**Pilot Test Report**

**Boeing Field Chevron**

**10805 East Marginal Way South**

**Tukwila, Washington 98168**

**Ecology Facility/Site No.: 2551**

**Agreed Order No.: DE-10947**

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**G‑Logics Project 01-0410-R**

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G‑Logics Project 01-01-0410-R

Mr. Dale Myers

Washington State Department of Ecology, NWRO

15700 Dayton Avenue North

Shoreline, Washington 98133

Subject: Revised Pilot Test Report

Boeing Field Chevron

10805 East Marginal Way South

Tukwila, Washington 98168

Dear Mr. Myers:

This revised Pilot Test Report presents the purpose, approach, and results of the in-situ chemical oxidation (ISCO) and total liquids extraction pilot test performed by G-Logics, an Atlas Geosciences NW Company, at the above-referenced property. The revised Pilot Test Report addresses comments made by the Washington State Department of Ecology on the draft Pilot Test Report dated November 20, 2023. We trust the information presented in this report meets your needs at this time. Should you require additional information or have any questions, please contact us at your convenience. Thank you again for this opportunity to be of service.

Sincerely,  
**G‑Logics, an Atlas Geosciences NW Company**

Thomas Cammarata, LG, LHG Mike Arnold, LG, LHG

*Principal Project Manager Principal Project Manager*

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# 1.0 INTRODUCTION

G‑Logics, an Atlas Geosciences NW company, completed an in-situ chemical oxidation (ISCO) and total liquids extraction pilot test at the Boeing Field Chevron property (Property) located at 10805 East Marginal Way South, in Tukwila, Washington 98168 (Figure 1). The pilot test was performed in accordance with the *Pilot Test Workplan, Boeing Field Chevron, 10805 East Marginal Way South, Tukwila, Washington,* prepared by G-Logics and dated June 21, 2022 (the Pilot Test Workplan). The purpose of the pilot test was to evaluate the reduction of light nonaqueous-phase liquid (LNAPL) and the reduction of dissolved and soil-sorbed gasoline contaminant mass in groundwater at the Property using the ISCO reagent product PetroCleanze™. PetroCleanze is a combination of RegenOx® Part A and PetroCleanze activator (the injectate). The Pilot Test Workplan presents a detailed discussion of the injectate.

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

# 2.0 BACKGROUND

Service-station operations have been conducted on, or adjacent to, the Property since at least 1941. During this period, the Site, as defined in the Remedial Investigation Report, prepared by G-Logics and dated October 7, 2020 (RI Report), has been impacted by at least three separate releases of petroleum products. The first two of these consisted of unquantified releases of petroleum products associated with service-station operations through approximately 1984 (reported in 1990) and a minor release in 1996 of unspecified petroleum products discovered during the removal of an underground storage tank. The most recent release of gasoline products was associated with a fuel supply line leak, first reported to the Washington State Department of Ecology (Ecology) in 2003.

Three general phases of environmental assessment and remediation efforts have been conducted at the Property since 1990. The first phase of work was performed in association with releases reported in 1990 and 1996 (soil excavation), and a second phase was performed as an initial response to the 2003 release (supply line repairs and additional soil excavation) and included enhanced fluid recovery in 2006, additional exploration, ISCO using Fenton’s Reagent, and passive fluid recovery between 2006 and 2008. Following the execution of the Agreed Order, a third phase of environmental assessment and remediation activities was initiated for the Site, which included additional site characterization, decommissioning of wells, a tidal study, aquifer testing, and a sparge and soil vapor extraction pilot test. A detailed discussion of the historical environmental actions at the Site between 1990 and 2017 is included in Section 2.7 of the RI Report.

## 2.1 Environmental Conditions

A review of a regional geologic map indicates that the surface of the Site is underlain by Quaternary Alluvium (Qa). Qa deposits are typically silt, sand, and gravel deposited in stream beds and river valleys.

Soil borings on the Site generally encountered fill materials, as well as silty sand and gravel to approximately 12 feet below ground surface (bgs). Beneath this layer, silty clay was found to depths of approximately 12 to 18 feet bgs. Deeper borings recovered coarser-grained black sand from approximately 18 feet to 40 feet bgs

**2.2** Hydrogeology

Two separate water-bearing zones underlie the Site. These two zones are identified as an upper, laterally discontinuous, perched zone (Upper Saturated Zone) and a lower, semi-confined aquifer (Lower Saturated Zone). The Upper Saturated Zone occurs within the fill materials and within native shallow silty sands. Tidal fluctuations in the Upper Saturated Zone are minimal to absent. The Lower Saturated Zone is within the lower sand unit and is tidally influenced by the Duwamish River located approximately 275 feet to the west. The two saturated zones are separated by a 2- to 6-foot-thick layer of clayey silt and organic material, which appears to serve as a semi-confining layer between the two zones. In the western portion of the Site, this layer may have been partially removed by previous remedial excavations and/or excavations for the utility corridor within the Tukwila International Boulevard (TIB) right-of-way.

Based on results from the 2016 tidal study performed at the Site by G-Logics, the tidal effect of the Duwamish River on the Lower Saturated Zone extends into the TIB right-of-way and partially into the Property. At high tide, the groundwater in the Lower Saturated Zone flows from the Duwamish River toward the Property. Groundwater in the Upper Saturated Zone at low and high tide generally flows from the Property toward the Duwamish River. At low tide, the groundwater in the Lower Saturated Zones flows from the Property toward the Duwamish River. Additional details regarding the hydrogeologic conditions at the Site, including tidal influence, are included in the RI Report.

# 3.0 Pilot Test Approach

The active applications of ISCO reagent during this pilot test were performed within the Upper Saturated Zone, in accordance with the Pilot Test Workplan. This focus was 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.

The injections targeted the Upper Saturated Zone near the suspected release point because of the high concentrations of GRO, DRO, and benzene in the groundwater at monitoring well IP-4 suggested the presence of LNAPL or anomalously high levels of residual petroleum entrained in soil near that well. Focus on injection within the Upper Saturated Zone in this area was expected to provide appropriate information to address the objectives of the pilot test.

Injection of ISCO reagent within the Lower Saturated Zone was not included as part of this pilot test. Injection into the Lower Saturated Zone was not planned for several reasons:

* Evaluation of hydraulic connection and LNAPL transport between the Upper Saturated Zone and Lower Saturated Zone could not be effectively evaluated if injections were completed in both zones.
* Pilot test injection into that zone was not expected to provide meaningful results because the larger contaminant mass within the Lower Saturated Zone was too large and stoichiometrically incompatible with even a full-scale ISCO injection program.
* The hydrogeologic complexities of the Lower Saturated Zone, including daily tidal influence on groundwater flow direction, were expected to further confound meaningful data interpretation for pilot test injections within that zone.

However, monitoring was performed during the pilot test to evaluate the remedy effects on the mass of petroleum hydrocarbons in the Lower Saturated Zone. The evaluation was completed using changes in LNAPL accumulation, dissolved-phase concentrations, and geochemical conditions in the Lower Saturated Zone resulting from the pilot testing efforts.

For the pilot test, ISCO reagent product PetroCleanze was used, which is a combination of RegenOxPart 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 the biodegradation of petroleum contaminants. The ISCO effect of the PetroCleanze reagent was expected to chemically oxidize and destroy the additional petroleum hydrocarbon mass made available by the PetroCleanze reaction. Additionally, the reagent is designed to mobilized LNAPL, which can be then physically removed by total liquids extraction at select wells by vacuum extraction.

# 4.0 Pilot Test Scope of Work

The objectives of the pilot test were to evaluate whether PetroCleanze and total liquids extraction can be effective at mobilizing and accelerating the reduction of LNAPL mass and reducing dissolved-phase petroleum concentrations. The pilot test began with the installation of monitoring wells TW-4 and TW-5 in the Upper Saturated Zone. A baseline groundwater sampling event was performed to document Site conditions prior to the implementation of the pilot test. Progress groundwater monitoring was performed during the pilot test. Pilot test target wells for baseline and progress groundwater monitoring events included 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. The pilot test target well locations are shown in Figure 2. Figure 3 shows a representative cross section of Upper and Lower Saturated Zones. Figures 2 and 3 show the nature and extent of petroleum hydrocarbons on the Property at the time of the baseline groundwater monitoring event. Boring logs for pilot test wells TW-4 and TW-5 are presented in Appendix A.

It was anticipated that the surfactant-like effect of the ISCO reactions would enhance the recovery of LNAPL entrained in soil pore spaces and render it more available for physical removal, mobilizing LNAPL to the Upper Saturated Zone well IP-4, which is located approximately 8 to 10 feet from the injection points and in an area of potential LNAPL accumulation as determined in the RI Report (Figure 2). Fluid levels were measured before and after each injection event and during progress groundwater sampling performed at the pilot test target 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 discussing the progress groundwater monitoring program are included in Pilot Test Workplan.

# 5.0 Pilot Test Implementation

The pilot test was implemented from August 2022 to July 2023. Scheduled pilot test events occurred as follows:

* Wells TW-4 and TW-5 were installed in the Upper Saturated Zone on August 12, 2022. The wells were installed by Cascade Drilling of Woodville, Washington (Cascade), under the observation of G-Logics. The wells were designed and installed in accordance with the Pilot Test Workplan. Four soil samples were collected from each of the borings. One soil sample from each boring was analyzed for total organic carbon (TOC) by U.S. Environmental Protection Agency (USEPA) Method 9060.
* G-Logics performed baseline groundwater monitoring on August 15, 2022, in accordance with the Pilot Test Workplan. Groundwater samples were analyzed for the following: GRO by Ecology Method NWTPH-Gx; benzene, toluene, ethylbenzene, and xylenes (BTEX) by USEPA Method 8260C; and diesel and oil range organics (DRO and ORO, respectively) by Ecology Method NWTPH-Dx. Groundwater samples collected during the baseline groundwater sampling event from Lower Saturated Zone wells IP-3, IP-5, and IP-7 were additionally analyzed for dissolved TOC by USEPA Method 9060A.
* Under the observation of G-Logics, Cascade advanced direct-push borings and performed injections in each boring on September 7, October 18, and December 20, 2022, in accordance with the Pilot Test Workplan. The injectate was only injected into the Upper Saturated Zone.. At each injection event, three borings were advanced and used as injection points. The first injection event occurred at injection points labeled with a “1” in Figure 2. The second and third injection events were performed at injection points labeled “2” and “3” in Figure 2. The direct-push drilling rig was 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 were then pulled back 3 feet to expose 3 feet of slotted screen. The annular space around the upper 5 feet of the rod (the void from utility check excavation) was filled with lean bentonite cement grout as an additional seal to prevent injectate from traveling up the drilling rod to the surface. After completion of each injection, the drilling tools were extracted from the borehole and the surface at the boring was restored.
* Cascade, under the direction of G-Logics, injected 360 to 375 gallons of injectate solution in each direct-push boring. Cascade mixed the injectate at the Site using RegenOx Part A and PetroCleanze activator, in accordance with the Pilot Test Workplan. The injectate was delivered to the subsurface at pressures ranging from 20 to 25 pounds per square inch (psi). The injection pressures at each well did not substantially vary from the beginning to the end of the injections. G-Logics did not observe injectate daylighting from the annular space of the borings or from near-surface utilities.
* G-Logics performed pilot test progress groundwater monitoring events on September 27, 2022, February 22 and 23, 2023, April 24 and 25, 2023, and July 19 and 20, 2023, in accordance with the Pilot Test Workplan. Groundwater samples were collected using a low-flow sampling method, and groundwater field parameters were measured using a YSI flow-through cell. LNAPL was present on the groundwater at well IP-7 during each groundwater sampling event; therefore, LNAPL was removed from the well using a hand-bailer prior to sampling. Groundwater samples were analyzed for GRO by Ecology Method NWTPH-Gx, BTEX by USEPA Method 8260C, and DRO and ORO by Ecology Method NWTPH-Dx.
* Under the direction of G-Logics, Northern Environmental performed liquid extraction events on October 7, 2022, December 16, 2022, and January 20, 2023, using a truck-mounted vacuum. The liquid extractions were performed in accordance with the Pilot Test Workplan. LNAPL was observed only in the Lower Saturated Zone well IP-7 during the extraction events. As presented in Table 1, the thickness of LNAPL at the beginning of the extraction events was measured at 2.37 feet on October 7, 2022, 2.14 feet on December 16, 2022, and 0.35 feet on January 20, 2023. The volume of water removed from well IP-7 during the extraction events ranged from 500 to 550 gallons over the time-lapse of the extraction events. According to Northern Environmental, approximately 3 gallons of LNAPL were extracted from well IP-7 at the first extraction event; thereafter, only trace amounts of fuel were extracted.

Field notes from the groundwater progress monitoring, injection, and extraction events are presented in Appendix B.

## 5.1 Deviations from Pilot Test Workplan

Deviations from the Pilot Test Workplan occurred during the life cycle of the pilot test, which are discussed below. The potential impact of the deviations on the pilot test results are presented in Section 7.0 of this report.

* Fluid extraction events were not performed at well IP-4 as presented in the Pilot Test Workplan because LNAPL did not accumulate in the well during the pilot test. Total fluids extraction was scoped in the Pilot Test Workplan for points where LNAPL was observed. Groundwater samples were not collected at monitoring wells TW-1, TW-2, and TW3 during the pre-injection baseline groundwater monitoring event or during the September 2022 event because the wells contained less than 18 inches of water, which is an insufficient volume for sampling. Well SVE-1, which was installed as vadose zone well, was not sampled during progress groundwater monitoring events because the well was dry.
* The Pilot Test Workplan indicated that the second extraction event was to occur 2 to 4 weeks after the second injection event. The second extraction event occurred 8 weeks after the second injection event. The additional 4 weeks between the second injection and second extraction event resulted from a scheduling error.
* Except for the event performed on December 20, 2022, all injections were performed at constant pressures of 20 psi. At one injection point on December 20, 2022, the injection pressure varied between 20 and 25 psi. The increased injection pressure of 25 psi did not result in daylighting of the injectate. It may have led to some minor fracking of the formation; however, empirical evidence does not support this hypothesis.
* G-Logics began measuring turbidity during progress groundwater monitoring events in February 2023 because the purge water in some pilot test target wells was often described in previous progress groundwater monitoring events as opaque or cloudy. This condition may have suggested the presence of oxidant or surfactant from the injectate. Although turbidity measurements were not scoped in the Pilot Test Workplan because turbidity was not anticipated as a relevant parameter for the pilot test, field observations indicated that turbidity measurements could have value for the test and were therefore added to the field measurements.
* During the life cycle of the pilot test, G-Logics attempted to measure the depth of the groundwater in pilot test target wells before and after injection and extraction events. G-Logics collected the water levels as one line of evidence to assess the radius of influence of injectate during injection events and drawdown in water levels in the saturated zones as a result of the vacuum applied during the excavation events at monitoring well IP-7. To this end, the most complete data sets were gathered from the injection event performed on September 7, 2022, because the injection events were performed and completed on the same day. For the October 2022 injection event, pre-injection water levels were collected the day before the injection event occurred on October 18, 2022, while the post-injection event water levels were collected after the injection event was completed on October 18, 2022. For the December 2022 pre-injection event, water levels were measured on December 19, 2022, but were not measured after the injection event was completed because the heavy snow event on that day required the field crew to be demobilized from the Site for health and safety reasons.

# 6.0 Pilot Test Performance Monitoring Results

Pilot test performance monitoring results were used to evaluate the efficacy of the injectate in mobilizing LNAPL and reducing dissolved and soil-sorbed petroleum hydrocarbon mass in the Upper and Lower Saturated Zones at the Site. G-Logics evaluated the efficacy of the injectate based on time-series analyses of dissolved-phase petroleum hydrocarbons, the presence or absence of LNAPL on the groundwater, the thickness of LNAPL, the volume of LNAPL recovered during liquid extraction events, and changes in groundwater field parameters during groundwater progress monitoring events. Groundwater elevations and LNAPL thickness are presented in Table 1. Groundwater analytical results are presented in Table 2. Groundwater field parameter measurements are presented in Table 3. Changes in groundwater elevations during the pilot test injection events and one extraction event are presented in Table 4. Laboratory reports are presented in Appendix C. Charts showing changes in field parameters and GRO, DRO, and benzene concentrations in groundwater over the life cycle of the pilot test are presented Appendix D. Appendix E presents statistical trend analyses of groundwater results for GRO, DRO, and benzene.

## 6.1 Soil Total Organic Carbon

TOC analyses were performed to support an evaluation of natural oxidant demand in the Upper Saturated Zone. It was expected that the TOC results would be helpful in calculating the final mass balance requirements for a full-scale ICSO injection. The TOC concentrations in the soil samples collected from TW-4 and TW-5 were reported at 0.38 percent and less than the laboratory reporting limit (0.150 percent), respectively. The samples were collected at 10 to 10.5 feet bgs in oreder to evaluate conditions within the Upper Saturated Zone. According to Regenesis, the percent TOC in the soil sample collected from boring/well TW-4 indicates the potential for a moderate natural oxidant demand for the injectate. However, it is unknown whether the presence of TOC in the sample is native to the formation or if it represents anthropogenic petroleum hydrocarbons in the soil. For any future remedy using an ISCO approach, the oxidant demand would need to be considered for any ISCO considered during the design phase. The laboratory report for the TOC results is presented in Appendix C.

## 6.2 Dissolved Phase Groundwater Concentrations

Prior to implementing the pilot test, G-Logics performed a baseline groundwater sampling event in August 2022. During the pilot test progress groundwater monitoring events performed in September 2022, February 2023, April 2023, and July 2023, G‑Logics collected groundwater samples from Upper Saturated Zone pilot test target wells AS-1, IP-4, TW-1, TW-2, TW-3, TW-4, and TW-5, and Lower Saturated Zone pilot target monitoring wells IP-3, IP-5, and IP-7. Groundwater samples were not collected from well SVE-1, as planned for in the Pilot Test Workplan because the well was dry during all sampling events. Groundwater samples were not collected from wells TW-1, TW-2, and TW‑3 during at least one of the groundwater sampling events because there was an insufficient volume of water in the wells to collect representative samples. Wells IP-3, IP-5, and IP-7 were sampled during the baseline groundwater sampling event but were not sampled again until after the September 2022 progress groundwater monitoring event, in accordance with the Pilot Test Workplan.

Appendix D presents a series of charts (D1 through D7) showing the qualitative changes in the concentrations of GRO, DRO, and benzene in the Upper and Lower Saturated Zone wells from August 2022 to July 2023, relative to the dates of the pilot test injection events. A chart was not prepared for well TW-1 because concentrations of GRO, DRO, and benzene in the groundwater were consistently below applicable groundwater cleanup levels. A chart was not prepared for well TW-3 because groundwater samples were only collected from the well during two progress groundwater monitoring events. Groundwater samples were not collected from the TW series wells before the baseline groundwater sampling event. Toluene, ethylbenzene, and total xylene (TEX) results are not presented in the charts but are presented in Table 2.

Appendix E presents the statistical trend analyses for pilot test target wells from the progress groundwater monitoring events performed during the life cycle of the pilot test. The trend analyses were performed following Ecology’s *Guidance on Remediation of Petroleum-Contaminated Ground Water by Natural Attenuation*, dated July 2005 (Ecology 2005). The trend analyses provide another line of evidence regarding the efficacy of the injectate to treat the media of concern at the Site. G-Logics performed the trend analyses using analytical results for GRO, DRO, and benzene. Pilot test target wells not included in the trend analysis did not contain concentrations of GRO, DRO, or benzene above the laboratory reporting limits; the concentrations were below groundwater cleanup levels for three consecutive progress groundwater monitoring events.

The “target wells” used to perform the trend analyses and evaluate the stability of the plume include Upper Saturated Zone monitoring wells AS-1, IP-4, TW-1, TW-2, and TW-5, and Lower Saturated Zone monitoring wells IP-3, IP-5, and IP-7. The statistical trend analyses were performed using the Mann-Kendell non-parametric trend analysis method if the data set contained four or more results, or linear regression parametric trend analysis if the data set contained three results. A trend analysis was not performed if the data set contained less than three results. Non-detect results were input at half the laboratory reporting limit to perform the trend analyses. Statistical trends in GRO, DRO, and benzene results are reported as expanding, shrinking, stable, or undetermined with time. Undetermined is defined as insufficient evidence to identify a significant trend at the specified level of significance, A summary table of trend analyses and output from the trend analyses is provided in Appendix E.

Changes observed in the concentrations of GRO, DRO, and benzene in the groundwater at pilot test target wells AS-1, TW-2, TW-5, IP-3, IP-4, IP-5, and IP-7 during the time-lapse of the pilot were as follows:

* As shown in Chart D-1, the concentrations of GRO, DRO, and benzene in the groundwater at Upper Saturated Zone well AS-1 appears to increase compared to their baseline concentrations during pilot test injections and declined in concentration thereafter. As shown in Table 2, concentrations of TEX behave similarly to GRO, DRO, and benzene. The statistical trend analysis for AS-1 indicates that the concentration of GRO is stable over the life cycle of the pilot test, and the trend in DRO and benzene concentrations are statistically undetermined. The observed trend in petroleum hydrocarbons at well AS-1 may be anomalous, since the baseline concentrations of GRO and benzene (474 micrograms per liter [µg/L] and 5.98 µg/L, respectively) are substantially lower than last reported in 2019 (4,150 µg/L and 702, µg/L, respectively), as shown in Table 5-1 of the RI Report, which is presented in Appendix F. The concentrations of GRO and benzene in April of 2019 are similar to concentrations observed during the progress groundwater monitoring events.
* As shown in Chart D-2, the concentrations of GRO and DRO in the groundwater at Upper Saturated Zone well TW-2 appear relatively stable 2 to 4 months after the last pilot test injection (December 20, 2022), while the concentration of benzene declines. After the April 2023 sampling event, concentrations of GRO and DRO increased. As shown in Table 2, TEX concentrations generally follow those of GRO and DRO. The statistical trend analyses for well TW-2 indicate that the concentration of GRO is expanding with time, the concentration of DRO is stable with time, and the trend in the benzene concentrations over time is statistically undetermined. Groundwater samples were not collected from the TW series wells prior to the baseline groundwater sampling event.
* As shown in Chart D-3, the concentration trends for GRO and benzene in the groundwater at Upper Saturated Zone well TW-5 appear to decline after the first injection event but remain relatively stable during the time-lapse of the pilot test compared to baseline conditions. The concentrations of DRO appear relatively stable over the same period. Seven months after the last injection event, the concentration of benzene was similar to the benzene baseline concentration. As shown in Table 2, concentrations of TEX appear to remain relatively stable during the time-lapse of the pilot test. The statistical trend analyses for well TW-5 indicate that the concentrations of GRO, DRO, and benzene over the life cycle of the pilot test are stable. There are no groundwater analytical results for well TW-5 before the baseline event.
* As shown in Chart D-4, the concentrations of GRO, DRO, and benzene in the groundwater at Upper Saturated Zone well IP-4 decreased compared to the baseline concentrations during the time-lapse of the pilot test. Seven months after the last injection event, the concentrations of GRO, DRO, and benzene appear to increase. Concentrations of GRO, DRO, and benzene for the baseline groundwater sample collected from well IP-4 are similar to their concentrations in Table 5-1 of the RI Report (Appendix F). As shown in Table 2, concentrations of toluene show a similar concentration trend as GRO, DRO, and benzene, while concentrations of ethylbenzene and total xylenes remain relatively stable. The statistical trend analyses for well IP-4 indicate that the concentrations of GRO and benzene are shrinking with time, while the concentration of DRO is stable with time.
* As shown in Chart D-5, the concentrations of GRO, DRO, and benzene in the groundwater at Lower Saturated Zone well IP-3 appear to increase compared to their baseline concentrations. Four months after the last injection event on December 20, 2022, concentrations of GRO, DRO, and benzene began to decline. As shown in Table 2, concentrations of TEX show similar trends as GRO, DRO, and benzene or remain relatively stable during the time-lapse of the pilot test. The baseline concentrations of GRO, DRO, benzene, and TEX in the groundwater at well IP-3 are similar to their concentrations presented Table 5-1 of RI Report (Appendix F). Concentrations of GRO, DRO, benzene, and TEX in the groundwater at well IP-3 after the baseline sampling event are substantially higher when compared to their concentrations in Table 5-1 of the RI Report. The statistical trend analyses for IP-3 indicate that concentrations of GRO, DRO, and benzene are stable over the life cycle of the pilot test.
* As shown in Chart D-6, the concentrations of GRO, DRO, and benzene in the groundwater at Lower Saturated Zone well IP-5 appear to remain relatively stable over time, confirmed by the statistical trend analyses for well IP-5. As shown in Table 2, the trend in the concentrations of TEX is similar to the trends for GRO, DRO, and benzene. The concentrations of GRO, DRO, and benzene in groundwater at well IP‑5 during the time-lapse of the pilot test are similar to concentrations presented in Table 5-1 of the RI Report (Appendix F).
* As shown in Chart D-7, the concentrations of GRO, DRO, and benzene in the groundwater at Lower Saturated Zone well IP-7 appear to decrease compared to the baseline concentrations during the time-lapse of the pilot test and remain relatively stable 4 months after the last injection event, except for benzene which appears to return to near its baseline concentration. As shown in Table 2, TEX concentration trends are similar to that of GRO, DRO, and benzene during the time-lapse of the pilot test. The statistical trend analyses for IP-7 indicates that concentrations of GRO and benzene are stable over time, while the trend in the concentration of DRO is undetermined. LNAPL was present on the groundwater at well IP-7 prior to each sampling event and was removed from the well with a bailer before sampling. Field notes indicate the presence of a sheen on the discharge water during purging. Groundwater samples were not collected from well IP-7 before the baseline groundwater sampling.

## 6.3 Groundwater Total Organic Carbon

Dissolved-phase TOC concentrations in groundwater samples collected from wells IP-3, IP‑5, and IP-7 were reported at 8.43, 7.94, and 20.7 milligrams per liter, respectively. Dissolved-phase TOC samples were collected to assess the natural oxidant demand in the Lower Saturated Zone for a full-scale ICSO injection program. Dissolved-phase TOC results likely represent dissolved petroleum hydrocarbons and not native or intrinsic oxidant sinks in the Lower Saturated Zones. Dissolved-phase TOC samples were not collected outside the known impacted areas to determine background TOC concentrations because the effort was not included in the Pilot Test Workplan.

## 6.4 Groundwater Field Parameters

During the pilot test groundwater performance monitoring events, G-Logics collected groundwater field parameters at each pilot test target in accordance with the Pilot Test Workplan. The field parameters included pH, conductivity, turbidity, temperature, oxidation-reduction potential (ORP), and dissolved oxygen. Changes in the field parameters were evaluated to determine whether they could be used to evaluate the presence or absence of injectate in the Upper and Lower Saturated Zones.

Groundwater field parameters measured during the groundwater performance monitoring events are presented in Table 3. Charts of groundwater field parameters with time are presented in Appendix D (Charts D-8 through D-12). The following conditions were observed in the field parameters:

* As shown in Chart D-8, the highest pH measurements for the pilot test target wells occurred during the February 2023 progress groundwater monitoring event, almost 3 months after the last injection event in December 2022. In February 2023, some of the highest pH readings were measured at Upper Saturated Zone wells TW-1, TW-4, TW-5, and Lower Saturated Zone wells IP-3 and IP-5. This condition could suggest the presence of the injectate at those wells, which could cause the degradation or mobilize petroleum hydrocarbons. However, statistically, concentrations of GRO, DRO, and benzene at Upper Saturated Zone well TW-5 and Lower Saturated Zone wells IP-3 and IP-5 remained stable over time. In contrast, concentrations of GRO are shrinking over time at well IP-4 even though pH readings are relatively stable with time compared to pH readings at wells TW-4 and TW-5. Since wells IP-4, TW-4, and TW-5 are similar in distance from the injection points, pH in this instance does not appear to be a solid indicator for the presence of the injectate.
* Changes in pH during the life cycle of the pilot test appear to be affected more by the changes in groundwater elevations than by the introduction of the injectate into the Upper Saturated Zone. Furthermore, the magnitude, direction, and permanence of the pH changes are dependent on several factors, such as the buffering capacity of the aquifer material, the amount and type of contaminant oxidized, and the mass of the oxidant. These factors are variable throughout a saturated zone. In consultation with Regenesis, introducing the injectate into the groundwater should have increased the pH into the alkaline range (i.e., 10 to 12) compared to baseline conditions. Regenesis suggested that the absence of alkaline conditions in the groundwater may indicate that the oxidant component of injectate was spent by the time the progress groundwater monitoring event was performed or the oxidant demand of petroleum hydrocarbons overwhelmed the injectate, limiting its effectiveness.
* As shown in Chart D-9, the highest electrical conductivity readings for pilot test target wells, except for Upper Saturated Zone wells IP-4, TW-4, and AS-1, occurred during February and April 2023 progress groundwater sampling events. The increases occurred 2 to 4 months after the last injection event on December 2022. The high conductivity readings that occurred in February and April 2023 at Upper Saturated Zone well TW-5 and Lower Saturated Zone wells IP-3 and IP-5 may suggest the presence of the injectate at those wells. This condition could cause the degradation or mobilization of petroleum hydrocarbons. However, since concentrations of GRO, DRO, and benzene at wells TW-5, IP-3, and IP-5 remain statistically stable over the life cycle of the pilot test, injectate appears to have had no substantial impact on petroleum hydrocarbon at those wells. In contrast, Upper Saturated Zone well IP-4 showed little change in conductivity readings, but GRO and benzene concentrations statically shrank during the pilot test. The increase in conductivity at Lower Saturated Zone wells IP-3 and IP-5 may also result from an influx of salt water from the Duwamish River in the Lower Saturated Zone at the time of sampling. There was an extremely high tide event (9 to 10 feet of change) at the time of sampling at wells IP-3 and IP-5. In consultation with Regenesis, they suggested an increase in electrical conductivity compared to baseline measurements may indicate the presence of salts released from the injectate but does not necessarily indicate the oxidant in the injectate is reacting in the groundwater to degrade petroleum hydrocarbons.
* As shown in Chart D-10, ORP readings measured during the baseline groundwater sampling event and progress groundwater monitoring events generally indicated that anoxic to anaerobic conditions were present in the Upper and Lower Saturated Zones until the July 2023 progress groundwater monitoring event. The July 2023 ORP readings at the pilot test target wells, except for well TW-5, indicated the groundwater was aerobic. The change to aerobic conditions in the Upper and Lower Saturated Zones is unexplained since the injectate was likely spent at the time of the July 2023 progress groundwater monitoring event; however, it does appear to coincide with a slight increase in concentrations of GRO or benzene in some the pilot test target wells (e.g., wells IP-4, IP-5, TW-2, and TW-5). In consultation with Regenesis, introducing an oxidant in the Upper Saturated Zone should have led to a substantial increase in ORP readings during the progress groundwater monitoring events compared to baseline conditions. They suggested that the injectate was likely spent within a week to two weeks after the last injection event. It is more likely that whatever was driving the anaerobic conditions observed during the progress groundwater monitoring event was no longer affecting the groundwater chemistry in July 2023.
* Dissolved oxygen results suggest groundwater in the saturated zones is under anoxic to anaerobic conditions, except for dissolved oxygen results from the February 2023 groundwater sampling event. Introducing an oxidant in the Upper Saturated Zone should have led to a substantial increase in dissolved oxygen concentrations compared to baseline conditions. The absence of elevated concentrations of dissolved oxygen may indicate that the oxidant component of injectate was spent by the time the progress groundwater monitoring event was performed, was overwhelmed by the oxidant demand in the saturated zones, or the oxygen sensor on the YSI meter was not calibrated correctly, or the calibration drifted during use (flow-through cells were rented from, and calibrated by, a vendor). It should be noted that except for well TW‑5, the February 2023 dissolved oxygen results are considered anomalous because dissolved oxygen concentrations in the groundwater reflect the solubility limit of oxygen at the temperatures in groundwater at the Site. The anomalous readings may suggest that YSI oxygen meter for the February 2023 monitoring event was not operating properly. Dissolved oxygen readings are not presented in a chart since there is some uncertainty in the readings and value to assess the efficacy of the injectate. Temperature readings did not substantially change in the groundwater during the time-lapses of the progress groundwater monitoring events compared to baseline conditions, except the temperature readings from the February 22, 2023, progress groundwater monitoring event, which are 3 to 4 degrees centigrade lower compared to temperature readings from previous groundwater progress monitoring events. This condition is shown in Chart D-11. According to Regenesis, the temperature of groundwater does not typically change because of the introduction of PetroCleanze. Furthermore, the elevated temperature readings are not anomalous for the Site. For example, the temperature readings at on-Property wells MW26S, MW27S, MW-28S, MW29S, and MW28D in August 2018 ranged from 17.28 to 19.74 degrees centigrade and are similar to temperature readings in the July 2023 sampling event at wells TW-1, TW-2, TW-3, and TW-4. Fluctuations in temperature could be due to the outdoor ambient air temperature at the time the readings were taken. The purge water passes through a flow cell that is outside of the well. The cell can be chilled or warmed by the outdoor ambient temperature. This may explain why temperature readings were lower during the February 22, 2023, progress groundwater monitoring event when the ambient temperature was 2 degrees centigrade.
* Turbidity is a measure of the cloudiness, or clarity, of water. As shown in Chart D-12, turbidity readings were the lowest during the April 2023 progress groundwater monitoring event, as was the pH. A reduction in pH can lead to greater chemical oxidation of substances that cause color in water, resulting in lower turbidity. Lower turbidity readings also appear to be associated with slightly lower concentrations of GRO, DRO, and benzene over the life cycle of pilot test; however, the significance of that relationship is unknown. Furthermore, since turbidity readings were not collected during the baseline groundwater sampling event and the first progress groundwater monitoring event, turbidity readings do not provide any useful information to aid in the interpretation of pilot test results.

Based on analysis of field parameters, it appears that pH and conductivity may in some instances suggest the presence of the injectate, although Regenesis did not find the changes in pH and conductivity during the life cycle of the pilot test, compared to baseline conditions, provided any evidence that injectate was performing as designed. In addition, elevated pH and conductivity readings may be influenced by tidal effect, changes in groundwater elevations, ambient conductions, or the drift in the instrument calibration.

## 6.5 Pilot Test Hydraulic Effect

The hydraulic effect of injection and extraction events on the groundwater elevations was assessed using changes in pre- and post-injection groundwater elevations measured from the September 7, 2022, injection event and changes in the water level of well IP-5 during the extraction event on October 7, 2022. G-Logics selected data collected during the September 2022 injection and October 2022 extraction events to assess the hydraulic effect of the pilot test because the water level measurements from the September and October 2022 events were the most complete. G-Logics also evaluated the temporal changes in groundwater elevations at the pilot test target well during the progress groundwater monitoring events.

The following hydraulic effects were observed:

* As shown in Chart D-13, groundwater elevations in the Upper and Lower Saturated Zones appear to be relatively stable after the baseline groundwater monitoring event. Overall, there was a moderate increase in groundwater elevations Upper Saturated Zone during the February and April 2023 progress groundwater monitoring events, which probably can be associated with seasonal flux in groundwater elevation during the rainy season Pacific Northwest.
* Immediately after the September 2022 injection event, groundwater elevations in the Upper Saturated Zone wells increased, except for groundwater elevation at well IP‑4. As shown in Table 4, the increase in groundwater elevations ranged from 0.01 feet at well TW-1 to 1.25 feet at well TW-3. The maximum hydraulic effect on the Upper Saturated Zone is estimated to extend approximately 30 feet from the injection points based on the groundwater elevation change at well TW-3. Water levels measured prior to the injections were measured during an ebbing tide. It is unlikely that tidal fluctuation affected the increase in groundwater elevations in the Upper Saturated Zone since, according the RI Report, the Upper Saturated Zone on the Property is not tidally influenced.
* Immediately after the September 2022 injections, groundwater elevations for the Lower Saturated Zone wells increased. As shown in Table 4, the increase in the groundwater elevation ranged from 1.59 feet at well IP-3 to 2.16 feet at well IP-5. The maximum hydraulic effect on the Lower Saturated Zone from the injection event is estimated at approximately 30 to 35 feet from the points of injection based on the groundwater elevation change at IP-7 of 2.01 feet immediately after the September 2022 injection event. Water levels measured after the injection event were measured during a rising tide. It is possible that tidal fluctuation increased the groundwater elevations in the Lower Saturated Zone since, according to the RI Report, the Lower Saturated Zone on the Property is tidally influenced.
* During the October 2022 extraction event, the hydraulic effect of the liquid extraction on the Lower Saturated Zone was monitored by measuring changes in groundwater elevation at Lower Saturated Zone well IP-5, while a vacuum was applied to well IP‑7. Well IP-5 is located approximately 40 feet south of well IP-7. A vacuum was applied to well IP-7 for approximately 110 minutes with an extraction rate of 0.2 gallons per minute (with a vacuum estimated at 12-inches of water)). During this time, the groundwater elevation at well IP-5 changed from 4.54 feet 20 minutes before the extraction event started to 3.78 feet 190 minutes after the extraction event ended, which is a difference of –0.76 feet. The maximum difference in the groundwater elevation compared to 20 minutes before the extraction event began was –1.03 feet 80 minutes after the start of the extraction event. Both the pre- and post-water levels measured during the extraction event were taken during a rising tide. It is possible that tidal fluctuation affected the observed changes in groundwater elevations in the Lower Saturated Zone, since according to the RI Report, the Lower Saturated Zone on the Property is tidally influenced. The results from the hydraulic effect observed during the extraction event may inform the design of various remedial alternatives for the Feasibility Study. The change in groundwater elevations at well IP-5 with time is shown in Table 4.
* As shown in Table 4, during injection events there are generally larger groundwater level responses observed in the pilot test target wells screened in the Lower Saturated Zone wells compared to the pilot test target wells screened in the Upper Saturated Zone wells. Since the saturated zones are separated by a semi-confining layer, it is not surprising groundwater levels in the Lower Saturated Zone responded to an increase in hydraulic press in the Upper Saturated during injection events. The large groundwater level response in the Lower Saturated Zone may also result from the pressure wave generated during tidal flux. It is unknown if the larger groundwater level responses in Lower Saturated Zones indicate that the injectate was lost to the Lower Saturated Zone instead of treating the Upper Saturated Zone. However, some injectate was likely lost to the Lower Saturated Zone because it is semi-confined and because remedial excavations performed at the Property may have created preferential pathways between the saturated zones.

## 6.6 Field Observations

During progress groundwater monitoring events, water was purged from wells following the procedure presented in the Pilot Test Workplan. Field observations made during progress groundwater monitoring events are presented in Appendix B. G-Logics made the following observations during the purging of the pilot test target wells:

* At the start of purging, the water discharged from some of the pilot test target wells emitted a mild to strong petroleum hydrocarbon odor. The petroleum odor from the purge water is not considered anomalous, since high concentrations of dissolved-phase petroleum hydrocarbons are present in the groundwater on the Site.
* At the start of purging, the water discharged from some of the pilot test target wells was described as opaque or cloudy. The purge water was generally clear by the end of the purge cycle. Initial cloudiness of purge water may suggest the presence of salts in groundwater from the degradation of the injectate oxidant, the formation of other precipitates (e.g., metal oxyhydroxides), the presence of the injectate surfactant, or the presence of an emulsion of petroleum hydrocarbons and surfactant in the groundwater.
* At the start of purging, the color of the water discharged from Upper Saturated Zone wells TW-1, TW-4, TW-5, and AS-1 and from Lower Saturated Zone wells IP-3 and IP-5 was sometimes described as amber or brown. In consultation with Regenesis, the amber and brown colors may represent an emulsion of surfactant and fine petroleum hydrocarbon droplets or the formation of precipitates (e.g., metal oxyhydroxides). An emulsifier acts like a detergent, dissolving the oil into the water. Instead of an oil layer on top of the water, there are dissolved oil and fine immiscible oil droplets in the water. The surfactant dissolves the oil and disperses it throughout the water column rather than allowing it to float on the surface (ITRC 2024a). The color of the water may also indicate the presence of non-petroleum precipitates in the water created from the presence of oxidant and salts from the injectate.
* At the start of purging during the July 2023 progress groundwater monitoring event, a sheen was observed on the discharge water at Upper Saturated Zone pilot test target well TW-5 and Lower Saturated Zone well IP-4. The presence of a sheen may indicate that LNAPL is present in the formation at or below residual saturation. LNAPL at residual saturation will not appear in the well, although the presence of a sheen is a possible indicator of petroleum hydrocarbon at residual saturation in the formation (ITRC 2024b).
* In the field notes for the February 2023 progress groundwater monitoring event, well TW-5 is shown to contain LNAPL (0.84 feet thick); however, no measurable product was observed in the well. This erroneous entry for product thickness was associated with well IP-7.

# 7.0 Deviation from THE PILOT TEST WorkPlan—Impact on Pilot Test Results

Deviations from the Pilot Test Workplan during the time-lapse of the pilot test are detailed in Section 5.1 of this Pilot Test Report. The potential impact of the deviations on the results from the pilot test are discussed below:

* During the time-lapse of the pilot test, LNAPL did not accumulate in Upper Saturated Zone well IP-4. The absence of LNAPL in the well, given the elevated concentrations of dissolved-phase hydrocarbons in the groundwater collected from the well, suggests that LNAPL in the formation proximal to well IP-4 is at residual saturation and will not flow to the well naturally or in the presence of a surfactant and, therefore, is not recoverable. In addition, extracting groundwater at well IP-4 in the absence of LNAPL would have generated large volumes of groundwater containing high concentrations of dissolved-phase petroleum hydrocarbons and would unnecessarily increase disposal costs.
* The absence of sufficient groundwater to collect groundwater samples from pilot test target wells SVE-1, TW-1, TW-2, and TW-3 during the pre-injection baseline groundwater monitoring event may have some impact on the interpretation of the pilot test results when trying to compare baseline concentrations with concentrations from later progress groundwater monitoring events. However, it is not surprising that wells TW-1, TW-2, and TW-3 are occasionally dry, since they were installed as vadose zone wells, as stated in Section 3.2.11 of the RI Report. Soil vapor extraction well SVE-1 was also installed as a vadose well, as discussed in Section 3.0 of the Feasibility Study Pilot Test Workplan (G-Logics 2019).
* The Pilot Test Workplan indicated that the second extraction event was to occur 2 to 4 weeks after the second injection event; however, the second extraction event occurred 8 weeks after the second injection event. The additional 4 weeks between the second injection and second extraction events does not appear to have any impact on interpreting the pilot test results, since LNAPL was not observed in the pilot test target wells at the time other extraction events were performed, except at Lower Saturated Zone Well IP-7.
* The increase in the injection pressure from 20 to 25 psi on the December 20, 2022, injection event unlikely had any bearing on the pilot test results, since the formation did not refuse the injectate at the higher pressure, which suggests the increased injection pressure did not exceed the overburn pressure of the formation.

# 8.0 Data Validation

Data validation for the laboratory analytical results was performed on samples collected from August 2022 to July 2023. The laboratory analyzed the groundwater samples for GRO, BTEX, DRO, and ORO. Select groundwater samples were analyzed for dissolved TOC. Soil samples collected from borings used to install wells TW-4 and TW-5 were analyzed for TOC. The usability of the laboratory analytical results to meet the data quality objective was evaluated based on holding times, preservation, field duplicate, laboratory method blanks, and accuracy and precision. Laboratory reports are presented in Appendix C.

## 8.1 Holding Times and Preservation

For Ecology Methods NWTPH-Gx and Dx and USEPA Method 8260, all groundwater samples analyzed met the acceptance criterion of analysis from the date of sample collection. For USEPA Method 9060 and 9060A, soil and groundwater sample holding times met the acceptance criterion of analysis from the date of the sample. The preservation for each sample met the acceptance criterion of 4 degrees Celsius at the time the samples were received at the laboratory.

## 8.2 Laboratory Method Blanks

A laboratory method blank is used to monitor for possible contamination resulting from either the reagents (acids) or the equipment used during sample processing, including filtration. Laboratory method blanks were prepared and analyzed for each analyte for each medium. Analytes of concern were not detected in the method blanks for each medium at concentrations above laboratory reporting limits.

## 8.3 Accuracy and Precision

The laboratory measured accuracy and precision with surrogate recoveries, blank spikes, and blank spike duplicates for each batch of samples analyzed for analytes of concern. Blank spikes and blank spike duplicates were spiked with analytes of interest as applicable to the analytical method. Percent recoveries and relative percent differences for all blank spikes blank, spike duplicates, and surrogate recoveries met the laboratory acceptance criteria with the following exception:

* The DRO and ORO surrogate recoveries for groundwater samples collected from well TW-5 on February 22, 2023, were outside the laboratory control limits. The laboratory reported the concentrations of DRO and ORO in the groundwater sample collected from well TW-5 at estimated concentrations greater than the laboratory reporting limit.
* The surrogate recoveries for DRO and ORO for groundwater samples collected from wells AS-1 and IP-3 on April 25, 2023, were outside the laboratory control limits. Concentrations of DRO and ORO in the groundwater samples collected from wells AS-1 and IP-3 were reported as less than the laboratory reporting limit.
* The DRO and ORO surrogate recoveries for groundwater samples collected from wells AS-1 on July 20, 2023, and TW-5 on July 19, 2023, were outside the laboratory control limits. Concentrations of DRO in the groundwater samples collected from wells AS-1 and TW-5 were reported at estimated concentrations greater than the laboratory reporting limit.
* The surrogate recoveries for AS-1 and IP-3 are biased low for the April and July 2023 sampling results. The concentration of DRO in these samples is likely a result of late-eluting gasoline-range compounds and not a separate DRO fraction. Therefore, the DRO results for AS-1 and IP-3, whether biased high or low based on surrogate recoveries, do not affect the usability of the results for purposes of the pilot test. The laboratory attributed the low surrogate recoveries to matrix interference. Results are likely biased low. The affected sample results are flagged with a Q in Table 2.

## 8.4 Groundwater Sample Field Duplicates

Groundwater field duplicates were collected from wells AS-1, IP-3, and TW-1. Duplicate results are presented in Table 2. The relative percent difference (RPD) for GRO ranged from 0 to 42%, DRO RPDs ranged from 10 to 41%, and benzene RPDs ranged from 1 to 29%. According to the USEPA, criteria for acceptance of duplicate results for environmental samples is generally in the range of 30 to 50% (Eva L Davis, USEPA Poster Session). RPDs were not calculated for TEX because RPDs likely fall within same range for GRO, DRO, and benzene. RPDs for GRO, DRO, and benzene fall within the USEPA criteria for acceptance.

# 9.0 Discussion of Pilot Test Findings

The purpose of the pilot test was to determine whether PetroCleanze injected into the Upper Saturated Zone could mobilize LNAPL and reduce dissolved and soil-sorbed gasoline contaminant mass in the Upper and Lower Saturated Zones at the Site. Changes in the dissolved-phase petroleum hydrocarbons concentrations, TOC concentrations, field parameter measurements, and presence or absence of LNAPL during the time-lapse of the pilot test may suggest the following conditions related to the efficacy of using PetroCleanze as a remedial alternative for Site:

* The TOC concentration in the soil sample collected from boring TW-5 at depth of 10.5 bgs may not be representative of natural organic carbon in soil because the field screening readings from a handheld photoionization detector (PID) indicated the presence of petroleum hydrocarbons in the soil at the depth the sample was collected. TOC was not detected above the laboratory reporting limit in the soil sample collected from boring TW-4, and PID readings did not indicate the presence of petroleum hydrocarbons. However, soil TOC results do not account for oxygen demand that may be placed on the injectate by reduced species of metals, such as ferrous iron, manganese, and sulfides. TOC results are presented in Appendix C.
* The concentrations of dissolved TOC reported in wells IP-3, IP-5, and IP-7 likely reflect dissolved-phase petroleum hydrocarbons in the groundwater from the release at the Site and not the natural background concentrations of TOC in the Lower Saturated Zone. Elevated concentrations of petroleum hydrocarbons were present in the groundwater at wells IP-3, IP-5, and IP-7 when samples for TOC analysis were collected.
* The increase in concentrations of dissolved-phase petroleum hydrocarbons after the baseline groundwater sampling event in the Upper Saturated Zone well AS-1 (assuming the baseline concentrations are not anomalous) and Lower Saturated Zone wells IP-3 and IP-5 (Charts D-1 , D-5, and D-6) may be the result of partitioning from LNAPL to the dissolved phase and desorption of petroleum hydrocarbons from the soil to the dissolved phase because of the surfactant properties of the injectate. According to Regenesis, the decrease in the concentration of dissolved-phase petroleum hydrocarbons at wells AS-1 and IP-3 4 months after the last injection event may indicate the loss of dissolved-phase mass due to intrinsic biodegradation. However, stable or undetermined statistical trends in the groundwater concentrations GRO, DRO, and benzene at wells AS-1, IP-3, and IP-5 may also suggest the mass petroleum hydrocarbons in Upper and Lower Saturated Zones puts an excessive oxidant demand on injectate, which limited its ability to continually create conditions that are conducive to the sustained degradation of petroleum hydrocarbons over time. The apparent decrease in GRO, DRO, and benzene concentrations in July 2023 progress groundwater monitoring event compared to the previous sampling events, excluding the baseline event, may be related to a seasonal decline in water levels during the dry season in the Pacific Northwest. During the dry times of year, the groundwater level may fall below the zone where the where the mass of petroleum hydrocarbons is greater.
* The apparent and statistical decrease in the concentration of GRO and benzene (DRO was statistically stable over time) in the groundwater at Upper Saturated Zone well IP-4 (Chart D-4) during the time-lapse of the pilot test suggests that surfactant properties of the injectate desorbed petroleum hydrocarbons from soil to the dissolved phase where petroleum hydrocarbons were likely oxidized by the oxidant properties of the injectate and biologically degraded. The apparent increase in the concentration of GRO and benzene in July 2023 may also suggest the surfactant and oxidative properties of the injectate are spent as of July 2023, the injectate did not reach the Upper Saturated Zone well IP-4, or the injectate was consumed between the injection event and the following groundwater monitoring event. This conclusion may be supported by the fact that conductivity and pH readings, which may reflect the presence of the injectate, were relatively stable over the life cycle of the pilot test when compared to baseline readings for example when compared to pH and conductivity readings taken at wells IP-5 and TW-5. One goal of the pilot test was to mobilize LNAPL to well IP-4. Measurable LNAPL was not observed at well IP-4 during the time-lapse of the pilot test.
* The apparent and statistical stability of GRO, DRO, and benzene concentrations in the groundwater at Upper Saturated Zone well TW-5 over time suggests that surfactant and oxidative properties of the injectate failed to impact the mass of petroleum hydrocarbon in the saturated zone proximal to the well, even though the well is located hydraulically downgradient and a similar distance from injection points as upgradient well IP-4. Furthermore, the relatively elevated readings of pH and conductivity at well TW-5 could suggest the presence of the injectate did not lead to the degradation of GRO, DRO, and benzene in the dissolved phase. The relative increase in the concentrations of GRO, DRO, and benzene in the groundwater at well TW-5, 7 months after the last injection event (July 20, 2023), may represent a seasonal fluctuation in the groundwater concentrations when compared to results presented in Table 5-1 of the RI Report (Appendix F).
* The location of well TW-2 in relationship to the injection area, approximately 20 feet, may account for the minimal hydraulic effect observed at well TW-2 during the September 7, 2022, injection event. The minimal hydraulic effect and relatively stable pH and conductivity readings over time may also suggest the injectate had no effect on petroleum hydrocarbons at well TW-2. The increase in concentrations of GRO, DRO, and benzene in the groundwater at well TW-2, 7 months after the last injection event (July 20, 2023), is likely related to a seasonal fluctuation in the water level when compared to historical water levels for other wells in the monitoring well network, as shown in Table 5-1 of the RI Report (Appendix F). However, the absence of baseline groundwater results for well TW-2, and the fact that the well was not sampled during the remedial investigation suggests that there is a high degree of uncertainty in the interpretation of analytical results for wells TW-2.
* The decrease in the concentrations of GRO, DRO, and benzene in the groundwater at Lower Saturated Zone well IP-7 during the time-lapse of the pilot test could suggest the injectate supported the degradation of petroleum hydrocarbons in the groundwater. However, given the distance of well IP-7 from the injection area (approximately 30 feet) and relatively stable pH and conductivity readings over time, it is unlikely the injectate had any impact on the concentrations of petroleum hydrocarbons at well IP-7. As seen in other pilot test wells, the increase in concentrations of GRO, DRO, and benzene in the groundwater at well IP-7, 7 months after the last injection event (July 20, 2023), is likely related to a seasonal fluctuation in the water level when compared to historical water levels for other wells in the monitoring well network, as shown in Table 5-1 of the RI Report (Appendix F). In addition, there is some uncertainty in groundwater results collected during the pilot test because of the presence of LNAPL in well IP-7 that ranged in thickness from 0.17 to 2.66 feet. LNAPL was removed from well IP-7 before each sampling event using a hand-bailer.
* In reviewing the field parameters results with Regenesis, they concluded that groundwater field parameters did not indicate that injecting PetroCleanze in the Upper Saturated Zone created optimum conditions to desorb petroleum hydrocarbons from the soil and degrade dissolved-phase petroleum hydrocarbons. Regenesis suggested that the absence of optimum conditions may indicate that the oxidant component of injectate was spent by the time the progress groundwater monitoring event was performed. Alternatively, the absence of optimum conditions to mobilize LNAPL and degrade dissolved-phase petroleum hydrocarbons may indicate that the mass of petroleum hydrocarbons in the saturated zones was greater than anticipated by the pilot test. This condition overwhelmed the oxidative and surfactant properties of the injectate and limited its effectiveness.
* Hydraulic effects data collected at the September 7, 2022, injection event suggested that the hydraulic pressure wave from injecting PetroCleanze into the Upper Saturated Zone extended approximately 30 feet from the perimeter of the injection area. However, field parameters and other lines of evidence previously discussed suggest the radius of influence for injectate may be 5 to 10 feet. The volume of PetroCleanze injected into each injection point was approximately 360 to 375 gallons. According to Section 4.1 of the Pilot Test Workplan, a design volume of 360 gallons was selected as the estimated available pore space volume within the expected radius of hydraulic influence of 15 feet from each injection point.
* Based on changes in groundwater elevations at measured during the September 2022 progress groundwater monitoring event at Lower Saturated Zone wells IP-3, IP-5 and IP-7, injections in the Upper Saturated Zone may have created a rise in water levels in the wells. In addition, conductivity and pH readings measured during the February 2023 progress groundwater monitoring event may suggest that the injectate reached wells IP-3 and IP-5. However, the Lower Saturated Zone is tidally influenced, which may have resulted in an influx of salts from a very high tidal cycle during the February 2023 progress groundwater monitoring event. Furthermore, GRO, DRO, and benzene concentrations were statistically stable over the life cycle of the pilot, which suggests the injectate had little or no impact on the mass of petroleum hydrocarbons in the saturated zone proximal to wells IP-3, IP-5, and IP-7.

# 10.0 ConclusionS

The pilot test gathered sufficient data to evaluate the efficacy of using the ISCO reagent PetroCleanze to reduce LNAPL and dissolve petroleum hydrocarbons in groundwater at the Site. The data collected for the pilot test suggests that the PetroCleanze injections may have resulted in minor reductions in dissolved-phase petroleum hydrocarbon concentrations in several wells (e.g., IP-4). The results may also provide some evidence that PetroCleanze was effective in increasing the desorption of petroleum hydrocarbons present in saturated soils through its surfactant-like properties, which is suggested by the increases in dissolved-phase petroleum hydrocarbon concentrations observed at monitoring wells IP-3 and IP-5, although statistically the concentrations of GRO, DRO, and benzene were stable over the duration of the pilot test.

However, collectively the lines of evidence presented in this Pilot Test Report do not provide sufficient evidence to suggest that a PetroCleanze-based remediation strategy would be successful at the Site. G-Logics believes that the uninspiring performance of PetroCleanze during the pilot test was due to the complex geology and hydrogeology at the Site, which may not be conducive to effectively introducing an oxidizing reagent to the areas where hydrocarbon contaminant mass is greatest. In addition, or alternatively, the mass of petroleum hydrocarbons present at the Site may be sufficiently large to have essentially overwhelmed the mass of ISCO reagent injected for the pilot test. Regardless of the cause, these results suggest that full-scale implementation of an ISCO-based remediation strategy would be unlikely to achieve the cleanup objectives for the Site in a cost-effective manner.

# 11.0 Recommendations

G-Logics recommends using the information and data collected during the air-sparge/soil vapor extraction pilot test previously conducted and the data collected as part of this ISCO pilot test to update and complete the Draft Feasibility Study.

G-Logics will revise the alternative screening sections and rescore the alternatives, taking the recently acquired data into consideration. Using the pilot test results, G-Logics will consider other active remedial alternatives as well as plume containment alternatives, which could be implemented until such time as the service station is no longer in use, at which time a full-scale remediation could be completed.

# 12.0 LIMITATIONS

The scope of work on this project was presented in our identified workplan and subsequently approved by RPNP Corporation. Please be aware our scope of work was limited to those items specifically identified in the Workplan and regulatory comments on deliverables. Other activities not specifically included in the presented scope of work (in a workplan, correspondence, or this report) are excluded and are therefore not part of our services.

Land use, site conditions (both on-site and off-site), and other factors will change over time. Since site activities and regulations beyond our control could change at any time after the completion of this report, our observations, findings, and opinions can be considered valid only as of the July 19, 2023.

The property owner is solely responsible for notifying all governmental agencies and the public at large of the existence, release, treatment, or disposal of any hazardous materials identified at the project site. G‑Logics assumes no responsibility or liability whatsoever for any claim, loss of property value, damage, or injury which results from pre-existing hazardous materials being encountered or present on the project site, or from the discovery of such hazardous materials.

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# 13.0 REFERENCES

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**FIGURES**

**TABLES**

**APPENDIX A**

**BORING LOGS**

**APPENDIX B**

**FIELD NOTES**

**APPENDIX C**

**LABORATORY REPORTS**

**APPENDIX D**

**PETROLEUM HYDROCARBON AND FIELD PARAMETER CHARTS**

ACRONYMS AND ABBREVIATIONS FOR

PETROLEUM HYDROCARBON AND FIELD PARAMETER CHARTS

µg/L micrograms per liter

Avg average

DRO diesel range organics

GRO gasoline range organics

GW groundwater

GWL groundwater level

LSZ Lower Saturated Zone

USZ Upper Saturated Zone

**APPENDIX E**

**STATISTICAL TREND ANALYSES**

**APPENDIX F**

**TABLE 5-1: REMEDIAL INVESTIGATION REPORT**