Pilot Test Workplan
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, Washington 98168
Ecology Facility/Site No.: 2551
Agreed Order No.: DE-10947

Prepared on behalf of:

Mr. Rajbir Sandhu
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, WA 98168

Mr. Nathan Blomgren
Chevron Environmental Management and Real Estate Company
6001 Bollinger Canyon Road
San Ramon, CA 94583

Prepared by:

G-Logics, Inc.
40 2nd Avenue SE
Issaquah, WA 98027

Telephone: (425) 391-6874
Facsimile: (425) 313-3074

June 21, 2022

G-Logics Project 01-0410-Q

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g-logics
AN ATLAS GEOSCIENCES NW COMPANY

June 21, 2022
G-Logics File Number 01-0410-Q

Mr. Dale Myers
Washington State Department of Ecology, NWRO
15700 Dayton Avenue North
Shoreline, Washington 98133

Subject: **Final Pilot Test Workplan**
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, Washington

Dear Mr. Myers:

With this document, G-Logics has prepared a Pilot Test Workplan (workplan) for evaluation of a combination of PetroCleanze®, an *in situ* chemical oxidation product, and total liquids extraction technologies to be used at the above-referenced property.

This workplan is, in part, developed based on comments received from the Washington State Department of Ecology (Ecology) from their review of the previous versions of this document. Based on an electronic mail message from you dated June 13, 2022, accepting the workplan without further comment.

We appreciate this opportunity to provide our services to Boeing Field Chevron. Please feel free to contact us with any questions.

Sincerely,

G-Logics

Rory Galloway

Rory L. Galloway, LG, LHG
Principal

Hydrogeologist
2222
RORY GALLOWAY

Mike Arnold, LG, LHG
Director of Technical Services

G-Logics
40 2nd Avenue SE, Issaquah, WA 98027
T: 425-391-6874, F: 425-313-3074

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1.0 INTRODUCTION AND OBJECTIVES

G-Logics has prepared this workplan to describe the methodology and procedures to conduct a pilot test at the Boeing Field Chevron property (Property) located at 10805 East Marginal Way South, in Tukwila, Washington 98168 (Figure 1). This pilot test includes the active technologies that were described as the preferred remedy in the draft Feasibility Study (FS) prepared by G-Logics in 2021, specifically the combined remedy of *in-situ* chemical oxidation (ISCO) and total liquids extraction. The goal of this pilot test will be to evaluate the reduction of light nonaqueous-phase liquid (LNAPL) and the reduction of dissolved and soil-sorbed gasoline contaminant mass in the Upper Saturated Zone.

For the purposes of this document, the “Site” refers to the areas of soil, groundwater, and/or soil gas that have been impacted with petroleum contaminants originating from the fuel storage and dispensing operations on the Property. Contaminants of concern (COCs) have been identified as the LNAPL, gasoline range organics (GRO), and benzene.

1.1 Pilot Test Approach

The active applications of ISCO reagent during this pilot test will be performed within the Upper Saturated Zone. This focus is expected to allow evaluation of the remedy effects with limited potential for interference from conditions in other portions of the contaminated area, such as from the Lower Saturated Zone. Direct pilot testing within the Lower Saturated Zone is not included as part of this pilot test in part because of the potential for inconclusive results related to interference by effects from groundwater flow from the Upper Saturated Zone and the larger expected mass of contaminants present in the Lower Saturated Zone. However, monitoring will be completed during the pilot test to evaluate the remedy effects in the Lower Saturated Zone. The evaluation will be completed using changes in LNAPL accumulation and geochemical conditions in the Lower Saturated Zone resulting from the pilot-testing efforts.

The ISCO reagent product PetroCleanze™ is a combination of RegenOx™ Part A and PetroCleanze activator. In addition to oxidizing contaminants, the reaction of these chemicals with petroleum contaminants generates surfactant-like properties, increasing the desorption of petroleum hydrocarbons present in saturated soils. Dissolved oxygen is also another byproduct of the PetroCleanze reaction, potentially increasing biodegradation of petroleum contaminants. The ISCO effects of the PetroCleanze reagent will act to chemically oxidize and destroy the additional petroleum-hydrocarbon mass made available by the PetroCleanze reaction. Additionally, mobilized LNAPL can be physically removed by total-liquids extraction, which periodically will be removed from select wells by vacuum extraction. The PetroCleanze reaction in the subsurface produces minimal heat and gas generation, is noncorrosive, and is suitable for use in areas with underground utilities and infrastructure.

Note that the preferred remedy in the Draft FS report indicates the use of surfactants. Use of a separate surfactant has been eliminated from this pilot test because of the expected surfactant-like properties that the PetroCleanze process is expected to produce.

Applicability of the preferred remedy at similar sites has been confirmed as part of the selection process. Information in scientific studies authored by Ciampi et al. (2021) and Daniels (2008) are included in Appendix A. These studies were used to support decisions regarding the application of the selected remedy in this pilot test.

1.2 Applicability to Feasibility Study and Cleanup Action Plan

Based on the results of G-Logics Remedial Investigation (RI) dated October 7, 2020, G-Logics has prepared a draft Feasibility Study (FS) report dated March 4, 2021. The draft FS report includes an evaluation of remedial alternatives to address contaminated media at the Site and was developed in accordance with Washington Administrative Code (WAC) 173-340-350(8). A combined-technology remedy including use of surfactant, ISCO, total liquids extraction, and monitored natural attenuation (MNA) was identified in the FS as the preferred cleanup action alternative for this Site to address the LNAPL, dissolved-phase, and sorbed-phase petroleum hydrocarbons at the Site. After completion of the pilot test, G-Logics will submit an updated FS report that will incorporate the pilot-test findings.

Should this remedy appear to be viable based on the results of the pilot test, additional information will be developed in a Cleanup Action Plan in order to scale the technology for use within both the Upper and Lower Saturated Zones. As a combined technology remedy addressing multiphase contamination, pilot-test data will be required to develop a reasonable predictive model for technology scaling.

1.3 Pilot Testing Performance and Data Collection Goals

Pilot testing of the recommended technologies has been identified to be an appropriate next step based on the Washington State Department of Ecology (Ecology) review of the draft FS and subsequent discussions. The purpose of the pilot test is to reduce the uncertainties associated with application of a remedy treatment to achieve Remedial Action Objectives (RAOs) by evaluating whether application of the selected remedy at full scale can meet the RAOs for the site. The selected remedy is designed to be applied to address site remedial objectives in the following stages.

- LNAPL recovery and removal from the Site by total liquids extraction. This will be facilitated by LNAPL desorption and mobilization enhanced by the surfactant-like effects of the PetroCleanze reagent.
- Reduction of dissolved- and sorbed-phase petroleum hydrocarbons by direct reaction with ISCO reagent.
- Further reduction of dissolved- and sorbed-phase hydrocarbons by MNA.

G-Logics will evaluate the effectiveness of the remedy toward meeting the goals for each of the remediation stages. Specifically, G-Logics will directly measure and observe the following.

- Accumulation and subsequent recovery of LNAPL from the Upper Saturated Zone.
- Reduction of dissolved-phase petroleum contaminants in groundwater in the Upper and Lower Saturated Zones.
- Radius of hydraulic and effective oxidation effects around the injection points and within the Lower Saturated Zone.
- Relevant groundwater conditions, including dissolved oxygen and reduction/oxidation potential, which will support evaluation of ISCO reagent distribution and remedy effectiveness.

2.0 PILOT TEST OVERVIEW

The objective of the pilot test is to evaluate if PetroCleanze and total liquids extraction can be effective in accelerating the reduction of LNAPL mass and reduce dissolved-phase petroleum concentrations.

This pilot test is based on the results of G-Logics RI and draft FS reports (G-Logics 2020 and G-Logics 2021, respectively). Based on the findings of environmental explorations conducted at the Site, remedial options were reviewed, including their abilities to protect human health and the environment, comply with cleanup standards, provide for compliance monitoring, use permanent solutions to the maximum extent practicable, provide for a reasonable restoration timeframe, and consider public concerns. In the draft FS report, ISCO combined with surfactant application, total liquids extraction, and MNA was identified as the preferred remedy to address site contaminants, notably the identified areas of LNAPL and the areas of highest dissolved-phase and sorbed petroleum hydrocarbon concentrations. For this pilot test, the reagent product selected will provide surfactant-like properties as a result of reactions with the target contaminants.

Several ISCO oxidant/surfactant options were reviewed for possible use. As part of this review, site information was shared with a remediation engineer working with G-Logics. This information also was shared with Regenesis, a company that specializes in contaminated soil and groundwater remediation. Based on the collaborative review of site conditions and contaminant concentrations, PetroCleanze was selected for this pilot test because of the demonstrated effectiveness of the reagent at reducing petroleum mass in soil and groundwater, the surfactant-like effect as the reagent reacts with the target contaminants, and the additive biodegradation capacity from dissolved oxygen created from the reactions. Although enhancing biodegradation was not a specific element of the preferred remedy in the draft FS, G-Logics considers it to be a compatible and beneficial additional feature of the PetroCleanze product. PetroCleanze was favored over other ISCO alternatives because the other products had lower or similar contaminant reduction capacity as the PetroCleanze reagent, would have required mixing and injection of a separate surfactant, and/or did not produce dissolved oxygen as a result of the reactions in the subsurface.

From the Regenesis website, PetroCleanze is described as a formulation of their RegenOx® ISCO technology, which is used to initiate the chemical oxidation of In-situ contaminants, and a PetroCleanze activator. When applied with the activator, this two-part reagent generates surfactant-like properties, significantly increasing the desorption of petroleum hydrocarbons bound in saturated soils, in order to make them more readily available for removal using physical recovery techniques and are more available for chemical oxidation and biodegradation.

PetroCleanze reaction byproducts and residual chemicals are non-toxic or low-toxicity materials common for a wide range of commercially-available ISCO remedies and include carbonate, silica, carbon dioxide, oxygen, water, phosphate, iron, alcohols, carboxylic acid, and sodium chloride. While most of the gases generated by the PetroCleanze reactions remain in solution in groundwater, small amounts of gas generation have been reported as part of PetroCleanze injection programs. Regenesis, the supplier of PetroCleanze, reports that the volumes of gas typically generated create effects that are limited to the immediate injection area during and immediately after injection and are not significant drivers of changes in vapor intrusion conditions outside the immediate injection area. In the case of the subject site, no vapor intrusion issues are anticipated related to the ISCO reactions.

The surfactant-like effects of the PetroCleanze reagent are very localized within the injection areas and the released petroleum hydrocarbons are then directly exposed to further reaction with the reagent and the dissolved oxygen generated as the reactions proceed. The surfactant-like effects are only engaged as part of the reagent reactions, are not temporally persistent, and do not propagate outside of the area of reagent chemical effect. The enhanced chemical oxidation and bioactivity afforded by the reagent are typically effective in minimizing expansion of dissolved-phase contaminant plumes. It is expected that the total-liquids extraction will be effective in containing and removing residual LNAPL mobilized by the PetroCleanze reactions. PetroCleanze products also are not expected to affect the quality of laboratory analytical results for petroleum hydrocarbon analyses.

The total liquids extraction events will be completed to remove accumulated LNAPL from well IP-4. It is expected that the surfactant-like effect of the ISCO reactions will enhance recovery of LNAPL entrained in soil pore spaces and render it more available for physical removal. Although LNAPL is expected to be observed only in well IP-4, total liquids extraction also will be completed at other site wells where LNAPL is identified during the pilot test.

Fluid-level and water-quality observations and measurement will be completed periodically during the pilot test, and groundwater samples will be collected from wells AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5 (Figure 2). Details of the groundwater monitoring program are included in Sections 3.3 and 4.3. A summary of key information needs for this pilot test, and the data collection planned to address these needs, is summarized in Table 1.

3.0 BASELINE CONDITIONS EVALUATION

Prior to performance of the pilot test, two additional monitoring wells will be installed at the site and groundwater quality will be monitored at select wells (see Section 3.2) in the Upper and Lower Saturated Zones. A groundwater monitoring summary for the pilot test, including the baseline monitoring program, is presented in Table 2.

3.1 Monitoring Well Installation and Development

Monitoring wells TW-4 and TW-5 will be installed at the locations shown on Figure 2 and Figure 3 prior to the initiation of the injection/extraction program at the site. The two-inch-diameter wells will be installed to allow evaluation of conditions in the Upper Saturated Zone during the pilot test. Well TW-4 will be installed to a depth of approximately 15 feet with a 10-foot length of slotted screen. TW-5 will be installed to a depth of approximately 12 feet with a 5-foot length of slotted screen. The new wells are designed to allow monitoring of the Upper Saturated Zone without penetrating the underlying aquitard. Planned well construction locations and depths are shown on the cross section in Figure 4.

Prior to drilling, a vacuum truck and air knife will be used to bore to 5 feet deep for subsurface utility clearance confirmation at each planned well location. The wells will be installed using a truck-mounted hollow-stem auger drilling rig. Soil conditions will be observed during drilling by recovering two 24-inch soil samples for each 5 feet of drilling depth. One soil sample from each boring will be collected within the Upper Saturated Zone will be analyzed for total organic carbon (TOC) by USEPA Method 9060 or equivalent. The TOC analyses will be performed to support an evaluation of the natural oxidant demand for the Upper Saturated Zone. It is expected that this information will be helpful in calculating the final mass balance requirements for full-scale ISCO injection. Note that natural oxidant demand in the Lower Saturated Zone will be approximated from results of TOC analysis of groundwater samples, as described in Section 3.2, since no soil sample collection from this zone is planned as part of this pilot test. Note that puncturing the aquitard between the Upper and Lower Saturated Zones increases the potential for enhancing contaminant migration. For this reason, direct collection of soil samples for TOC analysis is not planned, as drilling into the Lower Saturated Zone is not needed to address other scope requirements for this pilot test.

After installation, the wells will be developed by removing approximately 10 casing volumes of water or, if a well purges dry, by removing the accumulated water and allowing the well to recharge three times. The locations and elevations of new wells also will be measured based on the existing site datum.

3.2 Baseline Groundwater Conditions

Baseline groundwater sampling will be completed to document site conditions prior to the implementation of the pilot test. The sampling will be completed after installation and development of wells TW-4 and TW-5 and prior to the first injection event.

Upper Saturated Zone wells AS-1, IP-4, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5 and Lower Saturated Zone wells IP-3, IP-5, and IP-7 will be included in the pilot test monitoring program and are considered the pilot-test target wells. During the baseline sampling, fluid levels will be measured in each well, including evaluation of wells IP-4 and IP-7 for LNAPL using an oil/water interface probe. LNAPL presence in wells where LNAPL is measured may be confirmed using a bailer. Water levels will be measured in the remainder of the monitoring wells using an electronic water-level meter.

Groundwater samples will be collected from each of the listed wells using a peristaltic pump, with the intake located near the midpoint of the screened section of each well or, if the water level in the well is lower than the midpoint, approximately 1 foot below the groundwater surface. During purging, groundwater dissolved oxygen, reduction/oxidation potential, temperature, pH, and specific conductivity will be periodically measured using a sealed in-line flow cell. Purging will be completed at a maximum rate of 1 liter per minute and will continue until at least three liters of water have been removed from the well and the last two sets of groundwater quality readings each are within 10% as compared to the previous reading, whichever occurs last. Upon confirmation of these conditions, groundwater samples will be collected from the well and submitted to a Washington State-certified analytical laboratory for the following analyses:

- Gasoline-range petroleum hydrocarbons (GRO) by Ecology Method NWTPH-Gx with benzene, toluene, ethylbenzene, and xylenes (BTEX) by U.S. Environmental Protection Agency (USEPA) Method 8260C.
- Diesel-range petroleum hydrocarbons (DRO) by Ecology Method NWTPH-Dx (without silica gel cleanup).
- TOC by USEPA Method 9060A or equivalent (Lower Saturated Zone samples only).

In addition to the groundwater samples indicated above, one duplicate groundwater sample will be collected for each parameter during the baseline sampling program. The duplicate sample will be collected form a well that is likely to contain petroleum hydrocarbons, based on previous laboratory analytical results and on field observations during sample collection. Additional information regarding the quality assurance/quality control program for laboratory analytical samples collected during the pilot test is included in Section 5.5.

4.0 PILOT TEST IMPLEMENTATION AND MONITORING

Figures 2 and 3 depict the current estimated extent(s) of COCs in soil and groundwater within the upper saturated zone at the Site. These figures also indicate the area of possible LNAPL in the Upper Saturated Zone and the monitoring wells in the vicinity that will be used for data collection during the pilot test. For the pilot test, IP-4 is the primary monitoring well that will be used to evaluate LNAPL conditions in the Upper Saturated Zone. That well and wells AS-1, SVE-1, two monitoring planned for installation prior to the start of the pilot test (TW-4 and TW-5), and, if viable, wells TW-1, TW-2, and TW-3 will be used to evaluate dissolved contaminant concentrations and other groundwater conditions in the Upper Saturated Zone. Wells IP-3, IP-5, and IP-7 will be used to evaluate LNAPL presence, dissolved contaminant concentrations, and other groundwater conditions in the Lower Saturated Zone.

The pilot test will consist of three separate reagent-injection events. These injections then will be followed by three total-liquids extraction events approximately two to four weeks after each injection. The approximate schedule of the injection and extraction events are planned as follows:

- Injection #1: Week 1
- Total Liquids Extraction #1: Week 3

- Injection #2: Week 5
- Total Liquids Extraction #2: Week 8
- Injection #3: Week 10
- Total Liquids Extraction #3: Week 13

Note that the intervals between the injection events and the extraction events may be extended up to approximately 2 weeks based on conditions observed after the first injection. The total duration of the injection/extraction phase of the pilot test may vary from about 13 to 20 weeks.

Table 3-2 of the RI report indicates that LNAPL only has been detected in approximately 3 of the 21 monitoring events performed at IP-4 between May 2006 and July 2017. Based on these measurements, the amount of mobile LNAPL at well IP-4 has significantly decreased over time, but dissolved phase petroleum concentrations in groundwater suggest that residual LNAPL still remains in the vicinity of well IP-4, likely entrained in soils near the well. The expectation is that the pilot test will document a significant reduction of dissolved-phase petroleum in Upper Saturated Zone groundwater, indicating LNAPL mass reduction in that zone.

A description of the planned pilot test monitoring program for baseline conditions, injection performance, and groundwater conditions and quality monitoring are included in the sections below. The pilot test has been designed to provide data for evaluation of the following.

- Effectiveness of PetroCleanze and total liquids extraction at reducing LNAPL and dissolved-phase petroleum mass in groundwater.
- Measurement of the zone of effective influence of the ISCO reagent injection.
- Calculation of ISCO reagent mass required to remediate the dissolved and residual soil-sorbed petroleum compounds once LNAPL is removed.
- Effectiveness of the approach to address contaminant conditions in the Lower Saturated Zone.
- Identification of appropriate geochemical parameters that may be useful as indicators to evaluate remedial progress between groundwater monitoring events.

Monitoring of relevant groundwater conditions will be completed during each injection and extraction event during each of the three injection and extraction phases as summarized in Table 2.

4.1 Reagent Injections

The pilot-test program will include the introduction of PetroCleanze reagent into the Upper Saturated Zone during three separate injection events. The injections will target areas of known or suspected LNAPL and elevated groundwater concentrations for GRO and benzene that are present in the Upper Zone, as illustrated on Figure 2. Figure 3 presents a focused plan view of the pilot-test area and includes preliminary locations for each of the injection points planned for the pilot test. Figure 4 shows a cross-section across the same area.

The first injection event will be completed after the baseline groundwater monitoring is complete and the associated analytical data are available to confirm conditions in the planned injection area. Subsequent events will be completed based on the schedule summary included in Section 4.0 above.

The PetroCleanze reagent planned for use during the pilot test is a two-part mixture consisting of RegenOx Oxidant Part A combined with PetroCleanze Part B activator. Injection of 360 gallons of PetroCleanze reagent is planned at each injection point during each injection round (9 total points, 360 gallons injected at each point). This volume will consist of 302 pounds of RegenOx and PetroCleanze activator mixed in a 1:1 ratio and dissolved in approximately 350 gallons of water. This mixing will be completed in a portable tank on the site. A total of approximately 2,720 pounds of PetroCleanze reagent will be injected into the Upper Saturated Zone during the pilot test.

The ISCO reagent vendor (Regenesis) will supply PetroCleanze in powder form. Product information including safety data sheets and the vendor's mixing guidelines are included in Appendix B.

Preliminary injection locations for each injection round are shown in Figure 3, and a cross section of a typical injection point is shown in Figure 4. Injection points will be installed using a direct-push drill rig. Prior to drilling, a vacuum truck and air knife will be used to bore to 5 feet deep for subsurface utility clearance confirmation. A direct-push drilling rig will then be used to push hollow stainless steel drill rods with a retractable 4-foot slotted screen to the target depth of the injection borings, 13 feet. The rods will then be pulled pack 3 feet to expose 3 feet of slotted screen. The annular space around the upper 5 feet of rod (the void from utility check excavation) will be filled with lean bentonite cement grout as additional seal to prevent injectate from traveling up the drilling rod to the surface. After completion of each injection, the drilling tools will be extracted from the borehole and the surface at the boring will be restored.

To maintain an effective seal between the soil and boring rod, the drive point will be driven directly to the target depth without collection of soil samples. Consequently, no soils for logging, field screening, or sample collection will be available from the injection borings.

At each temporary injection point, 360 gallons of PetroCleanze solution will be injected, using as low of a pressure as necessary to deliver the product to the subsurface (estimated maximum injection pressure of 20 pounds per square inch). This volume was selected as it is the estimated available pore space volume within the expected radius of hydraulic influence of 15 feet from each injection point. Injection pressure will be monitored for indications of short-circuiting or rapid decreases that may indicate subsurface fracturing or other injectate breakthrough. Injection systems will include instrumentation for the monitoring of total flow and pressure. Injection pressures will be recorded at least every 10 minutes during active liquid injection.

4.1.1 Monitoring and Contingency Response: Injections

Monitoring will be conducted to assess the site conditions during each injection event and will include the following.

- Water levels in the pilot test target monitoring wells prior to commencing injection.
- The mass of ISCO reagent and volume of ISCO reagent solution injected at each boring.
- Injection fluid pressure during the injection process.
- Start and end time of each injection.
- Water levels at target monitoring wells at completion of injections.

For the pilot test target wells, water levels will be recorded periodically during the injections and immediately after injections are completed to evaluate the extent of hydraulic effect of the injections.

The injection rate and fluid pressures will be used to identify appropriate and reasonable injection rates for future injections, and to identify conditions that would suggest formation fracturing or other injectate hydraulic breakthrough. Breakthrough would be indicated by either a significant pressure loss and/or increased injection rate. In the event of evidence of breakthrough, injection pressures will initially be reduced. If evidence of breakthrough persists, injection in that boring will be terminated and the boring re-drilled approximately three feet away from the original location. The remaining volume of reagent will be injected into the secondary boring at a lowered injection pressure. If evidence of breakthrough conditions persists, the remaining reagent volume will be injected into one of the other injection points.

In the event that the full 360 gallons of ISCO reagent solution cannot be injected at a specific point, then the excess volume from that point will be redistributed for injection into the remaining injection points. If injection volume refusal is a persistent issue at each boring at the Site, then the injection program will be postponed pending an evaluation of injection techniques and subsurface conditions with the objective of identifying an injection method that will allow appropriate delivery of the reagent.

4.2 Total Liquids Extraction

Three total-liquids extraction events will be completed during the pilot test. As part of each extraction event, water and LNAPL accumulated in well IP-4 and in other wells in which LNAPL is observed will be removed using a truck-mounted vacuum or pump unit. Water and LNAPL levels will be evaluated at each well in the pilot test monitoring program prior to initiation of total liquids extraction during each of the three planned events. If LNAPL is observed accumulated in other wells at the site, then additional total liquids extraction will be performed at those wells.

The first total liquids extraction event will be completed approximately 2 weeks following the initial ISCO injection event. The two remaining events will be completed between 2 and 4 weeks after subsequent ISCO injection events, based on observations and measurements collected during the groundwater monitoring efforts prior to and during the first extraction event. Total liquids extraction guidance is included in Appendix B. Total liquids extraction will be conducted slowly using a vacuum or pump truck. Total liquids will be removed from well IP-4 for a period of approximately 2 hours, or until 450 gallons of liquid are removed from the well, whichever occurs first. Liquid extraction may be continued beyond the planned volume if significant LNAPL accumulation is measured on the water in the well immediately after the initial extraction period or if recovered liquid volume expectations are met.

For wells other than well IP-4 in which LNAPL is observed during each total liquids extraction event, total liquids will be removed using a vacuum or pump truck using a similar procedure as described for well IP-4 above. Note that total liquid volumes removed from these wells will be limited to the volume needed to complete removal of the accumulated LNAPL. No minimum volumetric removal target is established for these additional wells.

Volumes of water and LNAPL will be measured or estimated to the extent practicable regarding the extraction technology used to purge the wells. A totalizing flowmeter will be used if a pump system is used. The pump or vacuum contractor will also be tasked with recording volumes of water and LNAPL transported from the site for disposal. Extracted fluids will be transported from the site by the extraction contractor and will be disposed as mixed water and petroleum.

4.2.1 Monitoring and Contingency Response: Extraction

Prior to the commencement of each phase of total liquids extraction and immediately after completion of each extraction phase, water and LNAPL levels will be measured in the pilot-test target wells. Total volumes of liquids removed from each well will be measured or estimated, including quantification of the volume of LNAPL recovered during each event.

The effectiveness of the total-liquids extraction program will primarily be evaluated by comparison of the accumulation of LNAPL measured in well IP-4 and other site wells throughout the duration of the pilot test program.

No contingencies are considered outside of the time and volume limitations established for the total liquids extraction events as outlined above.

4.3 Groundwater Conditions Progress Monitoring

Four progress groundwater monitoring events are scheduled during the pilot test. A groundwater monitoring summary for the pilot test is included in Table 2. The planned groundwater monitoring events will be completed at the following intervals:

- After the first ISCO injection event is completed and immediately prior to the first total fluids extraction event.
- One month after the final total liquids extraction event.
- Three months after the final total liquids extraction event.
- Six months after the final total liquids extraction event.

The data collected from the initial event will be reviewed to evaluate site conditions for unexpected changes that could affect the implementation of future injection programs, such as a significant increase in dissolved contaminant concentrations and extent. The data from the remaining events will be used primarily to evaluate remedial response and effectiveness.

As stated in Section 3.2, fluid levels will be measured in each pilot-test target well, including evaluation of wells IP-4 and IP-7 for LNAPL using an oil/water interface probe. LNAPL presence in wells where LNAPL is measured may be confirmed using a bailer. Water levels will be measured in the remainder of the monitoring wells using an electronic water level meter.

For the monitoring event completed after the first ISCO injection event, groundwater samples will be collected from Upper Saturated Zone wells only (AS-1, IP-4, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5), Groundwater samples will be collected from each of the pilot test target wells during each progress monitoring event at 1 month, 3 months, and 6 months after the final extraction event.

During each of these monitoring events, wells slated for groundwater sample collection will be prepared and sampled as described in Section 3.2. Collected groundwater samples will be submitted to a Washington State-certified analytical laboratory for the following analyses.

- GRO by Ecology Method NWTPH-Gx with BTEX by USEPA Method 8260C.
- DRO by Ecology Method NWTPH-Dx (without silica gel cleanup).

In addition, one duplicate groundwater sample will be collected from a well during each sampling event. The duplicate sample will be collected form a well that is likely to contain petroleum hydrocarbons based on previous analytical results and field observations during sample collection activities. Monitoring wells with measurable LNAPL will be purged and sampled using a peristaltic pump only. If a peristaltic pump is not capable of effectively recovering water from beneath the LNAPL at these wells, no groundwater sample will be collected there.

5.0 FIELD WORK PROCEDURES

Field work procedures for the planned pilot test are discussed below.

5.1 Underground Utility Clearance and Air Knife/Vacuum Truck

Numerous subsurface utilities are present in the planned drilling areas. Before beginning fieldwork, G-Logics will contact public and private utility-locating services. Subsurface utility locations will be identified by marking their inferred location on the ground surface. Actual boring locations will be identified upon completion of the utility locate and confirmation of access availability. Additionally, at each drilling location for the monitoring well installation and each of the three injection events, the first five feet of soils will be removed using air-knife/vacuum-truck methods as a final underground utility clearance confirmation step.

5.2 Permitting

The understood permitting requirements are discussed below.

5.2.1 Injection Permitting

The injection points likely are considered to be Class B underground injection wells that are subject to the Underground Injection Control (UIC) Program managed by Ecology. Once approved by Ecology, this workplan will be submitted to the UIC Program along with application materials to request a UIC permit for the injection program.

5.2.2 Miscellaneous Permitting

Because all work will be performed on Property, right-of-way and/or street-use permits will not be required. However, a licensed driller will perform the injection-point installations in accordance with Ecology’s Well Regulations.

5.2.3 Spill Control Equipment

Spill-control equipment will be present at the site to protect surrounding infrastructure from releases to the environment. With guidance from Regenesis, secondary containment will be provided for the storage and handling of ISCO compounds. A 3% hydrogen peroxide and vinegar (approximately 6% acetic acid) solution will be available at the site to be sprayed on the injectate to buffer the pH and neutralize the oxidation process, if accidentally released onto the ground surface. At least five gallons each of the hydrogen peroxide and vinegar will be available for application to surface spills and will each be applied at a rate of 50% of the released ISCO reagent volume (1:1 application of equal parts hydrogen peroxide and vinegar). For larger releases of ISCO reagent solution, containment and recovery will be prioritized over neutralization. Spills resulting in the accumulation of free liquids on the ground surface will be removed using a wet/dry vacuum unit and the fluids will be containerized on site as investigation-derived waste (IDW) in plastic 55-gallon drums.

5.3 Drilling/Injection Methods

For the planned testing, monitoring wells and injection points will be drilled in areas indicated on Figures 3 and 4 using hollow-stem auger (wells) and direct-push (injection points) drilling methods. Actual boring locations may be adjusted based on site conditions. The new monitoring wells will be drilled to the depths shown on Figure 4. Injection points will be drilled to anticipated depths of approximately 13 feet. A G-Logics geologist will be present during the drilling to observe and document soil conditions.

5.4 Groundwater Depth Measurements

Water-level measurements will be referenced to the top of the well casings. The static-water level will be measured in each observation well using a conductivity type, water-level probe. The conductivity probe will be lowered into the well until the instrument detects water. The tape on the probe will be used to obtain a depth-to-water measurement, from the reference point, to within 0.01 feet.

5.5 Quality Assurance and Quality Control

The QA/QC process for the presented scope of work will include generally accepted procedures for sample collection, storage, tracking, and documentation. In addition, the laboratory will provide their own independent QA/QC procedures, including internal spikes and control blanks, as necessary to document the data meets the analytical method’s reporting limits. All sampling equipment will be washed and rinsed before the collection of the samples. All samples will be labeled with a sample number, date, time, and sampler name, and stored in an ice chest containing frozen “blue ice”. Appropriate chain-of-custody documentation will be completed.

One duplicate sample for each analytical parameter will be collected during each monitoring event to evaluate sample collection and analytical effects on precision and accuracy of results. Additional QA/QC samples may be added if conditions are identified that require more robust data quality evaluation procedures.

Laboratory analytical data reports will be validated using the available sample and batch QA/QC data included in standard reporting documentation from the laboratory. Analytical data will be appropriately flagged to indicate QA/QC exceptions identified, including diluted samples, estimated values, and rejected data.

5.6 Health and Safety Plan

A site-specific Health and Safety Plan will be developed for the field activities completed at the subject property. All field personnel will review the plan and will implement the procedures while conducting the on-site field activities.

5.7 Investigation-Derived Waste Disposal

Please note that this pilot test work will produce IDW that will be stored in steel or plastic 55-gallon drums. Soil cuttings, liquid release cleanup residue, and rinse/purge water generated during the pilot test activities will be temporarily stored on site in 55-gallon Department of Transportation-approved drums. Drums will remain on the Property pending characterization, profiling, and coordination of off-site transportation and disposal. The drums will need to **remain on the Property** pending results of analytical testing and profiling prior to disposal.

6.0 REPORTING

The results and findings of the pilot test will be summarized in a memorandum and incorporated into the draft FS for the Site. The memo will document the objectives, methods, and observations of the pilot test activities. The memo will include site diagrams showing injection locations, as well as current and identified former site features. Monitoring data, laboratory analytical results, and a discussion of our findings also will be included. The identified viability of using PetroCleanze at this site will be included in this memorandum. Should PetroCleanze be found to not work as anticipated, additional discussions for alternative oxidants or remedial methods will be included.

Following the preparation and approval of the findings, further refinement of a full-scale design then would be presented in Cleanup Action Plan, with details subsequently provided in an Engineering Design Report. Analytical data developed during this pilot test will be uploaded to Ecology's EIM database.

7.0 PROJECT SCHEDULE

The performance and monitoring for the planned pilot test are anticipated to take approximately 12 months. A comprehensive pilot test schedule is included in Table 3. Upon approval to proceed, we will begin work to coordinate the required activities to complete this work. G-Logics expects that monitoring well installation, baseline groundwater sample collection, and the initial injection event can be scheduled for completion within 6 weeks of receipt of authorization to proceed.

It is expected that a Pilot Test Report will be submitted to Ecology within 6 weeks of completion of the final groundwater-monitoring event.

8.0 PROJECT ASSUMPTIONS

The schedule estimate for the proposed effort is based on the following assumptions.

- Appropriate site access will be available to G-Logics personnel and all G-Logics subcontractors.
- Drilling at off- Property locations, including streets and rights-of-way, will not be conducted as part of this project.
- Traffic control will not be required.
- Concrete cores will be necessary at each of the two new monitoring well locations and the nine injection points.
- Direct-push drilling equipment can be successfully used at this site.
- Weekend and/or night work will not be required.
- G-Logics will provide all sampling equipment and will use laboratory-provided sample containers.
- The driller will provide drums for containing soil cuttings generated during this work. Sampling-equipment decontamination-water, and purge water from the wells, also will be placed into the drums.

- Sample analysis will be performed at a two-week reporting schedule (non-rush basis).

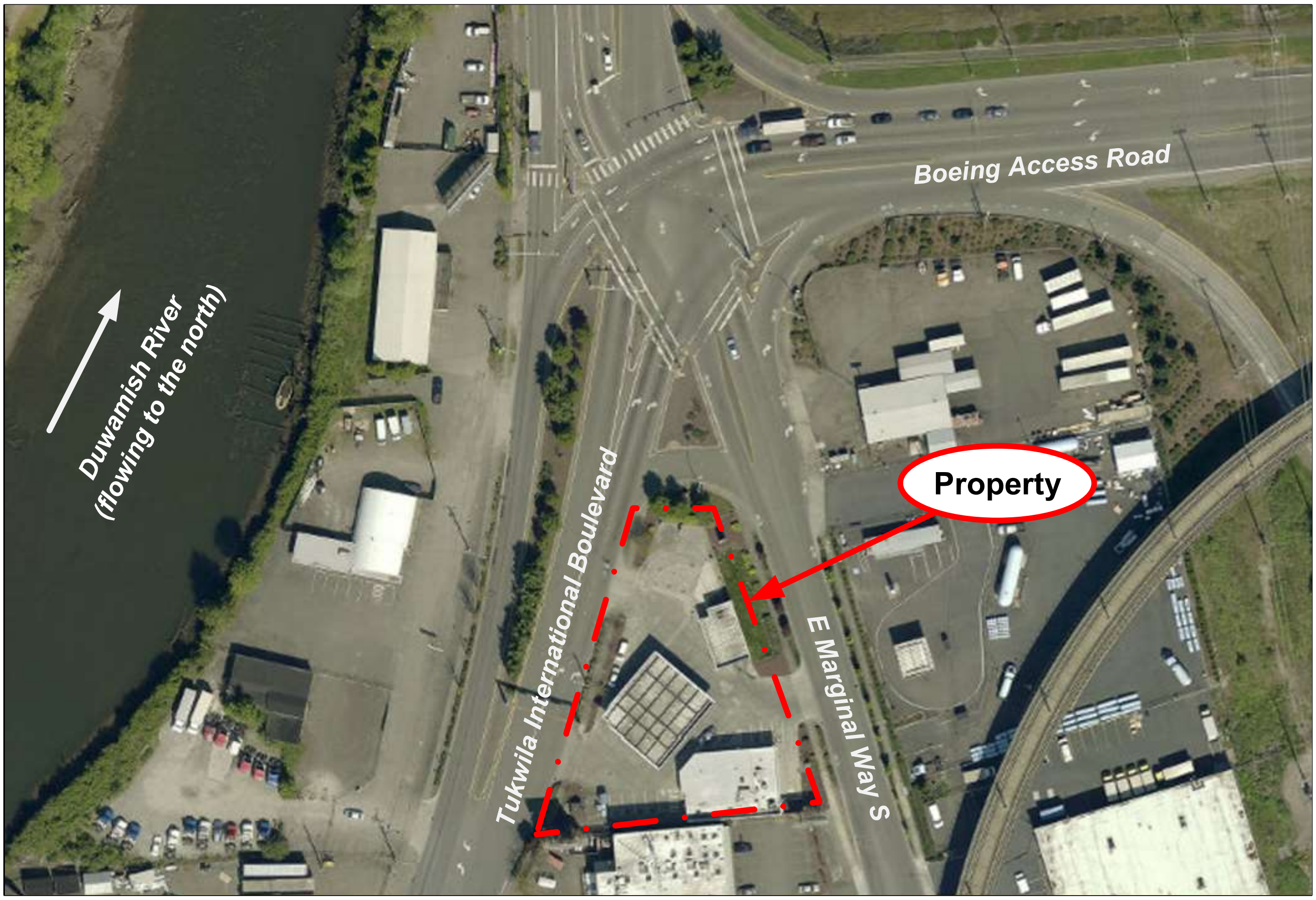
9.0 LIMITATIONS

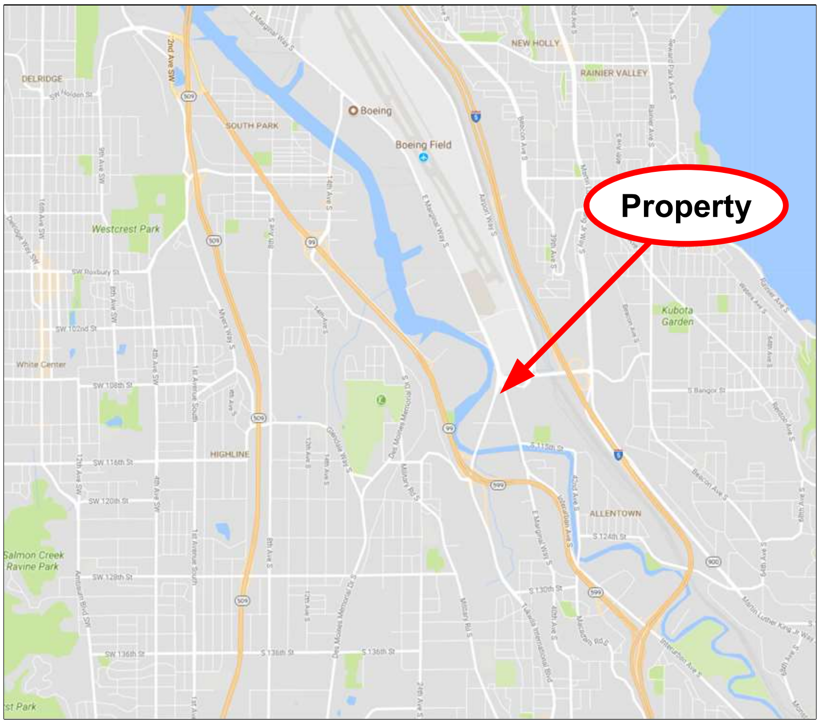
This pilot test workplan is not designed or intended to identify all potential concerns or to eliminate all risk associated with remediation efforts at the subject Property, nor does this work provide a guarantee regarding remedial options. This work will not include other services not specifically described above.

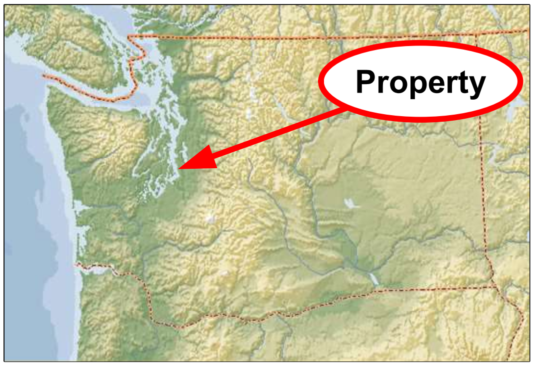
G-Logics has prepared this workplan in accordance with the generally accepted standards of care that exist in the state of Washington at the time of this work. This workplan is prepared for the sole use of our client and Ecology. The described information may not be appropriate for the needs of other users. Re-use of this document or the findings, conclusions, or recommendations presented herein, are at the sole risk of said user(s).

No warranty, express or implied, is made.

FIGURES







N

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Site Location Maps

Boeing Field Chevron

10805 East Marginal Way South
Tukwila, Washington

Figure

1

Project File: 01-0410-M F1-1.vsdx

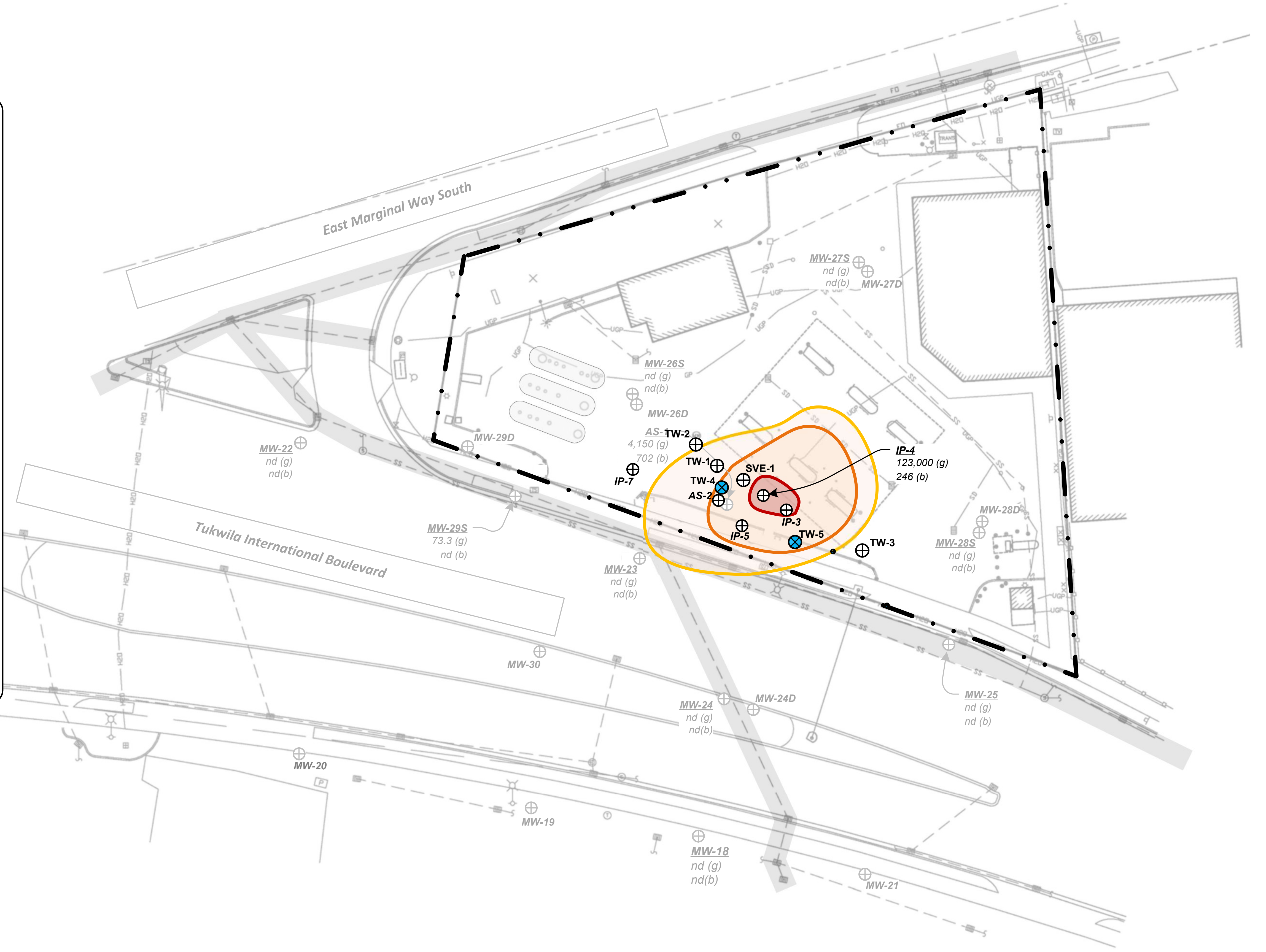
Mapping Reference: Delorme, King County iMap, and Google Maps

Legend

⊕	2018-2019 Monitoring Well (USZ)
⊗	Proposed New Monitoring Well
🟨	GRO/Benzene Detected Greater than Site Cleanup Levels (800/1.6 µg/L)
🟧	GRO/Benzene Detected Greater than 8,000/50 µg/L
🟥	Area of Possible LNAPL
— · · —	Property Boundary
▭	Understood Utility Trench Locations (Adjacent to Property)
⬭	Current UST Location (Approximate)

Note: Interpreted contours are based on available analytical data for groundwater samples collected in November 2018 and April 2019.

Note: Gray-scaled well locations are not part of the pilot test monitoring program.



Note: This figure contains information in color. Black & white photocopies may not be suitable for review.

Approximate Drawing Scale: 1" = 40'

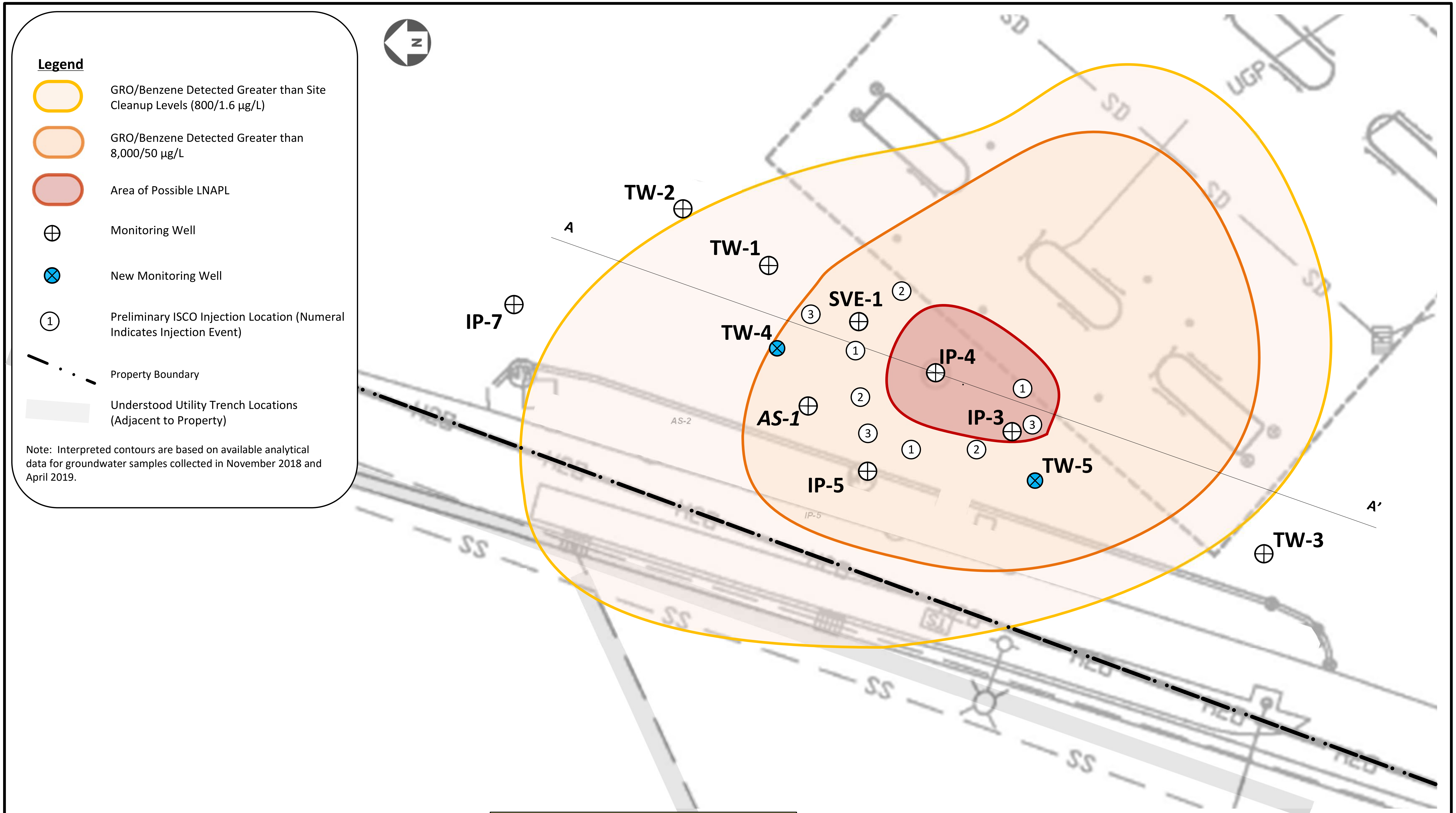
0 ft. 24 ft. 40 ft. 80 ft.

Monitoring Well Locations
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, Washington

Figure
2

Project File: 01-0410-Q F2 COCs USZ 2018-2019.vsdx

Mapping References: PLS Survey 2016, G-Logics Field Measurements, Previous Site Report Figures.



Legend

- GRO/Benzene Detected Greater than Site Cleanup Levels (800/1.6 µg/L)
- GRO/Benzene Detected Greater than 8,000/50 µg/L
- Area of Possible LNAPL
- ⊕ Monitoring Well
- ⊗ New Monitoring Well
- ① Preliminary ISCO Injection Location (Numeral Indicates Injection Event)
- Property Boundary
- Understood Utility Trench Locations (Adjacent to Property)

Note: Interpreted contours are based on available analytical data for groundwater samples collected in November 2018 and April 2019.

The contours represent an interpretation of available data for the indicated date. Site groundwater contours may change with additional measurements and/or data points, weather changes, construction activities, and/or other influences.

Note: This figure contains information in color. Black & white photocopies may not be suitable for review.

Approximate Drawing Scale: 1" = 10'

0 ft. 6 ft. 10 ft. 20 ft.

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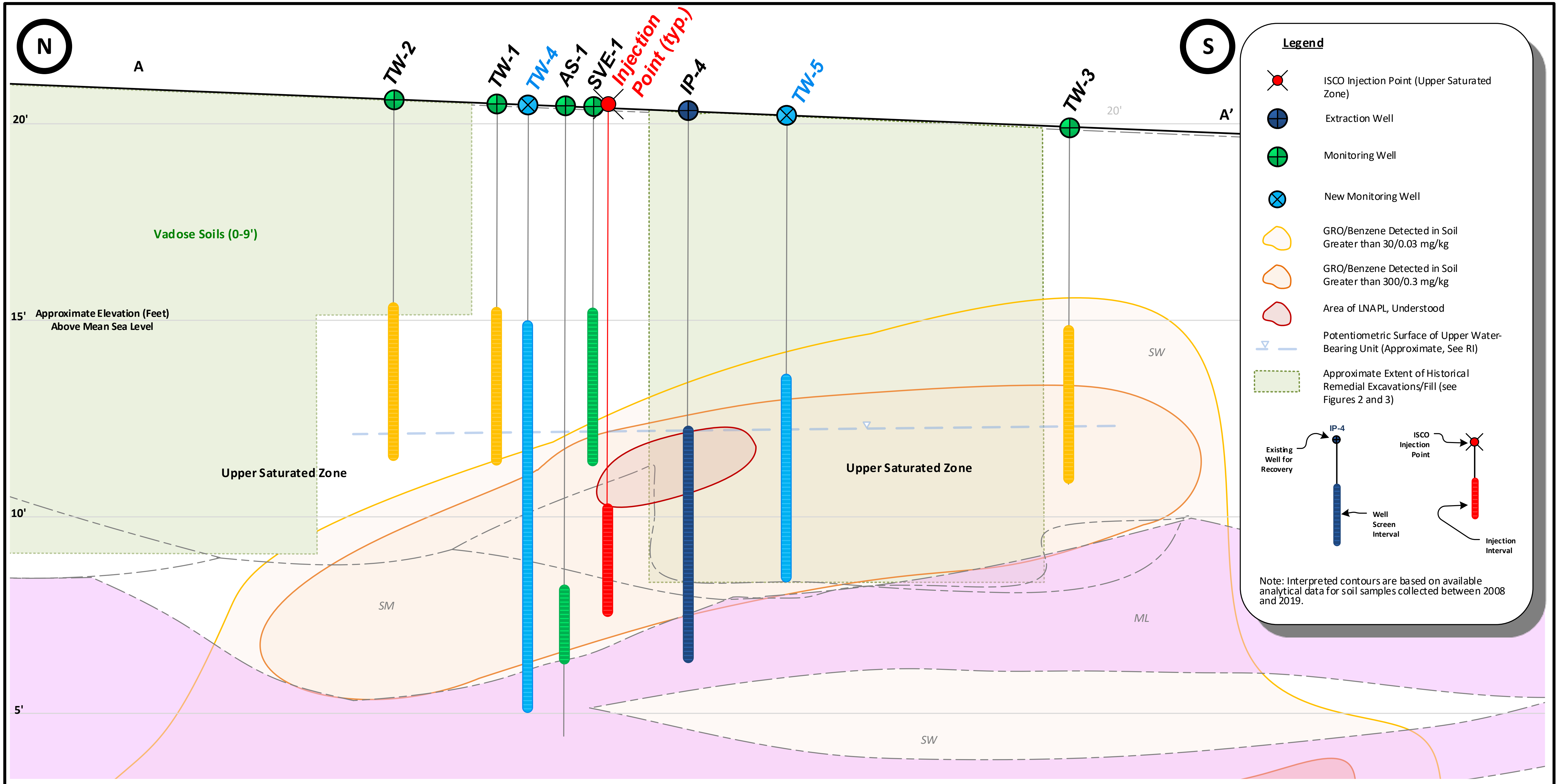
Project File: 01-0410-Q F3.vsdx

ISCO Injection and Monitoring Schematic
Boeing Field Chevron
10805 East Marginal Way South
Tukwila, Washington

Figure
3

Mapping References: PLS Survey 2016, G-Logics Field Measurements, Previous Site Report Figures.



The contours represent an interpretation of available data for the indicated date. Site groundwater contours may change with additional measurements and/or data points, weather changes, construction activities, and/or other influences.

Project File: 01-0410-Q F4 A-A.vsdx

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Approximate Horizontal Drawing Scale: 1" = 10'

0 ft. 6 ft. 10 ft. 20 ft.

4X Vertical Exaggeration

Note: This figure contains information in color. Black & white photocopies may not be suitable for review.

ISCO Injection and Monitoring Cross Section, A-A'
Upper Saturated Zone, Boeing Field Chevron
10805 East Marginal Way South
Tukwila, Washington

Figure
4

Mapping Reference: PLS Survey 2016, G-Logics Field Measurements, G-Logics Remedial Investigation Report, Compiled Data.

TABLES

Table 1
Summary of Information Needs
ISCO and Total Liquids Extraction Pilot Test
Boeing Field Chevron, 10805 East Marginal Way South
Tukwila, Washington

Information Need	Field Data Development Plan
Establish baseline groundwater quality conditions in the Upper and Lower Hydraulic Zones prior to pilot testing	Install two new monitoring wells (TW-4 and TW-5) in the pilot test injection area
	Collect groundwater samples from wells AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, and TW-1 through TW-5 prior to initial injection phase, field screen groundwater for presence of LNAPL (wells IP-4 and IP-7 only), pH, reduction/oxidation potential, dissolved oxygen, specific conductance, and temprerature; and analyze for GRO, DRO, BTEX, and total organic carbon
Evaluate LNAPL accumulation and reduction in Upper and Lower Hydraulic Zone wells	Measure LNAPL thickness in well IP-4 and IP-7 using an oil/water interface probe prior to each injection phase and prior to and immediately after each total liquids extraction phase
	Measure or estimate volume of recovered LNAPL during each total liquids extraction event
Evaluate ISCO injection delivery effectiveness	Confirm ISCO reagent mass and water volume injected at each point
	Record injection fluid pressure at each point
	Record start and end time of injection at each point
	Measure water levels in wells AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, and TW-1 through TW-5 during each injection phase
	Measure dissolved oxygen and reduction/oxidation potential in wells AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, and TW-1 through TW-5 during each groundwater monitoring event
Evaluate change in dissolved phase petroleum hydrocarbon concentrations in Upper Hydraulic Zone	Collect groundwater samples from AS-1, IP-4, SVE-1, and TW-1 through TW-5 prior to injections and analyze for GRO, DRO, and BTEX prior to injections, between first and second injection phases, and at 1 month, 3 months, and 6 months after the final phase of injection and total liquids extraction
Evaluate change in dissolved phase petroleum hydrocarbon concentrations in Lower Hydraulic Zone	Collect groundwater samples from IP-3, IP-5, and IP-7 and analyze for TPH-G and BTEX prior to injections and at 1 month, 3 months, and 6 months after the final phase of injection and total liquids extraction
Evaluate radius of hydraulic and chemical influence from injections (Upper and Lower Hydraulic Zones)	Measure water levels in wells AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, and TW-1 through TW-5 prior to each injection phase and and within 2 hours after each injection phase is completed
	Measure pH, reduction/oxidation potential, dissolved oxygen, specific conductance, and temprerature in AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, and TW-1 through TW-5 prior to the initial injection phase, between the first and second injection phases (omit Lower Zone wells), and at 1 month, 3 months, and 6 months after the final injection and total fluid extraction phases are complete
Evaluate effectiveness of total liquids extraction	Measure or approximate volume of liquids and LNAPL removed from well IP-4 and other wells containing LNAPL during each event. Record start and end time of total liquids extraction at wells IP-4 and other wells containing LNAPL.
Evaluate radius of hydraulic influence from total liquids extraction in the Upper and Lower Hydraulic Zones	Measure water levels in AS-1, AS-2, IP-3, IP-4, IP-5, IP-7, SVE-1, and TW-1 through TW-5 prior to each total liquids extraction phase and as soon as possible after each extraction phase is completed
Evaluate rebound of LNAPL accumulation in the Upper and Lower Hydraulic Zones	Measure LNAPL thickness in wells IP-4 using an oil/water interface probe at 1 month, 3 months, and 6 months after the final total liquids extraction event. Screen for LNAPL and, if present, measure LNAPL using an oil/water interface probe in the remaining wells in the pilot test monitroing program.
Evaluate rebound of dissolved-phase petroleum hydrocarbons in the Upper and Lower Hydraulic Zones	Collect groundwater samples from AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, and TW-1 through TW-5 and analyze for GRO, DRO, and BTEX at 1 month, 3 months, and 6 months after the final total liquids extraction event

Table 2
Pilot Test Groundwater Monitoring Summary
Boeing Field Chevron, 10805 East Marginal Way South
Tukwila, Washington

Event	Sample Points	Analysis/Measurement	Analytical/Measurement Method	Original Samples	Duplicate Samples	Total Samples
Pre-Injection Baseline	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
		Dissolved Oxygen, RedOx Potential, Temperature, pH, Specific Conductivity	In-line flow-through cell with electronic probe	N/A	N/A	N/A
		GRO	Ecology Method NWTPH-Gx	11	1	12
		DRO	Ecology Method NWTPH-Dx	11	1	12
		BTEX	USEPA Method 8260C	11	1	12
		Total organic carbon (Lower Saturated Zone wells only)	USEPA Method 9060A or equivalent	3	1	4
Injection #1	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
Post-Injection #1 Monitoring	AS-1, IP-4, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
		Dissolved Oxygen, RedOx Potential, Temperature, pH, Specific Conductivity	In-line flow-through cell with electronic probe	N/A	N/A	N/A
		GRO	Ecology Method NWTPH-Gx	8	1	9
		DRO	Ecology Method NWTPH-Dx	8	1	9
		BTEX	USEPA Method 8260C	8	1	9
	IP-3, IP-5, and IP-7	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
Extraction #1	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
Injection #2	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
Extraction #2	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
Injection #3	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
Extraction #3	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
Progress Monitoring: 1 month	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
		Dissolved Oxygen, RedOx Potential, Temperature, pH, Specific Conductivity	In-line flow-through cell with electronic probe	N/A	N/A	N/A
		GRO	Ecology Method NWTPH-Gx	11	1	12
		DRO	Ecology Method NWTPH-Dx	11	1	12
		BTEX	USEPA Method 8260C	11	1	12
Progress Monitoring: 3 months	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
		Dissolved Oxygen, RedOx Potential, Temperature, pH, Specific Conductivity	In-line flow-through cell with electronic probe	N/A	N/A	N/A
		GRO	Ecology Method NWTPH-Gx	11	1	12
		DRO	Ecology Method NWTPH-Dx	11	1	12
		BTEX	USEPA Method 8260C	11	1	12
Progress Monitoring: 6 months	AS-1, IP-3, IP-4, IP-5, IP-7, SVE-1, TW-1, TW-2, TW-3, TW-4, and TW-5	Product/Water Levels	Electronic sounding device	N/A	N/A	N/A
		Dissolved Oxygen, RedOx Potential, Temperature, pH, Specific Conductivity	In-line flow-through cell with electronic probe	N/A	N/A	N/A
		GRO	Ecology Method NWTPH-Gx	11	1	12
		DRO	Ecology Method NWTPH-Dx	11	1	12
		BTEX	USEPA Method 8260C	11	1	12
Total Groundwater Analytical Samples		**GRO**	**Ecology Method NWTPH-Gx**	**52**	**5**	**57**
		DRO	**Ecology Method NWTPH-Dx**	**52**	**5**	**57**
		BTEX	**USEPA Method 8260C**	**52**	**5**	**57**
		Total Organic Carbon	**USEPA Method 9060A or equivalent**	**3**	**1**	**4**

Notes:

BTEX = Benzene, toluene, ethylbenzene, and xylenes
Ecology = Washington State Department of Ecology
GRO = Gasoline-range petroleum hydrocarbons
RedOx = Reduction/oxidation
USEPA = United States Environmental Protection Agency

Table 3

Pilot Test Schedule
Boeing Field Chevron, 10805 East Marginal Way
Tukwila, Washington

Task/Milestone	Duration	Week Beginning	Week Ending
Workplan approval	Day 0	1	1
Field planning and coordination, health and safety plan development, procurement	3 weeks	1	4
BASELINE CONDITIONS EVALUATION			
Monitoring well installation and initial groundwater monitoring	1 week	4	5
Soil and groundwater sample analysis and results review	2 weeks	5	7
PILOT TEST IMPLEMENTATION AND MONITORING			
Reagent Injection Event #1	2 days	8	8
Progress Groundwater Monitoring Event #1	2 days	11	11
Total Liquids Extraction Event #1	1 day	12	12
Reagent Injection Event #2	1 day	13	13
Total Liquids Extraction Event #2	1 day	16	16
Reagent Injection Event #2	1 day	18	18
Total Liquids Extraction Event #2	1 day	21	21
Progress Groundwater Monitoring Event #2 (One Month)	2 days	25	25
Progress Groundwater Monitoring Event #3 (Three Months)	2 days	34	34
Progress Groundwater Monitoring Event #4 (Six Months)	2 days	47	47
REPORTING			
Report Development and Draft Report Submittal	4 weeks	47	51
Review, Response to Comments, and Final Report Submittal	6 weeks	51	57

APPENDIX A

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PMID: 34085199

A field-scale remediation of residual light non-aqueous phase liquid (LNAPL): chemical enhancers for pump and treat

Paolo Ciampi,☒[1] Carlo Esposito,[1] Giorgio Cassiani,[2] Gian Piero Deidda,[3] Paolo Rizzetto,[4] and Marco Petrangeli Papini[5]

[1]Department of Earth Sciences, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy
[2]Department of Geosciences, University of Padua, Via Gradenigo 6, 35131 Padua, Italy
[3]Department of Civil and Environmental Engineering and Architecture, University of Cagliari, via Marengo, 2, 09123 Cagliari, Italy
[4]Italian Air Force, Logistic Headquarter Viale dell'Università, 4, 00185 Rome, Italy
[5]Department of Chemistry, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy
Paolo Ciampi, Email: paolo.ciampi@uniroma1.it.
Contributor Information.
☒Corresponding author.

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Abstract

The remediation of petroleum-contaminated soil and groundwater is a challenging task. The petroleum hydrocarbons have a long persistence in both the vadose zone and in the aquifer and potentially represent secondary and residual sources of contamination. This is particularly evident in the presence of residual free-phase. Pump-and-treat is the most common hydrocarbon decontamination strategy. Besides, it acts primarily on the water dissolved phase and reduces concentrations of contaminants to an asymptotic trend. This study presents a case of enhanced light non-aqueous phase liquid (LNAPL) remediation monitored using noninvasive techniques. A pilot-scale field experiment was conducted through the injection of reagents into the subsoil to stimulate the desorption and the oxidation of residual hydrocarbons. Geophysical and groundwater monitoring during pilot testing controlled the effectiveness of the intervention, both in terms of product diffusion capacity and in terms of effective reduction of pollutant concentrations. In particular, non-invasive monitoring of the reagent migration and its capability to reach the target areas is a major add-on to the remediation technique. Most of the organic contaminants were decomposed, mobilized, and subsequently removed using physical recovery techniques. A considerable mass of contaminant was recovered resulting in the reduction of concentrations in the intervention areas.

Keywords: Hydrocarbon contamination, Hydrogeophysical monitoring, Light non-aqueous phase liquid desorption, Pilot test, Contaminant remediation, Residual hydrocarbons

Introduction

The remediation of the areas contaminated by petroleum hydrocarbons and the selection of the best decontamination methods represent a growing global concern (Kuppusamy et al. 2020; Ossai et al. 2020; Verardo et al. 2021). The natural aging of petroleum hydrocarbons in contaminated sites and the water table fluctuations result in the chemical sequestration and physical entrapment of these hydrophobic compounds (Gatsios et al. 2018; Teramoto et al. 2020). This aspect is particularly relevant in the case of contamination by fuels, which are complex mixtures of hydrocarbons made of substances with significantly different chemical, physical, and biodegradation properties (Vozka et al. 2019). The progressive aging of the contaminants corresponds to a reduction of the more mobile and degradable fractions and the increase of compounds with a higher molecular weight (Tran et al. 2018). Such immobile, less volatile, less soluble, more viscous, and high molecular weight materials constitute the residual hydrocarbons, which are difficult to be mobilized by traditional extraction (i.e., pumping) technologies (Lari et al. 2019b; Ossai et al. 2020; Teramoto et al. 2020; Trulli et al. 2016). This aging or weathering can cause modifications that are necessary to consider when selecting a remediation technique and is therefore essential to the polluted site's management (Lari et al. 2019a; Tang et al. 2012). The light non-aqueous phase liquid (LNAPL) recovery and contamination mitigation approaches may include hydraulic pumping (mainly to recover the LNAPL), soil vapor extraction (SVE), chemical oxidants (e.g., to reduce saturation and degrade contaminants), air sparging (e.g., to augment biodegradation and volatilization), thermal methods (e.g., to decrease LNAPL viscosity and increase volatilization), enhanced bioremediation, multiphase extraction (MPE), skimming of mobile LNAPL, and natural source zone depletion (i.e., NSZD) (Besha et al. 2018; Bortoni et al. 2019; Gatsios et al. 2018; Kuppusamy et al. 2020; Lari et al. 2019a; Lari et al. 2020; Ossai et al. 2020; Sharma et al. 2020; Verardo et al. 2021; Xie et al. 2020; Yao et al. 2020). Among the physical extraction-based remediation techniques, the pump-and-treat is traditionally the most commonly used approach for treating contaminated groundwater (Brusseau 2019; Teramoto et al. 2020). While the initial phase of pump-and-treat systems typically achieves a rapid reduction of light non-aqueous phase liquids (LNAPLs) aqueous concentrations, its long-term effectiveness diminishes, and the system often reaches asymptotic conditions (Truex et al. 2017). Further operations of the system provide small incremental benefits in treating soil or groundwater contamination, often not achieving the regulation cleaning goals and being operationally long and expensive (Lari et al. 2019b). Pump-and-treat efficacy tends to plateau as a result of a variety of factors such as (a) hydrocarbon distribution through zones of differential matrix permeability and (b) the presence of slowly dissolving smeared free phase and/or adsorbed hydrocarbon contamination (Lee et al. 2001; Lari et al. 2019a; Teramoto et al. 2020). Miscible solvents and surfactants can act as chemical enhancers for pump-and-treat: the petroleum hydrocarbon mass can be removed using reagent to enhance recovery of sorbed-phase or smeared hydrocarbon (McCray et al. 2011; Sharma et al. 2020). The hydrocarbons are made available in the dissolved or lower viscosity phase, to enhance the recoverability of the product in a separate phase, allowing a subsequent rapid and effective physical recovery (Birnstingl et al. 2014; Lari et al. 2019b). Characterization efforts are critical for determining the applicability, deployment, and efficacy of remediation technology. From the implementation perspective, field applications should continuously emphasize adequate site characterizations for a proper remedial design (Lari et al. 2020; Suthersan et al. 2016). Verification of amendment distribution in soils should be part of the performance monitoring (Fan et al. 2017).

A possible strategy for this monitoring relies on the use of non-invasive geophysical techniques to visualize the time-lapse distribution of reagents. Thus, the resulting physical changes due to the injected solution may be measured using physical methods. The use of repeated geophysical measurements to highlight changes in the system‘s condition is the state-of-the-art for several hydrological applications (Cassiani et al. 2006; Deiana et al. 2008; Morita et al. 2020; Perri et al. 2012; Haaken et al. 2017) but rarely implemented at contaminated sites, particularly during remediation activities (Cassiani et al. 2014; Perri et al. 2020). Although geophysical experiments and field studies provided valuable insights on the behavior of contaminants, the results are still ambiguous, leading to widely divergent explanations (Atekwana and Atekwana 2010; Deng et al. 2020; Hort et al. 2015). These methods can provide potentially critical information on where and how in situ remediation actions affect different portions of the subsurface, as an effect of subsoil hydraulic heterogeneity (Vereecken et al. 2006). The physical variable of interest, i.e., the electrical resistivity, is strongly linked to state variables of key environmental interest (Lesmes and Friedman 2005). In this regard, the joint modeling of geological-geophysical data enabled Ciampi et al. (2019a) to discretize the electrical response and to track the product diffusion resulting from reagent injection into a heterogeneous, dense non-aqueous phase liquid (DNAPL)-contaminated aquifer. The present paper, unlike the previous one, aims to unmask the decontamination dynamics induced by the injection of amendments in the context of an LNAPL-contaminated site. The geophysical-chemical cross-analysis can potentially explain the removal mechanisms of residual hydrocarbons, by identifying the different fractions of product involved in the degradative processes (Ossai et al. 2020). Effective remediation of a site contaminated with hydrocarbons requires a sound understanding of regulatory issues, technology options, and the site's hydrogeology (Lari et al. 2020). In this context, the challenge to be faced is to simultaneously integrate the information relating to the hydrogeophysical sphere in all its dimensions (Harris et al. 2004; Teramoto et al. 2020; Verardo et al. 2021). A cross-disciplinary geodatabase and an interactive model become the instruments for managing and analyzing multi-source data (Ciampi et al. 2019a). The hydrogeological complexity, geophysical manifestation, and contamination or decontamination processes are caught by information sharing, knowledge convergence, and high-resolution depiction of environmental diversity (Ciampi et al. 2019b). In this direction, the present work presents a case study that dealt with the application of an innovative technology to remediate a site contaminated with petroleum hydrocarbons. This paper focuses on a field injection of the PetroCleanze™ product (Regenesis, San Clemente, CA) for enhancing and extending the effectiveness of physical extraction systems. The technology combines in situ chemical oxidation (ISCO) and enhanced desorption to treat bound hydrocarbon and LNAPL (Besha et al. 2018; Wang et al. 2013). PetroCleanze™ is a two-part reagent, which targets sorbed-mass and residual NAPL, bringing each into the soluble and recoverable phase from where they may then be extracted through pumping systems (Sharma et al. 2020). This strategy was here verified through a pilot test, to evaluate the possible scaling up of the process. The pilot test, which was properly orchestrated via a multidisciplinary and multitemporal data management model, was assessed in terms of yield during the implementation process. Electrical resistivity tomography (ERT) monitoring and groundwater sampling were performed to evaluate the effectiveness of the intervention, both in terms of product diffusion capacity and in terms of effective reduction of pollutant concentrations. The near real-time observation of decontamination dynamics at the field scale can represent an added value to interpret the spatial and temporal physio-chemical changes during the remediation process, explaining the contaminant-geophysical behavior. The case study presents possibilities for optimizing LNAPL contaminant removal since it is substantially unrecoverable using traditional remediation technologies at long-term polluted sites.

Materials and methods

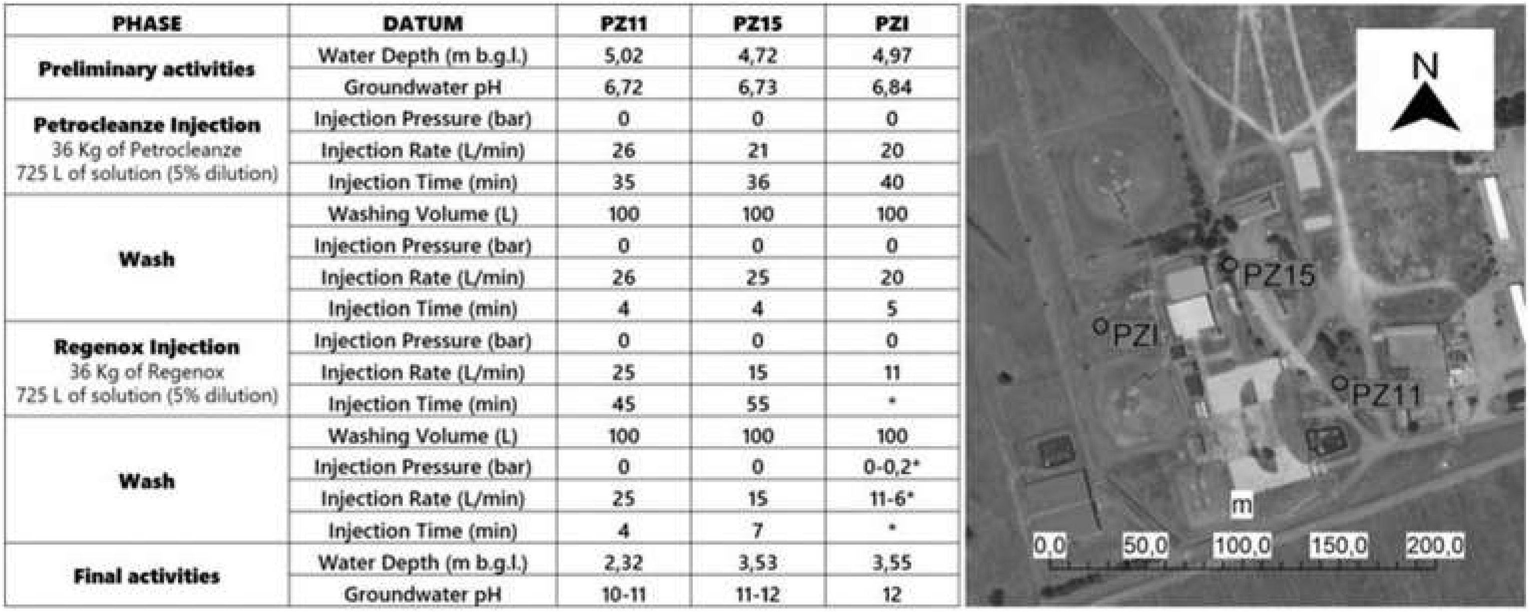
The study site is a large airport area (NATO Military Base of Decimomannu) located in Sardinia (Italy), where about ten years ago a jet fuel spill occurred due to leakage of a transfer pipeline around the fuel tanks. The detected contamination, despite being mainly caused by a single spill, is quite extensive and has been the subject of years of pump-and-treat intervention (Trulli et al. 2016). This is operational.

The Regenesis PetroCleanze$^{\text{TM}}$ was employed to develop an in situ enhanced chemical desorption strategy. The main technological functionality of the product is to enhance the desorption of hydrocarbons adsorbed to saturated soils or at the capillary fringe, and the product's recoverability as a separate phase (Sharma et al. 2020). The application of the product is aimed at making the hydrocarbons available in the dissolved phase, allowing a subsequent rapid and effective physical recovery (Birnstingl et al. 2014).

Pilot testing occurred in two different areas, by a direct application at existing wells and reactivating the pump-and-treat system a few days later. The chosen areas are characterized by two geological scenarios that are representative of the site's conditions. In addition, the two zones are close to the source of historical pollution and have been strongly impacted by contamination.

From the characterization phase to the application of the treatments, the processing of a vast volume of heterogeneous data accompanied the entire remediation process (Suthersan et al. 2016). An automated knowledge management and analysis dashboard containing information relating to geological, geophysical, hydrological, and chemical fields was employed to archive and coordinate multi-thematic data. The 4D multidisciplinary geodatabase (which takes into account the time factor) held the role of an effective "near real-time" decision support system (DSS), which manages and releases data from site characterization to technique application (Ciampi et al. 2019a; Huysegoms and Cappuyns 2017). The digital and thematic database constitutes a data source used for the modeling and the editing of georeferenced information (Artimo et al. 2008). The interpretation of the resulting hydrological-geophysical model and the selection of remediation solutions were subsequently accomplished using a multiscale and multiphase methodology. (Ciampi et al. 2019a). The essential hydrogeological characteristics of the site at full scale were collected and employed to populate the model in the first step. The research centered on the pilot test areas in the final stage, with higher resolution, to examine in depth the effects of geological complexity and chemical mechanisms in the intervention sector, beginning with the multidisciplinary conceptual model derived from the first step. (Ciampi et al. 2019b). The RockWorks 17 application was employed to recreate the hydrogeological 3D model (Lekula et al. 2018). This software enables the acquisition, analysis, visualization, and integration of information from geo-referenced data. The geological, geophysical, and hydrochemical variables were interpolated and modeled during the data integration and analysis procedure (Kaliraj et al. 2015; Safarbeiranvnd et al. 2018). Geologic-geophysical data and chemical analyses performed on water samples represent the variables involved in the modeling activities. The stratigraphic sequence was reconstructed based on data derived from 85 boreholes. Stratigraphic logs reach depths ranging from 10 m to 26 m and cover an investigation area of about 265000 m^2. A piezometric network consisting of 62 monitoring points was installed on the site. Piezometers completely intercept contaminated groundwater, generally reaching a depth of 10 m from the ground level. Data concerning chemical analyzes of water sampled and the presence of supernatant product from 2012 to 2018 are available. Dynamic and interactive extraction, both in time and space, of multi-source data from the multi-modality data source and joint model aimed to support decision-making (Lekula et al. 2018). The complete multi-temporal and multidisciplinary characterization helped the selection of a remediation technology. The joint management of geological and hydrochemical data oriented the location of the interventions at the field scale. Following an accurate reconstruction of the geochemical peculiarities, a field test was designed to optimize the operating conditions.

The pilot test aimed to assess the potential mobilization of sorbed-mass and residual LNAPL (McCray et al. 2011; Sharma et al. 2020). The remediation strategy involves the injection of reagents into the aquifer through piezometers. The reagents consist of two parts: a desorbent part (PetroCleanze™) and an oxidizing part (Regenox™, Regenesis, San Clemente, CA). The desorbed fractions can be partially oxidized but mainly physically removed by pumping. Partial oxidation intended to "break" the longest hydrocarbon chains, making the hydrophobic contaminants (slightly degradable) more soluble and easily degradable (Besha et al. 2018; Cheng et al. 2017). The injection of the parts constituting the reagent was carried out during various phases of implementation of the test at the field scale. The injections were performed at the three points of the piezometric network. Figure 1 presents the stages and the configuration of the pilot test, in terms of quantity of injected product and injection pressure or rate of the different reagents.



PHASE	DATUM	PZ11	PZ15	PZI
Preliminary activities	Water Depth (m b.g.l.)	5,02	4,72	4,97
	Groundwater pH	6,72	6,73	6,84
Petrocleanze Injection 36 Kg of Petrocleanze 725 L of solution (5% dilution)	Injection Pressure (bar)	0	0	0
	Injection Rate (L/min)	26	21	20
	Injection Time (min)	35	36	40
Wash	Washing Volume (L)	100	100	100
	Injection Pressure (bar)	0	0	0
	Injection Rate (L/min)	26	25	20
	Injection Time (min)	4	4	5
Regenox Injection 36 Kg of Regenox 725 L of solution (5% dilution)	Injection Pressure (bar)	0	0	0
	Injection Rate (L/min)	25	15	11
	Injection Time (min)	45	55	*
Wash	Washing Volume (L)	100	100	100
	Injection Pressure (bar)	0	0	0-0,2*
	Injection Rate (L/min)	25	15	11-6*
	Injection Time (min)	4	7	*
Final activities	Water Depth (m b.g.l.)	2,32	3,53	3,55
	Groundwater pH	10-11	11-12	12

Fig. 1

Configuration of pilot test and location of injection piezometers (PZI, PZ15, PZ11)

Groundwater sampling followed three different phases of implementation of the field test (i.e., pre-injection, post-injection, and after pumping activities). The water samples were subjected to gas chromatography and mass spectrometry (GC-MS) analysis to obtain the chemical speciation of the hydrocarbons (Fiorenza et al. 2000).

In addition to monitoring and laboratory activities, time-lapse geophysical investigations played a specific role in keeping track of cleanup mechanisms. ERT was cased in monitoring the remediation process (e.g., Chambers et al. 2010; Ciampi et al. 2019b), at injection points. The aim of the field application during the pilot test was to check the process performance and the extent of the treatment, which may differ based on the site's geological features. Time-lapse changes in observed electrical resistivity of the subsoil are likely to be related to the presence of injected solutions if these have an electrical conductivity different from that of native groundwater. Similar approaches have been used in a variety of cases with different specific goals, but always ultimately linked to identifying pathways of solute migrations in the subsurface (e.g., Cassiani et al. 2006; Perri et al. 2012, 2018; Camporese et al. 2015; Busato et al. 2019).

The analytical monitoring of the piezometric network is intended to weigh the yield of the remediation technology used, thus indirectly assessing the performance and contribution of the intervention methodology. The pilot test was designed to ameliorate the layout of the intervention, to check its efficiency, and to calibrate the preliminary design of an optimized full-scale intervention.

Results

The 3D geological model

In the spill area, the most recent deposits are related to a Plio-Quaternary depositional sequence of alluvial sediments (Bini 2013), organized in two macro-levels: an upper (and more recent) level is characterized by gravels and sands with the presence of fine fraction (recent alluvia), extending to maximum depth between 4 and 6 m, and a lower level featured by gravel and sand in a silty-clay matrix (ancient alluvia), reaching a depth between 8 and 10 m. The two levels have a highly variable thickness and are separated by a discontinuous horizon of sandy-gravelly clays with hazelnut color (intermediate clays) of ca. 1–2-m thickness. The whole sequence overlies a thick layer of clays and silty clays (base clays); both the base and the intermediate clays possess hydrogeological characteristics of an aquiclude and aquitard, respectively (Orozco et al. 2021). The latter reaches its maximum thickness in the western sector while locally disappears to the east, where the mixing groundwaters hosted in the two aquifers (recent and ancient alluvia) occur. The local subsoil is characterized by the alternation of fine- and coarse-grained materials hosting a groundwater circulation, with a mean depth to the water table of about 5 m showing significant fluctuations throughout the year. The geological model presented in Fig. 2 uses a vertical exaggeration factor and a representation offset between the different stratigraphic levels to mark the lithological steps.

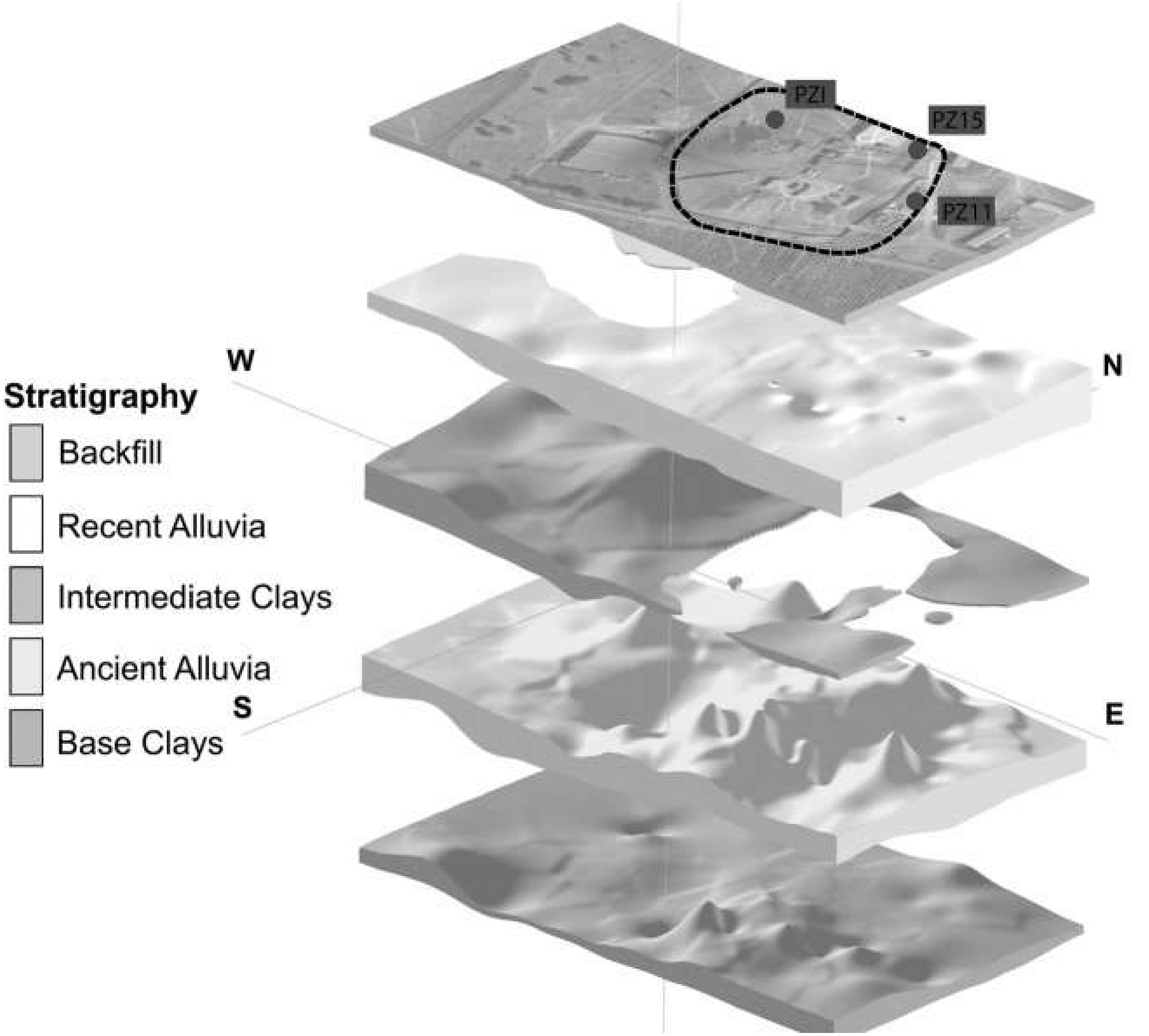


Fig. 2

Three-dimensional geological model (with vertical exaggeration) of the Decimomannu military airbase and location of injection points (PZI, PZ11, PZ15). The dashed line identifies the area used for the storage of fuel tanks

The 3D stratigraphic reconstruction reveals a different geologic context for the east and west portions of the model. In the eastern sector, the intermediate clays are absent while the alluvia are preponderant. In the western sector, the intermediate clays reach their maximum thickening at the site and the recent alluvia disappear. This inevitably affects the hydraulic properties of the system, delineating a more permeable zone to the east and a less permeable zone to the west.

Evolution of groundwater contamination

The reconstruction of the evolution of groundwater contamination status illustrates (1) the effects of pump-and-treat intervention over time, (2) the reduction of the total contaminant mass, and (3) a narrowing of the contaminant plume that progressively reaches an asymptotic trend (Truex et al. 2017) (Fig. 3).

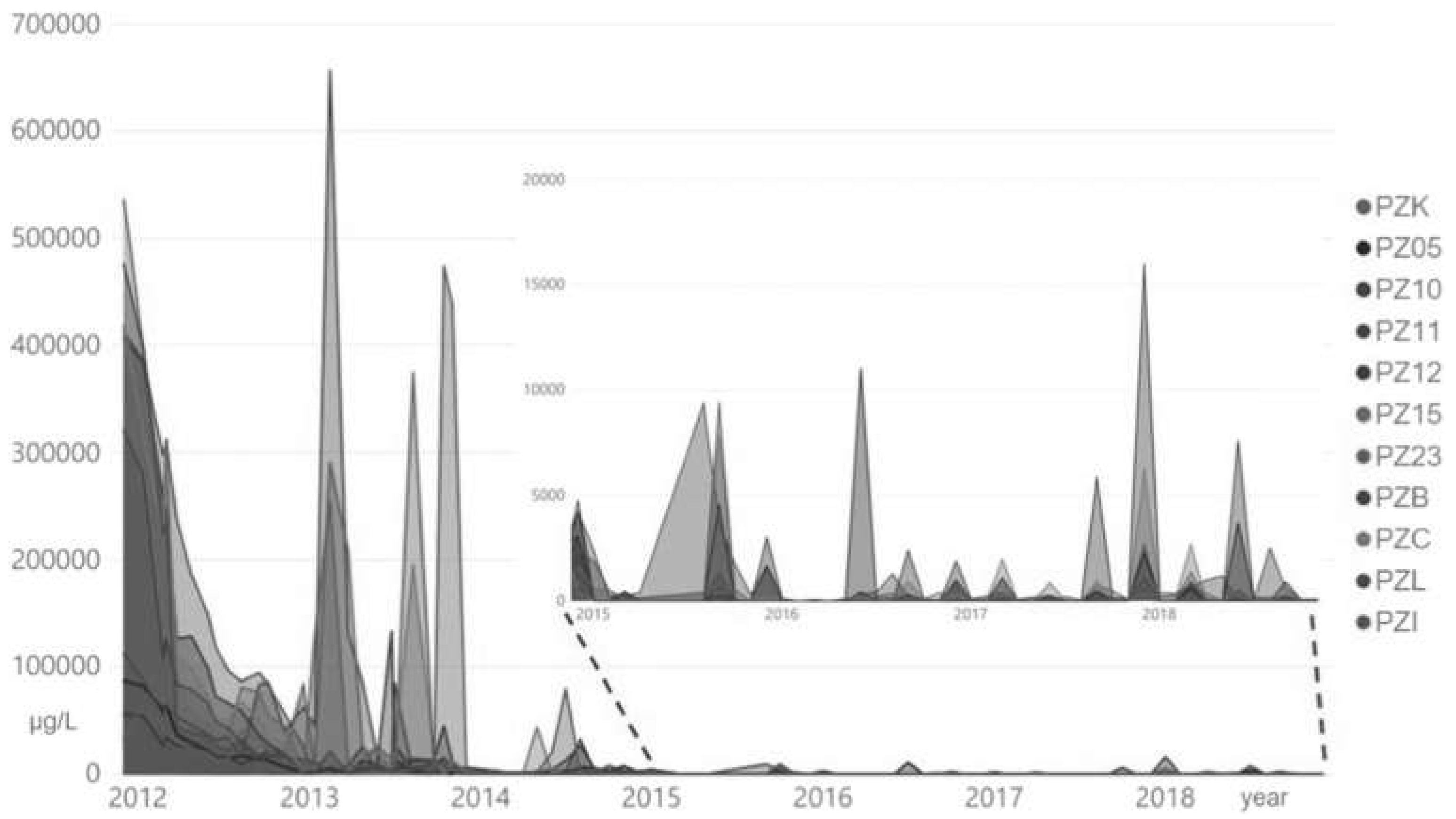


Fig. 3

Concentration of total petroleum hydrocarbons detected in the piezometers located inside the area used for the storage of the fuel tanks over time

The significant decrease in hydrocarbon concentrations over time suggests the aging of the contamination primary source (Atekwana and Atekwana 2010; Tran et al. 2018). This assertion is confirmed by the total absence of volatile organic compounds, such as benzene, ethylbenzene, toluene, and xylene, in the last years of monitoring (not shown here) (Trulli et al. 2016; Verardo et al. 2021). The recent measurement of hydrocarbon concentrations in groundwater reveals the presence of residual contaminants (Gatsios et al. 2018; Teramoto et al. 2020). They are considered not movable with the pump-and-treat technology being performed, due to the presence of phases adsorbed mainly to the less permeable portions of the aquifer and the occasional occurrence of LNAPL product in separate phase (limited thickness difficult to remove) (Lee et al. 2001; Lari et al. 2019a; Lari et al. 2019b).

Pilot testing

The zones selected for conducting the pilot test differ in terms of the presence or absence of the intermediate clay lens, which influences the hydraulic characteristics of the sediments below the airbase. In addition, the chosen areas recorded the highest contaminant concentrations in groundwater during the historical monitoring campaigns and a sporadic presence of supernatant thicknesses. Performing the test in areas affected by important historical contamination and a different geological setting provided valuable information to evaluate the efficiency of the implemented technology, furnishing insightful evidence about amendment and contaminant behavior in the subsurface. The results of the geophysical investigation reveal the reagent diffusion and the decontamination dynamics (Binley et al. 2010, 2015). The results of the ERT time-lapse surveys carried out in the two areas were expressed as resistivity changes with respect to the background. In particular, the results in correspondence to the long-term persistence 1 (LTP1) line (permeable zone), covering the PZ11 injection point illustrate a good diffusion of the second reagent in the aquifer shown by the light blue color in Fig. 4, as the injected solution is more electrically conductive than the resident groundwater (Morita et al. 2020).

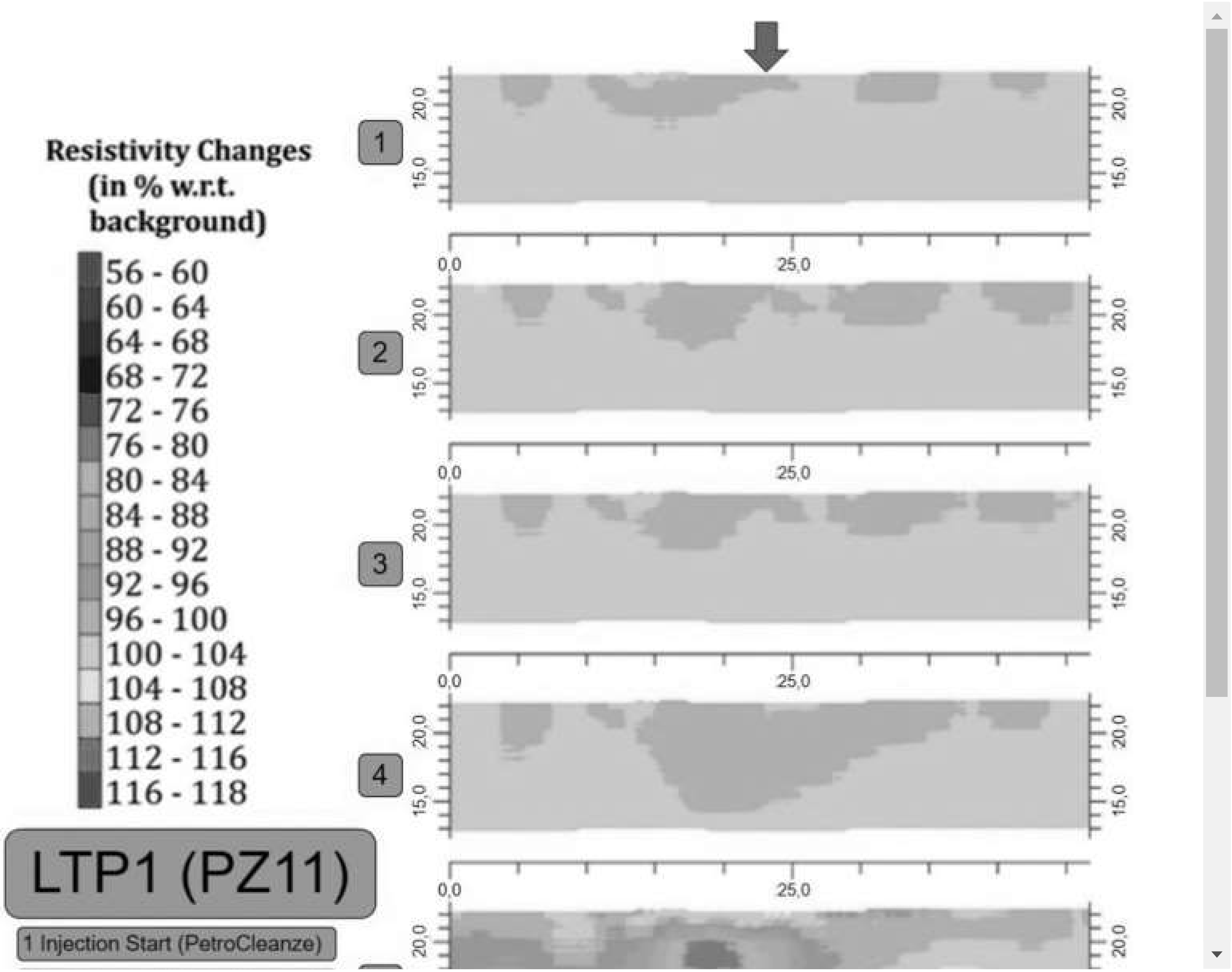


Fig. 4

ERT time-lapse results during different field test activities representing the LTP1 line, which covers the PZ11 injection point. The injection point corresponds to the vertical blue arrow

During the reagent injection activities, the product ascent along the PZI was observed (Fig. 1). The blue shallow anomaly in the ERT time-lapse imaging of the long-term persistence 3 (LTP3) line, covering the area of PZI (having a low permeability), reveals the ascent of the second reagent along the piezometric tube (Fig. 5). On the other hand, the red anomaly indicating the resistivity increase in Fig. 5 is likely to be linked to the mobilization of the contaminants desorbed from the solid matrix (Javanbakht and Goual 2016; Sharma et al. 2020). This assertion is confirmed by the chemical analysis executed on the water samples collected during the implementation of the field test. Monitoring performed on water samples, at the different phases of the pilot test, exhibits a substantial increase in post-application dissolved concentrations, with a subsequent decrease following the pumping activities. The data demonstrate how a considerable mass of contaminants was recovered and how the polluting load was reduced in the area of interest (Fig. 6).

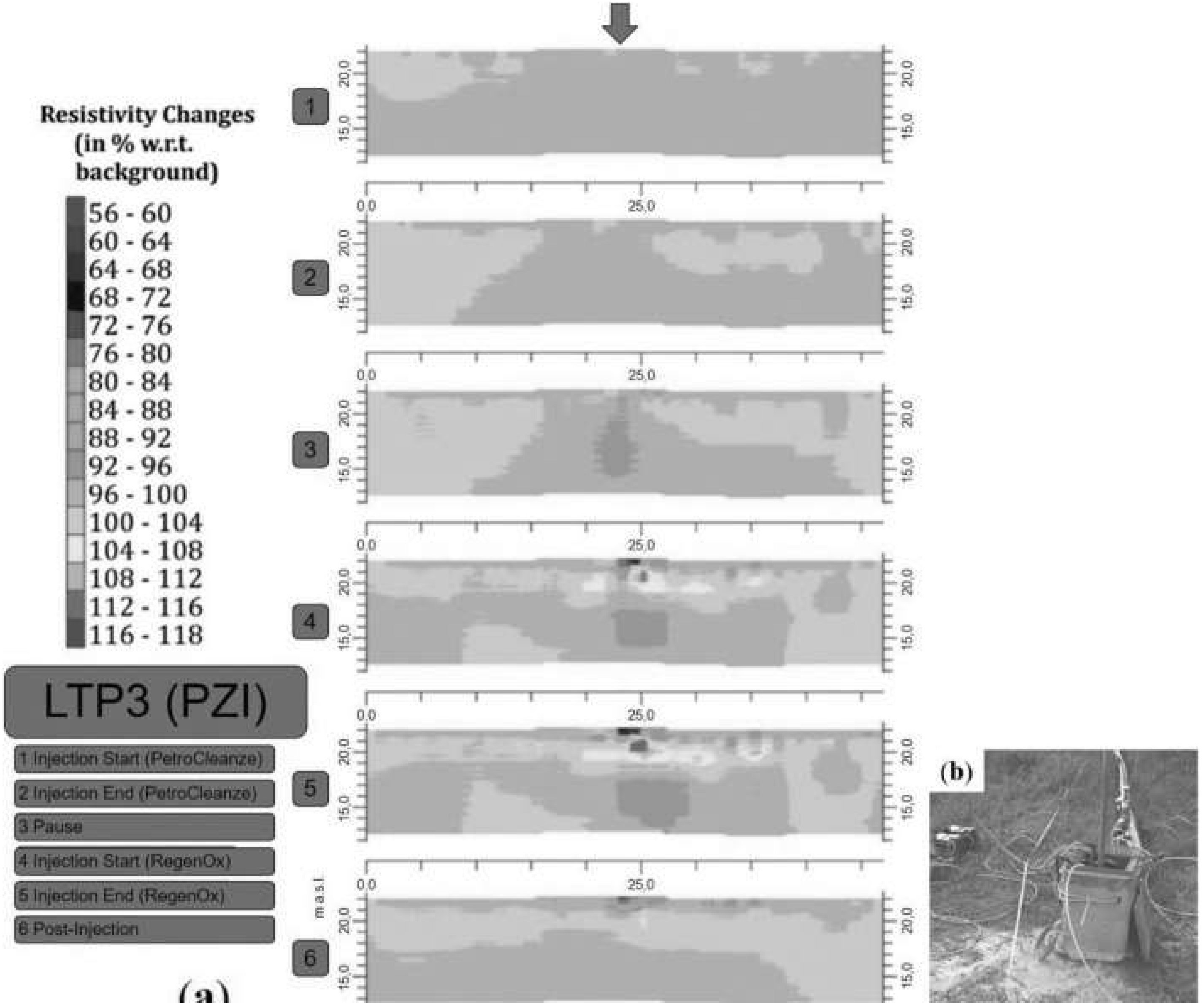


Fig. 5

ERT time-lapse results at different stages of reagent application corresponding to the LTP3 line, which covers the PZI injection point. The blue arrow indicates the injection point (**a**), the ascent of the product along the piezometric tube (**b**)

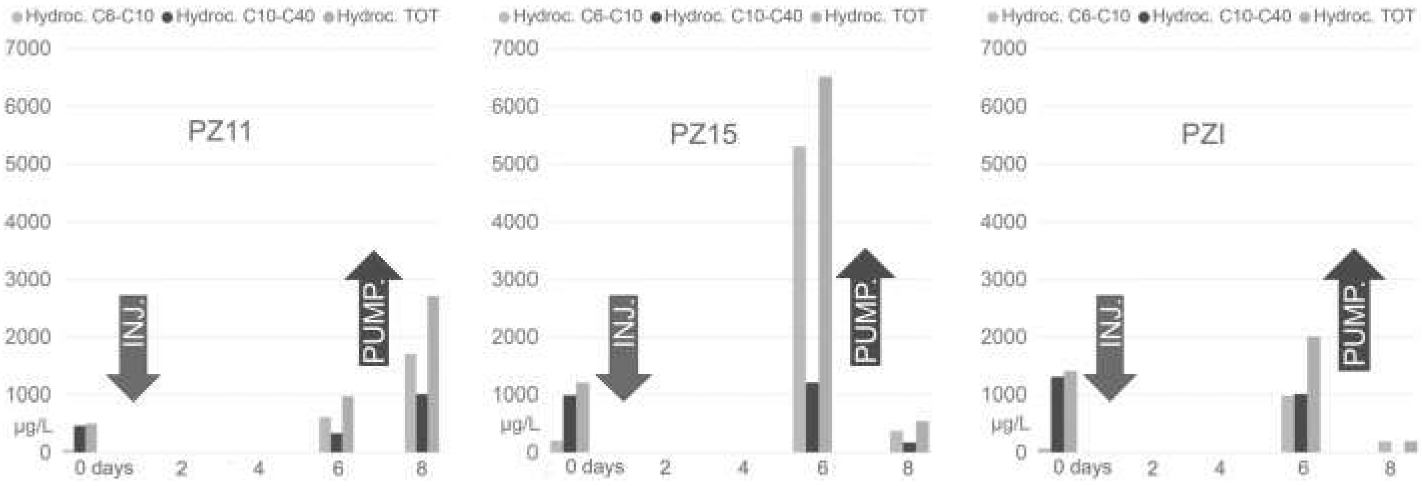


Fig. 6

Analysis of water samples recovered during the phases of the pilot test monitoring over time

Speciation analysis, by and large, revealed an increase in the shorter hydrocarbon chains, probably indicating the oxidative effect of the treatment, with partial rupture of longer chains (Tomlinson et al. 2017) (Fig. 7).

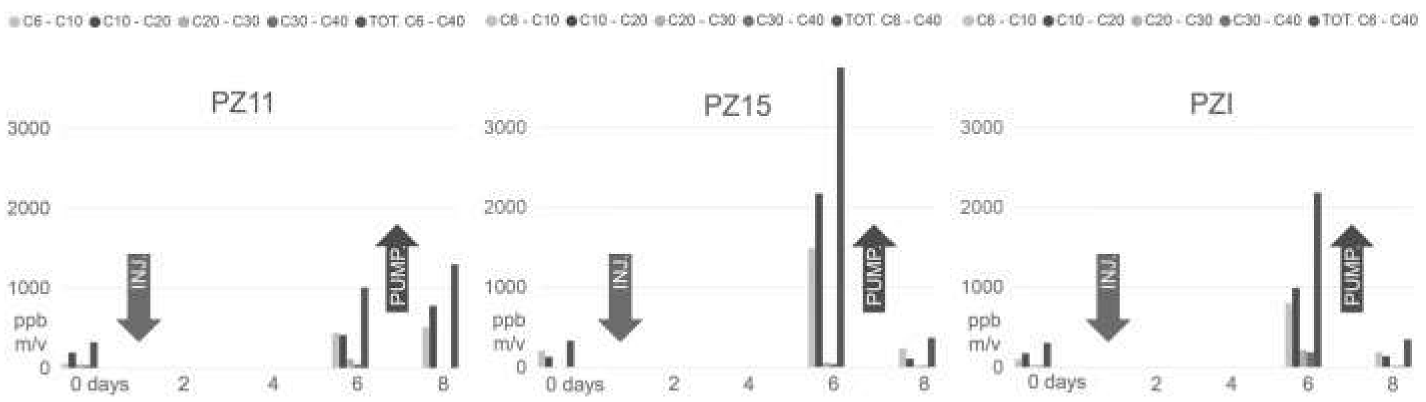


Fig. 7

Mass spectrometry and gas chromatography characterization of water samples recovered during the implementation of the experiment at the field scale over time

Discussion

The pilot test confirms the mobilization of petroleum products present in the residual phase, which constitutes the secondary source of contamination (Frollini et al. 2016; Teramoto et al. 2020; Verardo et al. 2021). The results obtained at PZ11 infer the occurrence of desorption and oxidation processes even after pumping activities (Besha et al. 2018; Sharma et al. 2020). This evidence provides a valuable indication concerning the site-specific reaction times, and this information will be used to optimize the full-scale intervention configuration. The presence of the hydraulic barrier does not bring issues concerning the possible migration of mobilized contaminants. The extracted water (in which the mobilization of the residual phase was provoked) was conveyed to the existing groundwater treatment plant (Brusseau 2019; Teramoto et al. 2020; Trulli et al. 2016). The monitoring data obtained during and after the test activities show the recovery of a significant mass of contaminants and highlight a reduction of the pollutant load in the application’s area. Data suggest a decrease in the effectiveness of pump-and-treat over time without coupling with technologies that favor the desorption of aged contaminants (Ossai et al. 2020).

The evolution of the concentration of total petroleum hydrocarbons (Fig. 3) detected in the piezometric network confirms that, at present, there is no dissolved plume of contamination. In a portion of the site corresponding to the primary spill events, a residual and insoluble fraction of hydrocarbons with a higher molecular weight remains (Lari et al. 2019b; Ossai et al. 2020; Teramoto et al. 2020; Verardo et al. 2021). This is occasionally “mobilized” and then captured during dynamic sampling activities (Javanbakht and Goual 2016; Sharma et al. 2020).

The results of the pilot test showed how it is possible to mobilize a fraction of this residual hydrocarbon phase (Besha et al. 2018; Sharma et al. 2020). The creation of "reactive" zones in the vadose and in the saturated zones favors the combined action of desorption of residual phase contaminants and oxidation of longer hydrophobic chains (Birnstingl et al. 2014; Lari et al. 2019b; Ossai et al. 2020). The mobilization capacity depends on the area of intervention and is strongly influenced by the different stratigraphic characteristics (Lari et al. 2020; Suthersan et al. 2016).

Geophysical methods represent valuable tools for monitoring the dynamics of decontamination processes that occur within the shallow subsurface (Binley et al. 2010, 2015). ERT measurements, especially performed in time-lapse modality, have furnished intriguing insights into the reactants' repartition in the saturated and unsaturated subsurface, which is greatly influenced by geologic inhomogeneity (Ciampi et al. 2019b). The physical variable of interest, i.e., electrical resistivity, is strongly related to state variables of key environmental interest (Lesmes and Friedman 2005). In the case considered here, the injected solutes (PetroClenze™ and Regenox™) are characterized by a good electrical conductivity (Birnstingl et al. 2014), generally higher than that of resident groundwater. Thus, it is relatively easy to track the injected amendments by using time-lapse ERT. Furthermore, geophysical investigations provide an estimation of the injection radius for each reagent, representing a tool for performance monitoring (Fan et al. 2017). The integrated use of geophysical measurements and chemical analyses is arguably the most effective means of explaining the contaminant-geophysical behavior. This physicochemical model links geophysical signals to contaminant characteristics within contaminated porous media. The coordination of the pilot test through the multidisciplinary and multitemporal data management model and the experimentation at the field scale are relevant indications for optimizing the selected strategy on a full scale.

The biggest constraint of this technique is related to the permeability of the sediments and the presence of preferential flow pathways, which affect the spreading of the product in the subsoil. Fine-grained deposits require low injection pressures to homogeneously redistribute the product or to avoid the rise of amendments along the piezometer. In the future, it is possible to envision combining this remediation technique with a more complex amendment distribution system. Groundwater circulation wells (GCW–IEG) (Ciampi et al. 2019a) could conceivably provide homogeneous product distribution due to the recirculation of fluids in the aquifer, by targeting underground portions classically unaffected by traditional extraction techniques.

Conclusion

Simultaneous data integration and the multi-source model enabled accurate pilot site selection and the implementation of innovative remediation approaches. Geophysical surveys and groundwater sampling during pilot testing evaluated the effectiveness of the intervention, both in terms of product diffusion capacity and effective reduction of pollutant concentrations. Time-lapse geophysical imagery throughout field experimentation yielded crucial insights, especially about where and how in situ remediation activities impacted distinct parts of the subsoil as a consequence of underground hydraulic inhomogeneity. Chemical analysis showed a significant recovery and a reduction of hydrocarbons, increasing the pumping system efficiency. The physicochemical model, which links geophysical signals to contaminant characteristics within contaminated porous media, was explained through the observation of contaminant-geophysical behavior. The mobilization of the immobile and residual material which constitutes the residual phase of hydrocarbons reveals the limitations of hydraulic barriers. Analysis of all data clearly shows that traditional extraction techniques are ineffective in removing secondary sources of fuel contamination. Our findings suggest that the desorption process using PetroClenze™ and Regenox™ can contribute significantly to the enhancement of hydrophobic pollutants' vacancy. When applied, this two-part reagent generates detergent-like properties, significantly increasing the desorption rates of hydrocarbons bound in saturated soils. Once the hydrocarbons are liberated into the dissolved phase, they are more readily available for removal using physical recovery techniques. The injections of PetroCleanze™ followed by contaminant extraction revealed a significant removal of residual LNAPL, acting as a chemical enhancer for pump and treat.

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Authors' contributions

PC, GC, CE, and MPP conceived and designed the methodological analysis of the research workflow regarding the integration of hydrogeochemical and geophysical data during pilot testing. GC and GPD acquired, collected, and analyzed geophysical data during reagent injection. PC, GC, and MPP curated the data and interpreted geophysical signals. PR managed the procedures for gas chromatography and mass spectrometry analyses. PC accomplished the modeling operations and the visualization of the results, while MPP, CE, GC, GPD, and PR validated and supervised the findings. PC prepared the original draft of the manuscript and GC participated in revising it critically for important scientific contents. MPP is the scientific coordinator of the research project. All the authors read and approved the final manuscript.

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Data availability

The data that support the findings of this study are available from the Italian Air Force and NATO, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the Italian Air Force and NATO.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Footnotes

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Contributor Information

Paolo Ciampi, Email: paolo.ciampi@uniroma1.it.

Carlo Esposito, Email: carlo.esposito@uniroma1.it.

Giorgio Cassiani, Email: giorgio.cassiani@unipd.it.

Gian Piero Deidda, Email: gpdeidda@unica.it.

Paolo Rizzetto, Email: paolo.rizzetto@am.difesa.it.

Marco Petrangeli Papini, Email: marco.petrangelipapini@uniroma1.it.

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Surfactant Technology Applications

Eric Daniels, Chevron Energy Technology Company, June 2008

Single Well Surfactant Treatments to Eliminate SPH Occurrence – Application Overview and Case Studies

Background:

Chevron has performed several pilot studies trials applying small scale low volume surfactant treatments in conjunction with a subsequent short-term vacuum extraction event, to determine if such treatments can be used cost-effectively to eliminate recurrence of floating separate phase hydrocarbon (SPH) in wells exhibiting minor SPH thickness. This application of surfactants differs significantly from the large scale aggressive remediation surfactant application (*SEAR*) described below. The single well surfactant application is designed to be a low-cost treatment to enhance the effectiveness of short-term (8 to 24 hour) mobile short-term extraction event (variously referred to as “EFR”, “MxT”, or more generally, mobile vacuum truck extraction treatments) for LNAPL recovery and SPH elimination in treated wells.

The cost objective for single well surfactant treatments is expected to be under $20,000 in addition to the typical mobile vacuum truck extraction treatment cost. The objective of the surfactant application is to reduce LNAPL saturations in the near-wellbore vicinity of monitoring wells exhibiting minor (few inches or less) SPH occurrence, sufficient to eliminate recurrence of SPH in these monitoring wells, in cases where eliminating SPH recurrence is the primary remedial driver at the site, and where LNAPL recoverability by other remedial alternatives will be limited and not cost-effective. The objective of these treatments is not to achieve source area wide soil LNAPL remediation, nor significant dissolved concentration reduction.

Site characteristics where single well surfactant applications are likely to be beneficial and cost-effective include the following:

1. Sites where remedial drivers are purely regulatory and site is considered to be a “low risk” category site, and with no sensitive receptors drivers, nor potential sensitive receptors near the site, such as surface water bodies or water supply wells adjacent to impacted area.
2. Sites where no further action, no further active remediation, closure, or significant reduction in site management costs would be achieved based solely on SPH recurrence elimination, and no dissolved concentration reduction required. (Remedial driver and cost driver is primarily SPH elimination rather then dissolved plume concentration reduction and remediation.)
3. Hydraulic containment is not required (no sensitive receptor impacts or driver; LNAPL plume is stable and immobile)
4. SPH occurrence at the site is relatively limited in areal extent and in maximum SPH thickness (such as one or a few wells with intermittent or consistent SPH occurrence of up to a few inches).
5. Other remedial alternatives (MPE, skimming or pumping) for managing or eliminating SPH occurrence in wells will not be cost effective, and/or are not

required or cost-effective for achieving other (dissolved concentration) remedial objectives.
6. Sites where agency is requiring or requesting mobile vacuum truck events to recover product and eliminate SPH occurrence.

Why single well surfactant treatments?
Surfactants have been demonstrated to be able to enhance effectiveness of LNAPL recovery and SPH elimination in wells via groundwater extraction, due to their ability to mobilize LNAPL at relatively low soil saturations. Short-term vacuum extraction events can recovery significant LNAPL in cases where LNAPL is at relatively high saturation and mobility. However, as LNAPL saturation approaches the irreducible saturation and LNAPL becomes largely immobilized in the soil, short-term vacuum extraction events becomes ineffective for LNAPL recovery and further reducing and eliminating SPH occurrence in wells. Therefore, while fluid extraction events can significantly reduce SPH thickness over time, these alternatives have very low success in eliminating SPH occurrence in wells, and are not cost-effective for achieving LNAPL recovery/ elimination remedial objectives when SPH thicknesses reach de minimus values, and/or SPH occurrence is intermittent over time due to groundwater table fluctuations. Surfactants usage costs (unit volume costs and volumes used in these treatments) are relatively low. Therefore, surfactant pre-treatment of near-wellbore soil prior to the fluid extraction event is a potentially cost-effective method to temporarily increase the mobility of residual LNAPL in the soil and thereby enhance effectiveness of LNAPL recovery during fluid extraction. The resultant reduction of LNAPL saturations to very low irreducible values during a subsequent short-term groundwater extraction event can eliminate SPH recurrence in that well. Because some LNAPL is likely to remain in the soil after the treatment, dissolved concentration reduction should not be considered an objective of this treatment.

Overview of Implementation:
- Selection of sites for use of single well surfactant treatments is a critical first step, and should include review of remedial drivers and objectives, and remedial alternatives, that include those criteria outlined above.
- Surfactants used in the field are/should be non-toxic, food grade, non-ionic and biodegradable. Several commercially available surfactant formulations are available that have been tested and used in the field, and formulated to work with gasoline and diesel. The surfactant chemical costs are very low. Therefore if the surfactant formulations already tested and successfully applied in the field can be obtained for use, no benchscale testing is required or recommended to determine the optimal surfactant formulation for use in these treatments. Be aware that regulatory agency may require such benchscale treatability testing before permitting field treatment.
- Surfactant treatments generally include the following elements
    - A surfactant solution with 4% by volume surfactant concentration in water; mixed onsite in a batch tank
    - **Application of 50 to 250 gallons of surfactant solution in SPH bearing well, which is introduced into the near-wellbore via gravity feed.**

    <u>Surfactant solution should not be injected under pressure, to minimize potential outward displacement of LNAPL in the soil.</u> The concept is to soak the soil with surfactant such that the LNAPL is contacted and enveloped, but not displaced, by the introduced surfactant. The actual volume injected is determined in the field by monitoring surrounding existing monitoring wells. If/when surfactant solution is observed in nearby wells (visual monitoring of periodic samples from surrounding monitoring wells), surfactant injection should cease. Surfactant injection should not be followed by subsequent injection of any fluid for any reason, including to "overflush" surfactant and expand the radius of influence of the surfactant.
  - The surfactant solution is allowed to soak the soil overnight, and groundwater extraction is commenced on the following day using a vacuum truck or pumps. At least three times the volume of injected solution should be extracted (4x is recommended). Extracted water should be sampled periodically or measured at end of extraction, to collect samples for dissolved concentration analysis and quantification of LNAPL recovered. Extraction should continue beyond the minimum volume if LNAPL is observed in the water, until LNAPL is no longer observed.
  - If well is high yield, and there is a long screen in the well where the lower interval of the well is across unimpacted soil, a inflatable packer can be used to help focus injection and extraction into the LNAPL-impacted upper portion of the screen interval.
  - Surrounding monitoring wells should be periodically monitored to visually observe for occurrence of LNAPL and surfactant solution. The field test for presence of surfactant is currently a qualitative visual analysis, based on observation of suds when a sample is shaken vigorously in a sample bottle, or via use of a methelene blue (MBAS) test kit. Improved field methods for surfactant quantification are currently being sought.
  - It is not recommended to install new monitoring wells for purposes of observation, injection or extraction, nor to perform any pre- and post-soil observation data collection
  - The treated well and surrounding monitoring wells should have groundwater gauging and SPH occurrence monitoring performed prior to surfactant application, immediately following conclusion of surfactant injection, immediately prior to extraction, several samples periodically during the injection and extraction treatment, immediately following cessation of extractions, weekly for one month following extraction, monthly for three months following extraction, and then quarterly for at least one year following the treatment.
  - The remediation success metrics should be based solely on recurrence of SPH in wells. No soil and groundwater concentration objectives should be set. No soil monitoring is recommended.
- Due to relatively new and "innovative" status of this technology application, regulatory approval continues to be an important part of the ability to implement these surfactant treatments.

- Project team should work with ETC, other EMC project teams, and outside vendors who have successfully negotiated implementation of low-cost surfactant treatments, to get input on surfactant treatment workplans and response strategies for agencies.
- Agency responses requiring onerous workplans that significantly increase the expected cost of the surfactant treatments, particular for extensive pre- and post-monitoring requirements, soil monitoring, installation of new wells, and multi-well injection-extraction protocols, need to be carefully considered. If total treatment costs will be significantly greater than $25,000 for the treatment due to agency scope expansion requirements, project team should consider other LNAPL management alternatives that may be more cost-effective than implementing the surfactant treatments.

Chevron Case Studies of Single-Well Surfactant Treatment Applications

Surfactant treatments at three EMC MBU sites in California have been conducted. At each site, one well contained SPH of up to 6” in thickness. Vacuum truck extraction events have previously been applied, and SPH recurrence was observed following those events. Sites were considered low risk, and SPH elimination in the wells was the primary driver for active remediation. Surfactant treatments were conducted generally in accordance as outlined above. Total costs were in the range of $15,000 to $25,000, with the higher end of costs driven by the need for several days of groundwater extraction to meet the minimum extraction volume (3x the injected volume) proposed in the workplan.

Results:

In 2005, the first application was tested at a site in Antioch, CA. Approximately 500 gallons of a 4% surfactant solution (supplied by Environmental Chemical Solutions, Inc, called “Accelerate +”, and also sold commercially as “GoldCrew”) was gravity fed into monitoring well MW-2, which had previously exhibited SPH thickess up to 1”. Monitoring wells at 20, 30 and 50 feet away from MW-2 were monitored during and following injection and extraction.

Stable and consistent thickness of measureable product was observed in MW-2 at the cessation of surfactant injection and immediately prior to extraction on the following day. Surfactant was observed to have reached the wells at 20 ft and 30 ft distance, however, no LNAPL was observed in any of the perimeter wells. Long-term monitoring of the surrounding wells indicated no change in dissolved BTEX concentrations. These observations together indicated that no LNAPL was mobilized outward away from the near-wellbore soil of the treated well.

Approximately 1,600 gallons of water was extracted from MW-2. Small volumes of LNAPL was observed in samples during the initial portion of the extraction event. A total of approximately 11 lb of hydrocarbon mass was estimated to have been recovered during extraction, although this is based on a few samples, and the total mass accumulated in the vacuum truck tank cannot be measured.

At the conclusion of extraction, no SPH was observed in the well, nor in extracted groundwater. Following the treatment, the weekly, monthly and then quarterly monitoring have indicated no recurrence of SPH in MW-2 through the current monitoring period in 2008. Dissolved concentrations of TPH and benzene decreased progressively by one to two orders of magnitude over several quarterly monitoring periods. Benzene decreased from 1,000 ppb immediately following treatment (SPH was observed prior to treatment, so no pre-treatment dissolved concentration data is available), and is currently averaging less than 50 ppb (fluctuating from 3 ppb to 150 ppb).

In October and November 2007, similar surfactant treatments as described for Anitoch site were conducted at a site in Oakland, CA and a site in Alturas, CA. These are only briefly summarized here, and are too recent to use to evaluate of long-term treatment effectiveness in reaching SPH elimination objectives.

- 350 gallons of surfactant were injected into well MW-1 at the Oakland site which has exhibited persistent SPH of up to 6". Approximately 1,300 gallons of water was extracted from the wells, and approximately 1 lb hydrocarbons was estimated to have been recovered. No SPH or dissolved concentration change has been observed in the surrounding monitoring wells. The treated well has exhibited no recurrence of LNAPL since the treatment, and dissolved concentrations have decreased, though not significantly.

- Only 15 gallons of surfactant solution was injected into well MW-5 at the Alturas site (persistent SPH of up to 6") due to rapid observation of surfactant in nearby monitoring well. Approximately 600 gallons of water was extracted from MW-5, and approximately 0.05 lb hydrocarbon estimated to have been recovered during extraction. SPH was not observed in the well for the first three weeks after the treatment. SPH observed during one post-treatment monitoring event (0.03 ft thickness) approximately four weeks after the treatment, but has not been observed in this well since then.

Summary:
The Antioch site has met all success metrics for the treatment. For the Alturas and Oakland sites, several more quarterly monitoring periods are required to evaluate the long term effectiveness of the surfactant treatments in eliminating SPH recurrence. Agency negotiations for implementation of these treatments was relatively long in some cases (up to two years between initial workplan submission and agency permission to proceed for Alturas), and required to some extent project team, vendor, and ETC technical assistance to work with agency to alleviate concerns about potential LNAPL mobilization and initial agency reaction to require more extensive monitoring than project team believed adequate. Agencies finally agreed to the limited monitoring recommended herein, using existing monitoring wells and conventional groundwater monitoring (lab analysis, and visual field observations). The extent of monitoring carried out at these pilot sites has been sufficient to demonstrate that no LNAPL source was mobilized away from the delineated areas using the recommended surfactant applications described here.

Workplans and agency negotiations are currently underway for similar surfactant treatments at other EMC MBU sites.

Similar successes have been reported by other companies for SPH elimination in monitoring wells, using similar low-volume surfactant pre-treatments in conjunction with vacuum truck extraction events. Overall, the results of case-study reports available suggest that single well small volume surfactant pre-treatments in conjunction with mobile vacuum truck extraction events can be a cost effective method to eliminate SPH recurrence in monitoring wells.

Pilot tests for surfactant applications to reduce dissolved petroleum hydrocarbon concentrations

Importantly, there have been numerous reports of companies applying similar single well low-volume surfactant treatments to achieve dissolved concentration reduction objectives. These have largely failed to achieve significantly concentration reduction targets, or required multiple treatment events to achieve targets. In conjunction with the large-scale SEAR surfactant flush treatments described above, the data generally suggests a high risk of failure for using surfactant treatments to achieve rigorous LNAPL source remediation sufficient to result in significant dissolved concentration reduction and source area remediation, regardless of volume of surfactant applied.

Chemical vendor sources for surfactants recommended for use in in-situ LNAPL recovery treatments:

Recommended Surfactant Products

The product used in the California MBU site pilot tests has been **Gold Crew Accelerate +** from ECS.

Product: Gold Crew Accelerate + (REM-E002)
Manufacturer and distributor: Environmental Chemical Solutions, Washington, USA
(877) 253-2665 **www.ecschem.com**

Chevron has not tested use of surfactant product from EnviroClean, but their surfactant product can be considered as it has been used by others with success. Both products would be expected to yield the same efficacy for enhancing product recovery, they have both been tested and optimized in the lab for use on gasoline and diesel product recovery. As the name suggests, EnviroClean has focused on clarifying that their product is “green” and nontoxic for in-situ use.

Product: EnviroClean (EC-165)
Manufacturer: EnviroClean Products, LLC, Oklahoma, USA
Distributor: Bio-Protect, Hidalgo, TX, USA (956) 843-5221 **www.bioprotect.net**

Aggressive Remediation Technology Application of Surfactants – Surfactant Enhanced Aquifer Remediation (SEAR)

Surfactant Enhanced Aquifer Remediation (SEAR) is a large-scale aggressive remediation surfactant application, in which large volume of surfactants are flushed through LNAPL-impacted soil horizons in a waterflood displacement process to sweep and recover mobile and residual LNAPL out of the soil. The objective is to enhance the effectiveness of LNAPL recovery via groundwater total fluids pumping extraction technology to achieve plume wide LNAPL soil source area remediation and significant dissolved contaminant concentration reduction. A patterned array of injection and extraction wells is installed across the LNAPL source area; surfactant-laden water is injected in some wells, and groundwater is extracted from other wells. The surfactants enhance the displacement efficiency of LNAPL by water, and groundwater extraction is used to contain and recover mobilized LNAPL, surfactant injectant, and contaminated groundwater. Generally at least 1 pore volume of surfactant fluid is swept through the impacted aquifer zone source area during these treatments over several months of operation.

Because LNAPL is intentionally mobilized by the process, hydraulic containment and capture of source area groundwater contacted by surfactant is essential. Unintentional LNAPL mobilization outside of the delineated source area is a significant risk particular to surfactant (or solvent) flushing remedial treatments that could result in significant increased site management liability, costs, and stakeholder visibility.

Surfactant (SEAR) Case Study (Surbec):
Chevron has not implemented a SEAR application in the field because in Chevron cases where this alternative has been considered to date, other remedial alternatives were considered more cost-effective. The SEAR case study presented below is one performed at a former service station in Golden, OK for the Oklahoma Corporation Commission, and documented in several technical conference presentations.

Background:
Former service station site had a LNAPL plume footprint (45,000 sq ft) across the site, delineated by approximately 25 monitoring wells with floating separate phase hydrocarbon (SPH) from 1' to 3' in thickness. Other monitoring wells in the source area exhibited elevated dissolved benzene concentrations of 10 to 20 mg/l, indicative of significant LNAPL source. LNAPL impacted soil consisted of a 6 to 10 ft interval containing silts, silty gravels, and silty clays.

Why SEAR?
Several other aggressive remedial alternatives had been implemented at the site without success, including AS/SVE and total fluids pumping. The Oklahoma Corporation Commission received a presentation about Surbec's SEAR technology, and allowed Surbec to implement a SEAR application at the site as a field pilot test to evaluate the technology.

Overview of Implementation:
Laboratory benchscale tests were performed to select the most cost effective surfactant solution (mixture of types of surfactants, surfactant concentrations, and aqueous solvent composition) for use in the field. Optimization of surfactant application cost included 1) use of lowest total surfactant concentration that would yield desired reactivity (low oil-water interfacial tension), 2) food-grade non-ionic surfactants that are non-toxic, biodegradable, and have no reactivity with soil matrix sediments, and 3) a recirculating water treatment system that recycles the surfactant to minimize the amount of surfactant chemical used in the treatment.

A gridded patterned array of injection and extraction wells (approximately 50 remediation wells spaced 20’ to 30’ apart) was installed over a 200’ by 280’ area covering the LNAPL footprint. Approximately 190,000 gallons (roughly 1 pore volume) of a 1% surfactant solution was flushed through the impacted interval over a two month period. Monitoring well sampling and observations were conducted for several months following the cessation of surfactant flushing.

Results:
6,500 gallons of gasoline LNAPL was recovered during the treatment. Post SEAR monitoring indicated that LNAPL occurrence was eliminated in 22 of the 25 SPH bearing wells, the other three exhibited LNAPL sheens. A second small SEAR flush was used to eliminate LNAPL sheen in the three monitoring wells exhibiting sheens. A follow-up monitoring event several years after the SEAR treatment found sheens in two monitoring wells in the core of the source area at the site. Benzene concentrations were reduced by 1 to 2 orders of magnitude in many wells; a few wells exhibited no concentration reduction, and a few exhibited 3 orders of magnitude reduction. However, post-treatment benzene concentrations of approximately 1 mg/l or higher were observed in a large fraction of the source area monitoring wells, indicating that residual LNAPL source still remained in the soil after surfactant treatment. No LNAPL mobilization outside of the treatment area was observed in perimeter monitoring wells during or following the test.

Cost:
Total project costs were $712,000, with estimate of $36/cu yd of impacted soil, based on treatment area and thickness of treated interval.

Summary:
The SEAR treatment was able to meet the objective of LNAPL elimination in most wells, but did not remove sufficient LNAPL source mass to meet stringent dissolved concentration reduction objectives. Results indicate that residual LNAPL source mass remained in the treated soil. Based on this study and subsequent SEAR pilot tests, Surbec (as well as other practitioners of SEAR treatment) acknowledge that SEAR treatment alone is not likely to achieve ppb-level dissolved concentration objectives, and recommends combining SEAR with subsequent second type of aggressive technology application (ISCO) to achieve groundwater remedial objectives. ISCO treatment (cost $150,000) was implemented at the Golden, OK site following the SEAR treatment,

although no data was provided on the dissolved concentration reduction achieved from the ISCO treatment.

Subsequent Surbec SEAR Tests Summary:
Surbec has recently reported on four additional SEAR projects conducted at Oklahoma LUST sites (Bixby, Douglass, Bristow, and Holdenville). These pilot studies were similar in design, objective, and results to the Golden site case study. Surfactant treatments involved flushing of roughly 1 to 1.5 pore volumes of surfactant solution through impacted soil via gridded pattern of closely spaced injection and extraction wells over 1 to 6 month periods. Post-treatment monitoring indicated elimination of LNAPL recurrence in all wells (except Douglass site, where SPH recurrence was eliminated in 10 of 11 SPH-bearing wells). Benzene concentrations were reduced to variable extent (data not provided for these sites), however, presentations document that 1 mg/l or higher benzene concentrations remained in source area monitoring wells after SEAR treatment, indicating SEAR was not successful in source-area wide residual LNAPL source remediation. Cost for treatment ranged from approximately $260,000 at Bristow and Bixby sites (relatively small treatment areas) to $1,453,000 at Douglass site (with a LNAPL source area footprint roughly similar in size to Golden site).

APPENDIX B

REGENESIS

Remedial Cost Proposal

To: Rory Galloway
roryg@g-logics.com
From: Brittain Griffiths
bgriffiths@regenesis.com 916.587.3098

7/12/2021
Proposal No. BRG64692

Subject: ***Pilot Test w/ Petrocleanze***

Site: *Boeing Field Chervon Pilot Test*

Location: Tukwila, WA

Applicable Product(s)	**Link(s) to View/Download Product Info**
PetroCleanze®	PetroCleanze

REGENESIS is pleased to present you with this design and cost estimate for the proposed treatment at your site utilizing the remediation technologies presented above. Included within this document you will find the following attachments supporting the proposed approach:

- Map Depicting Treatment Area
- Remedial Design and Cost Estimate
- Product Technical Sheet(s)
- Suggested Performance Monitoring Parameters
- Standard Assumptions
- Terms and Conditions

Remedial Approach

In the 200 square foot area in the upper zone around IP-4 we recommend the addtion of 2,720 lbs of Petrocleanze via three applications. The injection should occur from 9 to 18 ft bgs. Prior to applying the Petrocleanze we recommend free product be physically extracted from the IP. Following the extraction event inject Petrocleaze (Petrocleanze is a combination of RegenOx Part A and Petrocleaze activator) into 3 points spaced 8 ft on center (see attached spreadsheet for injection details). TEN DAYS to TWO WEEKS following the injection return to the site for a physical extraction event followed by injection number two. On the second application offset the 3 injection points by 4 feet. TEN DAYS to TWO WEEKS following application number 2 return to the site for a physical extraction event followed by application three. Once again offset the injection points on application number 3. TEN DAYS to TWO WEEKS following application 3 return to the site for a physical extraction event. *Many clients will take a small glass jar and take physical samples of the water prior to and following each application. You should see the water change from a dark oily color to relatively clear following application number 3. I recommend sampling prior to each application and two to four weeks following the third application.*

Product Requirement and Cost

2,720 lbs of Petrocleanze (RegenOx Part A = 1,320 lbs Petrocleanze Activatore = 1,320 lbs) x $3.09 = $8,404.80 plus shipping and sales tax.

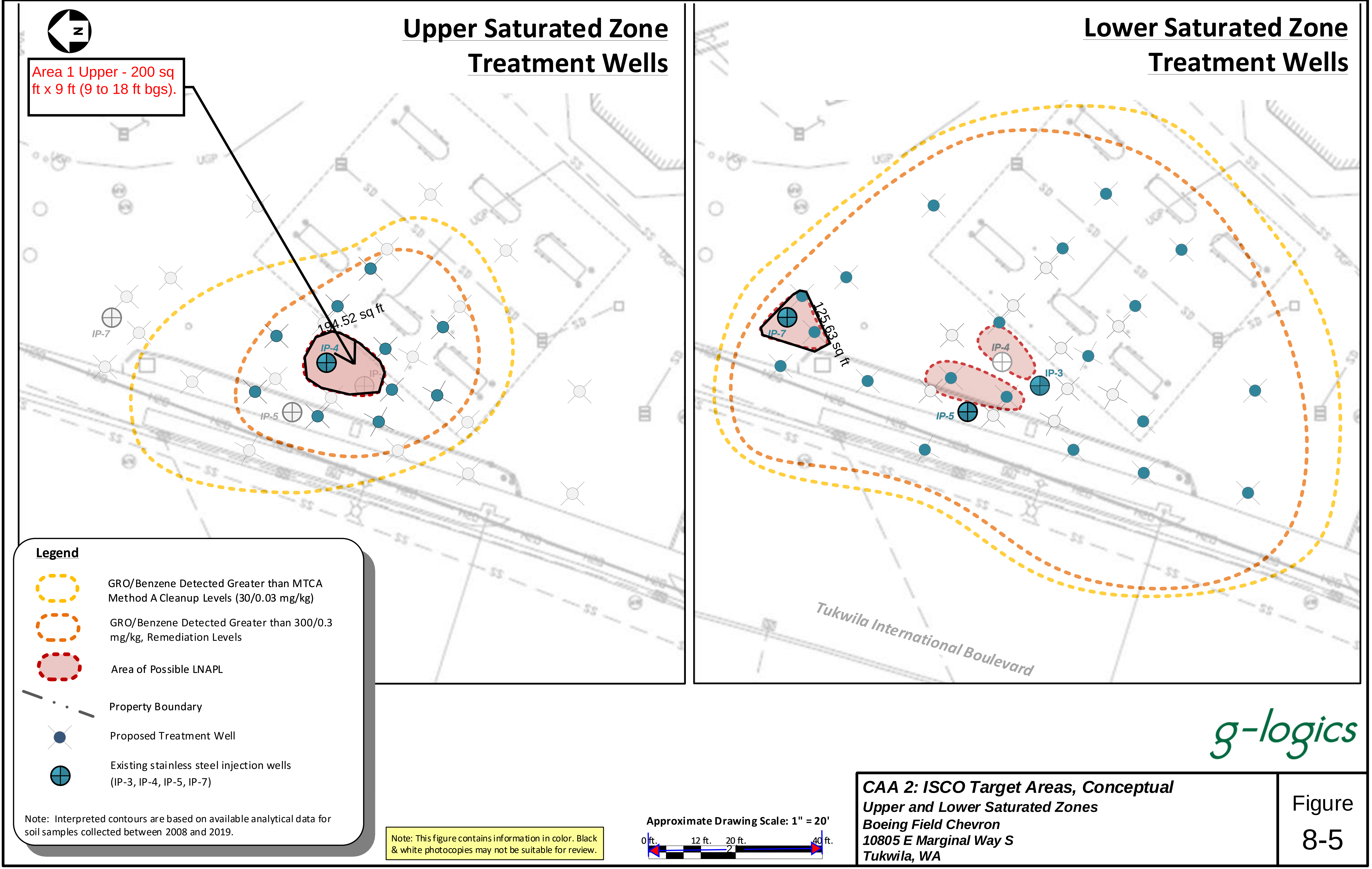
Assumptions

In generating this design proposal REGENESIS relied upon professional judgment and site specific information provided by others. Using this information as input, we performed calculations based upon known chemical and geologic relationships to generate an estimate of the mass of product and subsurface placement required to affect remediation of the site. The attached design summary tables specify the assumptions used in preparation of this technical design. We request that these modeling input assumptions be verified by your firm.

REGENESIS developed this Scope of Work in reliance upon the data and professional judgments provided by those whom completed the earlier environmental site assessment(s). The fees and charges associated with the Scope of Work were generated through REGENESIS' proprietary formulas and thus may not conform to billing guidelines, constraints or other limits on fees. REGENESIS does not seek reimbursement directly from any government agency or any governmental reimbursement fund (the "Government"). In any circumstance where REGENESIS may serve as a supplier or subcontractor to an entity which seeks reimbursement from the Government for all or part of the services performed or products provided by REGENESIS, it is the sole responsibility of the entity seeking reimbursement to ensure the Scope of Work and associated charges are in compliance with and acceptable to the Government prior to submission. When serving as a supplier or subcontractor to an entity which seeks reimbursement from the Government, REGENESIS does not knowingly present or cause to be presented any claim for payment to the Government.

Closing

Please feel free to contact me if you need additional information or have any questions regarding our evaluation and/or this correspondence (contact info listed above). Thank you for considering REGENESIS as part or your remedial solution for this project.



Note: This figure contains information in color. Black & white photocopies may not be suitable for review.

Approximate Drawing Scale: 1" = 20'

0 ft. 12 ft. 20 ft. 40 ft.

g-logics

CAA 2: ISCO Target Areas, Conceptual
Upper and Lower Saturated Zones
Boeing Field Chevron
10805 E Marginal Way S
Tukwila, WA

Figure
8-5

Project File: 01-0410-M F8-5 ISCO Target Area.vsdx

Mapping References: PLS Survey 2016, Tukwila Public Utility Documents, G-Logics Field Measurements, Previous Site Reports and Collected Analytical Data.

REGENESIS

RegenOx® PetroCleanze Application Design Summary

Upper Zone - Pilot Test

Plume

Application Method	**Direct Push**
Spacing Within Rows (ft)	8
Spacing Between Rows (ft)	8
Injection Points (per app.)	**3**
Number of Applications	**3**
Areal Extent (square ft)	200
Top Application Depth (ft bgs)	9
Bottom Application Depth (ft bgs)	18
Total PetroCleanze to be Applied (lbs)	**2,720**
RegenOx Oxidant Part A (lbs)	1,360
PetroCleanze Part B (lbs)	1,360
Oxidant Part A Solution %	5%
Volume Water (gals)	**3,096**
Total Solution Volume (gals)	**3,305**
Total PetroCleanze per App (lbs)	*907*
Part A per App (lbs)	*453*
Part B per App (lbs)	*453*

Field App. Instructions

Add Part A to water, mix until dissolved, then add Part B and mix until dissolved.

Field Mixing Ratios
Water per Pt per App (gals)
344
Part A per Pt per App (lbs)
151
Part B per Pt per App (lbs)
151
Total Volume per Pt per App (gals)
367

Volume per vertical ft gals)

41

Technical Notes/Discussion

Recommended Extraction Volume = 120% of injection Volume.

Total Extraction Volume (gallons) =	3,966
Extraction Volume per Event (gals) =	1,322

The objective of the extraction program should be to remove the injected volume of PetroCleanze plus the contaminated fluids (water, dissolved phase hydrocarbons, emulsions and/or non-aqueous phase) occupying the pore volume in the designated treatment zone. The suggested minimum target extraction volume on a per-event basis is specified as follows. Due to the high variability of saturated zone yield rates commonly observed, this volume should be considered an estimate which can be refined during implementation of the initial injection/extraction cycle. Further guidance on the extraction process is contained as an attachment.

Extraction wells should be situated in close proximity to the areas showing the highest baseline sorbed phase mass concentrations. The screened interval of these wells should be matched to the vertical zone exhibiting the highest contaminant concentrations.

Assumptions/Qualifications

In generating this preliminary estimate, Regenesis relied upon professional judgment and site specific information provided by others. Using this information as input, we performed calculations based upon known chemical and geologic relationships to generate an estimate of the mass of product and subsurface placement required to affect remediation of the site.

REGENESIS developed this Scope of Work in reliance upon the data and professional judgments provided by those whom completed the earlier environmental site assessment(s). The fees and charges associated with the Scope of Work were generated through REGENESIS' proprietary formulas and thus may not conform to billing guidelines, constraints or other limits on fees. REGENESIS does not seek reimbursement directly from any government agency or any governmental reimbursement fund (the "Government"). In any circumstance where REGENESIS may serve as a supplier or subcontractor to an entity which seeks reimbursement from the Government for all or part of the services performed or products provided by REGENESIS, it is the sole responsibility of the entity seeking reimbursement to ensure the Scope of Work and associated charges are in compliance with and acceptable to the Government prior to submission. When serving as a supplier or subcontractor to an entity which seeks reimbursement from the Government, REGENESIS does not knowingly present or cause to be presented any claim for payment to the Government.

PETRO CLEANZE™
Enhanced Desorption

PetroCleanze™ Technical Description

PetroCleanze is a customized formulation of the widely used RegenOx® *In Situ* chemical oxidation (ISCO) technology. When applied, this two-part reagent generates detergent-like properties, significantly increasing the desorption rates of hydrocarbons bound in saturated soils. Once the hydrocarbons are liberated into the dissolved-phase, they are more readily available for removal using a range of physical recovery techniques. PetroCleanze is designed to increase the viability and efficiency of enhanced recovery techniques such as dual-phase extraction, vacuum enhanced extraction and pump and treat systems.

Example of PetroCleanze

PetroCleanze is a patented alkaline surface catalyst system that is applied with RegenOx® oxidizer complex (RegenOx Part A). Like RegenOx, PetroCleanze stimulates the rapid chemical oxidation of contaminants *in situ*. A further benefit is the generation of surfactants from the partial oxidation of hydrocarbons. Surfactants are formed upon alkaline oxidation of linear or branched hydrocarbons contaminants, which assist in the desorption of more contaminants from soil. This process enhances the ability to physically remove hydrocarbons from the contaminated subsurface by extraction or other methods.

Example of RegenOx

For a list of treatable contaminants with the use of PetroCleanze, view the Range of Treatable Contaminants Guide

Chemical Composition – RegenOx Chemical Oxidant Part A

- Sodium Percarbonate – CAS #15630-89-4
- Sodium Carbonate Monohydrate – CAS #5968-11-6
- Silicic Acid – CAS #7699-11-6
- Silica Gel – CAS #63231

Chemical Composition – PetroCleanze

- Silicic Acid, Sodium Salt, Sodium Silicate – CAS#1344-09-08
- Ferrous Sulfate – CAS #7720-78-7
- Sodium Hydroxide – CAS #1310-73-2
- Sodium Tripolyphosphate – CAS #7758-29-4

Properties

- Bulk Density – Part A 0.9-1.2 g/cm3; Part B – 1.1-1.3 g/cm3
- pH - ~13 per recommended mixing ratios (3-5% oxidant in solution)
- Solubility – Oxidant - 14.5 g/100 g water; Activator – miscible in water
- Appearance – Brown to orange-brown when mixed with water
- Odor – Not detectable
- Vapor Pressure – None
- Chemical Hazard Classification - Part A – Class 5.1 Oxidizer; Part B is corrosive

PETRO CLEANZE™
Enhanced Desorption

PetroCleanze™ Technical Description

Storage and Handling Guidelines

Storage
Store locked up
Store in original tightly closed container
Maintain storage temperatures between 50°F to 140°F (10°C to 60°C)
Store away from incompatible materials
Do not use containers made of aluminum, fiberglass, copper, brass, zinc or galvanized metal
Recommended storage containers: steel or plastic
Store in a cool, dry, well-ventilated place

Handling
Do not breathe mist or vapor
Avoid contact with eyes, skin, and clothing
Avoid prolonged exposure
Provide adequate ventilation
Wear appropriate personal protective equipment
Observe good industrial hygiene practices

Applications

- RegenOx Part A and PetroCleanze are typically diluted with water at a rate of 3% to 8% oxidant-in-solution prior to application. The resulting mixture has a viscosity similar to water.
- Injects into formation through direct push injection points, injection wells or other injection delivery systems.
- The product is non-corrosive to most metals.

Application instructions for this product are contained here RegenOx Application Instructions.

Health and Safety

Material is relatively safe to handle; however, we recommend avoiding contact with eyes, skin and clothing. OSHA Level D personal protection equipment including vinyl or rubber gloves, eye protection (goggles or splash shield), and dust mask are recommended when handling this product. Please review the Material Safety Data Sheet for additional storage, usage, and handling requirements here: RegenOx Part A SDS and PetroCleanze SDS.

Remedial Design Assumptions and Qualifications

Cost Estimate Disclaimer: The cost listed assumes conditions set forth within the proposed scope of work and assumptions and qualifications. Changes to either could impact the final cost of the project. This may include final shipping arrangements, sales tax or application related tasks such as product storage and handling, access to water, etc. If items listed need to be modified, please contact Regenesis for further evaluation.

Shipping Estimates: Shipping estimates are valid for 30 days. All shipping charges are estimates and actual freight charges are calculated at the time of invoice. Additional freight charges may be assessed for any accessorial requested at the time of delivery. The estimate included within assumes standard shipping.

Standard delivery is between 8am -5pm Monday –Friday. *accessorial – can include, but not limited to lift gate and pallet jack at delivery, inside delivery, time definite deliveries, and delivery appointments.

Please communicate any requirements for delivery with the customer service department at the time the order is placed.

Return Policy: To initiate a return please contact your local sales manager for an RMA. A 15% re-stocking fee will be charged for all returned goods. Return freight must be prepaid. All requests to return product must be in original condition and no product will be accepted for return after 90 days from date of delivery.

Professional Judgement: In generating this estimate, REGENESIS relied upon professional judgment and site specific information provided by others. Using this information as input, we performed calculations based upon known chemical and geologic relationships to generate an estimate of the mass of product and subsurface placement required to affect remediation of the site.

REGENESIS developed this Scope of Work in reliance upon the data and professional judgments provided by those whom completed the earlier environmental site assessment(s), and in reliance upon REGENESIS' prior experience on similar project sites. The fees and charges associated with the Scope of Work were generated through REGENESIS' proprietary formulas and thus may not conform to billing guidelines, constraints or other limits on fees. REGENESIS does not seek reimbursement directly from any government agency or any governmental reimbursement fund (the "Government"). In any circumstance where REGENESIS may serve as a supplier or subcontractor to an entity which seeks reimbursement from the Government for all or part of the services performed or products provided by REGENESIS, *it is the sole responsibility of the entity seeking reimbursement to ensure the Scope of Work and associated charges are in compliance with and acceptable to the Government prior to submission*. When serving as a supplier or subcontractor to an entity which seeks reimbursement from Government, REGENESIS does not knowingly present or cause to be presented any claim for payment to the government.

REGENESIS
1011 Calle Sombra
San Clemente, CA 92673-6244
Tel: 949.366.8000 • Fax: 949.366.8090

Terms and Conditions
Products and Services

1. PAYMENT TERMS. Net 30 Days. Accounts outstanding after 30 days will be assessed 1.5% monthly interest. Volume discount pricing will be rescinded on all accounts outstanding over 90 days. An early payment discount of 1.5% Net 10 is available for cash or check payments only. We accept Master Card, Visa and American Express.

2. RETURN POLICY. A 15% re-stocking fee will be charged for all returned goods. All requests to return product must be pre-approved by seller. Returned product must be in original condition and no product will be accepted for return after a period of 90 days.

3 FORCE MAJEURE. Seller shall not be liable for delays in delivery or services or failure to manufacture or deliver due to causes beyond its reasonable control, including but not limited to acts of God, acts of buyer, acts of military or civil authorities, fires, strikes, flood, epidemic, war, riot, delays in transportation or car shortages, or inability to obtain necessary labor, materials, components or services through seller's usual and regular sources at usual and regular prices. In any such event Seller may, without notice to buyer, at any time and from time to time, postpone the delivery or service dates under this contract or make partial delivery or performance or cancel all or any portion of this and any other contract with buyer without further liability to buyer. Cancellation of any part of this order shall not affect Seller's right to payment for any product delivered or service performed hereunder.

4. LIMITED WARRANTY. Seller warrants the product(s) sold and services provided as specified on face of invoice, solely to buyer. Seller makes no other warranty of any kind respecting the product and services, and expressly DISCLAIMS ALL OTHER WARRANTIES OF WHATEVER KIND RESPECTING THE PRODUCT AND SERVICES, INCLUDING ALL WARRANTIES OF MERCHANTABILITY, FITNESS FOR PARTICULAR PURPOSE AND NON-INFRINGEMENT.

5. DISCLAIMER. Where warranties to a person other than buyer may not be disclaimed under law, seller extends to such a person the same warranty seller makes to buyer as set forth herein, subject to all disclaimers, exclusions and limitations of warranties, all limitations of liability and all other provisions set forth in the Terms and Conditions herein. Buyer agrees to transmit a copy of the Terms and Conditions set forth herein to any and all persons to whom buyer sells, or otherwise furnishes the products and/or services provided buyer by seller and buyer agrees to indemnify seller for any liability, loss, costs and attorneys' fees which seller may incur by reason, in whole or in part, of failure by buyer to transmit the Terms and Conditions as provided herein.

6. LIMITATION OF SELLER'S LIABILITY AND LIMITATION OF BUYER'S REMEDY. Seller's liability on any claim of any kind, including negligence, for any loss or damage arising out of, connected with, or resulting from the manufacture, sale, delivery, resale, repair or use of any goods or performance of any services covered by or furnished hereunder, shall in no case exceed the lesser of (1) the cost of repairing or replacing goods and repeating the services failing to conform to the forgoing warranty or the price of the goods and/or services or part thereof which gives rise to the claim. IN NO EVENT SHALL SELLER BE LIABLE FOR SPECIAL INCIDENTAL OR CONSEQUENTIAL DAMAGES, INCLUDING LOST PROFITS, OR FOR DAMAGES IN THE NATURE OF PENALTIES.

7. INDEMNIFICATION. Buyer agrees to defend and indemnify seller of and from any and all claims or liabilities asserted against seller in connection with the manufacture, sale, delivery, resale or repair or use of any goods, and performance of any services, covered by or furnished hereunder arising in whole or in part out of or by reason of the failure of buyer, its agents, servants, employees or customers to follow instructions, warnings or recommendations furnished by seller in connection with such goods and services, by reason of the failure of buyer, its agents, servants, employees or customers to comply with all federal, state and local laws applicable to such goods and services, or the use thereof, including the Occupational Safety and Health Act of 1970, or by reason of the negligence or misconduct of buyer, its agents, servants, employees or customers.

8. EXPENSES OF ENFORCEMENT. In the event seller undertakes any action to collect amounts due from buyer, or otherwise enforce its rights hereunder, Buyer agrees to pay and reimburse Seller for all such expenses, including, without limitation, all attorneys and collection fees.

9. TAXES. Liability for all taxes and import or export duties, imposed by any city, state, federal or other governmental authority, shall be assumed and paid by buyer. Buyer further agrees to defend and indemnify seller against any and all liabilities for such taxes or duties and legal fees or costs incurred by seller in connection therewith.

10. ASSISTANCE AND ADVICE. Upon request, seller in its discretion will furnish as an accommodation to buyer such technical advice or assistance as is available in reference to the goods and services. Seller assumes no obligation or liability for the advice or assistance given or results obtained, all such advice or assistance being given and accepted at buyer's risk.

11. SITE SAFETY. Buyer shall provide a safe working environment at the site of services and shall comply with all applicable provisions of federal, state, provincial and municipal safety laws, building codes, and safety regulations to prevent accidents or injuries to persons on, about or adjacent to the site.

12. INDEPENDENT CONTRACTOR. Seller and Buyer are independent contractors and nothing shall be construed to place them in the relationship of partners, principal and agent, employer/employee or joint ventures. Neither party will have the power or right to bind or obligate the other party except as may be expressly agreed and delegated by other party, nor will it hold itself out as having such authority.

13. REIMBURSEMENT. Seller shall provide the products and services in reliance upon the data and professional judgments provided by or on behalf of buyer. The fees and charges associated with the products and services thus may not conform to billing guidelines, constraints or other limits on fees. Seller does not seek reimbursement directly from any government agency or any governmental reimbursement fund (the “Government”). In any circumstance where seller may serve as a supplier or subcontractor to an entity which seeks reimbursement from the Government for all or part of the services performed or products provided by seller, it is the sole responsibility of the buyer or other entity seeking reimbursement to ensure the products and services and associated charges are in compliance with and acceptable to the Government prior to submission. When serving as a supplier or subcontractor to an entity which seeks reimbursement from the Government, seller does not knowingly present or cause to be presented any claim for payment to the Government.

14. APPLICABLE LAW/JURISDICTION AND VENUE. The rights and duties of the parties shall be governed by, construed, and enforced in accordance with the laws of the State of California (excluding its conflict of laws rules which would refer to and apply the substantive laws of another jurisdiction). Any suit or proceeding hereunder shall be brought exclusively in state or federal courts located in Orange County, California. Each party consents to the personal jurisdiction of said state and federal courts and waives any objection that such courts are an inconvenient forum.

15. ENTIRE AGREEMENT. This agreement constitutes the entire contract between buyer and seller relating to the goods or services identified herein. No modifications hereof shall be binding upon the seller unless in writing and signed by seller's duly authorized representative, and no modification shall be effected by seller's acknowledgment or acceptance of buyer's purchase order forms containing different provisions. Trade usage shall neither be applicable nor relevant to this agreement, nor be used in any manner whatsoever to explain, qualify or supplement any of the provisions hereof. No waiver by either party of default shall be deemed a waiver of any subsequent default.

RegenOx® PetroCleanze™

LIBERATES SORBED HYDROCARBON MASS FOR MORE EFFECTIVE ENHANCED RECOVERY AND CHEMICAL OXIDATION

Physical Extraction Guidance

The following information is designed to guide the environmental professional in the best practices associated with physical extraction as it relates to RegenOx PetroCleanze.

Physical extraction methods such as vacuum extraction trucks or dual phase extraction systems can be used to remove the desorbed hydrocarbon mass after RegenOx PetroCleanze injection. It is recommended that applicators wait between **two to four weeks** after injection to allow full desorption of hydrocarbon from soil before implementing a physical extraction system. The recommended volume of fluid extracted from targeted extractions wells is **120% of the injection volume** for each extraction event. This may vary from site to site depending on the geology and water depth. An extraction well may require less than the recommended 120% of the injection volume be removed in order to prevent dewatering of the wells. Dewatering a well may cause hydrocarbon to resorb to soil making extraction more difficult as well as increase the need for more injections.

We have found that in some circumstances higher hydrocarbon removal rates are achieved by removing ground water at a lower rate. More specifically at a rate that does not cause extraction wells to dewater. The thinking behind this observation is to allow the free product and hydrocarbon emulsions formed by use of PetroCleanze to flow into the extraction well via a ground water depression rather than to be trapped in the de-watered sand pack and/or native soil matrix surrounding the well.

RegenOx® PetroCleanze™

LIBERATES SORBED HYDROCARBON MASS FOR MORE EFFECTIVE ENHANCED RECOVERY AND CHEMICAL OXIDATION

Performance Monitoring Guidance

The following information is designed to guide the environmental professional in the best practices associated with performance monitoring as it relates to RegenOx PetroCleanze.

All monitoring wells and extraction wells within the target treatment zone should be assessed for presence of NAPLs prior to and following each application event. It is recommended that the user obtain accurate volume measurement of all free-phase hydrocarbon from the wells pre-treatment (baseline), post-treatment, and **especially** in extracted fluids. Pre-treatment and post-treatment ground water samples should be taken prior to and after each event (e.g. same day as the event, but before injecting or extracting).

Samples should be collected using a bailer before injection and **two to three weeks** after injection. Free phase hydrocarbon volume measurements can be recorded using the dimensions of the bailer and the height of the free phase in the bailer. Extraction samples should be collected directly from the extraction line or holding tank using a bailer or sample container.

For all pre-treatment, post-treatment and extraction samples, obtain laboratory measurement of dissolved and emulsified hydrocarbon in water. Exact parameters will vary depending on the site. Typical parameters should include all the possibly present diesel, gas, or oil-range hydrocarbons (e.g. TPH-d, TPH-g, TPH-mo), and may include BTEX or other specific petroleum constituents.

Recommended Sampling Equipment

- Interface probe
- Disposable SPH bailers (one for each sample)
- Wide mouth glass sample jars
- 3 to 4, 5 gallon waste buckets
- Water quality meter (e.g. YSI 556 meter)

Recommended Monitoring Program

Analyte	Type	Method	Sample Volume	Pre-Treatment (Baseline)	Post-Treatment (2-3 Weeks)	Extraction Fluids
					For Each Injection Event	
TPH	Gas, Diesel, Motor Oil Range Organics (GRO, DRO, ORO)	8015B or equivalent	Check with testing lab	GW	GW	Extraction Fluid Sample
BTEX		8021B or equivalent				
pH		Water Quality Meter. (e.g. YSI 556)				
ORP						
Dissolved Oxygen (DO)						
Conductivity						

RegenOx® PetroCleanze™

LIBERATES SORBED HYDROCARBON MASS FOR MORE EFFECTIVE ENHANCED RECOVERY AND CHEMICAL OXIDATION

Field Data Collection Form

*Please make copies for multiple monitoring wells or injection/extraction events as needed

Site Name		**Site Location**	
Well Number			

Well Characteristics

Application Event	1 2 3 4 5	Purge Volume	
Well Diameter	2″ 4″ 6″	Borehole Dia	6″ 8″ 12″ 16″

Method of Fluid Removal

Bailer	Size/Dia/Length	
Pump	GPM Removal Rate	
	Pump Type	

Fluid Container Volume

Bucket Size/Dia/Height	

Pre-Treatment (Baseline)

Date				
Ground Water Level	ft bgs			
Free Phase HC Height	in			
Lab Sample #	Time	pH	Cond	ORP
1				
2				
3				
4				

Post-Treatment (2-3 Weeks)

Date				
Ground Water Level	ft bgs			
Free Phase HC Height	in			
Lab Sample #	Time	pH	Cond	ORP
1				
2				
3				
4				

Extraction Fluids (2-3 weeks)

Lab Sample #	Date/Time	Gallons Extracted	Free Phase HC Height	pH	Cond	ORP	Color
1		gal	in				
2		gal	in				
3		gal	in				
4		gal	in				
5		gal	in				
6		gal	in				
7		gal	in				
8		gal	in				
9		gal	in				
10		gal	in				

Comments:

RegenOx® PetroCleanze™

FREES BOUND HYDROCARBONS FOR MORE EFFECTIVE ENHANCED RECOVERY AND CHEMICAL OXIDATION

DESCRIPTION

RegenOx® PetroCleanze™ is a customized formulation of the widely-used RegenOx® *in situ* chemical oxidation technology. The primary function of RegenOx PetroCleanze is to increase the desorption rates of hydrocarbons bound in saturated soil and make them available for more efficient and rapid treatment using enhanced recovery technologies.

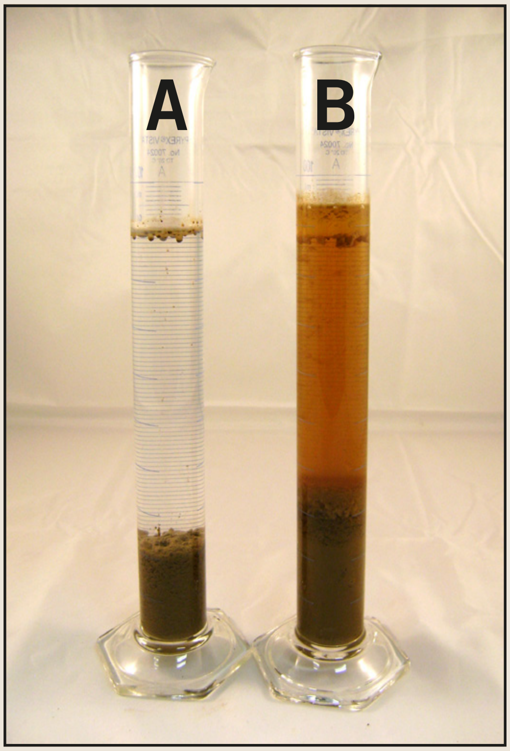


FIGURE 1: Treatment with RegenOx PetroCleanze

A. An untreated soil and hydrocarbon mixture in water

B. RegenOx PetroCleanze treated soil and hydrocarbon mixture with bound hydrocarbon clearly being released into the dissolved phase for removal or treatment

FEATURES & BENEFITS

RegenOx PetroCleanze offers the following features and benefits:

- Unique product chemistry proven highly effective on petroleum hydrocarbon contamination
- Detergent like technology moves bound hydrocarbons from the soil into the dissolved phase for better and more efficient recovery via physical/mechanical removal
- Designed to be used in conjunction with physical and/or mechanical recovery systems
- Powerful oxidation reactions equal to that of standard RegenOx oxidize more readily available hydrocarbons
- A two part integrated system comprised of standard RegenOx Part A and PetroCleanze, where the PetroCleanze component stays in-place providing an activation site for multiple applications if and when required.
- Engineered chemistry does not add surfactants but creates them aiding in enhanced hydrocarbon removal
- Avoids problematic carbon loading associated with the use of standard surfactant based technologies
- As part of an integrated site remediation approach RegenOx PetroCleanze reduces mass flux to facilitate risk-based and MNA site closures

FORM & FUNCTION

The RegenOx PetroCleanze formula is optimized to desorb bound hydrocarbon mass and drive it from the soil matrix into the aqueous phase (Figure 1). Once contaminants are moved into the dissolved phase, other methods such as chemical oxidation using standard RegenOx or enhanced recovery techniques such as dual-phase extraction, vacuum enhanced extraction, pump and treat systems and even enhanced bioremediation using Oxygen Release Compound (ORC®) or Oxygen Release Compound ADVANCED (ORC Advanced®) can be used. In some cases where significant mass removal is required, multiple applications of RegenOx PetroCleanze may be necessary along with multiple extraction events.

REGENESIS

Technology-Based Solutions for the Environment

SAFETY DATA SHEET

1. Identification

Product identifier	**PetroCleanze®**
Other means of identification	None.
Recommended use	Soil and Groundwater Remediation.
Recommended restrictions	None known.

Manufacturer/Importer/Supplier/Distributor information

Company Name	Regenesis
Address	1011 Calle Sombra San Clemente, CA 92673
Telephone	949-366-8000
E-mail	CustomerService@regenesis.com
Emergency phone number	CHEMTREC® at 1-800-424-9300 (International)

2. Hazard(s) identification

Physical hazards	Corrosive to metals	Category 1
Health hazards	Skin corrosion/irritation	Category 1A
	Serious eye damage/eye irritation	Category 1
OSHA defined hazards	Not classified.	

Label elements

Signal word	Danger
Hazard statement	May be corrosive to metals. Causes severe skin burns and eye damage.
Precautionary statement	
Prevention	Do not breathe mist or vapor. Wash thoroughly after handling. Wear protective gloves/protective clothing/eye protection/face protection.
Response	If swallowed: Rinse mouth. Do NOT induce vomiting. If on skin (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower. If inhaled: Remove person to fresh air and keep comfortable for breathing. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a poison center/doctor. Wash contaminated clothing before reuse.
Storage	Store locked up. Store in corrosive resistant container with a resistant inner liner.
Disposal	Dispose of contents/container in accordance with local/regional/national/international regulations.
Hazard(s) not otherwise classified (HNOC)	None known.

3. Composition/information on ingredients

Mixtures

Chemical name	**CAS number**	**%**
Silicic Acid, sodium salt, sodium silicate	1344-09-8	22-28
Sodium hydroxide	1310-73-2	7-10
Sodium phosphate, tribasic	7758-29-4	3-5
Ferrous sulfate	7720-78-7	1-4

Composition comments	All concentrations are in percent by weight unless otherwise indicated.

4. First-aid measures

Inhalation	Move to fresh air. Keep victim at rest in a position comfortable for breathing. Get medical attention.
Skin contact	Take off immediately all contaminated clothing. Rinse skin with water/shower. Call a physician or poison control center immediately. Chemical burns must be treated by a physician. Wash contaminated clothing before reuse.
Eye contact	Immediately flush eyes with plenty of water for at least 15 minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Call a physician or poison control center immediately.
Ingestion	Call a physician or poison control center immediately. Never give anything by mouth to a victim who is unconscious or is having convulsions. Rinse mouth. Do not induce vomiting. If vomiting occurs, keep head low so that stomach content doesn't get into the lungs.
Most important symptoms/effects, acute and delayed	Burning pain and severe corrosive skin damage. Causes serious eye damage. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Permanent eye damage including blindness could result.
Indication of immediate medical attention and special treatment needed	Provide general supportive measures and treat symptomatically. Keep victim under observation. Symptoms may be delayed.
General information	Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves.

5. Fire-fighting measures

Suitable extinguishing media	Water fog. Foam. Dry chemical powder. Carbon dioxide (CO_2).
Unsuitable extinguishing media	None known.
Specific hazards arising from the chemical	During fire, gases hazardous to health may be formed. Combustion products may include: silicon oxides, metal oxides.
Special protective equipment and precautions for firefighters	Self-contained breathing apparatus and full protective clothing must be worn in case of fire.
Fire fighting equipment/instructions	Move containers from fire area if you can do so without risk.
Specific methods	Use standard firefighting procedures and consider the hazards of other involved materials.
General fire hazards	No unusual fire or explosion hazards noted.

6. Accidental release measures

Personal precautions, protective equipment and emergency procedures	Keep unnecessary personnel away. Keep people away from and upwind of spill/leak. Wear appropriate protective equipment and clothing during clean-up. Do not breathe mist or vapor. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Ensure adequate ventilation. Local authorities should be advised if significant spillages cannot be contained. For personal protection, see section 8 of the SDS.
Methods and materials for containment and cleaning up	Large Spills: Stop the flow of material, if this is without risk. Dike the spilled material, where this is possible. Cover with plastic sheet to prevent spreading. Absorb in vermiculite, dry sand or earth and place into containers. Following product recovery, flush area with water. Small Spills: Wipe up with absorbent material (e.g. cloth, fleece). Clean surface thoroughly to remove residual contamination. Never return spills to original containers for re-use. For waste disposal, see section 13 of the SDS.
Environmental precautions	Avoid discharge into drains, water courses or onto the ground.

7. Handling and storage

Precautions for safe handling	Do not breathe mist or vapor. Do not get in eyes, on skin, or on clothing. Avoid prolonged exposure. Provide adequate ventilation. Wear appropriate personal protective equipment. Observe good industrial hygiene practices.
Conditions for safe storage, including any incompatibilities	Store locked up. Store in original tightly closed container. Store in a cool, dry, well-ventilated place. Maintain storage temperatures between 50°F to 140°F (10°C to 60°C). Store away from incompatible materials (see Section 10 of the SDS). Recommended storage containers: steel or plastic. Do not use containers made of aluminum, fiberglass, copper, brass, zinc or galvanized containers.

8. Exposure controls/personal protection

Occupational exposure limits

US. OSHA Table Z-1 Limits for Air Contaminants (29 CFR 1910.1000)

Components	Type	Value
Sodium hydroxide (CAS 1310-73-2)	PEL	2 mg/m3

US. ACGIH Threshold Limit Values

Components	Type	Value
Ferrous sulfate (CAS 7720-78-7)	TWA	1 mg/m3
Sodium hydroxide (CAS 1310-73-2)	Ceiling	2 mg/m3

US. NIOSH: Pocket Guide to Chemical Hazards

Components	Type	Value
Ferrous sulfate (CAS 7720-78-7)	TWA	1 mg/m3
Sodium hydroxide (CAS 1310-73-2)	Ceiling	2 mg/m3

Biological limit values No biological exposure limits noted for the ingredient(s).

Appropriate engineering controls Good general ventilation (typically 10 air changes per hour) should be used. Ventilation rates should be matched to conditions. If applicable, use process enclosures, local exhaust ventilation, or other engineering controls to maintain airborne levels below recommended exposure limits. If exposure limits have not been established, maintain airborne levels to an acceptable level. Eye wash facilities and emergency shower must be available when handling this product.

Individual protection measures, such as personal protective equipment

Eye/face protection When working with liquids wear splash-proof chemical goggles and face shield unless full facepiece respiratory protection is worn.

Skin protection

Hand protection Wear appropriate chemical resistant gloves.

Other Wear appropriate chemical resistant clothing.

Respiratory protection If engineering controls do not maintain airborne concentrations below recommended exposure limits (where applicable) or to an acceptable level (in countries where exposure limits have not been established), an approved respirator must be worn. Recommended use: Wear NIOSH approved respirator appropriate for airborne exposure at the point of use.

Thermal hazards Wear appropriate thermal protective clothing, when necessary.

General hygiene considerations Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and/or smoking. Routinely wash work clothing and protective equipment to remove contaminants.

9. Physical and chemical properties

Appearance

Physical state	Liquid.
Form	Semi-viscous liquid
Color	Green to black.
Odor	Odorless.
Odor threshold	Not available.
pH	13 (10% solution/water)
Melting point/freezing point	Not available.
Initial boiling point and boiling range	Not available.
Flash point	Not available.
Evaporation rate	Not available.
Flammability (solid, gas)	Not applicable.

Upper/lower flammability or explosive limits

Flammability limit - lower (%)	Not available.
Flammability limit - upper (%)	Not available.
Explosive limit - lower (%)	Not available.
Explosive limit - upper (%)	Not available.
Vapor pressure	Not available.
Vapor density	Not available.
Relative density	1.2 - 1.6

Solubility(ies)

Solubility (water)	Miscible
Partition coefficient (n-octanol/water)	Not available.
Auto-ignition temperature	Not available.
Decomposition temperature	Not available.
Viscosity	< 1000 cP

10. Stability and reactivity

Reactivity	Reacts violently with strong acids. This product may react with oxidizing agents.
Chemical stability	Material is stable under normal conditions.
Possibility of hazardous reactions	No dangerous reaction known under conditions of normal use.
Conditions to avoid	Contact with incompatible materials.
Incompatible materials	Hydrogen fluoride. Fluorine. Oxygen difluoride. Chlorine trifluoride. Strong acids. Strong bases. Oxidizing agents. Aluminum metal. Copper. Brass. Zinc. Galvanized metals.
Hazardous decomposition products	Thermal decomposition or combustion may produce: silicon oxides, metal oxides.

11. Toxicological information

Information on likely routes of exposure

Inhalation	May cause irritation to the respiratory system. Prolonged inhalation may be harmful.
Skin contact	Causes severe skin burns.
Eye contact	Causes serious eye damage.
Ingestion	Causes digestive tract burns.
Symptoms related to the physical, chemical and toxicological characteristics	Burning pain and severe corrosive skin damage. Causes serious eye damage. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Permanent eye damage including blindness could result.

Information on toxicological effects

Acute toxicity	Not expected to be acutely toxic.

Components	**Species**	**Test Results**
Sodium phosphate, tribasic (CAS 7758-29-4)		
Acute		
Dermal		
LD50	Rabbit	> 4640 mg/kg, 24 Hours

* Estimates for product may be based on additional component data not shown.

Skin corrosion/irritation	Causes severe skin burns and eye damage.
Serious eye damage/eye irritation	Causes serious eye damage.

Respiratory or skin sensitization

Respiratory sensitization	Not a respiratory sensitizer.
Skin sensitization	This product is not expected to cause skin sensitization.

Germ cell mutagenicity	No data available to indicate product or any components present at greater than 0.1% are mutagenic or genotoxic.
Carcinogenicity	This product is not considered to be a carcinogen by IARC, ACGIH, NTP, or OSHA.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Reproductive toxicity	This product is not expected to cause reproductive or developmental effects.
Specific target organ toxicity - single exposure	Not classified.
Specific target organ toxicity - repeated exposure	Not classified.
Aspiration hazard	Not an aspiration hazard.
Chronic effects	Prolonged inhalation may be harmful.

12. Ecological information

Ecotoxicity	The product is not classified as environmentally hazardous. However, this does not exclude the possibility that large or frequent spills can have a harmful or damaging effect on the environment.

Components		**Species**	**Test Results**
Sodium hydroxide (CAS 1310-73-2)			
Aquatic			
Crustacea	EC50	Water flea (Ceriodaphnia dubia)	34.59 - 47.13 mg/l, 48 hours
Acute			
Fish	LC50	Bluegill (Lepomis macrochirus)	99 mg/l, 48 hours
		Mosquitofish (Gambusia affinis affinis)	125 mg/l, 96 hours

Persistence and degradability	No data is available on the degradability of this product.
Bioaccumulative potential	No data available.
Mobility in soil	This product is water soluble and may disperse in soil.
Other adverse effects	The product may affect the acidity (pH-factor) in water with risk of harmful effects to aquatic organisms.

13. Disposal considerations

Disposal instructions	Collect and reclaim or dispose in sealed containers at licensed waste disposal site. Dispose of contents/container in accordance with local/regional/national/international regulations.
Local disposal regulations	Dispose in accordance with all applicable regulations.
Hazardous waste code	The waste code should be assigned in discussion between the user, the producer and the waste disposal company.
Waste from residues / unused products	Dispose of in accordance with local regulations. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions).
Contaminated packaging	Empty containers should be taken to an approved waste handling site for recycling or disposal. Since emptied containers may retain product residue, follow label warnings even after container is emptied.

14. Transport information

DOT

UN number	UN3266
UN proper shipping name	Corrosive liquid, basic, inorganic, n.o.s. (Sodium hydroxide RQ = 11403 LBS)
Transport hazard class(es)	
Class	8
Subsidiary risk	-
Label(s)	8
Packing group	II
Environmental hazards	
Marine pollutant	No
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Special provisions	B2, IB2, T11, TP2, TP27
Packaging exceptions	154
Packaging non bulk	202

Packaging bulk	242

IATA

UN number	UN3266
UN proper shipping name	Corrosive liquid, basic, inorganic, n.o.s. (Sodium hydroxide)
Transport hazard class(es)	
Class	8
Subsidiary risk	-
Packing group	II
Environmental hazards	No
ERG Code	8L
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.

IMDG

UN number	UN3266
UN proper shipping name	CORROSIVE LIQUID, BASIC, INORGANIC, N.O.S. (Sodium hydroxide)
Transport hazard class(es)	
Class	8
Subsidiary risk	-
Packing group	II
Environmental hazards	
Marine pollutant	No
EmS	F-A, S-B
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code	Not established.

15. Regulatory information

US federal regulations	This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200. All components are on the U.S. EPA TSCA Inventory List.

TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)

Not regulated.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

CERCLA Hazardous Substance List (40 CFR 302.4)

Ferrous sulfate (CAS 7720-78-7)	LISTED
Sodium hydroxide (CAS 1310-73-2)	LISTED
Sodium phosphate, tribasic (CAS 7758-29-4)	LISTED

Superfund Amendments and Reauthorization Act of 1986 (SARA)

Hazard categories	Immediate Hazard - Yes Delayed Hazard - No Fire Hazard - No Pressure Hazard - No Reactivity Hazard - No

SARA 302 Extremely hazardous substance

Not listed.

SARA 311/312 Hazardous chemical	Yes

SARA 313 (TRI reporting)

Not regulated.

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List

Not regulated.

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)

Not regulated.

Safe Drinking Water Act (SDWA)	Not regulated.

US state regulations

US. Massachusetts RTK - Substance List

Ferrous sulfate (CAS 7720-78-7)
Sodium hydroxide (CAS 1310-73-2)
Sodium phosphate, tribasic (CAS 7758-29-4)

US. New Jersey Worker and Community Right-to-Know Act

Ferrous sulfate (CAS 7720-78-7)
Sodium hydroxide (CAS 1310-73-2)

US. Pennsylvania Worker and Community Right-to-Know Law

Ferrous sulfate (CAS 7720-78-7)
Sodium hydroxide (CAS 1310-73-2)
Sodium phosphate, tribasic (CAS 7758-29-4)

US. Rhode Island RTK

Sodium hydroxide (CAS 1310-73-2)
Sodium phosphate, tribasic (CAS 7758-29-4)

US. California Proposition 65

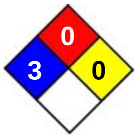
California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): This material is not known to contain any chemicals currently listed as carcinogens or reproductive toxins.

International Inventories

Country(s) or region	Inventory name	On inventory (yes/no)*
Australia	Australian Inventory of Chemical Substances (AICS)	Yes
Canada	Domestic Substances List (DSL)	Yes
Canada	Non-Domestic Substances List (NDSL)	No
China	Inventory of Existing Chemical Substances in China (IECSC)	Yes
Europe	European Inventory of Existing Commercial Chemical Substances (EINECS)	Yes
Europe	European List of Notified Chemical Substances (ELINCS)	No
Japan	Inventory of Existing and New Chemical Substances (ENCS)	Yes
Korea	Existing Chemicals List (ECL)	Yes
New Zealand	New Zealand Inventory	Yes
Philippines	Philippine Inventory of Chemicals and Chemical Substances (PICCS)	Yes
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

*A "Yes" indicates this product complies with the inventory requirements administered by the governing country(s).
A "No" indicates that one or more components of the product are not listed or exempt from listing on the inventory administered by the governing country(s).

16. Other information, including date of preparation or last revision

Issue date	26-March-2015
Revision date	-
Version #	01
Further information	HMIS® is a registered trade and service mark of the American Coatings Association (ACA).
HMIS® ratings	Health: 3 Flammability: 0 Physical hazard: 0
NFPA ratings	
Disclaimer	Regenesis cannot anticipate all conditions under which this information and its product, or the products of other manufacturers in combination with its product, may be used. It is the user's responsibility to ensure safe conditions for handling, storage and disposal of the product, and to assume liability for loss, injury, damage or expense due to improper use. The information in the sheet was written based on the best knowledge and experience currently available.

REGENESIS
Technology-Based Solutions for the Environment

SAFETY DATA SHEET

1. Identification

Product identifier	**RegenOx® Part A**
Other means of identification	None.
Recommended use	Soil and Groundwater Remediation.
Recommended restrictions	None known.

Manufacturer/Importer/Supplier/Distributor information

Company Name	Regenesis
Address	1011 Calle Sombra San Clemente, CA 92673
Telephone	949-366-8000
E-mail	CustomerService@regenesis.com
Emergency phone number	CHEMTREC® at 1-800-424-9300 (International)

2. Hazard(s) identification

Physical hazards	Oxidizing solids	Category 2
Health hazards	Acute toxicity, oral	Category 4
	Serious eye damage/eye irritation	Category 1
Environmental hazards	Hazardous to the aquatic environment, acute hazard	Category 2
OSHA defined hazards	Not classified.	

Label elements

Signal word	Danger
Hazard statement	May intensify fire; oxidizer. Harmful if swallowed. Causes serious eye damage. Toxic to aquatic life.

Precautionary statement

Prevention	Keep away from heat. Keep/Store away from clothing and other combustible materials. Take any precaution to avoid mixing with combustibles. Wash thoroughly after handling. Do not eat, drink or smoke when using this product. Avoid release to the environment. Wear protective gloves/eye protection/face protection.
Response	If swallowed: Call a poison center/doctor if you feel unwell. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a poison center/doctor. Rinse mouth. In case of fire: Use appropriate media to extinguish.
Storage	Store away from incompatible materials.
Disposal	Dispose of contents/container in accordance with local/regional/national/international regulations.
Hazard(s) not otherwise classified (HNOC)	None known.

3. Composition/information on ingredients

Mixtures

Chemical name	CAS number	%
Sodium Carbonate Peroxyhydrate	15630-89-4	≥95
Silicic Acid, Sodium Salt, Sodium Silicate	1344-09-8	<1

Composition comments	All concentrations are in percent by weight unless otherwise indicated.

4. First-aid measures

Inhalation	Move to fresh air. Call a physician if symptoms develop or persist.
Skin contact	IF ON CLOTHING: rinse immediately contaminated clothing and skin with plenty of water before removing clothes. Wash off with soap and water. Get medical attention if irritation develops and persists.
Eye contact	Do not rub eyes. Immediately flush eyes with plenty of water for at least 15 minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Get medical attention immediately.
Ingestion	Never give anything by mouth to a victim who is unconscious or is having convulsions. Rinse mouth. If vomiting occurs, keep head low so that stomach content doesn't get into the lungs. Get medical advice/attention if you feel unwell.
Most important symptoms/effects, acute and delayed	Severe eye irritation. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Permanent eye damage including blindness could result. Dusts may irritate the respiratory tract, skin and eyes.
Indication of immediate medical attention and special treatment needed	Provide general supportive measures and treat symptomatically. Keep victim warm. Keep victim under observation. Symptoms may be delayed.
General information	Take off all contaminated clothing immediately. Contact with combustible material may cause fire. Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves. Show this safety data sheet to the doctor in attendance. Wash contaminated clothing before reuse.

5. Fire-fighting measures

Suitable extinguishing media	Water spray, fog (flooding amounts).
Unsuitable extinguishing media	Dry chemical, CO2, halon. Foam.
Specific hazards arising from the chemical	Greatly increases the burning rate of combustible materials. Containers may explode when heated. During fire, gases hazardous to health may be formed. Combustion products may include: carbon oxides and metal oxides.
Special protective equipment and precautions for firefighters	Self-contained breathing apparatus and full protective clothing must be worn in case of fire.
Fire fighting equipment/instructions	In case of fire and/or explosion do not breathe fumes. Move containers from fire area if you can do so without risk. Use water spray to cool unopened containers.
Specific methods	Cool containers exposed to flames with water until well after the fire is out.
General fire hazards	May intensify fire; oxidizer. Contact with combustible material may cause fire.

6. Accidental release measures

Personal precautions, protective equipment and emergency procedures	Keep unnecessary personnel away. Keep people away from and upwind of spill/leak. Keep away from clothing and other combustible materials. Wear appropriate protective equipment and clothing during clean-up. Use a NIOSH/MSHA approved respirator if there is a risk of exposure to dust/fume at levels exceeding the exposure limits. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Ensure adequate ventilation. Local authorities should be advised if significant spillages cannot be contained. For personal protection, see section 8 of the SDS.
Methods and materials for containment and cleaning up	Eliminate all ignition sources (no smoking, flares, sparks, or flames in immediate area). Collect dust using a vacuum cleaner equipped with HEPA filter. Keep combustibles (wood, paper, oil, etc.) away from spilled material. Ventilate the contaminated area. This product is miscible in water. Stop the flow of material, if this is without risk. Absorb in vermiculite, dry sand or earth and place into containers. Large Spills: Sweep up or vacuum up spillage and collect in suitable container for disposal. Shovel the material into waste container. Minimize dust generation and accumulation. Avoid the generation of dusts during clean-up. Prevent product from entering drains. Following product recovery, flush area with water. Small Spills: Wipe up with absorbent material (e.g. cloth, fleece). Clean surface thoroughly to remove residual contamination. Never return spills to original containers for re-use. Place all material into loosely covered plastic containers for later disposal. For waste disposal, see section 13 of the SDS. Wear appropriate protective equipment and clothing during clean-up.
Environmental precautions	Avoid discharge into drains, water courses or onto the ground.

7. Handling and storage

Precautions for safe handling	Minimize dust generation and accumulation. Routine housekeeping should be instituted to ensure that dusts do not accumulate on surfaces. Keep away from heat. Provide appropriate exhaust ventilation at places where dust is formed. Keep away from clothing and other combustible materials. Take any precaution to avoid mixing with combustibles. Do not get this material in contact with eyes. Do not taste or swallow. When using, do not eat, drink or smoke. Wear appropriate personal protective equipment. Wash hands thoroughly after handling. Avoid release to the environment. Observe good industrial hygiene practices.
Conditions for safe storage, including any incompatibilities	Keep away from heat. Store in a cool, dry place out of direct sunlight. Store at temperatures not exceeding 40°C/104°F. Store in original tightly closed container. Store in a well-ventilated place. Do not store near combustible materials. Store away from incompatible materials (see Section 10 of the SDS). Protect from contamination.

8. Exposure controls/personal protection

Occupational exposure limits	No exposure limits noted for ingredient(s).
Biological limit values	No biological exposure limits noted for the ingredient(s).
Appropriate engineering controls	Good general ventilation (typically 10 air changes per hour) should be used. Ventilation rates should be matched to conditions. If applicable, use process enclosures, local exhaust ventilation, or other engineering controls to maintain airborne levels below recommended exposure limits. If exposure limits have not been established, maintain airborne levels to an acceptable level. If material is ground, cut, or used in any operation which may generate dusts, use appropriate local exhaust ventilation to keep exposures below the recommended exposure limits. Provide eyewash station.
Individual protection measures, such as personal protective equipment	
Eye/face protection	Unvented, tight fitting goggles should be worn in dusty areas.
Skin protection	
Hand protection	Wear appropriate chemical resistant gloves. Suitable gloves can be recommended by the glove supplier. Frequent change is advisable. Rubber, neoprene or PVC gloves are recommended.
Other	Wear appropriate chemical resistant clothing.
Respiratory protection	If engineering controls do not maintain airborne concentrations below recommended exposure limits (where applicable) or to an acceptable level (in countries where exposure limits have not been established), an approved respirator must be worn. Recommended use: Wear respirator with dust filter.
Thermal hazards	Wear appropriate thermal protective clothing, when necessary.
General hygiene considerations	Keep from contact with clothing and other combustible materials. Remove and wash contaminated clothing promptly. Keep away from food and drink. Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and/or smoking. Routinely wash work clothing and protective equipment to remove contaminants.

9. Physical and chemical properties

Appearance	
Physical state	Solid.
Form	Powder.
Color	White.
Odor	Odorless.
Odor threshold	Not available.
pH	10.5 (3% solution/water)
Melting point/freezing point	Not available.
Initial boiling point and boiling range	Not available.
Flash point	Not available.
Evaporation rate	Not available.
Flammability (solid, gas)	Oxidizer.
Upper/lower flammability or explosive limits	
Flammability limit - lower (%)	Not available.
Flammability limit - upper (%)	Not available.

Explosive limit - lower (%)	Not available.
Explosive limit - upper (%)	Not available.
Vapor pressure	Not available.
Vapor density	Not available.
Relative density	Not available.
Solubility(ies)	
Solubility (water)	14.5 g/100g water @ 20 ºC (minimum)
Partition coefficient (n-octanol/water)	Not available.
Auto-ignition temperature	Not available.
Decomposition temperature	122 °F (50 °C)
Viscosity	Not available.
Other information	
Bulk density	0.9 - 1.2 g/ml

10. Stability and reactivity

Reactivity	Greatly increases the burning rate of combustible materials.
Chemical stability	Product may be unstable at temperatures above: 50°C/122°F. Decomposes on heating.
Possibility of hazardous reactions	Reacts slowly with water.
Conditions to avoid	Moisture. Heat. Avoid temperatures exceeding the decomposition temperature. Contact with incompatible materials.
Incompatible materials	Acids. Bases. Salts of heavy metals. Reducing agents. Combustible material.
Hazardous decomposition products	Oxygen. Steam. Heat.

11. Toxicological information

Information on likely routes of exposure

Inhalation	Dust may irritate respiratory system.
Skin contact	Dust or powder may irritate the skin.
Eye contact	Causes serious eye damage.
Ingestion	Harmful if swallowed.
Symptoms related to the physical, chemical and toxicological characteristics	Severe eye irritation. Dusts may irritate the respiratory tract, skin and eyes. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Permanent eye damage including blindness could result.

Information on toxicological effects

Acute toxicity	Harmful if swallowed.

Components	Species	Test Results
Silicic Acid, Sodium Salt, Sodium Silicate (CAS 1344-09-8)		
Acute		
Oral		
LD50	Mouse	1100 mg/kg
	Rat	1.1 g/kg

* Estimates for product may be based on additional component data not shown.

Skin corrosion/irritation	Prolonged skin contact may cause temporary irritation.
Serious eye damage/eye irritation	Causes serious eye damage.
Respiratory or skin sensitization	
Respiratory sensitization	Not a respiratory sensitizer.
Skin sensitization	This product is not expected to cause skin sensitization.
Germ cell mutagenicity	No data available to indicate product or any components present at greater than 0.1% are mutagenic or genotoxic.

Carcinogenicity	This product is not considered to be a carcinogen by IARC, ACGIH, NTP, or OSHA.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Reproductive toxicity	This product is not expected to cause reproductive or developmental effects.
Specific target organ toxicity - single exposure	Not classified.
Specific target organ toxicity - repeated exposure	Not classified.
Aspiration hazard	Not an aspiration hazard.

12. Ecological information

Ecotoxicity	Toxic to aquatic life.

Components		**Species**	**Test Results**
Silicic Acid, Sodium Salt, Sodium Silicate (CAS 1344-09-8)			
Aquatic			
Crustacea	EC50	Water flea (Ceriodaphnia dubia)	0.28 - 0.57 mg/l, 48 hours
Fish	LC50	Western mosquitofish (Gambusia affinis)	1800 mg/l, 96 hours

* Estimates for product may be based on additional component data not shown.

Persistence and degradability	Decomposes in the presence of water. The product contains inorganic compounds which are not biodegradable.
Bioaccumulative potential	The product does not contain any substances expected to be bioaccumulating.
Mobility in soil	This product is water soluble and may disperse in soil.
Other adverse effects	None known.

13. Disposal considerations

Disposal instructions	Collect and reclaim or dispose in sealed containers at licensed waste disposal site. Do not allow this material to drain into sewers/water supplies. Do not contaminate ponds, waterways or ditches with chemical or used container. Dispose of contents/container in accordance with local/regional/national/international regulations.
Local disposal regulations	Dispose in accordance with all applicable regulations.
Hazardous waste code	The waste code should be assigned in discussion between the user, the producer and the waste disposal company.
Waste from residues / unused products	Dispose of in accordance with local regulations. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions).
Contaminated packaging	Empty containers should be taken to an approved waste handling site for recycling or disposal. Since emptied containers may retain product residue, follow label warnings even after container is emptied.

14. Transport information

DOT

UN number	UN3378
UN proper shipping name	Sodium carbonate peroxyhydrate
Transport hazard class(es)	
Class	5.1
Subsidiary risk	-
Label(s)	5.1
Packing group	II
Environmental hazards	
Marine pollutant	No
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Special provisions	IB8, IP2, IP4, T3, TP33
Packaging exceptions	152
Packaging non bulk	212
Packaging bulk	240

IATA

UN number	UN3378

UN proper shipping name	Sodium carbonate peroxyhydrate
Transport hazard class(es)	
Class	5.1
Subsidiary risk	-
Packing group	II
Environmental hazards	No
ERG Code	5L
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
IMDG	
UN number	UN3378
UN proper shipping name	SODIUM CARBONATE PEROXYHYDRATE
Transport hazard class(es)	
Class	5.1
Subsidiary risk	-
Packing group	II
Environmental hazards	
Marine pollutant	No
EmS	F-A, S-Q
Special precautions for user	Read safety instructions, SDS and emergency procedures before handling.
Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code	Not applicable.

15. Regulatory information

US federal regulations This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200.
All components are on the U.S. EPA TSCA Inventory List.

TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)

Not regulated.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

CERCLA Hazardous Substance List (40 CFR 302.4)

Not listed.

Superfund Amendments and Reauthorization Act of 1986 (SARA)

Hazard categories

Immediate Hazard - Yes
Delayed Hazard - No
Fire Hazard - No
Pressure Hazard - No
Reactivity Hazard - Yes

SARA 302 Extremely hazardous substance

Not listed.

SARA 311/312 Hazardous chemical Yes

SARA 313 (TRI reporting)

Not regulated.

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List

Not regulated.

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)

Not regulated.

Safe Drinking Water Act (SDWA) Not regulated.

US state regulations

US. Massachusetts RTK - Substance List

Not regulated.

US. New Jersey Worker and Community Right-to-Know Act

Not listed.

US. Pennsylvania Worker and Community Right-to-Know Law

Not listed.

US. Rhode Island RTK

Not regulated.

US. California Proposition 65

California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): This material is not known to contain any chemicals currently listed as carcinogens or reproductive toxins.

International Inventories

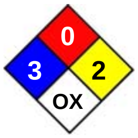
Country(s) or region	Inventory name	On inventory (yes/no)*
Australia	Australian Inventory of Chemical Substances (AICS)	Yes
Canada	Domestic Substances List (DSL)	Yes
Canada	Non-Domestic Substances List (NDSL)	No
China	Inventory of Existing Chemical Substances in China (IECSC)	Yes
Europe	European Inventory of Existing Commercial Chemical Substances (EINECS)	Yes
Europe	European List of Notified Chemical Substances (ELINCS)	No
Japan	Inventory of Existing and New Chemical Substances (ENCS)	Yes
Korea	Existing Chemicals List (ECL)	Yes
New Zealand	New Zealand Inventory	Yes
Philippines	Philippine Inventory of Chemicals and Chemical Substances (PICCS)	Yes
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

*A "Yes" indicates this product complies with the inventory requirements administered by the governing country(s).
A "No" indicates that one or more components of the product are not listed or exempt from listing on the inventory administered by the governing country(s).

16. Other information, including date of preparation or last revision

Issue date	26-March-2015
Revision date	-
Version #	01
Further information	HMIS® is a registered trade and service mark of the American Coatings Association (ACA).
HMIS® ratings	Health: 3 Flammability: 0 Physical hazard: 2

NFPA ratings



Disclaimer

Regenesis cannot anticipate all conditions under which this information and its product, or the products of other manufacturers in combination with its product, may be used. It is the user's responsibility to ensure safe conditions for handling, storage and disposal of the product, and to assume liability for loss, injury, damage or expense due to improper use. The information in the sheet was written based on the best knowledge and experience currently available.

REGENESIS
Technology-Based Solutions for the Environment

SAFETY DATA SHEET

1. Identification

Product identifier	**RegenOx® Part B**
Other means of identification	None.
Recommended use	Soil and Groundwater Remediation.
Recommended restrictions	None known.

Manufacturer/Importer/Supplier/Distributor information

Company Name	Regenesis
Address	1011 Calle Sombra San Clemente, CA 92673
Telephone	949-366-8000
E-mail	CustomerService@regenesis.com
Emergency phone number	CHEMTREC® at 1-800-424-9300 (International)

2. Hazard(s) identification

Physical hazards	Not classified.	
Health hazards	Skin corrosion/irritation	Category 2
	Serious eye damage/eye irritation	Category 2A
OSHA defined hazards	Not classified.	

Label elements

Signal word	Warning
Hazard statement	Causes skin irritation. Causes serious eye irritation.
Precautionary statement	
Prevention	Wash thoroughly after handling. Wear protective gloves. Wear eye/face protection.
Response	If on skin: Wash with plenty of water. If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If skin irritation occurs: Get medical advice/attention. If eye irritation persists: Get medical advice/attention. Take off contaminated clothing and wash before reuse.
Storage	Store away from incompatible materials.
Disposal	Dispose of waste and residues in accordance with local authority requirements.
Hazard(s) not otherwise classified (HNOC)	None known.

3. Composition/information on ingredients

Mixtures

Chemical name	CAS number	%
Silicic Acid, Sodium Salt, Sodium Silicate	1344-09-8	25-40
SILICON DIOXIDE (AMORPHOUS SILICA GEL)	63231-67-4	<10
Ferrous sulfate	7720-78-7	2-5

Composition comments	All concentrations are in percent by weight unless otherwise indicated.

4. First-aid measures

Inhalation	Move to fresh air. Keep victim at rest in a position comfortable for breathing. Call a physician if symptoms develop or persist.
Skin contact	Remove contaminated clothing. Wash with plenty of soap and water. If skin irritation occurs: Get medical advice/attention. Wash contaminated clothing before reuse.
Eye contact	Immediately flush eyes with plenty of water for at least 15 minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Get medical attention if irritation develops and persists.
Ingestion	Never give anything by mouth to a victim who is unconscious or is having convulsions. Rinse mouth. Get medical attention if symptoms occur.
Most important symptoms/effects, acute and delayed	Severe eye irritation. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Skin irritation. May cause redness and pain. Spray mist may irritate the respiratory system. Symptoms may include coughing, difficulty breathing and shortness of breath.
Indication of immediate medical attention and special treatment needed	Provide general supportive measures and treat symptomatically. Keep victim under observation. Symptoms may be delayed.
General information	Ensure that medical personnel are aware of the material(s) involved, and take precautions to protect themselves.

5. Fire-fighting measures

Suitable extinguishing media	Water fog. Foam. Dry chemical powder. Carbon dioxide (CO_2).
Unsuitable extinguishing media	None known.
Specific hazards arising from the chemical	During fire, gases hazardous to health may be formed. Combustion products may include: silicon oxides, metal oxides, sulfur oxides.
Special protective equipment and precautions for firefighters	Self-contained breathing apparatus and full protective clothing must be worn in case of fire.
Fire fighting equipment/instructions	Move containers from fire area if you can do so without risk.
Specific methods	Use standard firefighting procedures and consider the hazards of other involved materials.
General fire hazards	No unusual fire or explosion hazards noted.

6. Accidental release measures

Personal precautions, protective equipment and emergency procedures	Keep unnecessary personnel away. Keep people away from and upwind of spill/leak. Wear appropriate protective equipment and clothing during clean-up. Do not touch damaged containers or spilled material unless wearing appropriate protective clothing. Ensure adequate ventilation. Local authorities should be advised if significant spillages cannot be contained. For personal protection, see section 8 of the SDS.
Methods and materials for containment and cleaning up	Large Spills: Stop the flow of material, if this is without risk. Dike the spilled material, where this is possible. Cover with plastic sheet to prevent spreading. Absorb in vermiculite, dry sand or earth and place into containers. Following product recovery, flush area with water. Small Spills: Wipe up with absorbent material (e.g. cloth, fleece). Clean surface thoroughly to remove residual contamination. Never return spills to original containers for re-use. For waste disposal, see section 13 of the SDS.
Environmental precautions	Avoid discharge into drains, water courses or onto the ground.

7. Handling and storage

Precautions for safe handling	Avoid contact with eyes, skin, and clothing. Avoid prolonged exposure. Provide adequate ventilation. Wear appropriate personal protective equipment. Observe good industrial hygiene practices.
Conditions for safe storage, including any incompatibilities	Store in original tightly closed container. Store in a cool, dry, well-ventilated place. Maintain storage temperatures between 50°F to 140°F (10°C to 60°C). Store away from incompatible materials (see Section 10 of the SDS). Recommended storage containers: steel or plastic. Do not use containers made of aluminum, fiberglass, copper, brass, zinc or galvanized containers.

8. Exposure controls/personal protection

Occupational exposure limits

US. OSHA Table Z-3 (29 CFR 1910.1000)

Components	Type	Value
SILICON DIOXIDE (AMORPHOUS SILICA GEL) (CAS 63231-67-4)	TWA	0.8 mg/m3
		20 mppcf

US. ACGIH Threshold Limit Values

Components	Type	Value
Ferrous sulfate (CAS 7720-78-7)	TWA	1 mg/m3

US. NIOSH: Pocket Guide to Chemical Hazards

Components	Type	Value
Ferrous sulfate (CAS 7720-78-7)	TWA	1 mg/m3
SILICON DIOXIDE (AMORPHOUS SILICA GEL) (CAS 63231-67-4)	TWA	6 mg/m3

Biological limit values No biological exposure limits noted for the ingredient(s).

Appropriate engineering controls Good general ventilation (typically 10 air changes per hour) should be used. Ventilation rates should be matched to conditions. If applicable, use process enclosures, local exhaust ventilation, or other engineering controls to maintain airborne levels below recommended exposure limits. If exposure limits have not been established, maintain airborne levels to an acceptable level. Eye wash facilities and emergency shower must be available when handling this product.

Individual protection measures, such as personal protective equipment

Eye/face protection To avoid contact with eyes, wear chemical goggles or shielded safety glasses.

Skin protection

Hand protection Wear appropriate chemical resistant gloves.

Other Wear appropriate chemical resistant clothing.

Respiratory protection If engineering controls do not maintain airborne concentrations below recommended exposure limits (where applicable) or to an acceptable level (in countries where exposure limits have not been established), an approved respirator must be worn. Recommended use: Wear NIOSH approved respirator appropriate for airborne exposure at the point of use.

Thermal hazards Wear appropriate thermal protective clothing, when necessary.

General hygiene considerations Always observe good personal hygiene measures, such as washing after handling the material and before eating, drinking, and/or smoking. Routinely wash work clothing and protective equipment to remove contaminants.

9. Physical and chemical properties

Appearance	
Physical state	Liquid.
Form	Liquid.
Color	Green to dark blue.
Odor	Odorless.
Odor threshold	Not available.
pH	11 (10% solution/water)
Melting point/freezing point	Not available.
Initial boiling point and boiling range	Not available.
Flash point	Not available.
Evaporation rate	Not available.
Flammability (solid, gas)	Not applicable.

Upper/lower flammability or explosive limits

Flammability limit - lower (%)	Not available.
Flammability limit - upper (%)	Not available.
Explosive limit - lower (%)	Not available.
Explosive limit - upper (%)	Not available.
Vapor pressure	Not available.
Vapor density	Not available.
Relative density	1.2 - 1.4
Solubility(ies)	
Solubility (water)	Miscible.
Partition coefficient (n-octanol/water)	Not available.
Auto-ignition temperature	Not available.
Decomposition temperature	Not available.
Viscosity	< 10,000cP

10. Stability and reactivity

Reactivity	The product is stable and non-reactive under normal conditions of use, storage and transport.
Chemical stability	Material is stable under normal conditions.
Possibility of hazardous reactions	No dangerous reaction known under conditions of normal use.
Conditions to avoid	Contact with incompatible materials.
Incompatible materials	Hydrogen fluoride. Fluorine. Oxygen difluoride. Chlorine trifluoride. Strong acids. Strong bases. Oxidizers. Aluminum metal. Copper. Brass. Zinc. Galvanized metals.
Hazardous decomposition products	Thermal decomposition or combustion may produce: silicon oxides, metal oxides, sulfur oxides.

11. Toxicological information

Information on likely routes of exposure

Inhalation	Prolonged inhalation may be harmful. Spray mists may cause respiratory tract irritation.
Skin contact	Causes skin irritation.
Eye contact	Causes serious eye irritation.
Ingestion	Ingestion may cause irritation and malaise.
Symptoms related to the physical, chemical and toxicological characteristics	Severe eye irritation. Symptoms may include stinging, tearing, redness, swelling, and blurred vision. Skin irritation. May cause redness and pain. Inhalation may irritate lungs causing coughing and/or shortness of breath.

Information on toxicological effects

Acute toxicity	Not available.
Skin corrosion/irritation	Causes skin irritation.
Serious eye damage/eye irritation	Causes serious eye irritation.

Respiratory or skin sensitization

Respiratory sensitization	Not a respiratory sensitizer.
Skin sensitization	This product is not expected to cause skin sensitization.
Germ cell mutagenicity	No data available to indicate product or any components present at greater than 0.1% are mutagenic or genotoxic.
Carcinogenicity	This product is not considered to be a carcinogen by IARC, ACGIH, NTP, or OSHA.

IARC Monographs. Overall Evaluation of Carcinogenicity

SILICON DIOXIDE (AMORPHOUS SILICA GEL) (CAS 63231-67-4)	3 Not classifiable as to carcinogenicity to humans.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

Reproductive toxicity	This product is not expected to cause reproductive or developmental effects.
Specific target organ toxicity - single exposure	Not classified.
Specific target organ toxicity - repeated exposure	Not classified.
Aspiration hazard	Not an aspiration hazard.
Chronic effects	Prolonged inhalation may be harmful.

12. Ecological information

Ecotoxicity	The product is not classified as environmentally hazardous. However, this does not exclude the possibility that large or frequent spills can have a harmful or damaging effect on the environment.
Persistence and degradability	No data is available on the degradability of this product.
Bioaccumulative potential	No data available.
Mobility in soil	This product is water soluble and may spread in the water system.
Other adverse effects	None known.

13. Disposal considerations

Disposal instructions	Collect and reclaim or dispose in sealed containers at licensed waste disposal site. Dispose of contents/container in accordance with local/regional/national/international regulations.
Local disposal regulations	Dispose in accordance with all applicable regulations.
Hazardous waste code	The waste code should be assigned in discussion between the user, the producer and the waste disposal company.
Waste from residues / unused products	Dispose of in accordance with local regulations. Empty containers or liners may retain some product residues. This material and its container must be disposed of in a safe manner (see: Disposal instructions).
Contaminated packaging	Empty containers should be taken to an approved waste handling site for recycling or disposal. Since emptied containers may retain product residue, follow label warnings even after container is emptied.

14. Transport information

DOT

Not regulated as dangerous goods.

IATA

Not regulated as dangerous goods.

IMDG

Not regulated as dangerous goods.

Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code	Not established.

15. Regulatory information

US federal regulations	This product is a "Hazardous Chemical" as defined by the OSHA Hazard Communication Standard, 29 CFR 1910.1200. All components are on the U.S. EPA TSCA Inventory List.

TSCA Section 12(b) Export Notification (40 CFR 707, Subpt. D)

Not regulated.

OSHA Specifically Regulated Substances (29 CFR 1910.1001-1050)

Not listed.

CERCLA Hazardous Substance List (40 CFR 302.4)

Ferrous sulfate (CAS 7720-78-7)	LISTED

Superfund Amendments and Reauthorization Act of 1986 (SARA)

Hazard categories	Immediate Hazard - Yes Delayed Hazard - No Fire Hazard - No Pressure Hazard - No Reactivity Hazard - No

SARA 302 Extremely hazardous substance

Not listed.

SARA 311/312 Hazardous chemical Yes

SARA 313 (TRI reporting)
Not regulated.

Other federal regulations

Clean Air Act (CAA) Section 112 Hazardous Air Pollutants (HAPs) List
Not regulated.

Clean Air Act (CAA) Section 112(r) Accidental Release Prevention (40 CFR 68.130)
Not regulated.

Safe Drinking Water Act (SDWA) Not regulated.

US state regulations

US. Massachusetts RTK - Substance List
Ferrous sulfate (CAS 7720-78-7)

US. New Jersey Worker and Community Right-to-Know Act
Ferrous sulfate (CAS 7720-78-7)

US. Pennsylvania Worker and Community Right-to-Know Law
Ferrous sulfate (CAS 7720-78-7)

US. Rhode Island RTK
Not regulated.

US. California Proposition 65
California Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): This material is not known to contain any chemicals currently listed as carcinogens or reproductive toxins.

International Inventories

Country(s) or region	Inventory name	On inventory (yes/no)*
Australia	Australian Inventory of Chemical Substances (AICS)	Yes
Canada	Domestic Substances List (DSL)	Yes
Canada	Non-Domestic Substances List (NDSL)	No
China	Inventory of Existing Chemical Substances in China (IECSC)	Yes
Europe	European Inventory of Existing Commercial Chemical Substances (EINECS)	Yes
Europe	European List of Notified Chemical Substances (ELINCS)	No
Japan	Inventory of Existing and New Chemical Substances (ENCS)	Yes
Korea	Existing Chemicals List (ECL)	Yes
New Zealand	New Zealand Inventory	Yes
Philippines	Philippine Inventory of Chemicals and Chemical Substances (PICCS)	Yes
United States & Puerto Rico	Toxic Substances Control Act (TSCA) Inventory	Yes

*A "Yes" indicates this product complies with the inventory requirements administered by the governing country(s).
A "No" indicates that one or more components of the product are not listed or exempt from listing on the inventory administered by the governing country(s).

16. Other information, including date of preparation or last revision

Issue date 02-April-2015

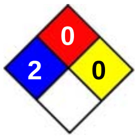
Revision date -

Version # 01

Further information HMIS® is a registered trade and service mark of the American Coatings Association (ACA).

HMIS® ratings
Health: 2
Flammability: 0
Physical hazard: 0

NFPA ratings



Disclaimer

Regenesis cannot anticipate all conditions under which this information and its product, or the products of other manufacturers in combination with its product, may be used. It is the user’s responsibility to ensure safe conditions for handling, storage and disposal of the product, and to assume liability for loss, injury, damage or expense due to improper use. The information in the sheet was written based on the best knowledge and experience currently available.

RegenOx® Technical Description

RegenOx is an advanced chemical oxidation technology that destroys contaminants through powerful, yet controlled chemical reactions. This product maximizes *in situ* chemical oxidation (ISCO) performance through use of a two-part product system; a sodium percarbonate oxidizer complex activated by a patented surface catalyst system. The technology degrades pollutants through direct oxidation, as well as through the generation of a suite of free radical compounds which in turn oxidize recalcitrant contaminants. RegenOX rapidly and effectively destroys a range of target contaminants including petroleum hydrocarbons and chlorinated compounds.

Close up of RegenOx

RegenOx is especially effective in destroying target contaminants present in high concentration source areas within the saturated and vadose zones. For petroleum hydrocarbon treatment, RegenOx produces oxygen as a result of its reactions, providing seamless transition from ISCO to enhanced aerobic bioremediation. RegenOx produces minimal heat when applied, and continues to destroy contaminants for up to 30 days on a single application. RegenOx is safe for use in direct contact with underground utilities, since it is non-corrosive to concrete and most metals.

$$C_2Cl_4 + 4/3\ Na_2CO_3 \bullet 2H_2O_2 + 4NaOH \rightarrow 2CO_2 + 4NaCl + 4H_2O + 4/3\ Na_2CO_3$$

- Free Radical Oxidation via production of:
  - Perhydroxyl Radical ($HO_2 \bullet$)
  - Hydroxyl Radical ($OH \bullet$)
  - Superoxide Radical ($O_2^{-} \bullet$)

For a list of treatable contaminants with the use of RegenOx, view the Range of Treatable Contaminants Guide

Chemical Composition – Part A Oxidant

- Sodium Percarbonate – CAS #15630-89-4
- Sodium Carbonate Monohydrate - CAS #5968-11-6
- Silicic Acid – CAS #7699-11-6
- Silica Gel – CAS #63231

Chemical Composition – Part B Activator Complex

- Silicic Acid, Sodium Salt, Sodium Silicate - CAS#1344-09-08
- Silica Gel – CAS #63231
- Ferrous Sulfate – CAS #7720-78-7
- Water – CAS#7732-18-5

Properties

- Bulk Density – Part A 0.9-1.2 g/cm3; Part B – 1.39 g/cm3
- pH - 10-11 per recommended mixing ratios (3-5% oxidant in solution)
- Solubility – Oxidant - 14.5 g/100 g water; Activator – miscible in water
- Appearance – Brown to orange-brown when mixed with water
- Odor – Not detectable
- Vapor Pressure – None
- Non-hazardous

RegenOx® Technical Description

Storage and Handling Guidelines

Storage
Store in a cool, dry place out of heat/direct sunlight
Store at temperatures not to exceed 40°C/104°F
Store in original tightly closed container
Store in a well-ventilated place
Do not store near combustible materials
Store away from incompatible materials
Protect from contamination
Provide appropriate exhaust ventilation in places where dust is formed

Handling
Minimize dust generation and accumulation
Observe good industrial hygiene practices
Keep away from clothing and combustible materials
Take any precaution to avoid mixing with combustibles
Avoid contact with eyes
Do not taste or swallow
Do not eat, drink or smoke nearby
Wear appropriate personal protective equipment
Wash hands thoroughly after handling
Avoid release to the environment

Applications

RegenOx is applied using direct-injection techniques or wells. The application process enables the two- part product to be combined, then pressure-injected into the zone of contamination and moved out into the aquifer media. Application instructions for this product are contained in the RegenOx Application Instructions Guide.

Health and Safety

Material is relatively safe to handle; however, we recommend avoiding contact with eyes, skin and clothing. OSHA Level D personal protection equipment including vinyl or rubber gloves, eye protection and dust mask are recommended when handling this product. Please review the Material Safety Data Sheet for additional storage, packaging, usage, and handling requirements here: RegenOx Part A SDS and RegenOx Part B SDS.

REGENESIS

www.regenesis.com
1011 Calle Sombra, San Clemente CA 92673
949.366.8000