HCl clear vial	AG2U	500mL unpres amber glass	BP2N	500mL HNO3 plastic
VG9T	40mL Na Thio. clear vial	AG3S	250mL H2SO4 amber glass	BP2O	500mL NaOH plastic
VG9U	40mL unpreserved **clear** vial	AG3U	250mL unpres amber glass	BP2S	500mL H2SO4 plastic
VGFX	40mL w/hexane wipe vial	AG3C	250mL NaOH amber glass	BP2U	500mL unpreserved plastic
VSG	Headspace septa vial & HCl	BG1H	1L HCl clear glass	BP2Z	500mL NaOH, Zn Ac
WGKU	8oz unpreserved clear jar	BG1S	1L H2SO4 clear glass	BP3B	250mL NaOH plastic
WGFU	4oz clear soil jar	BG1T	1L Na Thiosulfate clear glass	BP3N	250mL HNO3 plastic
JGFU	4oz unpreserved amber wide	BG1U	1L unpreserved glass	BP3F	250mL HNO3 plastic (field filtered)
CG3H	250mL clear glass HCl	BG3H	250mL HCl Clear Glass		

BP3U	250mL unpreserved plastic
BP3S	250mL H2SO4 plastic
BP3Z	250mL NaOH, Zn Ac plastic

AF	Air Filter
C	Air Cassettes
R	Terra core kit
SP5T	120mL Coliform Na Thiosulfate
U	Summa Can
ZPLC	Ziploc Bag

WT	Water
SL	Solid
NAL	Non-aqueous liquid
WP	Wipe

APPENDIX C: Henry’s Law Calculation

The following Henry's Law calculation was used to convert aqueous concentrations to millimoles of each analyte (Table 2-2):

$$Total\ millimoles = \frac{C_{liq} \cdot \left(V_{liq} + H \cdot V_{gas}\right)}{Molecular\ Weight\ \left(\frac{g}{mol}\right)}$$

Where

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

The following calculation was used to convert geologic material concentrations to millimoles of each analyte (Table 2-2):

$$Total\ millimoles = \frac{C_{GM} \cdot (m_{GM})}{Molecular\ Weight\ \left(\frac{g}{mol}\right)}$$

Where

C_{GM} = geologic material concentration (mg/kg)
m_{GM} = geologic material mass per bottle

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

Analyte	Molecular Weight (g/mol)	Henry's Law Constant [a] (dimensionless)
Benzene	78.11	0.222
p-Cymene	134.21	0.336

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

APPENDIX B

ISCO Dosing Calculations

Geosyntec
consultants

COMPUTATION COVER SHEET

Client: **Hercules, LLC**

Project: **Hercules/Pinova Brunswick Facility Shallow Zone of Upper Surficial Aquifer - Stillhouse Control Room Area - Interim Corrective Measure Work Plan**

Project/ Proposal No.: **GR6881K**

Task No. **1001**

Title of Computations **Interim Corrective Measure Work Plan – Injection Design Computations**

Computations by:
Signature
Printed Name Benjamin Mejia-Tickner, E.I.T
Title Engineer
4/14/2021
Date

Assumptions and Procedures Checked by:
Signature Shanna Thompson
Printed Name Shanna Thompson, P.E.
Title Principal / Project Manager
4/14/2021
Date

Computations Checked by:
Signature
Printed Name Ali Ciblak, P.E.
Title Project Engineer
4/14/2021
Date

Computations Backchecked by: (Originator)
Signature
Printed Name Benjamin Mejia-Tickner, E.I.T
Title Engineer
4/14/2021
Date

Approved by: (PM or Designee)
Signature Shanna Thompson
Printed Name Shanna Thompson, P.E.
Title Principal / Project Manager
4/14/2021
Date

Approval notes:

Revisions (number and initial all revisions)

No.	Sheet	Date	By	Checked by	Approval

Treatment Zone Injection Design Computations
Hercules/Pinova Brunswick Facility
Stillhouse Control Room Area
Interim Corrective Measure Work Plan 2021

Constants and Conversions

- 1 kilogram (kg) = 1,000 grams (g)
- 1 kg = 2.20462 pounds (lbs)
- 1 cubic foot (ft^3) = 28.3168 Liter (L)
- 1 ft^3 = 7.48052 gal
- 1 cubic yard (yd^3) = 27 ft^3
- 1 gal = 3.78541 L
- 1 L = 1,000 milliliters (mL)
- 1 kg/L = 8.3454 lbs/gal
- Pressure derivative = 0.73 pounds per square inch (psi)/feet (ft) (Hubbert, 1972)

Laboratory Results for Oxidant Demand and Base Demand

- oxidant demand = 33.9 grams of persulfate ion [$S_2O_8^{2-}$]) per kilogram of soil (g/kg) to treat more than 95% of the benzene in the studied samples
- aqueous base demand = 1.35 grams of sodium hydroxide [NaOH] per liter of groundwater (g/L)
- matrix base demand = 6.33 g/kg of sodium hydroxide [NaOH] per kilogram of soil (g/kg)

Assumptions and Vendor Specifications

- Effective Porosity of Upper Surficial Aquifer = 0.25 (Geosyntec, 2021a)
- Assumed soil density = 105 lbs/ft^3
- Klozur® SP Densities (PeroxyChem, 2021a):
    - Klozur® SP 10% wt% = 1.067 g/mL
    - Klozur® SP 20% wt% = 1.146 g/mL
    - Klozur® SP 30% wt% = 1.237 g/mL
- Sodium Hydroxide (NaOH) Solution Densities at 20°C (Green, D. W., & Southard, M. Z., 2019):
    - 16% NaOH = 1.1751 kg/L
    - 25% NaOH = 1.27377 kg/L (extrapolating)

Description

Hercules is implementing multiple interim corrective measures (ICM) for groundwater in the upper surficial aquifer at the Hercules/Pinova Brunswick facility in Brunswick, Georgia (Site). Based on a combination of desktop, laboratory, and field evaluations, in situ chemical oxidation (ISCO) has been selected for groundwater in the shallow zone of the upper surficial aquifer underlying the southern production area near the Stillhouse Control Room. The goal is to reduce the mass of contaminants of potential concern (COPCs) within the target treatment area, primarily benzene, which may contribute COPCs to the plume of volatile organic compounds (VOCs) in the deep zone of the upper surficial aquifer.

The injection design involves two stages to deliver sodium persulfate and the activator to the target treatment zone. The injection design calculations for Stage 1 are presented in the document herein. The injection design for Stage 2 will be based on the results obtained from Stage 1. Stage 1 will be comprised of two steps, with Step 1 involving the use of five injection wells with 15-20 ft long screens and Step 2 involving the use of five injection wells with 5-15 ft long screens. Detailed calculations will be provided for Step 1 while end results will be provided for Step 2.

Activated Persulfate Dosing for Stage 1 – Step 1

A laboratory treatability study to evaluate the base demand and soil oxidant demand (SOD) for the treatment of COPCs in the Stillhouse Control Room Area was performed by SiREM Laboratory (SiREM) in 2021 (SiREM, 2021). In support of the treatability study, soil and groundwater samples were collected from the proposed treatment area for SiREM to conduct the bench scale test. Laboratory analysis of the applied persulfate solution indicated an average oxidant dose (i.e., persulfate ion [$S_2O_8^{2-}$]) of 33.9 grams per kilogram of soil (g/kg) to treat more than 95% of the benzene in the studied samples. Additionally, the analysis indicated a matrix base demand (i.e., sodium hydroxide [NaOH]) 6.33 g/kg.

The area to be targeted in Stage 1 of this ISCO ICM is approximately 675 square feet (ft^2) at a depth of 15 to 20 feet below ground surface (ft bgs) (i.e., target treatment zone [TTZ] equivalent to 5 ft) for Step 1 and 5 to 15 ft bgs (i.e., TTZ equivalent to 10 ft) for Step 2.

The volume and mass of soil in the treatment area for Step 1 is estimated as:

$$\text{Soil Volume} = \text{Area} \times \text{TTZ}$$
$$\text{Soil Volume} = 675\ \text{ft}^2 \times 5\text{ft} = 3{,}375\ \text{ft}^3\ \text{Soil} \rightarrow 125\ \text{yd}^3\ \text{Soil}$$

$$\text{Soil Mass} = \text{Soil Volume} \times \text{Soil Density}$$
$$\text{Soil Mass} = 3{,}375\ \text{ft}^3 \times 105\frac{\text{lbs}}{\text{ft}^3} = 354{,}375\ \text{lbs Soil} \rightarrow 160{,}742\ \text{kg Soil}$$

Assuming an effective porosity of 0.25, the volume of groundwater in the Stage 1 - Step 1 treatment area (i.e., pore volume) is:

$$\text{Pore Volume} = \text{Soil Volume} \times \text{Effective Porosity}$$
$$\text{Pore Volume} = 3{,}375\ \text{ft}^3 \times 0.25 = 844\ \text{ft}^3 \rightarrow 31\ \text{yd}^3 \rightarrow 6{,}312\ \text{gal}$$

Klozur® SP is a commercial product manufactured by PeroxyChem LLC. Klozur® SP consists of sodium persulfate ($Na_2S_2O_8$). The Klozur® SP demand required to dose persulfate ($S_2O_8^{2-}$) measured in the treatability study is shown below:
According to the chemical equation below, 1 mol of sodium persulfate dissociates into one mole of persulfate ion. As such:

$$\text{Na}_2\text{S}_2\text{O}_8 \rightarrow\ 2Na^+ + \text{S}_2\text{O}_8^{2-}$$

$$\text{Klozur}^{\circledR}\ \text{SP Dose} = \text{Persulfate Dose}\ \times \frac{\text{M.W. Sodium Persulfate}}{\text{M.W. Persulfate}}$$

$$\text{Klozur}^{\circledR}\ \text{SP Dose} = 33.9 \frac{\text{g}\ \text{S}_2\text{O}_8^{2-}}{\text{kg}} \times \frac{238.10 \frac{\text{g}}{\text{mol}}\ \text{Na}_2\text{S}_2\text{O}_8}{192.13\ \frac{\text{g}}{\text{mol}}\ \text{S}_2\text{O}_8^{2-}} = 42\ \frac{\text{g Klozur}^{\circledR}\ \text{SP}}{\text{kg}}$$

$$\text{Total Klozur}^{\circledR}\ \text{SP Demand} = \text{Soil Mass} \times\ \text{Klozur}^{\circledR}\ \text{SP Dose}$$

$$\text{Total Klozur}^{\circledR}\ \text{SP Demand} =\ 160{,}742\ \text{kg Soil} \times 42\ \frac{\text{g Klozur}^{\circledR}\ \text{SP}}{\text{kg}} \times \frac{1\ \text{kg}}{1{,}000\ \text{g}}$$
$$= 6{,}753\ \text{kg Klozur}^{\circledR}\ \text{SP} \rightarrow 14{,}888\ \text{lbs Klozur}^{\circledR}\ \text{SP}$$

To calculate the total amount of activator (i.e., NaOH) required to activate the Klozur® SP, the aqueous and matrix base demands have to be taken into account in addition to the acidity generated during persulfate degradation. To estimate the aqueous and matrix base demands we do the following:

$$\text{NaOH Aqueous Base Demand (ABD)} = \text{Aqueous Base Demand} \times\ \text{Pore Volume}$$
$$\text{NaOH ABD} = 1.35 \frac{\text{g}}{\text{L}} \times 6{,}312\ \text{gal} \times \frac{3.78541\ \text{L}}{1\ \text{gal}} \times \frac{1\ \text{kg}}{1{,}000\ \text{g}} = 32\ \text{kg NaOH}$$

$$\text{NaOH Matrix Base Demand (MBD)} = \text{Matrix Base Demand} \times\ \text{Soil Mass}$$
$$\text{NaOH MBD} = 6.33 \frac{\text{g}}{\text{kg}} \times 160{,}742\ \text{kg} =\ 1{,}017\ \text{kg NaOH}$$

To estimate the amount of activator required to neutralize the acidity generated during persulfate degradation we take into account the chemical reaction formula for persulfate oxidation presented below, where 2 moles of persulfate ion generate 4 moles of hydrogen ion. To neutralize 1 mol of hydrogen (H^+) ion, 1 mol of hydroxide ion (OH^-) is required (as shown below). As such:

$$2S_2O_8^{2-} + 2H2O \rightarrow 3SO_4^{2-} + SO_4^{\bullet -} + O_2^{\bullet -} + 4H^+$$

$$H^+ + OH^- \rightarrow H_2O$$

$$\text{Base Demand from Acidity Generation} = \text{Persulfate Dose} \times \frac{1}{\text{M.W. } S_2O_8^{2-}} \times \text{Ratio H}: S_2O_8^{2-} \times \text{M.W. NaOH}$$

$$\text{Base Demand from Acidity Generation} = 33.9\,\frac{\text{g } S_2O_8^{2-}}{\text{kg}} \times \frac{1\text{ mol}}{192.13\text{ g } S_2O_8^{2-}} \times \frac{4\text{ mol H}^+}{2\text{ mol } S_2O_8^{2-}} \times 39.997\,\frac{\text{g NaOH}}{\text{mol}} = 14.11\,\frac{\text{g}}{\text{kg}}$$

$$\text{NaOH Acidity Demand (AD)} = \text{Base Demand from Acidity Generation} \times \text{Soil Mass}$$

$$\text{NaOH AD} = 14.11\,\frac{\text{g}}{\text{kg}} \times 160{,}742\text{ kg} = 2{,}269\text{ kg NaOH}$$

To estimate the total base demand or total activator required, we do the following:

$$\text{Total NaOH Demand (Total Activator)} = \text{NaOH ABD} + \text{NaOH MBD} + \text{NaOH AD}$$

$$\text{Total NaOH Demand (Total Activator)} = 32\text{ kg} + 1{,}017\text{ kg} + 2{,}269\text{ kg} = 3{,}319\text{ kg NaOH} \rightarrow 7{,}316\text{ lbs NaOH}$$

Injection Volumes

Having estimated the total amount of Klozur® SP and NaOH required, the injection volumes can also be estimated. To allow for flexibility, three concentrations of Klozur® SP were considered while evaluating potential injection volumes (i.e., 10%, 20%, and 30% weight percent). As an example, the total injection volume for a 20% Klozur® SP solution is shown below:

$$\text{Klozur}^{\circledR}\text{ SP Injection Volume} = \text{Total Klozur}^{\circledR}\text{ SP} \times \frac{1}{\text{Solution Density}}$$

$$\text{Klozur}^{\circledR}\text{ SP Injection Volume} = 6{,}753\text{ kg Klozur}^{\circledR}\text{ SP} \times \frac{1{,}000\text{ g}}{1\text{ kg}} \times \frac{1\text{ mL}}{1.146\text{ g}} \times \frac{1\text{ gal}}{3{,}785.41\text{ mL}} = 1{,}557\text{ gal } 20\%\text{ Klozur}^{\circledR}\text{ SP}$$

Mass to be Delivered	Potential Injection Volumes for Different Klozur® SP Solution Densities (gallons)		
	10%	20%	30%
6,753 kg Klozur® SP	1,672	1,557	1,442

A concentration of 16% NaOH is within the range of NaOH concentrations recommended by the manufacturer for persulfate activation (PeroxyChem, 2021b). The volume of 16% NaOH is estimated in a similar manner as with respect to the 20% Klozur® SP solution. As such:

$$\text{Activator Injection Volume (16\% NaOH)} = \frac{\text{Total Activator}}{\text{Solution Density} \times 16\%\ \text{wt\%}}$$

$$\text{Activator Injection Volume (16\% NaOH)} = \frac{7{,}316\ \text{lbs NaOH}}{1.1751\,\frac{\text{kg}}{\text{L}} \times \frac{8.3454\,\frac{\text{lbs}}{\text{gal}}}{1\ \frac{\text{kg}}{\text{L}}} \times \frac{16\ \text{g NaOH}}{100\ \text{g Solution}}}$$

$$= 4{,}663\ \text{gal 16\% NaOH}$$

Given that 16% weight percent is not a commercially available concentration for a NaOH solution, the volume for a 25% NaOH solution will be estimated as well:

$$\text{Activator Volume (25\% NaOH)} = \frac{16\%\ \text{wt\%} \times \text{Volume (16\% NaOH)} \times \text{Density 16\% NaOH}}{25\%\ \text{wt\%} \times \text{Density 25\% NaOH}}$$

$$\text{Activator Volume (25\% NaOH)} = \frac{\frac{16\ \text{g}}{100\ \text{g}} \times 4{,}663\ \text{gal} \times 1.1751\,\frac{\text{kg}}{\text{L}} \times \frac{8.3454\,\frac{\text{lbs}}{\text{gal}}}{1\ \frac{\text{kg}}{\text{L}}}}{\frac{25\ \text{g}}{100\ \text{g}} \times 1.27377\,\frac{\text{kg}}{\text{L}} \times \frac{8.3454\,\frac{\text{lbs}}{\text{gal}}}{1\ \frac{\text{kg}}{\text{L}}}}$$

$$= 2{,}753\ \text{gal 25\% NaOH}$$

This solution will have to be diluted in the field in a 1:1.44 water to 25% NaOH solution ratio (i.e., 2,753 gal of 25% NaOH diluted in 1,910 gal of water) to achieve the injection volume of 4,663 gal corresponding to a 16% NaOH solution.

Gallons per Injection Well

Injection wells at the site will be screened at two different intervals: (i) 5-15 ft bgs; and (ii) 15-20 ft bgs; however, for Step 1, only the deepest wells within the targeted treatment area will be used for injection (i.e., 15-20 ft bgs).

In order to avoid mounding and daylighting and provide enough injection volume to enhance advection processes, a Klozur® SP solution of 20% was selected for a Klozur® SP injection volume of 1,557 gal. The total injection volume is estimated as:

$$\text{Total Injection Volume} = \text{Klozur}^{®}\ \text{SP Injection Volume} + \text{Activator Injection Volume}$$
$$\text{Total Injection Volume} = 1{,}557\ \text{gal} + 4{,}663\ \text{gal} = 6{,}219\ \text{gal}$$

In order to estimate the percent of pore volume displaced by injection fluid we do the following:

$$\text{Percent Pore Volume Displaced} = \frac{\text{Total Injection Volume}}{\text{Pore Volume}}$$
$$\text{Percent Pore Volume Displaced} = \frac{6{,}219\ \text{gal}}{6{,}312\ \text{gal}} \times 100 = 99\%$$

If the field implementation of this quantity leads to daylighting or flow rates with declining efficiency, the dosing can be delivered in sequential events that allow time for the subsurface pore space to return to pressure and water level equilibrium before receiving the next portion of the dose. The total injection volume per well is estimated as follows:

$$\text{Total Injection Volume per Well} = \frac{\text{Total Injection Volume}}{\#\ \text{Injection Wells}}$$
$$\text{Total Injection Volume per Well} = \frac{6{,}219\ \text{gal}}{5\ \text{Injection Wells}} = 1{,}244\ \text{gal/well}$$

As such, for each injection well, 311 gal of 20% Klozur® SP and 933 gal of 16% NaOH activator will be injected.

A summary table for Stage 1 – Step 1 is presented in Table 1.

.

Table 1. Summary Table for Activated Persulfate Dosing for Stage 1 – Step 1

Calculations	**Design Parameters**	
	Quantity	**Units**
General Calculations		
ISCO Injection Wells	5	
Screen Interval of Injection Wells	15-20	ft bgs
TTZ Thickness	5	ft
Treatment Area	675	ft^2
Soil Volume in Treatment Zone	3,375	ft^3
Mass of Soil in Treatment Zone	354,375	lbs Soil
Volume of Groundwater in Treatment Zone (Pore Volume)	844	ft^3
Total Base and Oxidant Requirements		
Total Oxidant Requirement (Total Klozur)	14,888	lbs Klozur
Total Base Requirement (Total Activator)	7,316	lbs NaOH
Injection Volumes		
Klozur Injection Volume (20% Klozur)	1,557	gal 20% wt% Klozur
Activator Injection Volume (16% NaOH)	4,663	gal 16% wt% NaOH
Activator Injection Volume (25% NaOH)	2,753	gal 25% wt% NaOH
Volume of Water for 25% NaOH Dilution	1,910	gal Water
Gallons per Injection Well		
Total Injection Volume (20% Klozur + 16% NaOH)	6,219	gal
Percent Pore Volume	99%	
Total Volume per Well (20% Klozur)	311	gal per well
Total Volume per Well (16% NaOH)	933	gal per well
Total Volume per Well (20% Klozur + 16% NaOH)	1,244	gal per well

Activated Persulfate Dosing for Stage 1 – Step 2

As previously mentioned, detailed injection calculations for Step 2 are not provided herein. A summary of the calculations for Stage 1 – Step 2 are provided in Table 2.

Table 2. Summary Table for Activated Persulfate Dosing for Stage 1 – Step 2

Calculations	Design Parameters	
	Quantity	Units
General Calculations		
ISCO Injection Wells	5	
Screen Interval of Injection Wells	5-15	ft bgs
TTZ Thickness	10	ft
Treatment Area	675	ft^2
Soil Volume in Treatment Zone	6,750	ft^3
Mass of Soil in Treatment Zone	708,750	lbs Soil
Volume of Groundwater in Treatment Zone (Pore Volume)	1,688	ft^3
Total Base and Oxidant Demands		
Total Oxidant Demand (Total Klozur)	29,775	lbs Klozur
Total Base Demand (Total Activator)	14,632	lbs NaOH
Injection Volumes		
Klozur Injection Volume (20% Klozur)	3,113	gal 20% wt% Klozur
Activator Injection Volume (16% NaOH)	9,325	gal 16% wt% NaOH
Activator Injection Volume (25% NaOH)	5,506	gal 25% wt% NaOH
Volume of Water for 25% NaOH Dilution	3,819	gal Water
Gallons per Injection Well		
Total Injection Volume (20% Klozur + 16% NaOH)	12,439	gal
Percent Pore Volume	99%	
Total Volume per Well (20% Klozur)	623	gal per well
Total Volume per Well (16% NaOH)	1,865	gal per well
Total Volume per Well (20% Klozur + 16% NaOH)	2,488	gal per well

Theoretical Injection Pressure

In order to avoid hydraulic fracturing, injection pressures shall be kept below the maximum theoretical injection pressure for the given injection well. The maximum theoretical injection pressure is a function of the depth to the wells top of screen (TOS) and is estimated as follows:

$$\text{Max Pressure} = \text{Depth to TOS} \times 0.73\,\frac{\text{psi}}{\text{ft}}$$

Based on the in-situ injection pilot test performed in the area (Geosyntec, 2021b), which used well screens starting at 2 ft bgs, liquid injection of amendments performed at pressures above 1 psi resulting in daylighting. This field observation is consistent with expectations based on the maximum theoretical injection pressure:

$$\text{Max Pressure}_{2-12\text{ ft bgs}} = 2\text{ ft} \times 0.73\frac{\text{psi}}{\text{ft}} = 1.46\text{ psi}$$

As mentioned previously, injection wells for this ICM have been adjusted to deeper depths to mitigate potential for contact with subsurface utilities, and they will be screened at two different intervals: (i) 5-15 ft bgs; and (ii) 15-20 ft bgs. The maximum theoretical injection pressure for each of the wells is estimated as:

$$\text{Max Pressure}_{5-15\text{ ft bgs}} = 5\text{ ft} \times 0.73\frac{\text{psi}}{\text{ft}} = 3.65\text{ psi}$$
$$\text{Max Pressure}_{15-20\text{ ft bgs}} = 15\text{ft} \times 0.73\frac{\text{psi}}{\text{ft}} = 10.95\text{ psi}$$

Assuming a 25% safety factor:

$$\text{Max Pressure}_{5-15\text{ ft bgs}} = 3.65\text{ psi} \times (1 - 0.25) = 2.74\text{ psi}$$
$$\text{Max Pressure}_{15-20\text{ ft bgs}} = 10.95\text{ psi} \times (1 - 0.25) = 8.21\text{ psi}$$

References

Geosyntec Consultants, 2021a. *Corrective Action Plan*. Hercules/Pinova Brunswick Facility, Brunswick, Georgia. February 2021.

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