FEASIBILITY STUDY ADDENDUM

West of 4th - Site Unit 1

Prepared for: West of 4th Group

Project No. 050067 • April 2023 PUBLIC REVIEW DRAFT

Aspect CONSULTING

earth + water

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Acronyms

AO	Agreed Order
ABP	Art Brass Plating
ARAR	applicable or relevant and appropriate requirement
Aspect	Aspect Consulting, LLC
AS	air sparging
BE	Burlington Environmental
BDC	Blaser Die Casting
bgs	below ground surface
CI	Capital Industries
cis-DCE	cis-1,2-dichloroethene
COC	constituent of concern
CUL	Cleanup level
CVOC	chlorinated volatile organic compounds
DCA	disproportionate cost analysis
DCE	dichloroethene
EAnB	Enhanced Anaerobic Bioremediation
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
ISCO	*In-Situ* Chemical Oxidation
ISCR	*In-Situ* Chemical Reduction
M	million
mg/kg	milligrams/kilograms
mg/L	milligrams per liter
µg/L	micrograms per liter
MNA	Monitored Natural Attenuation
MTCA	Model Toxics Control Act
NPV	Net Present Value

O&M	operation and maintenance
PCE	tetrachloroethene
PCUL	preliminary cleanup level
PGG	Pacific Groundwater Group
PLP	potentially liable person
PRB	permeable reactive barrier
RAO	Remedial Action Objective
RI	Remedial Investigation
ROW	right-of-way
SCM	Site Conceptual Model
SU1	Site Unit 1
SU2	Site Unit 2
SVE	soil vapor extraction
TCE	trichloroethene
TOC	total organic carbon
UIC	underground injection control
VC	vinyl chloride
VI	vapor intrusion
VIAMM	vapor intrusion assessment monitoring and mitigation
VOC	volatile organic compound
W4	West of 4th
WAC	Washington Administrative Code
Waterway	Lower Duwamish Waterway
ZVI	zero-valent iron

Executive Summary

This West of 4th (W4) Group Site Unit 1 Feasibility Study (FS) Addendum report (SU1 FS Addendum) has been prepared on behalf of potentially liable persons (PLPs) [Art Brass Plating (ABP), Blaser Die Casting (BDC), Capital Industries (CI), and Burlington Environmental, LLC (BE)] identified by the Washington State Department of Ecology (Ecology) in Agreed Order (AO) No. DE10402 for the W4 Site. The W4 Site is located in the Georgetown neighborhood of Seattle, between 4th Avenue South and the Lower Duwamish Waterway (Waterway). For the purposes of the FS, the Site has been divided into two site units, Site Unit 1 (SU1; ABP and BE) and Site Unit 2 (SU2; BDC, CI, and BE), as described in the AO and shown on Figure 1-1.

The W4 SU1 and SU2 FS reports (Aspect, 2016 and PGG, 2016, respectively) were approved by Ecology in a letter dated October 25, 2016 (Ecology, 2016). Based on subsequent discussions with Ecology, additional actions were selected to be implemented, including two pilot studies in SU1 to further evaluate certain remedial technologies that were identified in the FS, and then a re-evaluation of potential remedies in two focused FS Addenda – one for SU1 and one for SU2. This work was described in AO Amendment No. 1 dated November 20, 2017 (AO Amendment). This SU1 FS Addendum develops and evaluates a focused set of remedial alternatives to address contaminated media at SU1 in accordance with Washington Administration Code (WAC) 173-340-350(8) and the AO Amendment, to enable Ecology to select a cleanup action.

This Executive Summary provides an overview of the SU1 FS Addendum.

Background

SU1 constituents of concern (COCs) include the chlorinated volatile organic compound (CVOC) tricholoroethene (TCE) and associated degradation products (primarily vinyl chloride [VC]), and metals used in electroplating (primarily nickel). The ABP Facility at 5516 3rd Avenue South is a source of COCs in SU1; other sources include groundwater containing TCE and VC that has migrated into SU1 from upgradient of the ABP Facility.

Groundwater is relatively shallow, with a depth to water between 4 and 10 feet. A plume of TCE-contaminated groundwater extends from the ABP Facility southwest to the Waterway. The plume migrates laterally and downward until approximately 1st Avenue South, at which point advective flow transitions upward and the plume becomes shallower as it approaches the Waterway.

Interim remedial actions in SU1 that have been implemented include the following:

- Source control through operation of a soil vapor extraction (SVE) and air sparging (AS) system to remove chlorinated COCs from soil and groundwater at and around the ABP Facility.

- Implementation of a vapor intrusion assessment, monitoring and mitigation plan (VIAMMP) for permanent structures within the footprint of contaminated shallow soil and groundwater.

Remedial actions upgradient of SU1 include source control measures at the BE facility.

Basis for Remedial Action

Preliminary cleanup levels (PCULs) for COCs are based on potential exposure pathways. PCULs and potential exposure pathways are summarized in Section 3 of this SU1 FS Addendum. Potentially affected media include soil, groundwater, surface water, and air. Potential receptors include aquatic organisms in the Waterway and humans (including workers, residents, recreational beach users, and fishers/shellfish harvesters), via direct contact with soil or groundwater, inhalation of dust or air, or ingestion of contaminated aquatic organisms.

Three generalized areas within SU1 where PCULs are exceeded have been defined for consideration of remedial actions. These areas and their drivers for cleanup are as follows:

- **The ABP Source Area** (Source Area) includes the ABP Facility and its immediate vicinity where soil and groundwater are impacted by chlorinated COCs (primarily TCE) and plating metals (primarily nickel). Groundwater in the area of plating metals impacts also has low pH.
- **Downgradient TCE Plume** includes groundwater downgradient of the Source Area where chlorinated COCs including TCE exceed PCULs.
- **Vinyl Chloride Plumes Outside SU1 Source Area and Downgradient TCE Plume**.

It is assumed, for the purposes of this SU1 FS Addendum, that PCULs identified herein will become CULs after Ecology's approval of the draft Cleanup Action Plan (dCAP). Remedial Action Objectives (RAOs) are generally stated as follows:

- Achieve CULs at the standard point of compliance for soil, groundwater, air, and surface water, if practicable within a reasonable time frame.
- Use engineered and institutional controls to protect potential receptors from contaminants exceeding CULs for potentially complete exposure pathways.

Specific RAOs for each medium and exposure pathway were described in the SU1 FS.

Remediation levels (RELs) for CVOCs in groundwater were developed in the SU1 FS to help determine when and where active treatment may be appropriate. RELs are defined in Ecology's Model Toxics Control Act (MTCA) as a concentration (or other method of identification) of a hazardous substance in soil, water, air, or sediment above which a particular cleanup action component will be required as part of a cleanup action at a site (WAC 173-340-355). RELs do not replace CULs, which define the concentration of hazardous substances above which a contaminated medium must be remediated in some manner.

RELs for groundwater near the Waterway, including in porewater (Porewater RELs), were further refined in this SU1 FS Addendum based on the results of groundwater and porewater monitoring conducted in 2020 and the results of the pilot studies (see Section 2).

Remedial Alternative Descriptions

The SU1 FS evaluated nine alternatives that provided a broad range of treatment and containment options. In accordance with the AO Amendment, this SU1 FS Addendum evaluates two alternatives, which are modifications of alternatives evaluated in the FS, as follows:

The alternatives evaluated in this SU1 FS Addendum, and their primary treatment components, are as follows:

- **Alternative 2A[1]:**
  - **Source Area:** pH neutralization
  - **Downgradient TCE Plume:** *In-Situ* Chemical Reduction (ISCR)/ Enhanced Anaerobic Bioremediation (EAnB) in South Fidalgo Street
  - **Contingency Actions:** ISCR in the Source Area to further reduce TCE concentrations, and ISCR/EAnB near the shoreline to address VC in porewater
- **Alternative 2B[2]:**
  - **Source Area:** pH neutralization
  - **Downgradient TCE Plume:** ISCR/EAnB in South Fidalgo Street and ISCR/EAnB along the Waterway shoreline

Both alternatives also incorporate engineered and institutional controls and monitored natural attenuation (MNA) in conjunction with active treatment, to ensure protectiveness during the restoration period and ultimately achieve cleanup levels across the Site.

Remedial Alternative Evaluation

The two remedial alternatives were evaluated in accordance with MTCA requirements (WAC 173-340-360). Both alternatives meet MTCA threshold requirements, including protection of human health and the environment; complying with cleanup standards; complying with applicable state and federal laws; and providing for compliance monitoring.

MTCA requires that the selected cleanup action use permanent solutions to the maximum extent practicable. A disproportionate cost analysis (DCA) was conducted to determine

[1] Alternative 2A is an updated version of Alternative 2 of the FS.
[2] Alternative 2B is what Ecology had identified as its preferred alternative in its FS comment letter, with modifications as described above. It has been named ‘2B’ for the purposes of this SU1 FS Addendum because it is most like Alternative 2A.

which alternatives meet this requirement. The DCA quantifies the environmental benefit of each remedial alternative, and then compares alternative benefits versus costs. Environmental benefit was quantified by first rating the alternatives with respect to six criteria: (1) protectiveness; (2) permanence; (3) long-term effectiveness; (4) management of short-term risks; (5) technical and administrative implementability; and (6) consideration of public concerns. Rating values were assigned on a scale of 1 to 10, where 1 indicates the criterion is satisfied to a very low degree, and 10 indicates the criterion is satisfied to a very high degree. Primary differentiating factors among the alternatives are as follows:

- **Protectiveness.** Both alternatives are protective. Alternative 2B is rated slightly higher than Alternative 2A because it potentially achieves RELs in porewater faster[3].
- **Management of short-term risks.** Alternative 2B is rated slightly lower than Alternative 2A because Alternative 2B has the potential for generating secondary water quality impacts closer to the Waterway.
- **Implementability.** Alternative 2B is rated slightly lower than Alternative 2A because it requires access and active treatment on private property.
- **Consideration of Public Concerns.** Alternative 2B is rated slightly higher than Alternative 2A because of the potential for achieving RELs in porewater faster.
- **Cost.** The total cost (combined capital and O&M costs) of Alternative 2B was higher ($4.7 million [M]) than Alternative 2A ($4.0 M).

Alternatives were ranked based on a weighted, quantitative scoring system consistent with the FS and used at other Ecology sites. The MTCA benefits ranking was obtained for each alternative by multiplying the rating values assigned for the six evaluation criteria by their corresponding weighting factors and summing the weighted values. The benefit rankings were 5.9 for Alternative 2A and 6.1 for Alternative 2B.

The benefit/cost ratio, which is a relative measure of cost-effectiveness, is obtained by dividing each alternative's benefits ranking by its estimated cost. Alternative 2A has the higher benefit/cost ratio, at 1.5 versus 1.3, and was deemed to satisfy the MTCA requirement for an alternative to be permanent to the maximum extent practicable.

Both alternatives provide for a reasonable restoration time frame. The estimated times to achieve particular cleanup objectives range as follows:

- The time to achieve VI-based CULs is estimated at 25 years for Alternatives 2A and 2B.
- The time to achieve surface water-based CULs discharging to the Waterway is estimated at 35 years for Alternative 2B and 50 years for Alternative 2A.

[3] The ability of EAnB/ISCR treatment to be as effective at the shoreline as it was shown to be in Fidalgo Street is uncertain because of different hydraulic (i.e., tidal fluctuation) and biogeochemical conditions.

- The time to achieve Porewater RELs discharging to the Waterway is estimated at 5 years for Alternative 2B and 13 years for Alternative 2A.
- The time to achieve surface water-based CULs everywhere is estimated to be close to 280 years.

EPA is overseeing the design of the cleanup plan for the Lower Duwamish Waterway Superfund Site (LDW Site). The LDW Site cleanup is being conducted sequentially, moving from upstream to downstream in three separate sections (“upper reach”, “middle reach”, and “lower reach”). Pre-design work is underway for the southernmost 2 miles (the upper reach) of the waterway, and cleanup expected to begin in 2025. Separate pre-design work is also underway for the approximately 1.5 mile middle reach.

SU1 groundwater discharges to the lower reach, for which there currently is no schedule for design or cleanup. Based on the expected time for design and cleanup and the upper and middle reaches, cleanup of the lower reach is expected to be conducted at least 10 years in the future.

Cleanup activities vary by location and include capping, dredging, enhanced natural recovery, and monitored natural recovery. In the area of SU1 groundwater discharge, a combination of capping and monitored natural recovery is planned. Ecology is conducting a source control sufficiency analysis along the LDW to determine whether upland contamination is a risk for re-contaminating sediments after implementation of the remedy. Because SU1 COCs in groundwater near the Waterway are not LDW Site COCs, the SU1 groundwater plume does not represent a concern for this analysis. Dredging would not be an effective remedy for a VC plume discharging to the LDW; therefore, disturbance of the future sediment cap is not a concern.

According to the LDW Site Record of Decision (ROD), shellfish concentrations are expected to reach target goals within 17 years of beginning construction (EPA, 2014). Therefore, Porewater RELs (i.e., concentrations protective of human health via shellfish consumption) should be achieved by 2042 (i.e., within 20 years) to be consistent with the expectations for the LDW Site cleanup. As noted above, both Alternative 2A and 2B exceed this goal, with a maximum estimated time to achieve Porewater RELs of 13 years. Monitoring will be conducted to confirm this estimate, and contingency actions can be implemented if needed.

Conclusions and Recommendations

The SU1 FS considered nine remedial alternatives that provide a range of treatment options for metals and CVOC contamination. This SU1 FS Addendum identified two remedial alternatives that were modified from the original nine based on Ecology comments and the results of interim pilot studies and monitoring. Both alternatives meet MTCA Threshold Requirements, including protection of human health and the environment. To date, interim actions and the CVOC Pilot Study have substantially reduced CVOC concentrations in the Source Area and in the Downgradient TCE Plume.

Alternative 2A is the preferred cleanup action for SU1 based on the analysis and considerations presented in this SU1 FS Addendum. There are no unacceptable risks to human health or the environment under current conditions, and this alternative will achieve levels protective of human health and the environment under future exposure conditions within the time frame of the ongoing LDW Site cleanup. Alternative 2A has the highest benefit-to-cost ratio, satisfies the MTCA requirement to be permanent to the maximum extent practicable, and will achieve the applicable cleanup levels at the designated points of compliance within a reasonable restoration time frame. This alternative is protective of human health and the environment and is significantly less expensive—$4.0 M—than Alternative 2B ($4.7 M).

Under implementation of Alternative 2A, groundwater and porewater monitoring would be conducted to determine if the remedy is performing as expected, verify that receptors are protected, and confirm that groundwater restoration will occur within a reasonable time frame.

This Executive Summary should be used in the context of the full report.

1 Introduction

The West of 4th Group Site Unit 1 Feasibility Study Addendum report has been prepared on behalf of potentially liable persons (PLPs) [Art Brass Plating (ABP), Blaser Die Casting (BDC), Capital Industries (CI), and Burlington Environmental, LLC (BE)] identified by the Washington State Department of Ecology (Ecology) in Agreed Order (AO) No. DE10402 for the West of 4th (W4) Site (the Site). The AO requires the four PLPs (the W4 Group) to complete a Feasibility Study (FS) and prepare a Draft Cleanup Action Plan (dCAP) for the W4 Site. The environmental consultants addressing technical aspects of the FS and dCAP on behalf of the W4 Group are: Aspect Consulting (Aspect) for ABP; Farallon Consulting (Farallon) for CI; Pacific Groundwater Group (PGG) for BDC; and Pacific Crest Environmental (Pacific Crest) for BE.

The W4 SU1 and SU2 FS reports (Aspect, 2016 and PGG, 2016, respectively) were approved by Ecology in a letter dated October 25, 2016 (Ecology, 2016). Based on subsequent discussions with Ecology, additional actions were selected to be implemented, including two pilot studies in SU1 to further evaluate certain remedial technologies that were identified in the FS, and then a re-evaluation of potential remedies in two focused FS Addenda – one for SU1 and one for SU2. This work was described in AO Amendment No. 1 dated November 20, 2017 (AO Amendment).

The Site is located in the Georgetown neighborhood of Seattle. The Site extends from 4th Avenue South to the Lower Duwamish Waterway (the Waterway), a distance of about 2,200 feet, and is generally flat with a gradual slope to the west. The Site includes a mixture of commercial, industrial, and residential land uses. For the purposes of the FS, the W4 Site has been divided into two site units, Site Unit 1 (SU1; ABP and BE) and Site Unit 2 (SU2; BDC, CI and BE), as described in the AO. Figure 1-1 shows the locations of the four PLPs and the SU1 and SU2 boundaries. This SU1 FS Addendum is specific to the SU1 portion of the Site.

1.1 Purpose

This SU1 FS Addendum, in accordance with AO Amendment No. 1 dated November 20, 2017 (AO Amendment), has been prepared to refine the evaluation of remedial alternatives that was conducted in the *Final Feasibility Study, W4 Group – Site Unit 1* (SU1 FS: Aspect 2016). This refinement has been completed to address Ecology comments on the SU1 FS and within the context of data collected in SU1 since 2016, including pilot studies, groundwater and porewater monitoring, and the collection of water level data to evaluate groundwater flow variability. This SU1 FS Addendum is intended to be an extension and part of the SU1 FS rather than a replacement.

The W4 FS reports for SU1 and SU2 developed and evaluated remedial alternatives to address contaminated media in accordance with Washington Administrative Code (WAC) 173-340-350(8) and enable Ecology to select a cleanup action (SU1 FS, Aspect 2016; SU2 FS, PGG, 2016). The W4 FS reports integrated and built upon information developed in previous technical memoranda. Information that has already been presented in the W4 FS reports and memoranda are not repeated in this document unless additional information allows refinement relevant to evaluation of remedial alternatives. The following documents are available for reference on the W4 website (http://clients.aspectconsulting.com/W4/):

- *Revised Preliminary Site Cleanup Standards* (Farallon, 2014)
- *Site Conceptual Model Technical Memorandum (Revised)* (Aspect, 2014)
- *Revised Fate and Transport Modeling Plan* (PGG, 2015a)
- *Revised Technology Screening FS Technical Memorandum* (PGG, 2015b)
- *Draft Fate and Transport Summary Memorandum for SU1* (Aspect, 2015a)
- *Draft Remedial Alternatives Technical Memorandum for Site Unit 1* (Aspect, 2015b)
- *Feasibility Study, W4 Group – Site Unit 1 (Aspect, 2016)*

1.2 Report Organization

This report is organized as follows:

- Section 1 describes the purpose of the SU1 FS Addendum and the organization of this report.
- Section 2 summarizes activities completed since submittal of the W4 FS Reports in 2018.
- Section 3 provides a summary of the Site Conceptual Model (SCM), including a discussion of preliminary cleanup levels (PCULs) and any updates to the SCM since the W4 FS Reports.
- Section 4 identifies the Basis for Remedial Action, including ARARs, Cleanup Standards, Remedial Action Objectives (RAOs).
- Section 5 describes updated remedial alternatives for SU1.
- Section 6 evaluates and compares the alternatives being considered for remediation of SU1, and discusses potential uncertainties associated with remedy evaluation and selection.
- Section 7 identifies a preferred alternative.
- Section 8 proposes an implementation schedule for the cleanup action plan.
- Section 9 provides references used in the preparation of this report.

The text is followed by tables and figures that support the text and illustrate conditions at the Site and conceptual layouts for the alternatives.

Appendices to this report provide supporting information referenced within the text. These appendices include a summary of data collected during post-FS investigations and pilot study results.

2 Overview of Activities Completed Since 2016

This section provides an overview of data collection and pilot studies completed since the 2016 W4 FS reports submittal as well as on-going SU1 interim actions.

2.1 2020 Porewater Monitoring

As outlined in the *2020 Groundwater Sampling and Lower Duwamish Waterway Sediment Porewater Sampling Work Plan* (Aspect, 2020*),* the objectives of the porewater sampling were to determine current porewater concentrations of chlorinated volatile organic compounds (CVOCs) within the SU1 plume discharge area of the Waterway and measure concentrations of geochemical parameters to provide additional lines of evidence for biodegradation. Data are also being used in development of remediation levels (RELs; refer to Section 4.5). Porewater monitoring data are presented in Section 3.3.

2.2 Ongoing Groundwater Monitoring

Semi-annual groundwater monitoring has continued since submittal of the *Site Conceptual Model Technical Memorandum* (SCM Memo; Aspect, 2014). Groundwater monitoring data are reported in quarterly progress reports. A summary of current groundwater monitoring data is provided in Section 3.3. A monitoring well location figure is provided for reference (Figure 2-1)

2.3 Groundwater Flow Direction Study

Starting in 2018, the W4 PLPs conducted a 13-month water level study in the area of 1st Avenue South and East Marginal Way South. Continuous water levels were collected from 32 select wells to enable a detailed assessment of groundwater flow paths in the area, as discussed in the *Groundwater Elevation Data Collection Work Plan* (Aspect, 2017). Results were submitted to Ecology in the *Groundwater Elevation Data Collection Study Technical Memorandum* (Groundwater Flow Memorandum; Pacific Crest Environmental, 2020).

As detailed in the results memo, data confirmed groundwater flow at the Site is to the west and southwest. Water level study results illustrate that, despite the fluctuations in groundwater elevations induced by Waterway tides and seasonal variations, flow paths in the study area are relatively stable over extended periods of time. The flow stability improves confidence in the long-term protectiveness of monitored natural attenuation (MNA) as a component of the selected remedial alternative. The relative stability of the groundwater flow direction also has implications for the location and design of treatment elements that are based on intercepting contaminants in groundwater in both site units. The design of cut-off walls in a stable environment can be targeted to a specific area with a higher degree of confidence rather than cut-off walls in a more variable groundwater flow environment previously assumed.

Factors influencing groundwater flow direction include:

- **Tidal fluctuation in the Waterway.** Tidal influence decreases with distance from the Waterway[4]. Low tide in the Waterway is correlated with a more westerly groundwater flow direction and high groundwater gradient value. High tides are correlated with more southerly groundwater flow directions and lower groundwater gradient value. These opposing tidal extreme conditions occur daily for a few hours at a time, and their net effect is implicitly accounted for in the analysis of groundwater flow directions provided in the Groundwater Flow Memorandum.
- **Construction dewatering associated with construction of the Georgetown Wet Weather Treatment Station (WWTS).** Construction dewatering began August 7, 2018 in an area south of SU2 at the corner of 4th Avenue South and South Michigan Street. Calculations of groundwater gradient and flow direction were completed for two data sets representing conditions before and after initiation of WWTS pumping. The influence on groundwater flow decreases further away from the WWTS. In general, the WWTS construction dewatering resulted in a southerly shift in gradient weighted flow directions; for example, in well sets with flows to the west-southwest prior to pumping shift to the southwest. Influences on groundwater flow from the WWTS pumping do not represent long-term average groundwater flow directions.

2.4 Summary of SU1 Pilot Studies

In accordance with the AO Amendment, two pilot studies were conducted to evaluate the potential effectiveness and determine conceptual design basis for SU1 FS alternatives. One pilot study (CVOC Pilot Study) evaluated *in situ* treatment of CVOCs (primarily trichloroethene [TCE], cis-1,2-dichloroethene [cis-DCE], and vinyl chloride [VC]) in groundwater in the South Fidalgo Street (Fidalgo Street) area near the Waterway. The other pilot study (Metals Immobilization Pilot Study) evaluated *in situ* treatment methods for immobilizing elevated metals (primarily nickel) in groundwater at the ABP Facility through pH adjustment. Details and results of the pilot studies are provided in the *CVOC Pilot Study Completion Report* and the *Metals Immobilization Pilot Study Completion Report* in Appendices A and B, respectively. A summary of pilot study activities and conclusions is described below.

2.4.1 CVOC Pilot Study

The CVOC Pilot Study included injection of 9,051 gallons of a combined ELS-microemulsion and EHC-Liquid powder solution to stimulate both *in-situ* chemical reduction (ISCR) and enhanced anaerobic bioremediation (EAnB) of CVOCs. Injections were completed using direct-push technology along a transect in Fidalgo Street orthogonal to groundwater flow. Injections were completed in October 2018.

Performance monitoring of groundwater and soil gas has been conducted regularly in and downgradient of the treatment area since 2018, with the most recent monitoring event conducted in September 2021. Performance monitoring data have indicated effective and

[4] The 2018 groundwater elevation study did not extend to the Waterway. Tidal influences on water levels diminish to 0.5 feet or less approximately 800 feet east/northeast (upgradient) of the Waterway. Tidal studies are detailed in RI reports from ABP (Aspect, 2012) and CI (Farallon, 2012).

sustained treatment, with greater than 90 percent reduction in total CVOCs as of the last monitoring event. Treatment appears to be a combination of biotic and abiotic mechanisms. Secondary effects from the treatment were limited and manageable. Refer to Appendix A for additional details.

2.4.2 Metals Immobilization Pilot Study

The Metals Immobilization Pilot Study included bench testing of potential amendments, initial field injection of a sodium bicarbonate reagent, and follow-up injection of an adapted reagent that combined sodium bicarbonate and sodium hydroxide. The initial field injection consisted of injecting 9,940 gallons of 1.0 Molar sodium bicarbonate solution into two injection wells located adjacent to the ABP Facility. This injection was performed in September 2018 and groundwater was monitored for 6 months following the injection. The results of this injection showed modest treatment of metals, but effectiveness was limited by density-driven flow of the reagent below the targeted treatment zone.

To mitigate the density effects, a follow-up injection of a lower-density solution (20,300 gallons of 0.1Molar sodium bicarbonate and 0.1Molar sodium hydroxide) was performed in August 2019 and monitored for 6 months following injection. The results of the second injection showed greater than 90 percent reduction in nickel concentrations that were sustained for at least six months, indicating that the modified reagent solution was effective at immobilizing metals. Refer to Appendix B for additional details.

2.5 SU1 Interim Actions

Chlorinated solvents in SU1 groundwater in the Water Table Interval[5] exceed screening levels for the vapor intrusion (VI) pathway. Because of the concern for this pathway, two interim actions were implemented prior to the completion of the ABP RI Report: (1) a VI mitigation program; and (2) source control interim action. These actions are described below.

2.5.1 Vapor Intrusion Mitigation Program

The VI mitigation program is outlined in the joint W4 deliverable, *Revised Vapor Intrusion Assessment, Monitoring, and Mitigation Plan* (VIAMM Plan; Farallon, 2015). The VIAMM Plan provides an overview of the tiered process used to assess potential VI issues and the VI mitigation process. The VIAMM Plan included a tabulated listing of the buildings where Tier 1 through Tier 5 VI Assessment and Mitigation measures will be continued as interim action work through completion of the Cleanup Action Plan.

Currently, vapor mitigation remains active at the ABP Facility and two properties west of ABP (218 and 220 South Findlay Street). Groundwater monitoring data are reviewed consistent with the tiered decision process to confirm that vapor mitigation is being implemented where appropriate.

[5] The Water Table Interval includes monitoring wells screened above 20 feet bgs. Hydrogeologic units are discussed further in Section 3.2.

2.5.2 ABP Source Control Interim Action

In September 2008, ABP installed an air sparging/soil vapor extraction (AS/SVE) system to remove CVOCs from soil and groundwater at and around the ABP Facility. The system includes 28 AS wells, 13 SVE wells, and 10 trenches. Extracted vapors are treated with granular activated carbon.

The objectives of the AS/SVE system were as follows:

- Prevent vapor intrusion at the ABP Facility and the adjacent 220 Findlay office building.
- Reduce soil and groundwater concentrations of TCE, cis-DCE, and VC to levels that significantly reduce the restoration time frame and are protective of the indoor air pathway.

The SVE system has operated continuously (except for periodic shutdowns for monitoring and maintenance) since startup in 2008. In late 2011, the AS portion of the system was shut down to conduct a rebound analysis. Between October 2012 and October 2015, the AS operated on an approximate six-month on-off pulsing schedule, and in October 2015, the AS system was shut down indefinitely to conduct an extended rebound analysis. The system has removed approximately 87 pounds of TCE from the subsurface. During AS operation, groundwater concentrations of TCE declined 92 to 99.8 percent at wells in and around the treatment area.

After AS shutdown, TCE concentrations rebounded in several source area wells, most notably at MW-1 and MW-3 where overall reductions in 2020[6] compared to baseline data in 2008 were 83 percent and 69 percent, respectively. Concentrations at these wells show seasonal variability but overall appear to be relatively stable since 2017. A full description of system monitoring, and an analysis of system performance was provided in the ABP RI Report (Aspect, 2012). Recent SVE monitoring data is provided in the 2020 Q1 quarterly progress report (Aspect, 2020).

The interim action has reduced CVOC concentrations downgradient of the ABP Facility. Trend plots of total CVOC concentrations at monitoring wells along the TCE plume centerline are shown on Figure 2-2. In 2020, Ecology agreed the existing SVE system could be transitioned to vapor mitigation. In 2022, vapor mitigation equipment was installed in accordance with the Ecology-approved mitigation plan (Aspect, 2022).

[6] Percent reduction based on the average concentration in March and September 2020.

3 Site Conceptual Model

3.1 Background

The hydrogeologic units encountered in borings completed at the Site include Younger Alluvium and Older Alluvium. The upper portion of the Younger Alluvium has been modified and is referred to as the Fill Unit. The lithologic units correspond to the hydrogeologic units encountered at the Site. Figures illustrate data in three separate panels using the W4 standardized nomenclature for groundwater monitoring and sampling intervals which are:

- **Water Table Interval.** This interval includes monitoring wells screened above 20 feet below ground surface (bgs) and reconnaissance groundwater samples collected above 20 feet bgs.
- **Shallow Interval.** This interval includes monitoring wells screened below 20 feet and above 40 feet bgs, and reconnaissance groundwater samples collected between 21 feet and 40 feet bgs.
- **Intermediate Interval.** This interval includes monitoring wells and reconnaissance groundwater samples screened below 40 feet bgs.

3.2 Preliminary Cleanup Levels and Constituents of Concern

The W4 joint deliverable, *Revised Preliminary Site Cleanup Standards* outlined the preliminary cleanup standards for the Site (Farallon, 2014). Since 2014, surface water criteria for protection of human health have been updated (EPA, 2022). Groundwater and air criteria for the protection of indoor air have been updated as well in accordance with Washington State's Draft Guidance for Evaluation Soil Vapor Intrusion in Washington State (Ecology, 2018) and Ecology's Cleanup Level and Risk Calculation (CLARC) database. Updated preliminary cleanup levels (PCULs) are presented in Table 3-1, where applicable. Appendix C includes summary tables of prospective cleanup levels considered during the selection process.

SU1 COCs can be categorized as follows (Farallon, 2014):

CVOCs

- Tetrachloroethene (PCE)[7]
- TCE
- cis-DCE
- trans-1,2-Dichloroethene (trans-DCE)
- 1,1-Dichloroethene (1,1-DCE)
- VC

[7] PCE is not a degradation product of TCE, and ABP did not use PCE in its manufacturing processes. Localized detections of PCE in groundwater suggest the potential for a source other than ABP.

Plating Metals

- Cadmium
- Copper
- Nickel
- Zinc

Non-plating Metals[8] (aka Redox-Sensitive Metals)

- Arsenic
- Manganese

Ecology identified 1,4-dioxane[9] as a groundwater COC for the W4 Site in the AO and iron as a groundwater COC during the RI process; based on updates to the PCULs, they are not carried forward as site COCs. The concentrations of 1,4-dioxane in groundwater samples collected in the W4 Site are well below the PCUL for 1,4-dioxane (20,000 micrograms per liter [µg/L]). The maximum concentration of 1,4-dioxane in the W4 Site as reported in the SCM Memo was 150 µg/L. Previously freshwater criteria were listed for iron; however, the Waterway is a tidally influenced marine environment and freshwater criteria are not applicable. Iron does not have criteria for marine waters.

3.3 Nature and Extent of Contamination

The nature and extent of contamination within SU1 has been discussed in detail in the RI reports prepared for ABP (Aspect, 2012) and BE (PSC, 2003) and the SCM Memo (Aspect, 2014). This section provides a summary of current conditions.

3.3.1 Soil

The nature and extent of soil contamination is assumed to have not significantly changed since the preparation of the SCM Memo (Aspect, 2014), which identified concentrations of CVOCs and plating metals (primarily TCE and nickel) above preliminary cleanup levels in soil at and immediately adjacent to the ABP Facility. Soil sampling for metals was conducted at the ABP Facility as part of the Metals Immobilization Pilot Study in 2018 (Aspect, 2018). That soil sampling event identified elevated metals concentrations in soil within the area of the pilot study, consistent with the SCM previously documented in the ABP RI (Aspect, 2012), SCM Memo (Aspect, 2014), and SU1 FS (Aspect, 2016).

3.3.2 Groundwater

Groundwater nature and extent figures for TCE, cis-DCE, VC, and total chlorinated ethenes are provided in Figures 3-1 through 3-4. Porewater data for these same parameters are provided in Figures 3-5 through 3-8. Figures have also been updated for select metals: dissolved copper, dissolved nickel, dissolved zinc, and total arsenic (Figures 3-9 through 3-12, respectively). Data are presented relative to PCULs listed in Table 3-1, when available.

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[8] Elevated concentrations of the non-plating metals in groundwater are due to microbial degradation of organic materials in the aquifer matrix that has resulted in generally anaerobic conditions. Anaerobic conditions favor the dissolution of the non-plating metal COCs from the native aquifer materials.

[9] The presence of 1,4-dioxane at concentrations below the CUL in SU1 groundwater appears to be due to migration of groundwater originating from areas east of 4th Avenue South (East of 4th Area) and is being addressed by Burlington Environmental under AO DE 7347.

3.4 Potential Receptors and Exposure Pathways

The following provides a summary of the potential receptors and exposure pathways, detailed in the SCM Memo (Aspect, 2014).

3.4.1 Potential Receptors

The Site includes upland and aquatic areas. Potential receptors in the upland areas include:

- Aboveground workers (e.g., employees at commercial facilities)
- Belowground workers (e.g., construction workers conducting digging or trenching operations)
- Residents

Potential receptors in aquatic areas include:

- Recreational beach users
- Recreational fisher/shellfish harvesters
- Subsistence fisher/shellfish harvesters
- Aquatic organisms

As described in the SU1 FS with Ecology concurrence (Aspect, 2016), the Site qualifies for a terrestrial ecological exclusion.

3.4.2 Potential Exposure Pathways

Potentially impacted media at the Site include soil, groundwater, air, and surface water. Potential exposure pathways for each medium are identified below. Site use includes a mixture of industrial, commercial, and residential.

Soil

Potential direct exposure pathways for soil contamination include:

- Direct contact
- Dust inhalation

Although existing surface materials (asphalt and concrete) prevent contaminated soils from being inhaled or contacted, this is a potential future exposure pathway in the event that coverings are removed or below-ground work is conducted.

Soil contamination may also contribute to contamination in other media through intermedia transport, as follows:

- Air contamination, via the soil-to-air migration pathway (i.e., volatilization)
- Groundwater contamination, via the soil-to-groundwater migration pathway (i.e., leaching)

Potential groundwater and air exposure pathways are discussed below.

Groundwater

Potential direct exposure pathways for groundwater contamination include:

- Incidental direct contact

This pathway is considered a potential current and/or future exposure pathway only for below-ground workers. Above-ground residents and workers are not expected to contact groundwater, which is located 4 to 10 feet bgs.

As described in the SU1 FS with Ecology concurrence, Site groundwater will not be a source of drinking water in the foreseeable future.

Groundwater contamination may also contribute to contamination in other media, as follows:

- Air contamination, via the groundwater-to-air migration pathway (i.e., volatilization)
- Surface water contamination, via the groundwater-to-surface water migration pathway (i.e., discharge to surface water)

Air

VOCs in contaminated soil and groundwater may volatilize into soil gas, which in turn may migrate into indoor or outdoor air (i.e., vapor intrusion). Potential exposure pathways for VOCs in air include:

- Inhalation of outdoor air
- Inhalation of indoor air

Surface Water/Sediments

The nearest surface water/sediment receptor, the Waterway, is a brackish water body that is not a potential drinking water source. Potential exposure pathways for contaminated surface water and sediment include:

- Incidental direct contact to humans
- Direct contact by aquatic organisms
- Aquatic or terrestrial organism ingestion of contaminated aquatic organisms
- Human ingestion of contaminated aquatic organisms

4 Basis for SU1 Remedial Action

This section identifies the ARARs, RAOs, and PCULs used as the basis for developing and evaluating remedial alternatives, as follows:

- Section 4.1 identifies the SU1 ARARs that are most likely to have a significant influence on the identification and assembly of remedial alternatives to be evaluated in this SU1 FS Addendum.
- Section 4.2 discusses the cleanup standards.
- Section 4.3 discusses the remediation levels.
- Section 4.4 identifies three areas of SU1 with distinct characteristics that are targeted for remedial action.
- Section 4.5 identifies the RAOs that describe what the proposed remedy is expected to accomplish.

4.1 Applicable or Relevant and Appropriate Requirements (ARARs)

ARARs are discussed in the SU1 FS and no updates are necessary to those listed therein (Aspect, 2016).

4.2 Cleanup Standards

A cleanup standard includes both a cleanup level (CUL; chemical- and media-specific concentration of a contaminant that is protective of human health and the environment via all exposure pathways) and a point of compliance (the location where the CUL must be attained to achieve protectiveness). For the purposes of the FS, the PCULs are the presumptive CULs, but the Ecology-issued Cleanup Action Plan will define final CULs and points of compliance.

Updates to PCULs were presented in Section 3 and Table 3-1 reflects changes to these criteria since completion of the SU1 FS.

As discussed in the SU1 FS with Ecology concurrence, the following points of compliance are used to evaluate remedial alternatives (Aspect, 2016):

- **Soil**
    - Protection of Groundwater Quality: throughout SU1
    - Protection of Air: from ground surface to the uppermost water table
    - Protection of Direct Contact: throughout SU1 to a depth of 15 feet bgs
- **Groundwater**: Standard point of compliance defined as *"…throughout the site from the uppermost level of the saturated zone extending vertically to the lowest*

most depth which could potentially be affected by the site." WAC 173-340-720(8)(b).

- Protection of Surface Water and Direct Contact throughout SU1
- Protection of Indoor Air: at Water Table Interval throughout SU1

- **Air**
  - Ambient air (indoor and outdoor air): throughout the site (WAC 173-340-750)

4.3 Remediation Levels

MTCA recognizes that a cleanup action may involve a combination of cleanup action components and provides that RELs may be used to identify concentrations (or other methods of identification) of hazardous substances at which different cleanup action components will be used (WAC 173-340-355). RELs are concentration thresholds above which particular cleanup action components may be applied and are usually specific to a particular remediation technology.

CULs must be established for every site, whereas RELs may not be necessary, and do not replace CULs. CULs define the concentration of hazardous substances above which a contaminated medium (e.g., groundwater) must be remediated in some manner (e.g., treatment, containment, institutional controls). RELs may be applied when a combination of cleanup action components are used to achieve cleanup standards, to define where and when each component is applied.

Potential RELs for TCE and VC in different areas of the Site were identified in Section 7.2.4.1 of the SU1 FS (Aspect, 2016) based on concentrations that were predicted using fate-and-transport modeling. These RELs were predicted to not result in concentrations exceeding the surface water CUL at the mudline in the Waterway. The groundwater RELs for TCE and VC define concentrations at which it may be appropriate to transition from active treatment to MNA at locations downgradient from the source.

For this SU1 FS Addendum, empirical data from the 2020 porewater monitoring data and the results of the CVOC Pilot Study were used to develop RELs for Waterway porewater (Porewater RELs). These RELs are used in alternative development in Section 5 as a basis for the extent and duration of active treatment near the Waterway in the Fidalgo Street area. The Porewater RELs will provide treatment goals that would protect exposure pathways until CULs can be achieved throughout the Site. Porewater REL development is described in Appendix D. The Porewater RELs for the Site are as follows:

- 3.2 µg/L TCE
- 0.82 µg/L VC

As described in Appendix D, achievement of Porewater RELs is evaluated on a surface area-weighted average concentration (SWAC) basis because the risk driver for this analysis is human consumption of shellfish exposed to contaminated porewater. Because porewater sampling is a complex undertaking and frequent porewater studies are impracticable, groundwater monitoring upgradient of the Waterway will be used for remedial design and as a preliminary indication of remediation performance, with follow-up porewater monitoring to verify protectiveness. RELs along a treatment transect will be determined by calculating CVOC concentrations in groundwater along treatment transects or in porewater on a SWAC basis, as described in Appendix D, and applying the estimated reduction needed to achieve Porewater RELs.

The approach is to assess groundwater at the shoreline and estimate a reduction needed in groundwater to achieve Porewater RELs. Based on the 2020 porewater data, Site porewater exceeds Porewater RELs by a factor of approximately six; therefore, the goal of treatment upgradient of the porewater study area is to reduce the average concentration of CVOCs by at least 83 percent. Based on the CVOC Pilot Study results (summarized in Section 2.4.1 and provided in Appendix A), this is an achievable goal within a restoration time frame using the preferred Alternative 2A described in detail below.

4.4 Remedial Action Objectives

RAOs are specific goals to be achieved by remedial alternatives that meet cleanup standards and provide adequate protection of human health and the environment under a specified land use. Site-wide and SU1-specific RAOs for the W4 area are identified in the SU1 FS with Ecology concurrence. Specific RAOs for each medium and exposure pathway are provided in Section 5.4 of the SU1 FS. In summary, RAOs are:

- Achieve CULs at the standard point of compliance for soil, groundwater, air, and surface water, if practicable;
- Protect potential exposure pathways using engineered and institutional controls for contaminants exceeding CULs. A comprehensive list of exposure pathways by media and receptor is provided in the SCM Memo (Aspect, 2014) and summarized above in Section 3.3. The key exposure pathways at the Site affecting development and evaluation of remedial alternatives include:
    - Direct contact with (ingestion of) contaminated soil;
    - Inhalation of contaminated vapors; and
    - Ingestion of contaminated shellfish.

Exceedances of direct contact-based cleanup levels are very limited[10] beneath the ABP Facility and are or will be effectively addressed through institutional controls. The primary risk drivers for remediation at the Site are vapor inhalation and shellfish consumption.

4.5 Areas Targeted for Remedial Action in SU1

The nature and extent of contamination for the Site was provided in the SCM Memo (Aspect, 2014; Ecology approval December 19, 2014); current conditions based on

[10] It is unclear whether direct-contact exceedances still exist, as areas where such exceedances were identified have undergone subsequent treatment but are inaccessible for confirmation sampling under current Site conditions.

subsequent groundwater and porewater monitoring is described above in Section 3.3. For the purposes of the SU1 FS, three generalized areas within SU1 were defined for consideration of remedial actions. These areas have not been updated since the SU1 FS but are summarized here for reference. The areas targeted for remedial action, and their drivers for cleanup, are as follows:

- **Source Area:** The Source Area includes the ABP Facility and its immediate vicinity. Soil and Water Table Interval groundwater in the Source Area are impacted by CVOCs[11] and plating metals. The estimated areal extent of TCE and nickel PCUL exceedances are depicted on the Figures 3-1 and 3-10, respectively. TCE is the dominant CVOC COC and nickel is the dominant plating metal COC.
- **Downgradient TCE Plume:** The areal extent of TCE PCUL exceedances in groundwater downgradient of the Source Area is shown on Figure 3-1. The TCE plume occurs in the Shallow and Intermediate Intervals. TCE is the dominant CVOC over much of this area, but through a combination of natural attenuation and treatment during the CVOC Pilot Study, degradation products cis-DCE and VC become more dominant west of 2nd Avenue South to the Waterway.
- **Disperse VC Plume(s):** As depicted on Figure 3-3, VC PCUL exceedances in groundwater also occur outside the two areas described above.

[11] CVOC concentrations in the Source Area have been reduced by the ongoing AS/SVE interim action.

5 Description of SU1 Alternatives

This section describes the remedial alternatives evaluated in this SU1 FS Addendum. The SU1 FS identified and evaluated nine remedial alternatives (Alternatives 1 through 9) that incorporated varying degrees of aggressiveness in their conceptual designs to achieve Site RAOs for COCs. AO Amendment No. 1 expected that, at a minimum, this SU1 FS Addendum would evaluate the preferred alternative identified in the SU1 FS (FS Alternative 1)[12] and the preferred alternative identified by Ecology in their comment letter[13]. Those alternatives have been modified, based on the results of the pilot studies and monitoring conducted during the FS, as follows:

- The preferred alternative identified in the SU1 FS has been modified to include treatment in Fidalgo Street, based on the efficacy of the CVOC Pilot Study and recent groundwater and porewater monitoring.
- The preferred alternative identified in Ecology's comment letter has been modified, as discussed with Ecology in FS Addendum coordination calls, to replace the air sparge curtain along the Waterway with treatment using ISCR and EAnB, based on the efficacy of the CVOC Pilot Study.
- Both alternatives have been modified to include combined ISCR/EAnB, rather than one or the other of these technologies. The technology selected for the pilot study, which resulted in effective CVOC treatment, combined ISCR and EAnB.

The alternatives evaluated in this SU1 FS Addendum are as follows:

- **Alternative 2A[14]:**
  - **Source Area:** pH neutralization
  - **Downgradient TCE Plume:** ISCR/EAnB in Fidalgo Street
  - **Contingency Actions**: ISCR in the Source Area to further reduce TCE concentrations, and ISCR/EAnB near the shoreline to address VC in porewater.
- **Alternative 2B[15]:**
  - **Source Area:** pH neutralization

[12] Based on Ecology comments on the SU1 FS, a modified version of FS Alternative 2 (Alternative 2A) was selected instead of FS Alternative 1.
[13] Ecology had identified their preferred alternative as FS Alternative 5, but without additional source area treatment of CVOCs.
[14] Alternative 2A is an updated version of Alternative 2 of the SU1 FS.
[15] Alternative 2B is what Ecology had identified as its preferred alternative in its FS comment letter, with modifications as described above. It has been named '2B' for the purposes of this SU1 FS Addendum because it is most like Alternative 2A.

  - **Downgradient TCE Plume:** ISCR/EAnB in Fidalgo Street and ISCR/EAnB along the Waterway shoreline
  - **Contingency Actions**: ISCR in the Source Area to further reduce TCE concentrations

Both alternatives also incorporate engineered and institutional controls and MNA in conjunction with active treatment to ensure protectiveness during the restoration period, and ultimately achieve cleanup levels across the Site.

Each alternative is described below, including conceptual design and implementation strategies and an estimated cost of implementation. Cost estimates have been updated based on the results of the pilot studies and conceptual design criteria. Restoration time frame estimates have not been updated from the SU1 FS, because incorporation of recently collected data is not expected to significantly change those estimates.

5.1 Alternative 2A

Alternative 2A uses pH neutralization to immobilize dissolved metals in groundwater and relies on MNA to address the residual CVOC impacts in the Source Area following the interim AS/SVE removal action. MNA is also used to address CVOC impacts in the Downgradient TCE Plume and VC in areas outside the Downgradient TCE Plume. This alternative includes the following elements:

- Applying a pH neutralization solution in areas of depressed groundwater pH (in the Source Area) through injection points to raise the pH and immobilize/precipitate plating metals dissolved in groundwater.
- MNA of CVOCs and plating metals in soil and groundwater in and downgradient of the Source Area following pH neutralization.
- Applying an EAnB/ISCR amendment as a permeable reactive barrier (PRB) along Fidalgo Street in the Downgradient TCE Plume Area to treat CVOCs dissolved in groundwater.
- Implementing engineered and institutional controls and monitoring until RAOs are achieved, including:
  - Converting the SVE system to a VI mitigation system for the ABP Facility until CVOC concentrations in soil and groundwater are protective of air.
  - Maintaining existing vapor mitigation systems at 218 and 220 South Findlay Street until CVOC concentrations in soil and groundwater are protective of air.
  - Maintaining the ABP Facility as an effective cap until concentrations of TCE in soil are demonstrated to be protective of direct contact with soil.
  - Placing an environmental covenant on the ABP property.
  - Providing notifications to area underground utility providers until CVOC CULs in water table groundwater are achieved.

- Periodic compliance monitoring (protection, performance, and confirmation monitoring) of the remedial action.

Application of these components is described below.

5.1.1 AS/SVE System

The existing AS/SVE system has been in operation since 2008 and is at a point of diminishing returns. Pulsed operation of the AS system was conducted from 2012 and 2015. Some rebound in groundwater concentrations was observed after AS shutdown from 2015 to 2017, but concentrations of CVOCs in groundwater remain below Source Area RELs. Mass removal of CVOCs by the SVE system is minimal.

Elevated concentrations of CVOCs are present in the vadose zone and are expected to remain after shutdown of the AS/SVE system. These concentrations are expected to slowly dissipate through natural attenuation processes such as volatilization, leaching, and degradation. The majority of CVOC exceedances in the vadose zone are in the seasonally saturated zone where natural attenuation processes are expected to flush out and degrade contamination over time.

The SVE system will be transitioned to provide vapor mitigation for the ABP Facility. A mitigation performance assessment and evaluation of soil vapor conditions to aid this transition is underway. Optimization of the mitigation system will be performed to determine which remaining wells and trenches should be maintained, and whether the blower should be resized or replaced to reduce power consumption. Treatment of vapor mitigation system discharge is not anticipated based on current mass removal rates.

5.1.2 pH Neutralization

Figure 5-1 shows the estimated extent of groundwater with pH less than 6 at the Water Table Interval beneath and immediately downgradient of the ABP Facility. As discussed in the Revised Technology Screening Memo (PGG, 2015b), raising the groundwater pH to more-neutral conditions (i.e., around pH 7) can induce precipitation of metals from groundwater and sorption to soil. The effectiveness of pH adjustment for immobilizing plating metals at the ABP Facility was demonstrated through pilot testing (see Appendix B).

Based on the results of the pilot study, for the purposes of this SU1 FS Addendum, the following application is assumed[16]:

- Injection wells will be used to introduce an aqueous pH neutralization solution consisting of 0.1M sodium bicarbonate and 0.05M sodium hydroxide.
- Injection will be conducted at 6 existing SVE or monitoring wells within the footprint of the ABP Facility, the 2 existing injection wells installed for the *Metals Immobilization Pilot Study* (see Appendix B), and up to 60 additional temporary direct-push injection points to be installed in the area shown on Figure 5-1 for application of the buffer solution. Up to 140,000 gallons of reagent will be

[16] The final design for full-scale application will evaluate and consider local pH conditions and will focus reagent application on areas and depth intervals of lowest pH.

injected over 10 days, and the total number of injection points will be determined in remedial design. The injection points are assumed to be installed approximately 20 feet deep and reagent injected into the 10- to 20-foot depth (Water Table Interval).

- For temporary injection point application, the reagent solution would be pumped from the tank into a piping manifold connected to injection points. Instrumentation would be provided for monitoring and controlling solution flow rates to different segments of the injection-well system.
- Existing monitoring wells would be used to track system performance and adjust injection parameters to achieve near-neutral groundwater pH and reduced concentrations of dissolved metals.

More than one injection may be needed to achieve sufficient distribution and the desired pH shift. For the purposes of the FS, we have assumed an initial injection of 135,000 gallons throughout the depressed pH area, monitoring for one year to evaluate rebound, and a contingency for a follow-up injection of 25,000 gallons at existing wells in the area of lowest pH in the event that the minimum target pH is not sustained after the first injection.

5.1.3 Fidalgo Street ISCR/EAnB Application and Assumptions

The purpose of treatment of the Downgradient TCE Plume along Fidalgo Street is to reduce groundwater concentrations of CVOCs approaching the Waterway and achieve Porewater RELs. The CVOC Pilot Study demonstrated that ISCR/EAnB substantially reduces CVOC concentrations in and downgradient of the treatment area (see Appendix A).

Based on the results of the pilot study, for the purposes of this SU1 FS Addendum, the following application is assumed:

- The lateral and vertical extent of treatment will target the area of the plume requiring treatment to achieve Porewater RELs. The lateral extent based on historical groundwater and porewater data is shown on Figure 5-2, and the vertical extent of treatment is assumed to be from 20 to 30 feet bgs based on pilot study recommendations (see Appendix A). As part of design, a baseline investigation would be conducted along potential treatment transects as follows:
    - CVOC concentrations along each transect would be evaluated through a combination of monitoring wells, to be used as future performance monitoring points, and direct-push sampling to refine the lateral and vertical extent of CVOCs.
    - The area targeted for treatment would be determined by the area required to reduce the average concentration in groundwater upgradient of the porewater study area by at least 75 percent (see Section 4.5).
- The ISCR/EAnB reagent used in the pilot study (ELS-emulsion and EHC-Liquid power) would be applied using the same pressurized delivery (approximately 15 to 44 pounds per square inch [psi]) via direct-push injections as were employed

for the pilot study. Transects would consist of two offset rows of injection points spaced approximately 6 feet on-center.

- A reagent mixture containing approximately 13,000 mg/L total organic carbon (TOC) would be injected.
- Methane in soil gas would be monitored during the treatment period, and accumulation of methane beneath nearby structures would be mitigated using passive venting wells.

As explained in more detail in the CVOC Pilot Study Completion Report (Appendix A), more than one injection will likely be needed to maintain treatment during the time period until upgradient groundwater has sufficiently attenuated such that additional active treatment is no longer needed to meet Porewater RELs[17]. Subsequent injections would be located along the same transects and likely require less reagent to achieve objectives. The frequency of injections to maintain treatment is expected to decrease with time. For the purposes of the FS, we have assumed that four subsequent injection events would be performed using approximately two-thirds of the initial reagent quantity.

5.1.4 Monitoring, Engineered Control, and Institutional Control Assumptions

Engineered and institutional controls would be maintained until compliance monitoring indicates they are no longer necessary. For the purposes of preparing FS cost estimates, the following assumptions were made:

- Vapor mitigation systems at the ABP Facility and 218 and 220 South Findlay Street properties would be operated until groundwater in the Water Table Interval achieves CULs protective of VI (approximately 15 years for ABP Facility and 25 years for 218 and 220 South Findlay Street properties based on modeling [Aspect, 2016]). A VI assessment, monitoring, and mitigation program will continue to be a part of this engineered control while soil and groundwater concentrations exceed levels protective of indoor air quality.
- An environmental covenant would be placed on the ABP property.
- Groundwater monitoring in SU1 would be conducted until CULs are attained across SU1, which is approximately 55 years for CVOCs and 280 years for metals, based on modeling (Aspect, 2016). The monitoring program would be identified in the dCAP and subject to adjustments during periodic reviews. For the purposes of cost estimating for this SU1 FS Addendum, monitoring assumptions were, as follows:
    - Performance monitoring would be conducted at wells in the Source Area during pH adjustment to evaluate effectiveness and modify neutralization applications as appropriate.

[17] The proposed location of an additional injection transect in Fidalgo Street (east of the pilot study area) is subject to access limitations, due to the 24/7 operation of the Westrock shipping department located here.

- Performance monitoring would be conducted at wells in the Downgradient TCE Plume Area during ISCR/EAB to evaluate effectiveness and determine if additional injections are appropriate. Once groundwater treatment objectives are met, porewater sampling would be conducted to confirm that Porewater RELs are met.

- Confirmation soil monitoring would be performed to evaluate achievement of CULs in the vadose zone. Achievement of soil cleanup levels protective of groundwater would be evaluated via groundwater monitoring for empirical demonstration.

- Confirmation monitoring would be conducted at a subset of existing wells to confirm the plume boundaries, including concentrations at the shoreline, are stable or shrinking.

- Confirmation monitoring after active treatment, through Year 55 would be conducted biannually with a subset of wells along the plume centerline and at the shoreline monitored annually. Potential monitoring costs after Year 55 were not included as these do not significantly affect costs in a Net Present Value (NPV) analysis.

5.1.5 Cost and Restoration Time Frame

Cost estimates were developed in accordance with EPA cost estimating guidance (EPA, 2000) and are FS-level (+50/-30 percent of actual costs). Total project costs were calculated using NPV analysis assuming a discount rate of 2 percent. Cost estimates include construction, operation and maintenance (O&M), and monitoring costs through the estimated restoration time frame for CVOCs (approximately 55 years). Monitoring requirements for residual metals contamination beyond this time frame are assumed to be limited, and the costs are expected to be insignificant under an NPV analysis.

Restoration time frame was estimated based on the time for all RAOs to be achieved, which is driven by the time to achieve surface water protection CULs in groundwater. Restoration time frames were estimated in the SU1 FS.

The estimated NPV cost for Alternative 2A is $4.0 M. Details are provided in Table 5-1. The estimated time to achieve all SU1 RAOs, including surface water CULs in groundwater at the standard point of compliance is approximately 50 years for CVOCs and 280 years for metals.

5.1.6 Potential Contingency Actions

Contingency actions may be implemented if an alternative is insufficiently protective or RAOs for achieving CULs within a reasonable restoration time frame are not met. The potential pathways of greatest concern—and therefore the most likely to trigger contingency actions—are achieving VI-based CULs in shallow groundwater near the Source Area and achieving Porewater RELs in groundwater discharging to the Waterway. Therefore, this alternative includes potential contingency actions for addressing CVOCs in the Source Area and the Waterway.

Similar to SU1 FS Alternative 2, the contingency action identified for this alternative was ISCR in the Source Area to further address CVOCs if required to achieve vapor-intrusion-based cleanup levels within a reasonable time frame (see Section 7.2.5 of the 2016 SU1 FS Report). The estimated NPV cost for Source Area treatment at year 5 is $1.1 M. Details are provided in Table 5-3.

At the Waterway, performance monitoring data will be evaluated at the time of Ecology's 5-year review to determine whether contingency actions may be necessary. The data will be used to update the estimated time to achieve Porewater RELs and will be considered in context of the LDW Site cleanup time frame. This will provide sufficient time to implement a contingency action to accelerate treatment, if needed. For the purposes of this SU1 FS Addendum, the contingency action identified for this alternative to achieve Porewater RELs is implementation of ISCR or ISCR/EAnB near the shoreline, which is described as part of Alternative 2B below.

The evaluation and implementation of contingency actions will occur as follows:

- Review performance monitoring groundwater trends in shoreline wells
- Use the performance monitoring data to recalculate the time predicted to achieve Porewater RELs
- If the updated time frame to achieve Porewater RELs based on groundwater data is unacceptable (i.e., longer than the LDW Site cleanup time frame), then:
    - Porewater sampling may be conducted to evaluate whether Porewater RELs have been achieved; and/or
    - The contingency action for shoreline treatment will be implemented (ISCR or ISCR/EAnB), following the general approach for shoreline treatment described under Alternative 2B in Section 5.2.1.

The performance monitoring plan, including methods for estimating restoration time frame, would be included in the dCAP.

The estimated NPV cost for shoreline EAnB treatment at year 5 is $0.77 M. Details are provided in Table 5-4.

5.2 Alternative 2B

Alternative 2B includes the same components as Alternative 2A but adds ISCR/EAnB treatment of dissolved CVOC impacts along the Waterway shoreline as a remedy component instead of a contingency action. In summary, Alternative 2B includes the following:

- Application of a pH neutralization solution in areas of depressed groundwater pH (in the Source Area) through injection points and wells to raise the pH and immobilize/precipitate plating metals dissolved in groundwater.
- Application of an EAnB/ISCR amendment as a PRB along Fidalgo Street in the Downgradient TCE Plume Area to treat CVOCs dissolved in groundwater.
- Application of an EAnB/ISCR amendment as a PRB along the shoreline in the Downgradient TCE Plume Area to treat CVOCs dissolved in groundwater.

- MNA of CVOCs and plating metals in soil and groundwater in and downgradient of the Source Area following pH neutralization.
- Implementing engineered and institutional controls and monitoring until RAOs are achieved.

Refer to Alternative 2A (Section 5.1) for the conceptual design for pH neutralization, ISCR/EAnB along Fidalgo Street, and monitoring, engineered controls, and institutional controls. Application of ISCR/EAnB along the Waterway shoreline is described below.

5.2.1 Shoreline ISCR/EAnB Application and Assumptions

The purpose of treatment of the Downgradient TCE Plume along the Waterway shoreline is to reduce groundwater concentrations of CVOCs discharging to the Waterway faster than can be achieve by treatment in Fidalgo Street alone.

The effectiveness and suitability of the ISCR/EAnB reagent used in the CVOC pilot study is more uncertain close to the shoreline for the following reasons:

- More tidal mixing
- Groundwater geochemistry influenced by saltwater
- Dominance of TCE degradation products
- Secondary effects to surface water

It is possible that an alternative reagent (e.g., one that is more focused on ISCR mechanisms than EAnB) would be better suited for the Waterway shoreline area. As a result, a phased approach may be appropriate with implementing on a limited field-scale, followed by modification of the approach, if warranted, based on performance monitoring data. For the purposes of this SU1 FS Addendum, the following assumptions were made:

- The injection transect would be located along the shoreline but as close to the existing building as practicable, to reduce potential secondary effects to water quality from impacting the Waterway.
- The lateral and vertical extent of treatment will target the area of the plume requiring treatment to achieve Porewater RELs. The lateral extent based on historical groundwater and porewater data is shown on Figure 5-3, and the vertical extent of treatment is assumed to be from 20 to 30 feet bgs based on pilot study recommendations (see Appendix A). As part of the design, a baseline investigation would be conducted along potential treatment transects as follows:
    - CVOC concentrations along each transect would be evaluated through a combination of monitoring wells, to be used as future performance monitoring points, and direct-push sampling to refine the lateral and vertical extent of CVOCs.
    - The area targeted for treatment would be determined by the area required to reduce the average concentration in groundwater upgradient of the porewater study area by at least 83 percent (see Section 4.5).

- An ISCR-only pilot study (described further below) would be conducted to determine the optimum reagent prior to full-scale implementation.
- Reagent would be applied using the same pressurized delivery (approximately 15 to 44 psi) via direct-push injections. The transect would consist of two offset rows of injection points spaced on approximately 6-foot centers. For cost estimating purposes, an ISCR/EAnB reagent and a contingency for inclusion of a zero-valent iron (ZVI)-based amendment have been included. The results of the ISCR-only pilot test will determine whether the ZVI contingency is needed.
- A reagent mixture containing ZVI would be injected.
- Two injections will be performed. It is anticipated that treatment in Fidalgo Street would reduce CVOC concentrations entering the Shoreline Treatment Area before additional injections would be needed.

As noted above, an ISCR pilot study would be conducted along the shoreline before implementing the full-scale shoreline treatment. The CVOC pilot study in South Fidalgo Street utilized an ISCR/EAnB reagent, but it may not be as effective or suitable along the shoreline. An ISCR reagent may be better suited for the Waterway shoreline area due to the increased tidal mixing, groundwater geochemistry, dominance of TCE degradation products, and secondary effects to surface water.

For the purposes of this SU1 FS Addendum, the pilot test would be implemented with the same assumptions noted above regarding injection transect location, vertical treatment depth, reagent, and delivery. Other assumptions include:

- The lateral and vertical extent of treatment for the pilot study will target the area of the plume with the highest VC concentrations, based on the results of the baseline investigation.
- One injection will be performed. Monitoring will be conducted to determine whether the reagent enhanced chemical reduction of VC. Results will be used to determine the following:
  - Whether ISCR alone or a combination of ISCR/EAnB reagent is likely more effective in the shoreline area;
  - Design parameters for a full-scale injection program;
  - Whether shoreline injections are likely to significantly reduce the time to achieve Porewater RELs. If effectiveness near the shoreline is limited due to tidal effects and geochemical conditions, or secondary water quality impacts from treatment are a concern, the implementation of shoreline treatment will be reconsidered in consultation with Ecology.

Treatment at the Waterway would be on private property, operated by CertainTeed Gypsum, and an access agreement would need to be negotiated. No public property is available for the pilot study between the Waterway and South Fidalgo Street.

5.2.2 Cost and Restoration Time Frame

The estimated cost for Alternative 2B is $4.6 M. Details are provided in Table 5-2. The estimated time to achieve all SU1 RAOs, including surface water CULs at the standard point of compliance, is approximately 50 years for CVOCs and 280 years for metals.

5.2.3 Potential Contingency Actions

This remedial alternative relies on MNA to achieve RAOs for CVOCs in the Source Area. Similar to Alternative 2A, the contingency action identified for this alternative was ISCR in the Source Area to further address CVOCs if required to achieve vapor-intrusion-based cleanup levels within a reasonable time frame. The estimated NPV cost for Source Area treatment at year 5 is $1.1 M. Details are provided in Table 5-3.

6 Evaluation of SU1 Remedial Alternatives

In this section, the two remedial alternatives described in Section 5 are evaluated with respect to MTCA criteria. MTCA criteria for evaluating remedial alternatives include[18]:

- Meeting MTCA threshold requirements
- Achieving cleanup within a reasonable restoration time frame
- Using permanent solutions to the maximum extent practicable as determined through a disproportionate cost analysis (DCA)

This evaluation is described below, and a summary of this evaluation is provided in Table 6-1.

6.1 MTCA Threshold Requirements

Cleanup actions selected under MTCA must meet four "threshold" requirements identified in WAC 173-340-360(2)(a) to be accepted by Ecology. All cleanup actions must:

- Protect human health and the environment
- Comply with cleanup standards
- Comply with applicable state and federal laws
- Provide for compliance monitoring

All nine alternatives evaluated in the SU1 FS met these threshold requirements and Ecology concurred in its comment letter (Ecology 2016). Alternatives 2A and 2B are variations on FS Alternative 2 and also meet threshold requirements for the same reasons detailed in the SU1 FS.

6.2 Evaluation with Respect to Reasonable Restoration Time Frame

MTCA places a preference on remedial alternatives that can achieve the required CULs at the points of compliance in a shorter period of time. Factors to be considered in evaluating whether an alternative provides for a reasonable restoration time frame are identified in WAC 173-340-360(4)(b).

A cleanup action is considered to have achieved restoration once cleanup standards have been met. As discussed in Section 8.2.2 of the SU1 FS (Aspect, 2016), all nine alternatives are expected to comply with cleanup standards. The restoration time frame for SU1 is driven by the time to meet groundwater CULs based on surface water

[18] MTCA criteria also require consideration of public concerns. As described in the SU1 FS, consideration of public concerns is an inherent part of the Site cleanup process under MTCA. The draft FS and CAP will be issued for public review and comment, and Ecology determines whether changes to the reports are needed in response to public comments

protection at the standard point of compliance. The restoration time frames for surface water protection for CVOCs for the nine FS alternatives ranged from 30 years to 55 years[19]. Restoration time frames for surface water protection for plating metals for the nine FS alternatives ranged from 280 to more than 1,000 years. Based on the FS analysis, the estimated restoration time frames for Alternatives 2A and 2B are 50 years for CVOCs and 280 years for metals.

WAC 173-340-360(4)(b) provides a list of factors to be considered to determine whether a cleanup action provides for a reasonable restoration time frame, including:

- Potential risks posed by the site to human health and the environment
- Practicability of achieving shorter restoration time frame
- Current and potential future use of the site, surrounding areas, and associated resources that are, or may be, affected by releases from the site
- Availability of alternate water supplies
- Likely effectiveness and reliability of institutional controls
- Ability to control and monitor migration of hazardous substances from the site
- Toxicity of the hazardous substances at the site
- Natural processes, which reduce concentrations of hazardous substances and have been documented to occur at the site or under similar site conditions

A longer period of time may be used for the restoration time frame for a site to achieve cleanup levels at the point of compliance if the cleanup action selected has a greater degree of long-term effectiveness than on-site or off-site disposal, isolation, or containment options (WAC 173-340-360(4)(c)). Extending the restoration time frame cannot be used as a substitute for active remedial measures when such actions are practicable (WAC 173-340-360(4)(f)).

Contamination at SU1 represents a relatively low risk because there are no unacceptable exposures, and potential future exposures can be reliably treated or controlled under all nine remedial alternatives. In particular:

- Drinking water is not a current or potential future use of groundwater (Appendix F of SU1 FS)

[19] As discussed in the SU1 FS, estimated restoration time frames are based on groundwater modeling that involves significant uncertainty. As a result, the estimated time frames are only very rough approximations, and should primarily be used to evaluate alternatives relative to one another. The modeled time frames are used in this SU1 FS Addendum as a measure of how alternatives would perform relative to each other, not as absolute estimates of when restoration will occur. Variation of many of these parameters are expected to result in similar adjustments among the range of alternatives, and the modeled restoration time frames are used as a relative indication of alternative effectiveness to inform the DCA.

- Engineered and institutional controls, including vapor intrusion monitoring and mitigation programs, have been effective at controlling exposures to date, and are expected to continue to do so as the plume attenuates[20]
- Contamination discharging at the Waterway does not represent an unacceptable risk to human or ecological receptors (Aspect, 2012)

There is some inherent uncertainty, particularly for alternatives with long estimated restoration time frames, in future conditions and associated future risks. Ecology has noted a preference for quickly achieving cleanup levels, particularly in groundwater approaching the Waterway. Whether a restoration time frame is reasonable is based partly on the ability to practicably achieve a significantly shorter time frame by more permanently addressing particular exposure pathways. For the alternatives evaluated, the estimated times to achieve particular cleanup objectives based on modeling described in the SU1 FS range as follows:

- The time to achieve VI-based CULs is estimated at 25 years for Alternatives 2A and 2B.
- The time to achieve surface water-based CULs discharging to the Waterway is estimated at 35 years for Alternative 2B and 50 years for Alternative 2A.
- The time to achieve surface water-based CULs everywhere is estimated to be close to 280 years.

Based on the CVOC Pilot Study results and analysis (see Appendix B), it is anticipated that Porewater RELs could be achieved within 13 years under Alternative 2A and within 5 years under Alternative 2B based on the estimated time for the clean water front migrating from the treatment area(s) to reach the Waterway (see Appendix E) and assuming a 2-year time frame for design and implementation. These time frames are significantly faster than the time predicted for the LDW Site cleanup to achieve its target levels (at least 20 years)[21].

Both alternatives potentially provide for a reasonable restoration time frame. The practicability of achieving a shorter restoration time frame depends on the DCA described in Section 6.3.

6.3 Disproportionate Cost Analysis

A DCA was performed to evaluate whether a cleanup action uses permanent solutions to the maximum extent practicable. The DCA quantifies the environmental benefits of each

[20] The effectiveness of engineered and institutional controls relies, in part, on owner willingness to allow the controls to be implemented and operated.

[21] According to the LDW ROD (EPA, 2014), protective levels are anticipated to be achieved within 17 years of beginning construction, assuming that construction will take 7 years. This time frame is consistent with Ecology guidance that sediment cleanups will generally achieve protective levels within 10 years of completing construction (Ecology, 2019). Construction of the LDW Site remedy for the upper reach is currently scheduled to begin in 2025. For the lower reach (the area where the groundwater plume discharges), this time frame will be significantly longer as design and construction is not currently scheduled.

remedial alternative, and then compares alternative benefits versus costs. Alternatives are ranked from most to least permanent, and the most permanent alternative is the 'baseline' alternative against which other alternatives are compared. Costs are disproportionate to benefits if the incremental cost of a more permanent alternative over that of a lower-cost alternative exceeds the incremental benefits achieved by the alternative over that of the lower-cost alternative. Alternatives that exhibit disproportionate costs are considered "impracticable" under MTCA.

Seven criteria are considered in the evaluation as specified in WAC 173-340-360(3)(f):

- **Protectiveness.** Overall protectiveness of human health and the environment, including the degree to which existing site risks are reduced, time required to reduce the risks and attain cleanup standards, on-site and off-site risks during implementation, and improvement in overall environmental quality.
- **Permanence.** Degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of destroying hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of treatment, and the characteristics and quantity of the treatment residuals.
- **Cost.** Remedy design, construction, and long-term O&M costs to implement the alternative.
- **Long-term effectiveness.** Degree of certainty that the alternative will successfully and reliably address contamination that exceeds applicable CULs until CULs are attained, the magnitude of the residual risk with the alternative in place, and the effectiveness of controls to manage treatment residue and remaining wastes.
- **Short-term risk management.** The risks to human health and the environment during construction and implementation of the alternative, and the effectiveness of measures that will be taken to manage such risks.
- **Implementability.** Includes consideration of whether the alternative is technically possible; the availability of necessary off-site facilities, services, and materials; administrative and regulatory requirements; scheduling, size, and complexity of the alternative; monitoring requirements; access for construction, operations, and monitoring; and integration with existing facility operations and other current or potential remedial actions.
- **Consideration of public concerns.** Concerns from individuals, community groups, local governments, tribes, federal and state agencies, and other interested organizations are addressed by Ecology responding to public comments on the Draft FS report and the Draft Cleanup Action Plan.

The DCA is provided in the following sections and summarized in Table 6-1. Environmental benefit is quantified by first rating the alternatives with respect to six of the seven criteria[22]. Rating values are assigned on a scale of 1 to 10, where 1 indicates the criterion is satisfied to a very low degree, and 10 indicates the criterion is satisfied to a very high degree. Since Ecology does not consider the criteria to be of equal importance, each criterion is assigned a "weighting factor." Consistent with feasibility studies and cleanup action plans conducted on other Ecology cleanup sites, weighting factors are assigned as follows:

- Overall protectiveness: 30 percent
- Permanence: 20 percent
- Long-term effectiveness: 20 percent
- Short-term effectiveness: 10 percent
- Implementability: 10 percent
- Consideration of public concerns: 10 percent

A MTCA benefits ranking is then obtained for each alternative by multiplying the six rating values by their corresponding weighting factors and summing the weighted values. The method used here is consistent with the DCA completed for the W4 SU1 and SU2 FS reports (Aspect, 2016 and PGG, 2016, respectively). Finally, the benefits ranking of each alternative is divided by the alternative's estimated cost to obtain a benefit/cost ratio, which is a relative measure of the cost effectiveness of the alternative[23].

Below, Alternatives 2A and 2B are compared for each criterion. This discussion is focused on the key differences between the two alternatives.

6.3.1 Overall Protectiveness

Both remedial alternatives would be protective of human health and the environment and incorporate the same elements to address most exposure pathways. The differentiating factor between the two alternatives with respect to overall protectiveness is the time frame for achieving protective levels at the Waterway.

Groundwater concentrations exceed surface water CULs at the point of discharge to the Waterway and are predicted to exceed these levels for an extended period of time; however, a Site-specific assessment during the RI indicated that potential exposure scenarios do not provide an unacceptable level of risk currently or in the foreseeable future. The REL analysis (Appendix D) identified concentrations in porewater that would be protective of hypothetical long-term future use.

Both alternatives include treatment of groundwater prior to discharge to the Waterway along Fidalgo Street approximately 300 feet from the shoreline. Alternative 2B includes

[22] Cost is not considered in quantifying environmental benefit but is used to determine the cost-to-benefit ratio of each alternative (see Section 6.3.7).
[23] The described method is one of several possible ways to conduct the DCA. This method has been chosen to be consistent with the DCA of the SU1 and SU2 FS and is consistent with Ecology's preference at other sites. Other DCA methods include quantitative analysis with different weighting systems or purely qualitative analyses.

treatment along the shoreline and is likely to achieve RELs faster than Alternative 2A. However, implementation of treatment along the shoreline will need to be carefully designed, tested, and potentially implemented in a phased approach to avoid secondary water quality impacts.

Porewater RELs are anticipated to be achieved faster than surface water CULs, based on the estimated time for the clean water front migrating from the treatment area(s) to reach the Waterway. Surface water CULs in groundwater at the shoreline are predicted to be achieved in approximately 50 years for Alternatives 2A and RELs within 13 years. For Alternative 2B, surface water CULs are predicted to be achieved in approximately 35 years at the shoreline and Porewater RELs may be achieved within 5 years.

Alternative 2A was given a rating of moderate (6). Alternative 2B would achieve RELs at the Waterway faster through shoreline treatment and was given a rating of high (7).

6.3.2 Permanence

All alternatives are considered to have a relatively high permanence because, in general, the CVOCs are ultimately destroyed through a combination of active treatment and natural attenuation; and the plating metals (which cannot be 'destroyed') are immobilized to prevent migration to the Waterway, and do not present a health risk when immobilized in place because of their relatively low human toxicity. In the SU1 FS, alternatives were differentiated on this criterion primarily on the irreversibility of immobilization.

Alternatives 2A and 2B would have the same permanence as FS Alternative 2, and therefore were both given a rating of moderate (5).

6.3.3 Long-Term Effectiveness

Both alternatives involve treatment technologies that, coupled with natural attenuation and engineered and institutional controls, are all considered highly likely to maintain protectiveness during the cleanup period and ultimately achieve cleanup standards within a reasonable restoration time frame. Capping and vapor mitigation are considered highly reliable as they would be accompanied by monitoring programs to confirm protectiveness. Institutional controls such as notifications to potentially affected utility companies during the period of restoration can also be effective, but depend on the utility company invoking procedures to address potential contamination and following best management practices (BMPs) when appropriate.

The CVOC and metals pilot studies demonstrated that the proposed technologies are effective at the Site. Therefore, the long-term effectiveness of both alternatives was rated higher than similar alternatives evaluated in the SU1 FS.

The effectiveness of each alternative at meeting RAOs were differentiated based on the time frame for restoration of groundwater discharging to the Waterway, the potential effectiveness of shoreline treatment, and the potential need for contingency actions. Alternative 2B includes treatment along the shoreline to reduce the time frame to achieve Porewater RELs, while Alternative 2A includes the same treatment as a contingency. The pilot study demonstrated successful treatment in Fidalgo Street, which is targeted by both alternatives. However, the efficacy demonstrated in the pilot study is not predictive of the effectiveness of ISCR/EAnB treatment along the shoreline because of the saline intrusion, greater tidal fluctuations in groundwater elevations, and different biogeochemical groundwater conditions at the shoreline groundwater.

Based on these considerations, both alternatives were rated moderate (6) for this criterion.

6.3.4 Short-Term Risk Management

For both alternatives, the short-term risks to workers and the public can generally be managed using appropriate BMPs. Both alternatives involve handling of relatively low toxicity materials (pH neutralization solution and EAnB or ISCR amendments) and low-risk construction activities (well drilling, amendment injection).

Alternative 2A is rated high (8) for short-term risk management. Alternative 2B includes a slightly greater potential for secondary water quality effects due to treatment adjacent to the shoreline and is rated high but slightly lower (7) than Alternative 2A.

6.3.5 Implementability

Both alternatives target areas that are considered relatively accessible and would use readily available services/equipment and common implementation techniques. Injection programs in street ROWs will require a street-use permit and will be constrained by utilities. However, drilling during the RI was completed successfully in the general areas targeted for injection under these alternatives. Logistical challenges may include weekend or nighttime work during drilling on arterial streets or adjacent to sensitive businesses.

Alternative 2A was given a rating of high (7). Alternative 2B presents greater implementability challenges compared to Alternative 2A because of the need to conduct injections on private property (including associated access requirements and uncertainty in future accessibility to the shoreline area) and constraints to control potential secondary water quality impacts. This alternative was given a rating of moderate (6).

6.3.6 Consideration of Public Concerns

Ecology expects, based on its experience at other local sites, that the public will, in general:

1) Prefer alternatives that more quickly restore groundwater discharging to the Waterway
2) Generally support exposure controls (e.g., vapor mitigation, deed restrictions) when coupled with active remedial measures
3) Desire shrinkage of the extent of groundwater contamination
4) Be reluctant to allow free access to private property for implementation of remediation and monitoring.

Based on these expectations, the alternatives were rated as follows:

- Alternatives 2A was rated moderate (5).
- Alternative 2B was also rated moderate but slightly higher (6), due to its shorter time frame for achieving Porewater RELs.

This category will be reevaluated after the public comment period for the Draft Cleanup Action Plan.

6.3.7 Benefits Rankings, Estimated Costs, and Benefit/Cost Ratios

The MTCA benefits rankings, estimated costs, and benefit/cost ratios for the two remedial alternatives are presented at the bottom of Table 6-1. As previously noted, the MTCA benefits ranking is obtained for each alternative by multiplying the rating values assigned for the six evaluation criteria by their corresponding weighting factors and summing the weighted values. The benefit rankings were 6.0 for Alternative 2A and 6.2 for Alternative 2B.

The benefit/cost ratio, which is a relative measure of cost-effectiveness, is obtained by dividing each alternative's benefits ranking by its estimated cost. Alternative 2A has the higher benefit/cost ratio, at 1.5 versus 1.3 for Alternative 2B (Table 6-1).

6.3.8 Disproportionate Cost Analysis Conclusion

Based on the results of the DCA presented above, Alternative 2A has the highest benefit-to-cost ratio and is deemed to satisfy the MTCA requirement for an alternative to be permanent to the maximum extent practicable.

6.4 Uncertainty Analysis

This FS analysis involves uncertainty regarding a number of items, including:

- Accuracy of Site characterization
- Fate and transport of contaminants
- Future land and resource use
- Effectiveness and reliability of remedial technologies
- Effectiveness, cost, reliability, restoration time frame, and protectiveness of FS alternatives

Refer to the SU1 FS for discussion of these factors. As noted in the SU1 FS, the primary purpose of the FS is to identify likely viable remedial alternatives, comparatively evaluate them, and select a preferred cleanup action. Much of the uncertainty listed above is less critical when evaluating alternatives on a relative basis. Although specific metrics, such as cost, restoration time frame, and treatment effectiveness discussed in this SU1 FS Addendum may vary from the estimates provided in the FS, it is likely that the key conclusions reached in this report are still valid, since inaccuracies in assumptions often apply to a greater or lesser extent to all alternatives.

7 Conclusions and Recommendations

The SU1 FS considered nine remedial alternatives that provide a range of treatment options for metals and CVOC contamination. This SU1 FS Addendum identified two remedial alternatives that were modified from the original nine based on Ecology comments and the results of interim pilot studies and monitoring. All alternatives meet MTCA Threshold Requirements, including protection of human health and the environment. To date, interim actions and the CVOC Pilot Study have substantially reduced CVOC concentrations in the Source Area and in the Downgradient TCE Plume.

Alternative 2A is the recommended cleanup action for SU1 based on the analysis and considerations presented in this SU1 FS Addendum. Alternative 2A has the highest benefit-to-cost ratio and satisfies the MTCA requirement to be permanent to the maximum extent practicable and will achieve the applicable cleanup levels at the designated points of compliance within a reasonable restoration time frame. The cost for Alternative 2A is $4.0 M compared to Alternative 2B at $4.7 M. This alternative is protective of human health and the environment, and is significantly less expensive than Alternative 2B.

The primary benefit of Alternative 2B is that it is likely to achieve Porewater RELs faster; however, there are no unacceptable risks based on current conditions in the foreseeable future. Alternative 2B has additional uncertainty as to effectiveness and potential for secondary water quality impacts from treatment adjacent to the Waterway. Groundwater and porewater monitoring would be conducted to determine if the remedy is performing as expected, verify that receptors are protected, and confirm that groundwater restoration will occur within a reasonable time frame.

8 Schedule

Upon receipt of Ecology concurrence of the SU1 and SU2 FS Addenda, the FS and FS Addenda will undergo a period of public review and comment. If Ecology requires revisions to either or both of the FS Addenda based on public comments, the revised reports will be submitted to Ecology for approval. After Ecology approves the FS Addenda, a dCAP will be prepared that presents details regarding implementation of Alternative 2A, including a proposed schedule for key elements of the cleanup action and associated compliance monitoring. The dCAP will be submitted to Ecology within 120 days of Ecology concurrence.

9 References

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10 Limitations

Work for this project was performed for the West of Fourth PLP Group (Client), and this report was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

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TABLES

Table 3-1. Summary of Preliminary Cleanup Levels

Project No. 050067, West of 4th Site, Site Unit 1, Seattle, Washington

Constituent of Concern	Carcinogen or Non-Carcinogen	Preliminary Cleanup Levels											
		Soil			Groundwater				Air		Surface Water		Sediment
		Puget Sound Background Concentrations for Metals[1]	Soil Cleanup Level Protective of Direct Contact Pathway (Unrestricted Land Use)[2]	Soil Cleanup Level Protective of Groundwater concentrations, Protective of Surface Water Quality (Vadose Zone)[4]	Groundwater Screening Level Protective of Air Quality Water Table Zone (Unrestricted Land Use)[5]	Groundwater Screening Level Protective of Air Quality Water Table Zone (Commercial Worker)[5]	Groundwater Cleanup Level Protective of Surface Water[6]	Groundwater Cleanup Level Protective of Sediment[7]	Air Cleanup Level Protective of Inhalation Pathway (Unrestricted Land Use)[5]	Air Cleanup Level Protective of Inhalation Pathway (Industrial Land Use)[5]	Surface Water Cleanup Level Protective of Human Health[8]	Surface Water Cleanup Level Protective of Aquatic Life	Sediment Cleanup Level[9]
		(Milligrams/kilogram)			(Micrograms/liter)				(Micrograms/cubic meter)		(Micrograms/liter)		(Milligrams/kilogram)
Tetrachloroethene	Carcinogen	--	480	0.03	25	120	2.9	250,000	9.6	40	2.9	--	190
Trichloroethene	Carcinogen	--	12	0.004	1.4	12	0.7	5,200	0.33	2	0.7	194 [12]	8,950
cis-1,2-Dichloroethene	Non-Carcinogen	--	160	--	--	--	--	360,000	--	--	--	--	--
trans-1,2-Dichloroethene	Non-Carcinogen	--	1,600	5	77	650	1,000	3,700,000	18	40	1,000	--	--
1,1-Dichloroethene	Non-Carcinogen	--	4,000	26	130	1,100	4,000	6,600,000	91	200	4,000	--	--
Vinyl chloride	Carcinogen	--	0.67	0.001	0.33	1.6	0.18	1,900	0.28	2.8	0.18	210 [12]	202
1,4-Dioxane	Carcinogen	--	10	0.32	4,700	22,000	--	20,000	0.5	5	--	--	--
Arsenic	Carcinogen	**7.3**	24	0.082	Not Applicable	Not Applicable	8 [10]	220	Not Applicable	Not Applicable	0.14	36 [14]	7
Barium	Non-Carcinogen	--	16,000	**165**	Not Applicable	Not Applicable	--	930,000	Not Applicable	Not Applicable	--	200 [12]	--
Cadmium	Non-Carcinogen	0.77	80	**1.2**	Not Applicable	Not Applicable	7.9	1.2	Not Applicable	Not Applicable	--	7.9 [13]	5.1
Copper	Non-Carcinogen	**36**	3,200	1.4	Not Applicable	Not Applicable	3.1	14	Not Applicable	Not Applicable	--	3.1 [13]	390
Iron	Non-Carcinogen	36,100	56,000	--	Not Applicable	Not Applicable	--	--	Not Applicable	Not Applicable	--	--	--
Manganese	Non-Carcinogen	1,200	3,700	1.3	Not Applicable	Not Applicable	100	--	Not Applicable	Not Applicable	100 [11]	--	--
Nickel	Non-Carcinogen	48	1,600	11	Not Applicable	Not Applicable	8.2	2,600	Not Applicable	Not Applicable	100	8.2 [13]	15.9
Zinc	Non-Carcinogen	85	24,000	101	Not Applicable	Not Applicable	81	770	Not Applicable	Not Applicable	1,000	81 [8]	410

NOTES:

Preliminary cleanup levels presented represent the most stringent cleanup levels for the constituent of concern listed in the media indicated.

-- indicates no value is available. In the case of ARARs, the reference sources do not publish values for the noted chemicals. In the case of calculated values, one or more input parameters are not available.

"Not Applicable" is used where the constituent of concern will not affect the media of potential concern due to an incomplete pathway.

[1] Background metals values from Ecology Publication No. 94-115, Natural Background Soil Metals Concentrations in Washington State. Updated for arsenic, cadmium, and iron provided by Ecology 5/25/2022 for inclusion in this table .

[2] Cleanup level is based on standard Washington State Model Toxics Control Act Cleanup Regulation (MTCA) Method B (unrestricted land use) or Method C (industrial land use) values from the Cleanup and Risk Calculations tables (CLARC).

[3] Cleanup levels for protection of air quality are calculated using MTCA Equation 747-1 where the potable Method B groundwater cleanup level was used as Cw. Concentrations of hazardous substances in soil that meet the potable groundwater protection standard currently are considered sufficiently protective of the air pathway

[4] Soil cleanup levels for protection of surface water quality are based on vadose conditions. Achievement of soil cleanup levels protective of groundwater would be evaluated via groundwater monitoring for empirical demonstration. Values are calculated using Washington State Model Toxics Control Act Cleanup Regulation (MTCA) Equation 747-1 where the groundwater cleanup level protective of surface water in this table was used as Cw.

[5] Cleanup levels protective of the air pathway for unrestricted land use (residential and commercial sites) based on Guidance for Evaluating Vapor Intrusion in Washington State: Investigation and Remedial Action (Ecology, 2009) and listed in Cleanup and Risk Calculations tables (CLARC; database dated July 2022). Commercial worker assumes 10 hour work day, 5 days a week.

[6] Human health and marine aquatic ecologic receptors were considered. Refer to the Surface Water Cleanup Levels Protective of Human Health and Aquatic Life in this table. The more stringent value of the two receptors has been listed for the Groundwater Cleanup Level Protective of Surface Water.

[7] Groundwater screening levels based on the transfer of contaminants from groundwater to sediment were calculated by dividing the sediment screening level by the associated partition coefficients. Updated values provided by Ecology 5/25/2022 for inclusion in this table.

[8] Criteria in this column are based on EPA's Partial Approval/Partial Disapproval of Washington's Human Health Water Quality Criteria and Implementation Tools (November 15, 2016), unless otherwise noted below.

[9] Sediment has not been confirmed to be affected by groundwater discharge to surface water. Sediment cleanup levels were derived from the Lower Duwamish Waterway Superfund Site Record of Decisions (EPA, 2014), which does not contain values for nickel, TCE, PCE, or vinyl chloride. These constituents are not listed in the

[10] Arsenic Cleanup level of 8 ug/L based on background concentrations for Puget Sound Basin (Ecology Publication Number 14-09-044).

[11] CWA Section 304, National Recommended Water Quality Criteria, Human Health based on consumption of organisms. Provided by Ecology 5/25/2022 for inclusion in this table.

[12] Aquatic Life, literature value provided by Ecology 5/25/2022 for inclusion in this table

[13] National Recommended Water Quality Criteria published by EPA under 304 of the Federal Clean Water Act - Aquatic Life Criteria Table

Table updated August 14, 2015 based on revisions to AWQC; July 20, 2016 based on Ecology comments on the Draft FS Reports for SU1 and SU2 (clarify footnotes, add sediment values, add surface water CULs protective of aquatic life); October 10, 2020 based on revisions to surface water criteria for protection of human health and updates to CLARC for protection of air pathway (CLARC dated August 2020); August 2022, based on comments from Ecology dated 5/25/2022.

Table 5-1. Detailed Cost Estimate for Alternative 2A

Project No. 050067, West of 4th Site, Site Unit 1, Seattle, Washington

Remedial Action Description:	Source pH neutralization, Downgradient ISCR/EAnB @Fidalgo
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate c	2.0%
Inflation since January 2021	1.15

Direct Installation Costs	Quantity	Units	Unit Cost	Extension	Description
Source Area pH Neutralization					
Mobilization/demobilization	5%	percent	$193,488	$9,674	percentage of capital costs below
Injection well installation (Cascade)	1	LS	$85,963	$85,963	2 weeks
Additional subcontractor support	1	LS	$14,375	$14,375	Traffic control
Sodium bicarbonate and sodium hydroxide amendment	1	LS	$60,950	$60,950	Silver Fern Chemical. 1M/0.5M solution. 5,000 gal per well.
Performance monitoring	8	EA	$4,025	$32,200	10 wells. Plating metals, redox metals, cations, and alkalinity.
Downgradient Area EAB Treatment - Fidalgo St					
mobilization/demobilization	5%	percent	$215,050	$10,753	percentage of capital costs below
EAnB injection well installation (Cascade)	1	LS	$92,000	$92,000	Cascade cost for direct push
Passive venting well installation	10	EA	$2,300	$23,000	10 wells, 5-foot depth, constructed like SVE well
Monitoring well installation	4	EA	$2,875	$11,500	4 wells, 2-inch PVC, 30-foot depth
Performance monitoring	5	EA	$9,545	$47,725	16 wells. Diss gases, CVOCs, TOC, sulfate.
Additional subcontractor support	1	LS	$14,375	$14,375	Traffic control and hydrant permit
EAnB amendments	1	LS	$26,450	$26,450	Peroxychem ELS+EHC
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	LS	$11,500	$11,500	@ Art Brass Plating
VI assessment	1	Event	$2,875	$2,875	
			Direct Installation Cost (Subtotal):	$443,000	
			Contingency (20%):	$89,000	
			Sales Tax (10.1% DI):	$45,000	
			Total Direct Installation Cost (DI):	***$577,000***	$117,700.0

Professional Services Costs	Quantity	Units	Unit Cost	Extension	Description
Record Environmental Covenant	1	LS	$11,500	$11,500	
Project Management and Construction Oversight	20%	percent	$588,500	$117,700	Percentage of DI+Env Covenant costs
Remedial Design	30%	percent	$588,500	$176,550	Percentage of DI+Env Covenant costs. Pilot, phased implementation, EDR, contracting, Completion Report
Contingency	20%	percent	$305,750	$61,150	Percentage of DI+Env Covenant+PM+Remedial Design costs
			Total Professional Services (PS) Cost:	***$366,900***	

TOTAL CAPITAL INVESTMENT (TCI) [DI + PS]: $944,000

Annual Operations and Monitoring Costs	Quantity	Units	Unit Cost	Extension	Description
Compliance Monitoring					
Quarterly source area performance monitoring	5	Event	$41,400	$207,000	10 wells quarterly, years 1-5
Annual source area performance monitoring	10	Event	$10,350	$103,500	10 wells annually, years 6-15
Annual long term groundwater monitoring (MNA) for 10 years	10	Event	$31,050	$310,500	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	45	Event	$10,350	$465,750	10 wells annually, years 11-55
Biannual long term groundwater monitoring (MNA) after year 10	45	Event	$20,700	$931,500	20 additional wells biannually, years 11-55
Porewater monitoring	1	Event	$57,500	$57,500	at 15 years
Confirmation groundwater sampling	1	Event	$124,200	$124,200	30 wells quarterly @ 56 years
Confirmation soil sampling	1	Event	$28,750	$28,750	vadose zone soil @ 56 years
Well decommissioning	125	each	$575	$71,875	65 monitoring, 28 sparge, 5 sve, 24 pH @ 56 years
Source Area pH Neutralization					
Second Injection Event and Performance Monitoring (Contingenc	1	ls	$70,000	$70,000	Year 1 contingency
Downgradient Area EAB Treatment - Fidalgo St					
EAB Injection (Fidalgo) and Performance Monitoring Event[6]	4	Event	$167,200	$668,800	Years 3, 7, 12, 18
Vapor Mitigation					
VI Mitigation O&M - ABP Facility	15	Event	$2,875	$43,125	Semi-annually, years 1-15
VI Mitigation O&M - 220 & 218 S Findlay	25	Event	$2,875	$71,875	Semi-annually, years 1-25
VI assessment program	25	Event	$2,875	$71,875	Semi-annually, years 1-25
Equipment replacement	1	Event	$57,500	$57,500	once @ 10 years
Decommissioning	1	Event	$23,000	$23,000	@ 25 years
Reporting	55	Event	$13,800	$759,000	Annual for 55 years
Project Management	55	Event	$8,625	$474,375	Annual for years 1-55

TOTAL O&M COST : *$4,540,125*

TOTAL ALTERNATIVE COST (Actual Dollars, 56 years): $5,480,000

TOTAL ALTERNATIVE COST (NPV, 56 years): $3,950,000

Notes:

EAnB - Enhanced Anaerobic Bioremediation; SVE - Soil Vapor Extraction

Table 5-2. Detailed Cost Estimate for Alternative 2B

Project No. 050067, West of 4th Site, Site Unit 1, Seattle, Washington

Remedial Action Description: Source pH neutralization, Downgradient ISCR/EAnB @Fidalgo and Shoreline
Cost Estimate Accuracy: Feasibility Level (+50/-30 percent)

Key Assumptions:
Future costs are adjusted to present value using a discount rate 2.0%
Inflation since January 2021 1.15

Direct Installation Costs	Quantity	Units	Unit Cost	Extension	Description
Source Area pH Neutralization					
Mobilization/demobilization	5%	percent	$182,275	$9,114	percentage of capital costs below
Injection points - installation and application	1	LS	$74,750	$74,750	2 weeks
Additional subcontractor support	1	LS	$14,375	$14,375	Traffic control
Sodium bicarbonate and sodium hydroxide amendment	1	LS	$60,950	$60,950	Silver Fern Chemical. 1M/0.5M solution. 5,000 gal per well.
Performance monitoring	8	EA	$4,025	$32,200	10 wells for 8 quarters. Plating metals, redox metals, cations, and alkalinit
Downgradient Area EAB Treatment - Fidalgo St					
mobilization/demobilization	5%	percent	$215,050	$10,753	percentage of capital costs below
EAnB injection point installation and application	1	LS	$92,000	$92,000	Cascade cost for direct push
Passive venting well installation	10	EA	$2,300	$23,000	10 wells, 5-foot depth, constructed like SVE well
Monitoring well installation	4	EA	$2,875	$11,500	4 wells, 2-inch PVC, 30-foot depth
Performance monitoring	5	EA	$9,545	$47,725	16 wells. Diss gases, CVOCs, TOC, sulfate.
Additional subcontractor support	1	LS	$14,375	$14,375	Traffic control
EAnB amendments	1	LS	$26,450	$26,450	Peroxychem ELS+EHC, for 2 transects
Downgradient Area EAB Treatment - Shoreline					
mobilization/demobilization	5%	percent	$315,100	$15,755	percentage of capital costs below
supplemental pilot study	1	LS	$92,000	$92,000	phased implementation to mitigate secondary effects
EAnB injection well installation (Cascade)	1	LS	$92,000	$92,000	Cascade cost for direct push
Passive venting well installation	10	EA	$2,300	$23,000	10 wells, 5-foot depth, constructed like SVE well
Monitoring well installation	4	EA	$2,875	$11,500	4 wells, 2-inch PVC, 30-foot depth
Performance monitoring	5	EA	$9,545	$47,725	16 wells. Diss gases, CVOCs, TOC, sulfate.
Additional subcontractor support	1	LS	$14,375	$14,375	Traffic control
EAnB amendments	1	LS	$26,450	$26,450	Peroxychem ELS+EHC
ZVI contingency	1	LS	$8,050	$8,050	additional material cost for ZVI amendment
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	LS	$11,500	$11,500	@ Art Brass Plating
VI assessment	1	Event	$2,875	$2,875	
			Direct Installation Cost (Subtotal):	$762,000	
			Sales Tax (10.1% DI):	$77,000	
			Contingency (20% DI):	$168,000	
			Total Direct Installation Cost (DI):	***$1,007,000***	

Professional Services Costs	Quantity	Units	Unit Cost	Extension	Description
Record Environmental Covenant	1	LS	$11,500	$11,500	
Project Management and Construction Oversight	20%	percent	$1,018,500	$203,700	Percentage of DI+Env Covenant costs
Remedial Design	30%	percent	$1,018,500	$305,550	Percentage of DI+Env Covenant costs. Pilot, phased implementation, EDR, contracting, Completion Report
Contingency	20%	percent	$521,000	$104,200	Percentage of DI+Env Covenant+PM+Remedial Design costs
			Total Professional Services Cost (PS):	***$624,950***	
			TOTAL CAPITAL INVESTMENT (TCI) [DI + PS]:	**$1,631,950**	

Annual Operations and Monitoring Costs	Quantity	Units	Unit Cost	Extension	Description
Compliance Monitoring					
Quarterly source area performance monitoring	5	Event	$41,400	$207,000	10 wells quarterly, years 1-5
Annual source area performance monitoring	10	Event	$10,350	$103,500	10 wells annually, years 6-15
Annual long term groundwater monitoring (MNA) for 10 years	10	Event	$31,050	$310,500	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	45	Event	$10,350	$465,750	10 wells annually, years 11-55
Porewater monitoring	1	Event	$57,500	$57,500	at 10 years
Confirmation groundwater sampling	1	Event	$124,200	$124,200	30 wells quarterly @ 56 years
Confirmation soil sampling	1	Event	$28,750	$28,750	vadose zone soil @ 56 years
Well decommissioning	125	each	$575	$71,875	65 monitoring, 28 sparge, 5 sve, 24 pH @ 56 years
Source Area pH Neutralization					
Second Injection Event and Performance Monitoring (Contingen	1	ls	$180,000	$180,000	Year 1 contingency
Downgradient Area EAB Treatment - Fidalgo St					
EAB Injection (Fidalgo) and Performance Monitoring Event[6]	4	Event	$167,200	$668,800	Years 3, 7, 12, 18
Downgradient Area EAB Treatment - Shoreline					
EAB Injection (Fidalgo) and Performance Monitoring Event[6]	2	Event	$172,700	$345,400	Year 2, 4
Vapor Mitigation					
VI Mitigation O&M - ABP Facility	15	Event	$2,875	$43,125	Semi-annually, years 1-15
VI Mitigation O&M - 220 & 218 S Findlay	25	Event	$2,875	$71,875	Semi-annually, years 1-25
VI assessment program	25	Event	$2,875	$71,875	Semi-annually, years 1-25
Equipment replacement	1	Event	$57,500	$57,500	once @ 10 years
Decommissioning	1	Event	$23,000	$23,000	@ 25 years
Reporting	55	Event	$13,800	$759,000	Annual for 55 years
Project Management	55	Event	$8,625	$474,375	Annual for years 1-55
			TOTAL O&M COST :	***$4,064,025***	
			TOTAL ALTERNATIVE COST (Actual Dollars, 56 years):	***$5,700,000***	
			TOTAL ALTERNATIVE COST (NPV, 56 years):	***$4,570,000***	

Notes:
EAB - Enhanced Anaerobic Bioremediation; SVE - Soil Vapor Extraction

Table 5-3. Cost Estimate: Source Area ISCR Contingency

Project No. 050067, West of 4th Site, Site Unit 1, Seattle, Washington

Remedial Action Description: Source Area ISCR Contingency
Cost Estimate Accuracy: Feasibility Level (+50/-30 percent)

Key Assumptions:
Future costs are adjusted to present value using a discount rate 2.0%
Inflation since January 2021 1.15
Inflation since August 2016 1.55

Direct Installation Costs	**Quantity**	**Units**	**Unit Cost**	**Extension**	**Description**
Source Area ISCR Treatment					
Lab scale bench testing	1	ls	$23,250	$23,250	engineers estimate
Field scale pilot testing	1	ls	$23,250	$23,250	engineers estimate
mobilization/demobilization	5%		$415,776	$20,789	percentage of capital costs below
ISCR direct push injection	38	days	$4,650	$176,700	112 points, 5-20 feet bgs, 4 points/day
ISCR amendment	1	ls	$239,076	$239,076	scaled from vendor estimate
			Direct Installation Cost (Subtotal):	$483,000	
			Sales Tax (10.1% DI):	$49,000	
			Contingency (20% DI):	$106,000	
			Total Direct Installation Cost (DI):	***$638,000***	

Professional Services Costs	**Quantity**	**Units**	**Unit Cost**	**Extension**	**Description**
Project Management and Construction Oversight	20%	percent	$638,000	$127,600	Percentage of DI+Env Covenant costs
Remedial Design	30%	percent	$638,000	$191,400	Percentage of DI+Env Covenant costs. Pilot, phased implementation, EDR, contracting, Completion Report
Contingency	20%	percent	$319,000	$63,800	Percentage of DI+Env Covenant+PM+Remedial Design costs
			Total Professional Services Cost (PS):	***$382,800***	
			TOTAL ALTERNATIVE COST (Actual Dollars, 5 years):	***$1,020,000***	

Table 5-4. Cost Estimate: Downgradient S Fidalgo Area EAnB Treatment - Shoreline Contingency

Project No. 050067, West of 4th Site, Site Unit 1, Seattle, Washington

Remedial Action Description:	Downgradient S Fidalgo Area EAnB Treatment - Shoreline Contingency
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate	2.0%
Inflation since January 2021	1.15
Inflation since August 2016	1.55

Direct Installation Costs	Quantity	Units	Unit Cost	Extension	Description
Downgradient S Fidalgo Area EAB Treatment - Shoreline					
mobilization/demobilization	5%	percent	$315,100	$15,755	percentage of capital costs below
supplemental pilot study	1	LS	$92,000	$92,000	phased implementation to mitigate secondary effects
EAnB injection well installation (Cascade)	1	LS	$92,000	$92,000	Cascade cost for direct push
Passive venting well installation	10	EA	$2,300	$23,000	10 wells, 5-foot depth, constructed like SVE well
Monitoring well installation	4	EA	$2,875	$11,500	4 wells, 2-inch PVC, 30-foot depth
Performance monitoring	5	EA	$9,545	$47,725	16 wells. Diss gases, CVOCs, TOC, sulfate.
Additional subcontractor support	1	LS	$14,375	$14,375	Traffic control
EAnB amendments	1	LS	$26,450	$26,450	Peroxychem ELS+EHC
ZVI contingency	1	LS	$8,050	$8,050	additional material cost for ZVI amendment
			Direct Installation Cost (Subtotal):	$331,000	
			Sales Tax (10.1% DI):	$33,000	
			Contingency (20% DI):	$73,000	
			Total Direct Installation Cost (DI):	***$437,000***	

Professional Services Costs	Quantity	Units	Unit Cost	Extension	Description
Project Management and Construction Oversight	20%	percent	$437,000	$87,400	Percentage of DI+Env Covenant costs
Remedial Design	30%	percent	$437,000	$131,100	Percentage of DI+Env Covenant costs. Pilot, phased implementation, EDR, contracting, Completion Report
Contingency	20%	percent	$219,000	$43,800	Percentage of DI+Env Covenant+PM+Remedial Design costs
			Total Professional Services Cost (PS):	***$262,300***	
			TOTAL ALTERNATIVE COST (Actual Dollars, 5 years):	***$700,000***	

Table 6-1. Disproportionate Cost Analysis and Comparison to MTCA Criteria

Project No. 050067, West of 4th, Site Unit 1, Seattle, Washington

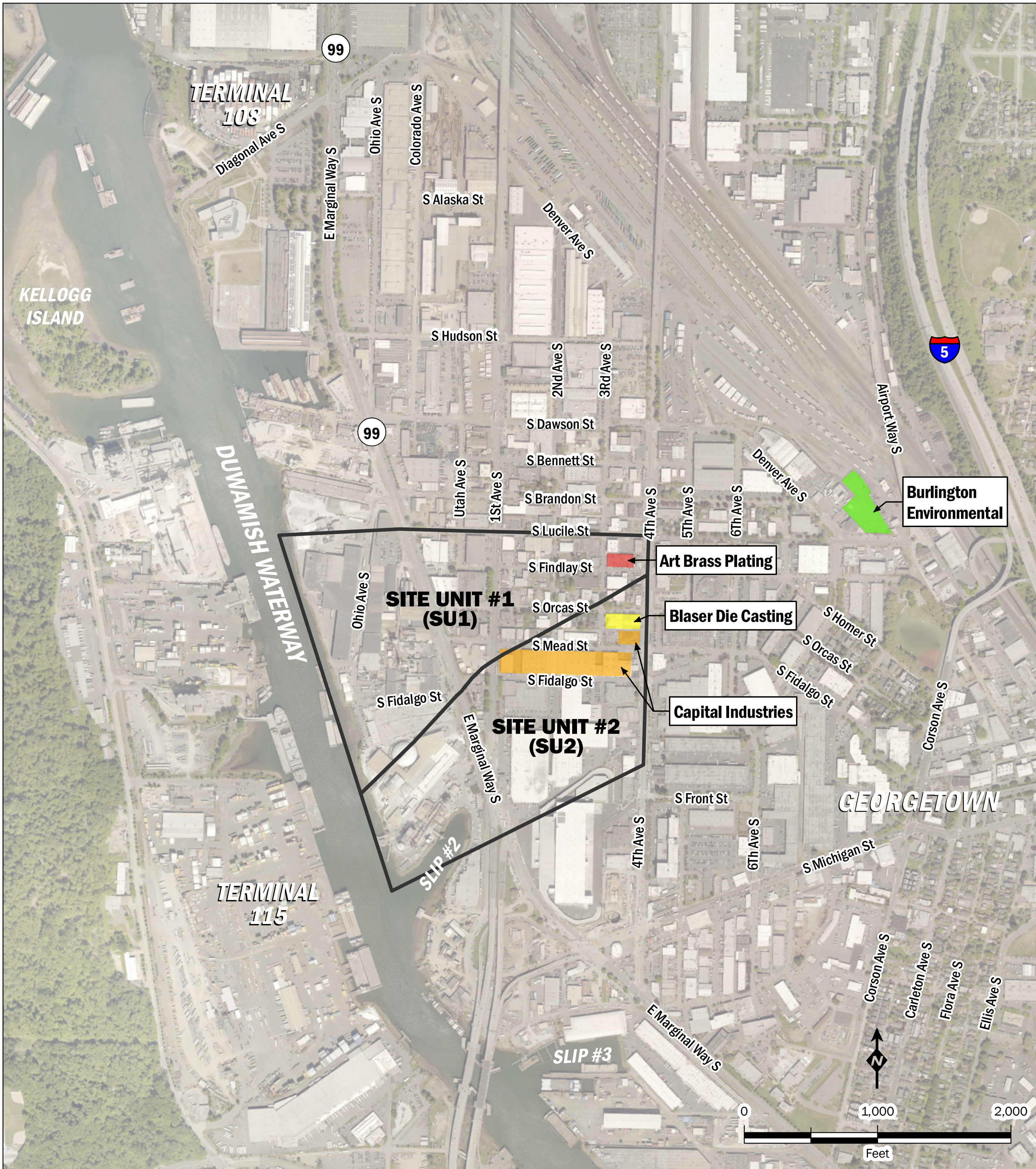
		Alternative 2A	Alternative 2B
		Source pH neutralization, Downgradient ISCR/EAnB @Fidalgo	**Source pH neutralization, Downgradient ISCR/EAnB @Fidalgo and Shoreline**
Threshold Criteria			
Protection of Human Health and the Environment		Yes	Yes
Compliance with Cleanup Standards		Yes	Yes
Compliance with Applicable State and Federal Laws		Yes	Yes
Provision for Compliance Monitoring		Yes	Yes
Weighted Benefits Ranking for Disproportionate Cost Analysis (Score 1-10)			
Weighting Criteria			
30%	Overall Protectiveness	6	7
20%	Permanence	5	5
20%	Long Term Effectiveness	6	6
10%	Management of Short Term Risk	8	7
10%	Implementability	7	6
10%	Consideration of Public Concerns	5	6
MTCA Overall Benefit Score (1-10)		**6**	**6.2**
Disproportionate Cost Analysis			
Estimated Remedy Cost		$3,950,000	$4,570,000
Estimated Initial Capital Cost		$944,000	$1,631,950
Estimated O&M Cost		$3,006,000	$2,938,050
Relative Benefit to Cost Ratio (multiplied by 1,000,000)		1.5	1.4
Estimated contingency cost		$1,900,000	$1,130,000
Evaluation of Restoration Time Frame			
Time to Achieve RAOs		280 Years	280 Years
Estimated Time to Achieve VI CULs		25 Years	20 Years
Estimated Time to Achieve cVOC SW CULs at Waterway		50 Years	35 Years
Estimated Time to Achieve cVOC SW CULs		50 Years	50 Years
Estimated Time to Achieve metals SW CULs		280 Years	280 Years
Provides for a Reasonable Restoration Time Frame		Yes	Yes

Notes:

Remedial Alternative cost details in Tables 5-1 and 5-2. Contingency cost details in Tables 5-3 and 5-4.

Restoration Time Frame based on time to achieve surface water cleanup levels across the Site.

FIGURES



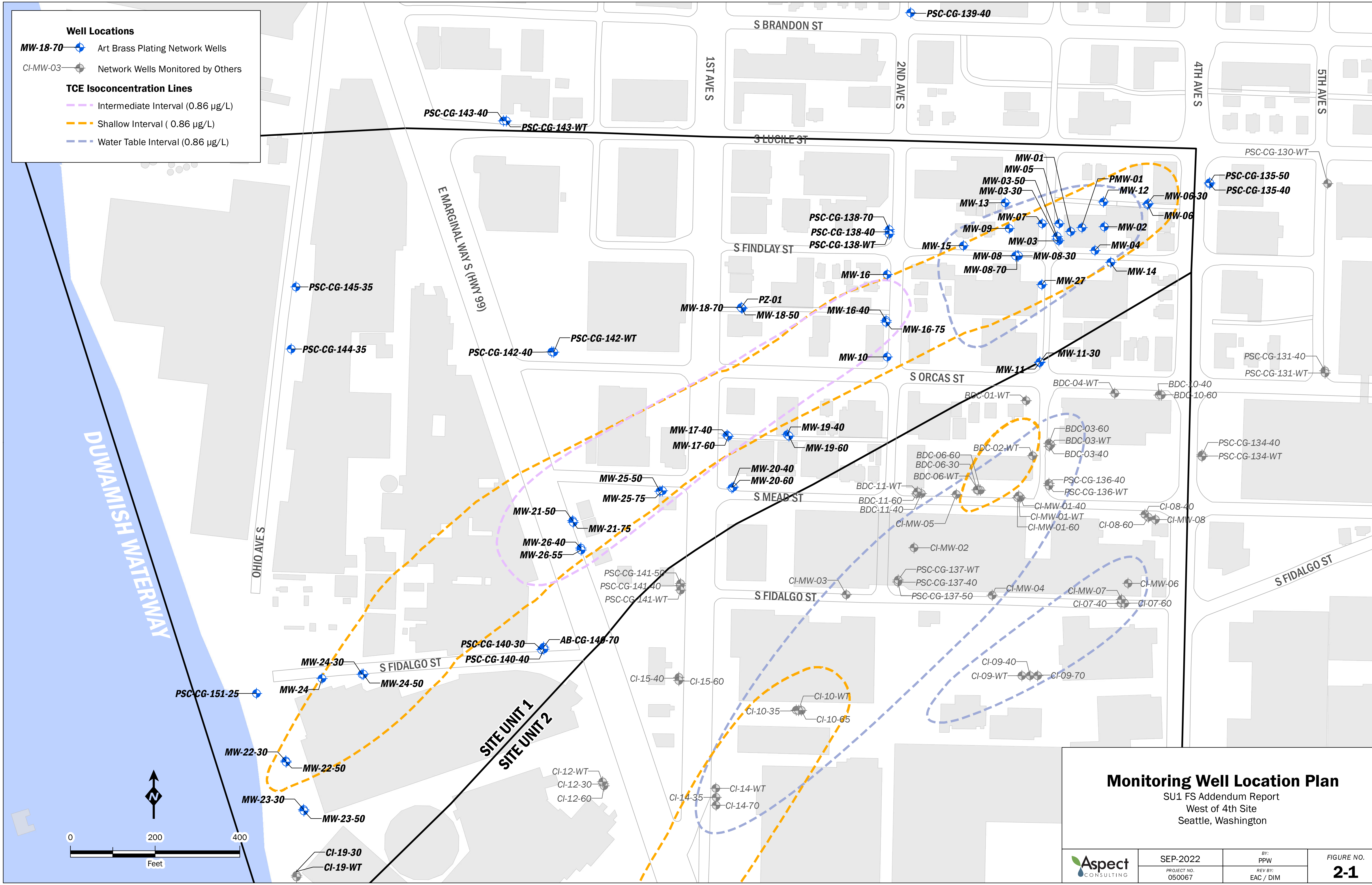
Site Diagram

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW	FIGURE:
PROJECT NO. 050067	REVISED BY: EAC	1-1

GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\1-1 Site Diagram.mxd || Coordinate System: NAD83 HARN Washington North || Date Saved: 9/8/2022 || User: rkochie || Print Date: 9/8/2022



Well Locations
MW-18-70 Art Brass Plating Network Wells
CI-MW-03 Network Wells Monitored by Others
TCE Isoconcentration Lines
Intermediate Interval (0.86 µg/L)
Shallow Interval (0.86 µg/L)
Water Table Interval (0.86 µg/L)
S BRANDON ST
S LUCILE ST
S FINDLAY ST
S ORCAS ST
S MEAD ST
S FIDALGO ST
1ST AVE S
2ND AVE S
4TH AVE S
5TH AVE S
E MARGINAL WAY S (HWY 99)
OHIO AVE S
DUWAMISH WATERWAY
SITE UNIT 1
SITE UNIT 2
PSC-CG-139-40
PSC-CG-143-40
PSC-CG-143-WT
PSC-CG-130-WT
PSC-CG-135-50
PSC-CG-135-40
MW-01
MW-05
MW-03-50
MW-03-30
MW-13
PMW-01
MW-12
MW-06-30
MW-06
MW-07
MW-09
MW-02
MW-03
MW-04
MW-15
MW-08
MW-08-30
MW-08-70
MW-14
MW-27
PSC-CG-138-70
PSC-CG-138-40
PSC-CG-138-WT
MW-16
PZ-01
MW-18-70
MW-18-50
MW-16-40
MW-16-75
MW-10
MW-11-30
MW-11
PSC-CG-145-35
PSC-CG-144-35
PSC-CG-142-WT
PSC-CG-142-40
PSC-CG-131-40
PSC-CG-131-WT
BDC-04-WT
BDC-10-40
BDC-10-60
BDC-01-WT
BDC-03-60
BDC-03-WT
BDC-03-40
BDC-02-WT
BDC-06-60
BDC-06-30
BDC-06-WT
BDC-11-WT
BDC-11-60
BDC-11-40
PSC-CG-134-40
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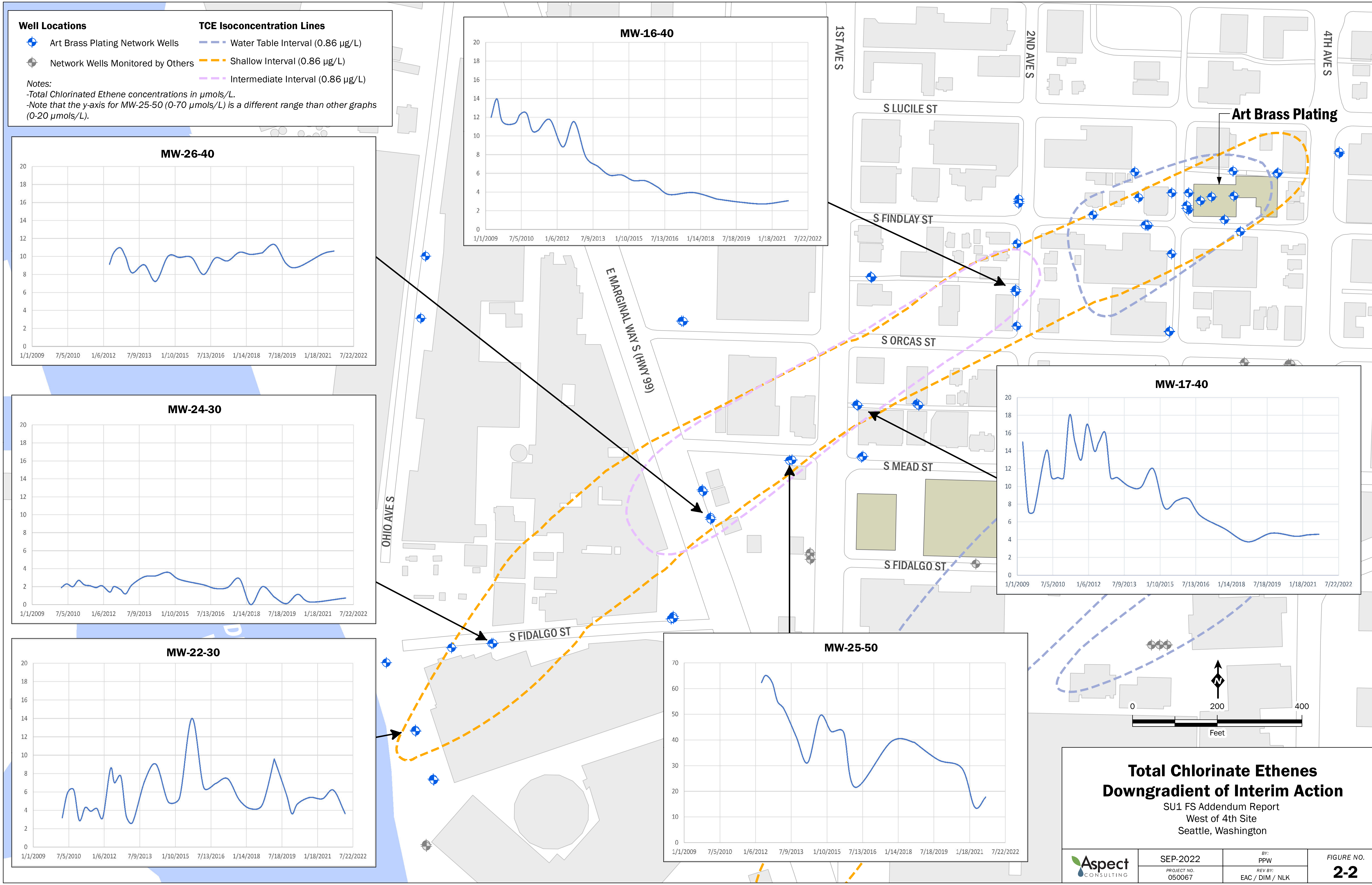
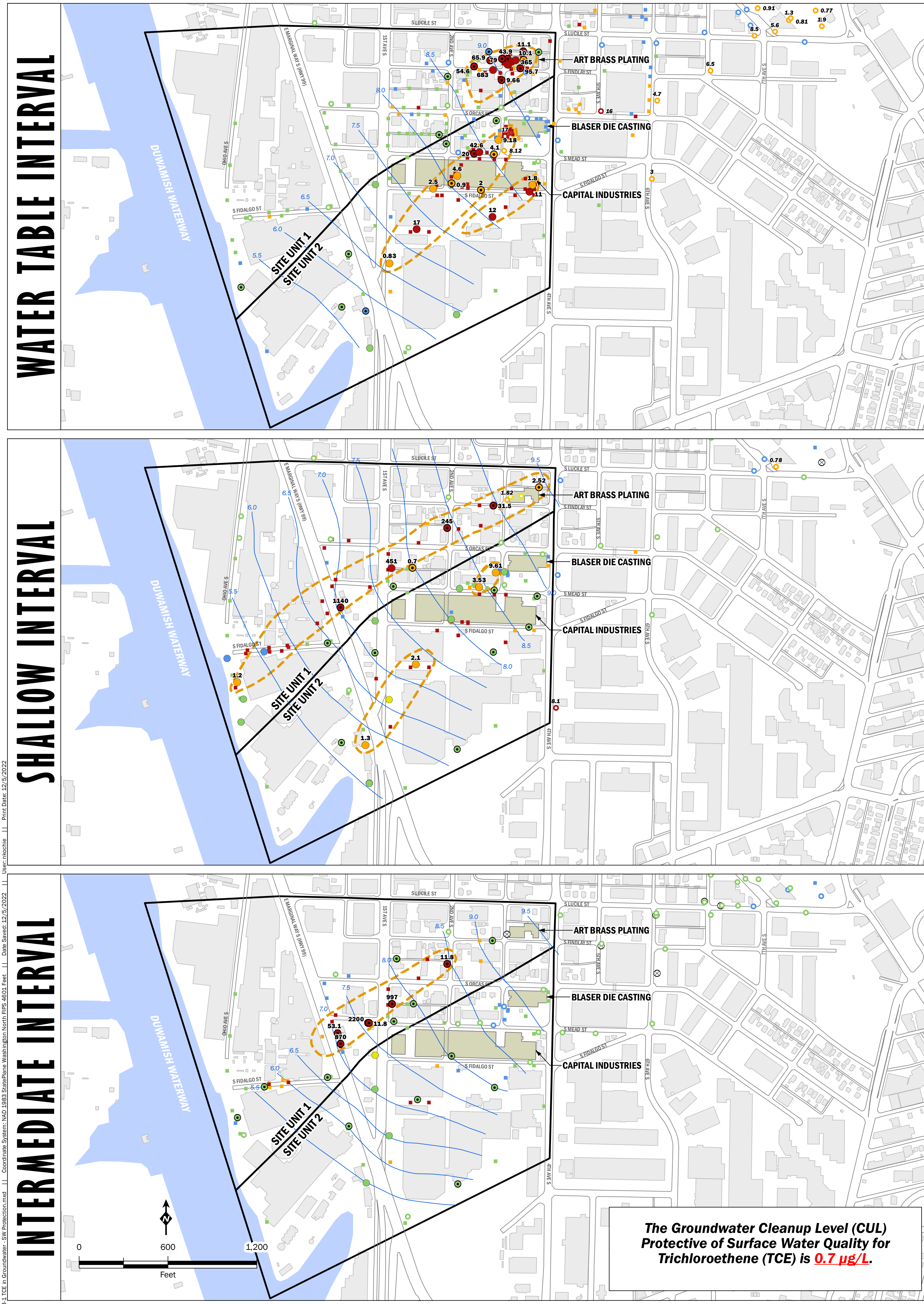
CI-MW-08
CI-08-60
CI-MW-05
CI-MW-02
MW-17-40
MW-17-60
MW-19-40
MW-19-60
MW-20-40
MW-20-60
MW-25-50
MW-25-75
MW-21-50
MW-21-75
MW-26-40
MW-26-55
PSC-CG-141-50
PSC-CG-141-40
PSC-CG-141-WT
CI-MW-03
PSC-CG-137-WT
PSC-CG-137-40
PSC-CG-137-50
CI-MW-04
CI-MW-07
CI-MW-06
CI-07-40
CI-07-60
PSC-CG-140-30
AB-CG-140-70
PSC-CG-140-40
MW-24-30
MW-24-50
MW-24
PSC-CG-151-25
CI-15-40
CI-15-60
CI-09-40
CI-09-WT
CI-09-70
CI-10-WT
CI-10-35
CI-10-65
MW-22-30
MW-22-50
CI-12-WT
CI-12-30
CI-12-60
CI-14-WT
CI-14-35
CI-14-70
MW-23-30
MW-23-50
CI-19-30
CI-19-WT
N
0
200
400
Feet
Monitoring Well Location Plan
SU1 FS Addendum Report
West of 4th Site
Seattle, Washington
Aspect CONSULTING
SEP-2022
PROJECT NO.
050067
BY:
PPW
REV BY:
EAC / DIM
FIGURE NO.
2-1



Total Chlorinate Ethenes Downgradient of Interim Action

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING | SEP-2022 | PROJECT NO. 050067 | BY: PPW | REV BY: EAC / DIM / NLK | FIGURE NO. 2-2



TCE in Groundwater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

DEC-2022	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK	3-1

Aspect CONSULTING

Groundwater Sample Locations:

- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  - * Note: Probe data are from 2000 to 2012
- Well without data for analyte/interval

Sample Location Symbol Color:

- Detected at > 10x CUL
- Detected Above CUL
- Detected Below CUL
- Not Detected (Reporting Limit Above CUL)
- Not Detected

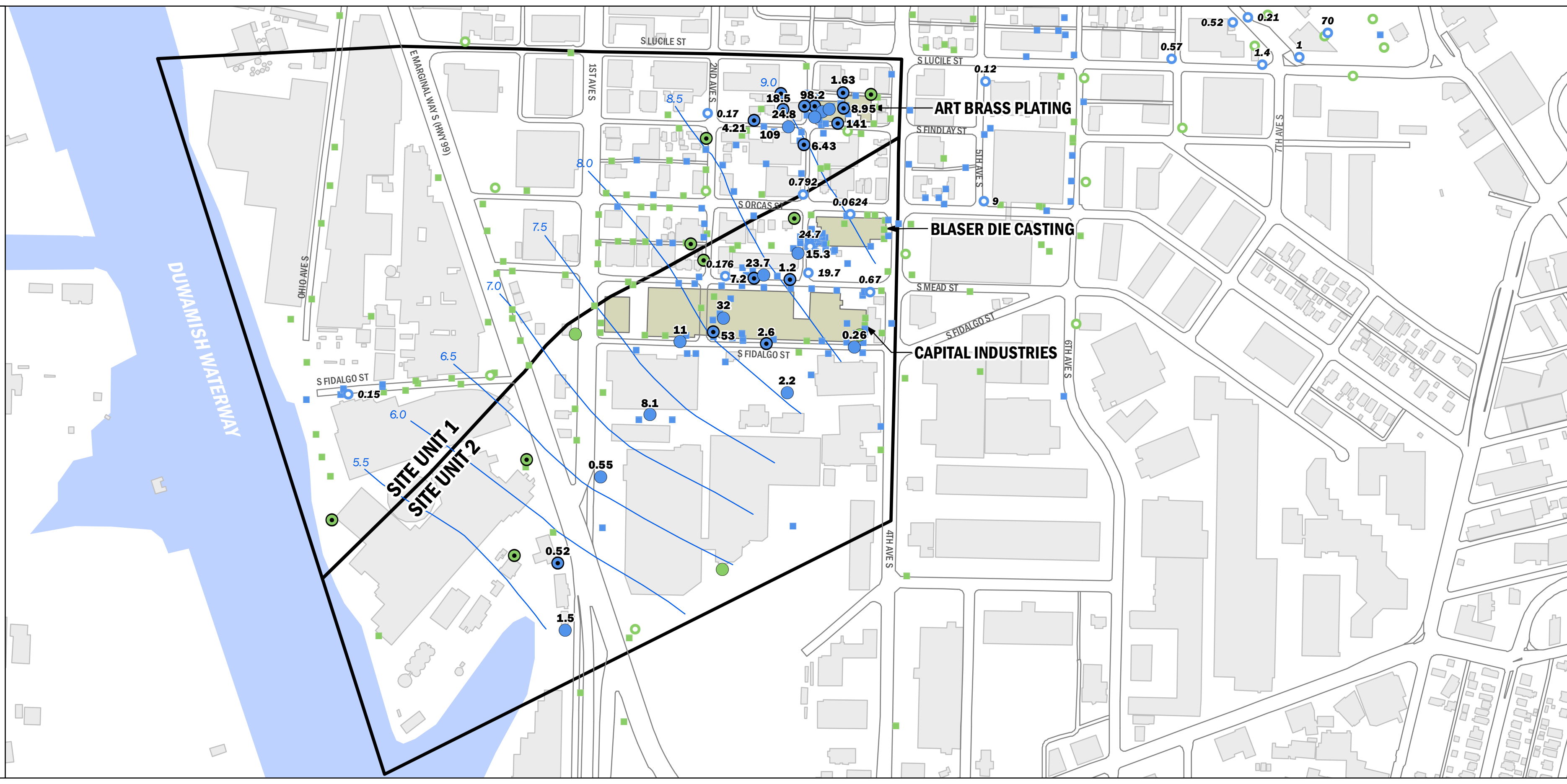
Well locations with CUL exceedances are labeled with the exceeding concentration: 55 Trichloroethene (TCE) Concentration (in µg/L)

8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

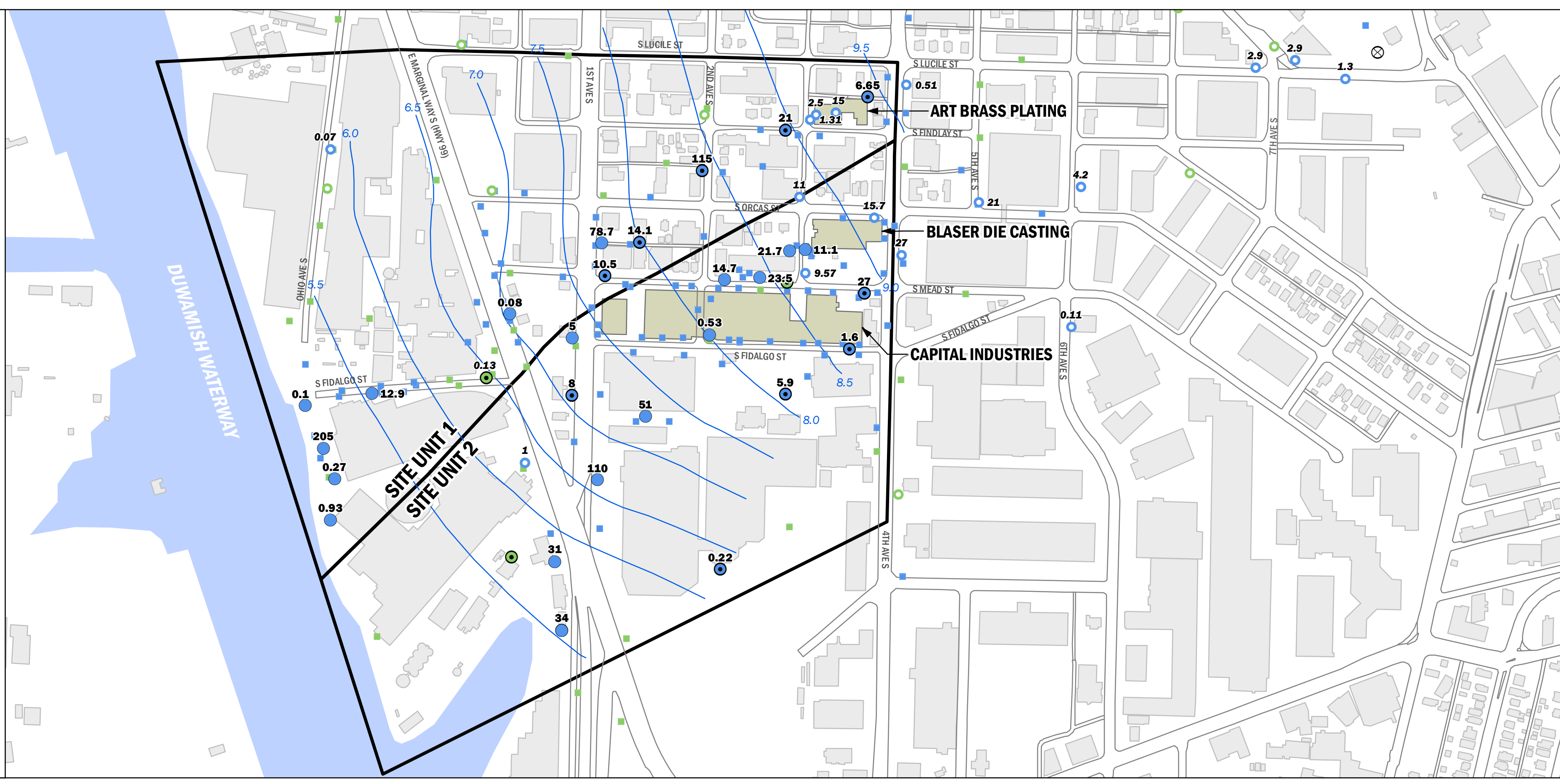
TCE Isoconcentration Line at 0.86 µg/L Cleanup Level

GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\3-1 TCE in Groundwater - SW Protection.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 12/5/2022 || User: nkochie || Print Date: 12/5/2022

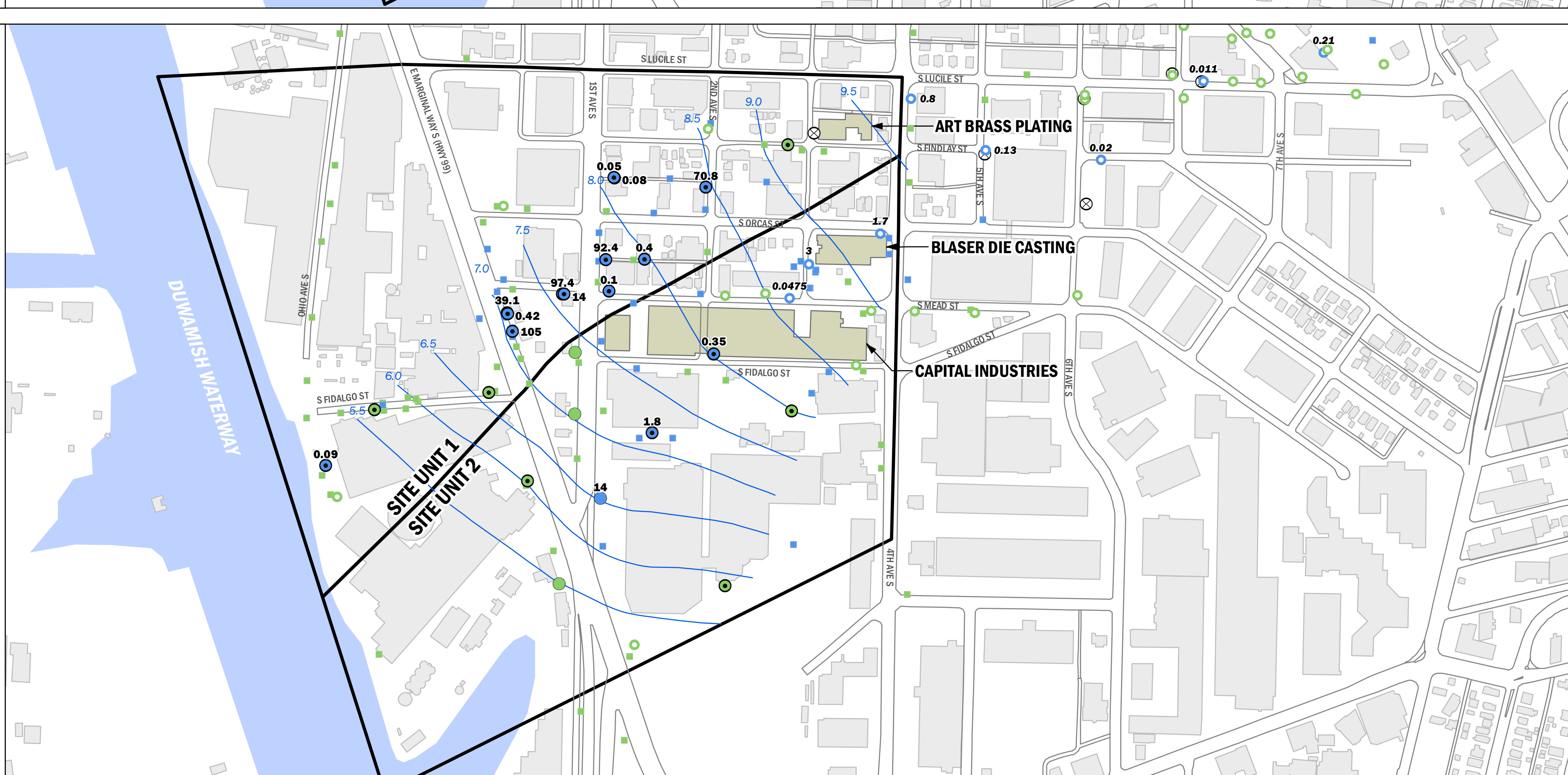
WATER TABLE INTERVAL



SHALLOW INTERVAL



INTERMEDIATE INTERVAL



GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\3-2 DCE in Groundwater - SW Protection.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/8/2022 || User: nkochie || Print Date: 9/14/2022

cis-DCE in Groundwater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK	3-2

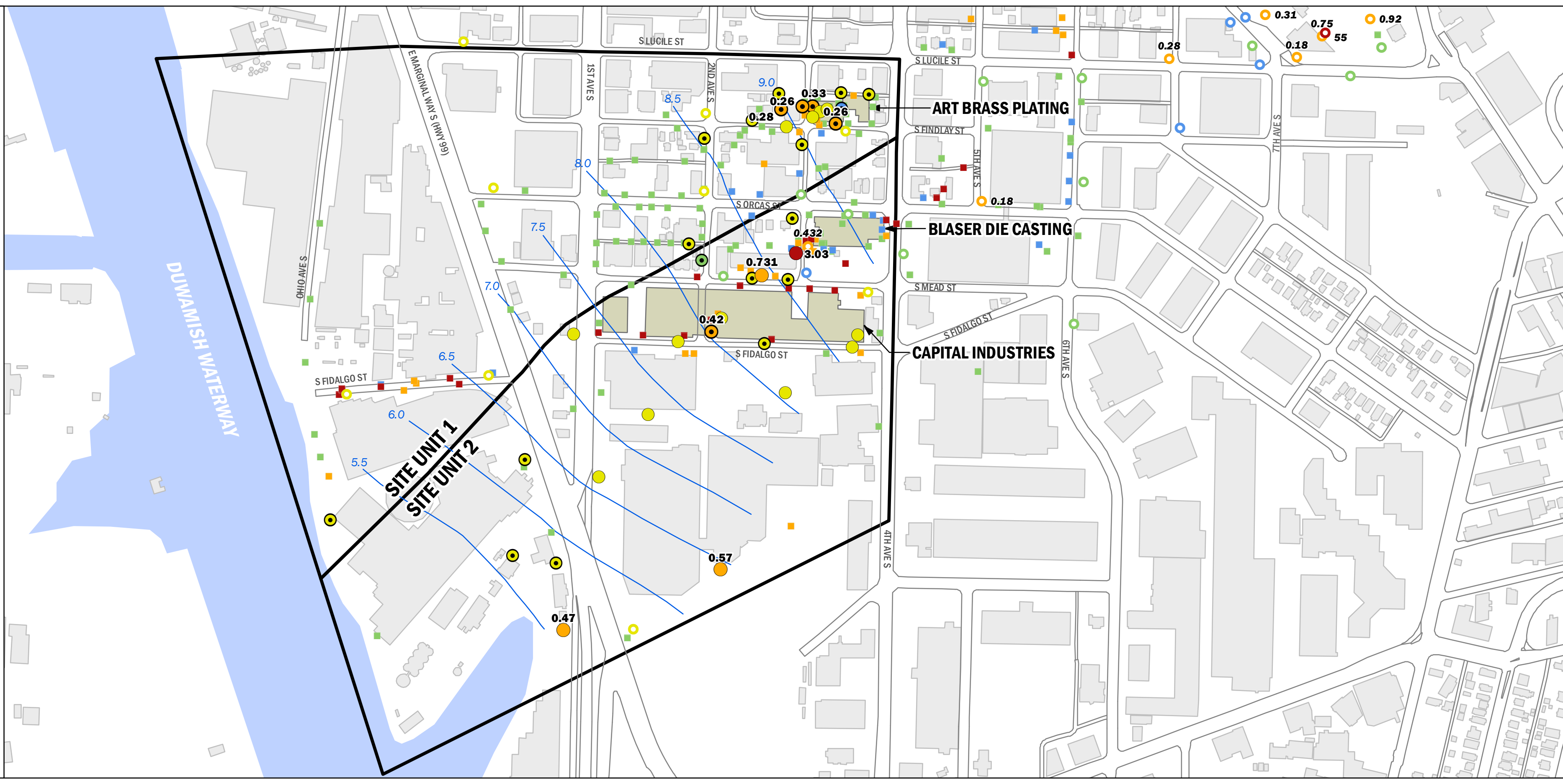
Groundwater Sample Locations:
- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  ** Note: Probe data are from 2000 to 2012*
- Well without data for analyte/interval

Sample Location Symbol Color:
- Detected
- Not Detected

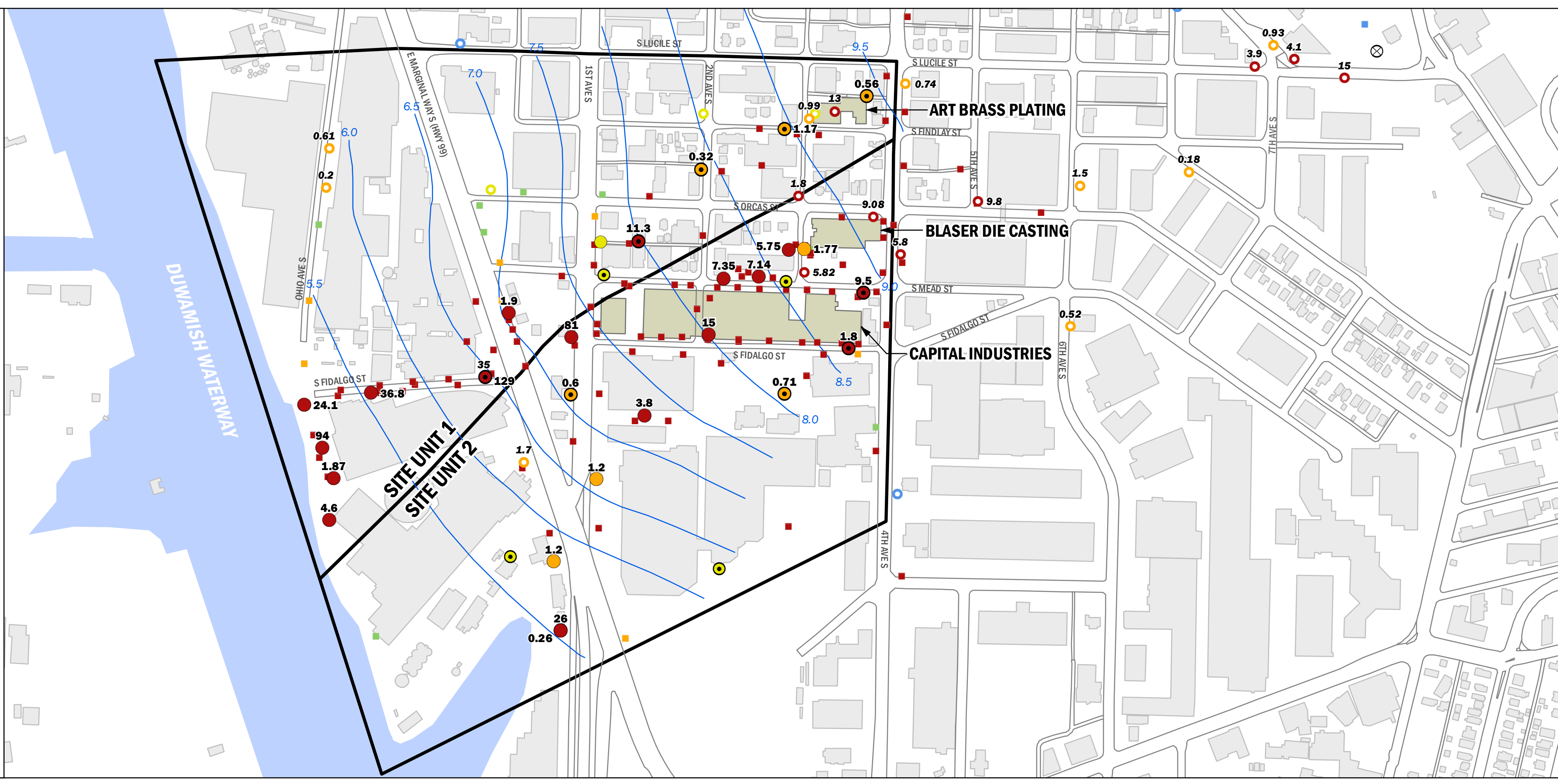
8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

0 600 1,200
Feet

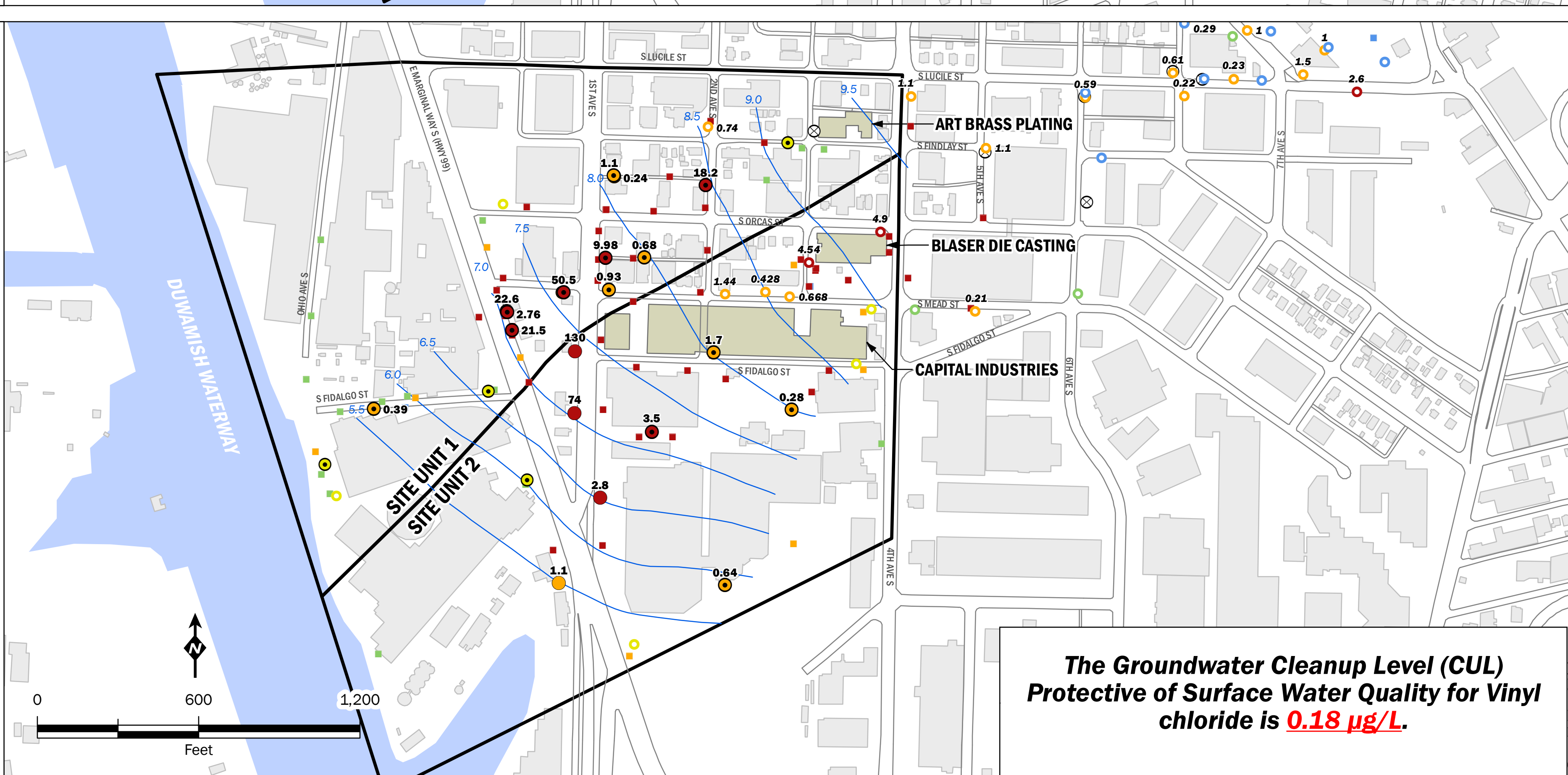
WATER TABLE INTERVAL



SHALLOW INTERVAL



INTERMEDIATE INTERVAL



The Groundwater Cleanup Level (CUL) Protective of Surface Water Quality for Vinyl chloride is 0.18 µg/L.

GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\3-3 VC in Groundwater - SW Protection.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/8/2022 || User: nkochie || Print Date: 9/14/2022

VC in Groundwater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW	FIGURE NO.	3-3
PROJECT NO. 050067	REV BY: TDR / NLK		

Groundwater Sample Locations:

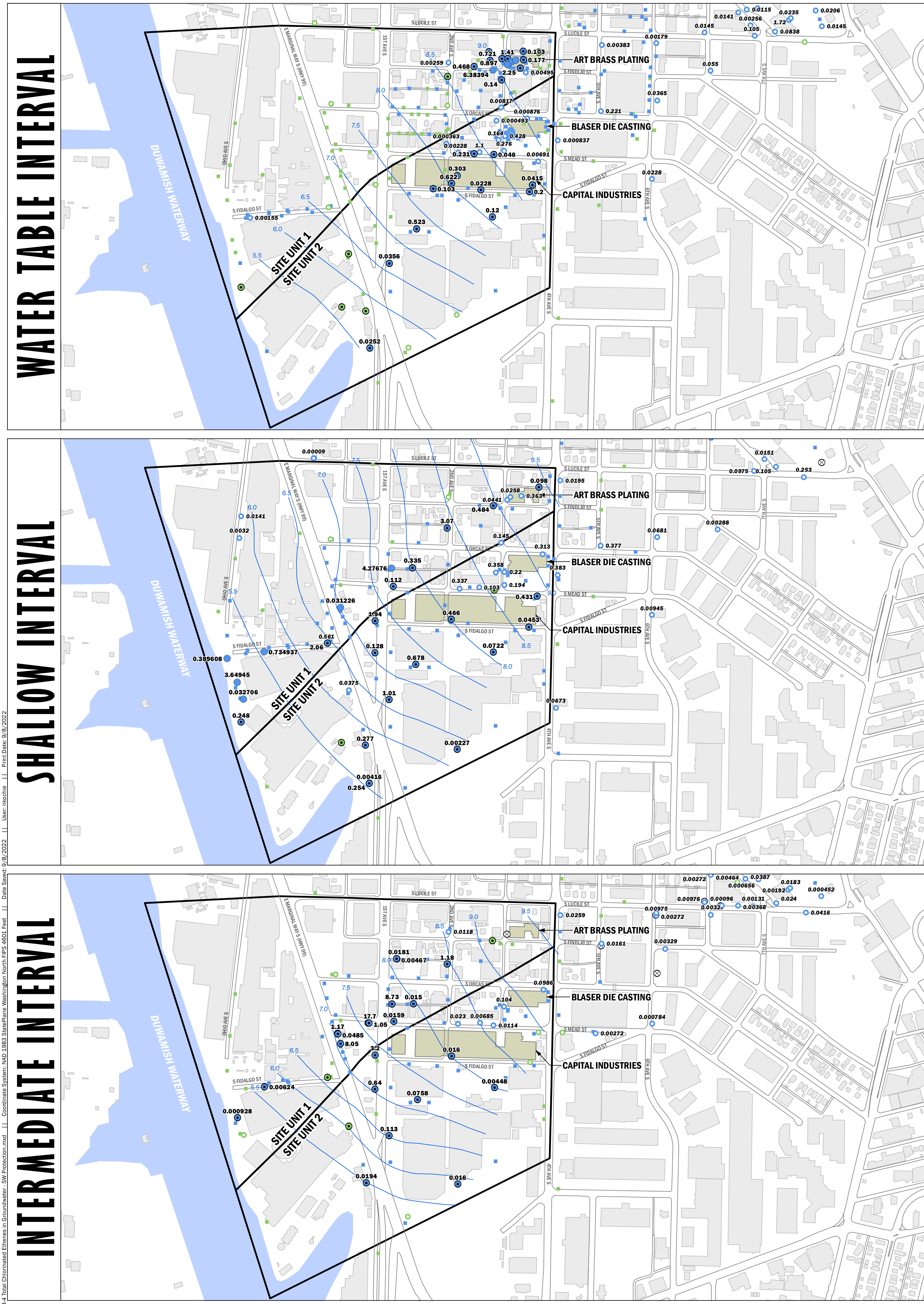
- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  - * Note: Probe data are from 2000 to 2012
- Well without data for analyte/interval

Sample Location Symbol Color:

- Detected at > 10x CUL
- Detected Above CUL
- Detected Below CUL
- Not Detected (Reporting Limit Above CUL)
- Not Detected

Well locations with CUL exceedances are labeled with the exceeding concentration: 55 *Vinyl chloride Concentration (in µg/L)*

8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)



Total Chlorinated Ethenes in Groundwater

Surface Water Protection

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

SEP-2022	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK	3-4

Aspect CONSULTING

Groundwater Sample Locations:

- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  - ** Note: Probe data are from 2000 to 2012*
- Well without data for analyte/interval

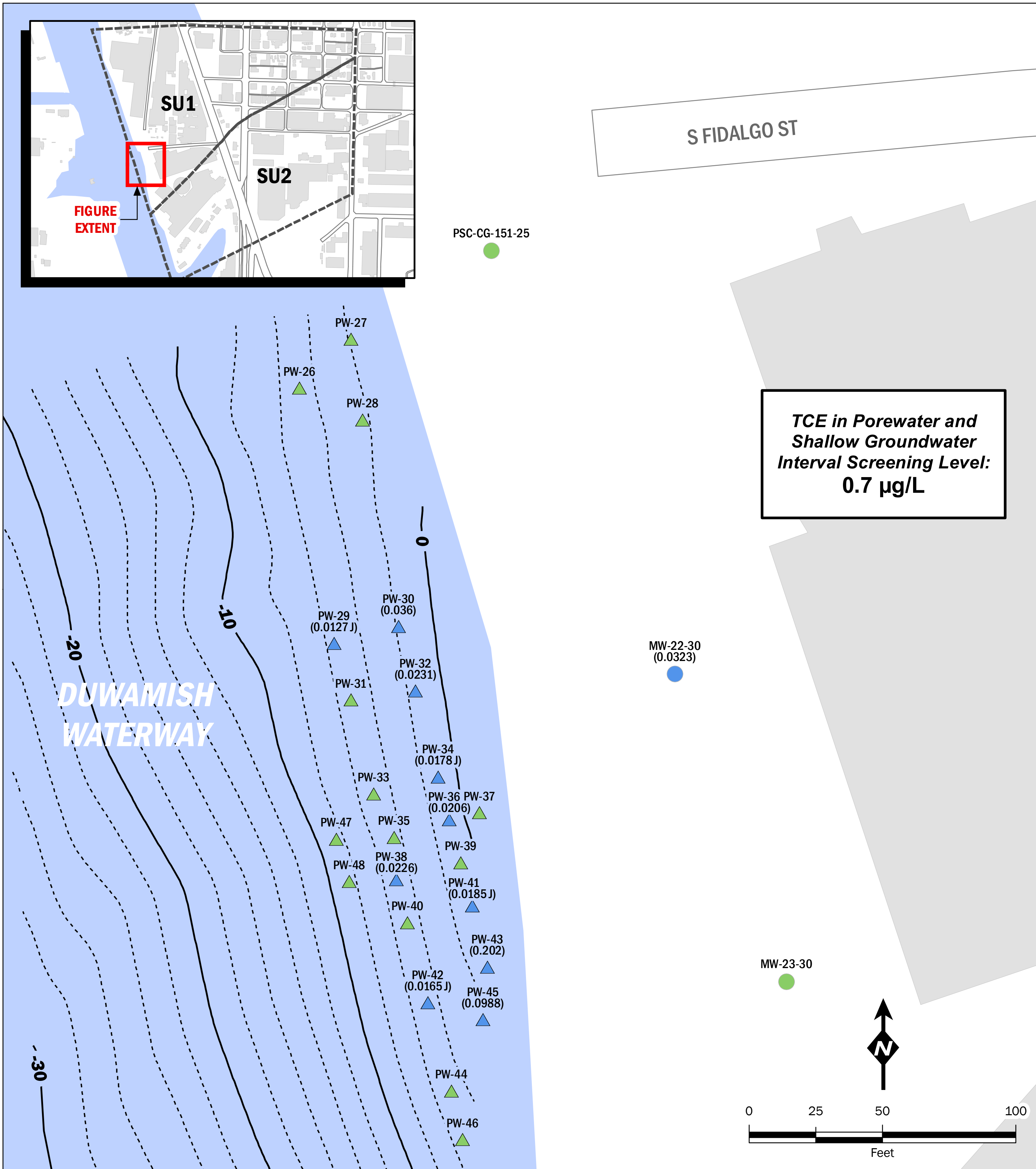
Sample Location Symbol Color:

- Detected
- Not Detected

8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

0 600 1,200
Feet

N



Sample Locations:

- Porewater Sample Locations*
- Well (Groundwater Samples)*

Sample Location Symbol Color:

- Detected at > 10x CUL
- Detected Above Screening Level
- Detected, No Exceedance
- Not Detected, No Exceedance

Feb, 2011 Bathymetric Elevation Contours, 2-ft. intervals (NAVD88)

*Porewater data from August 2020.
Well data from August 2020.*

Notes:

-Porewater data from August 3, 2020. Well data from August 4, 2020.

-Groundwater well data illustrated in this figure was collected using the same method as porewater data (passive diffusive bag samplers).

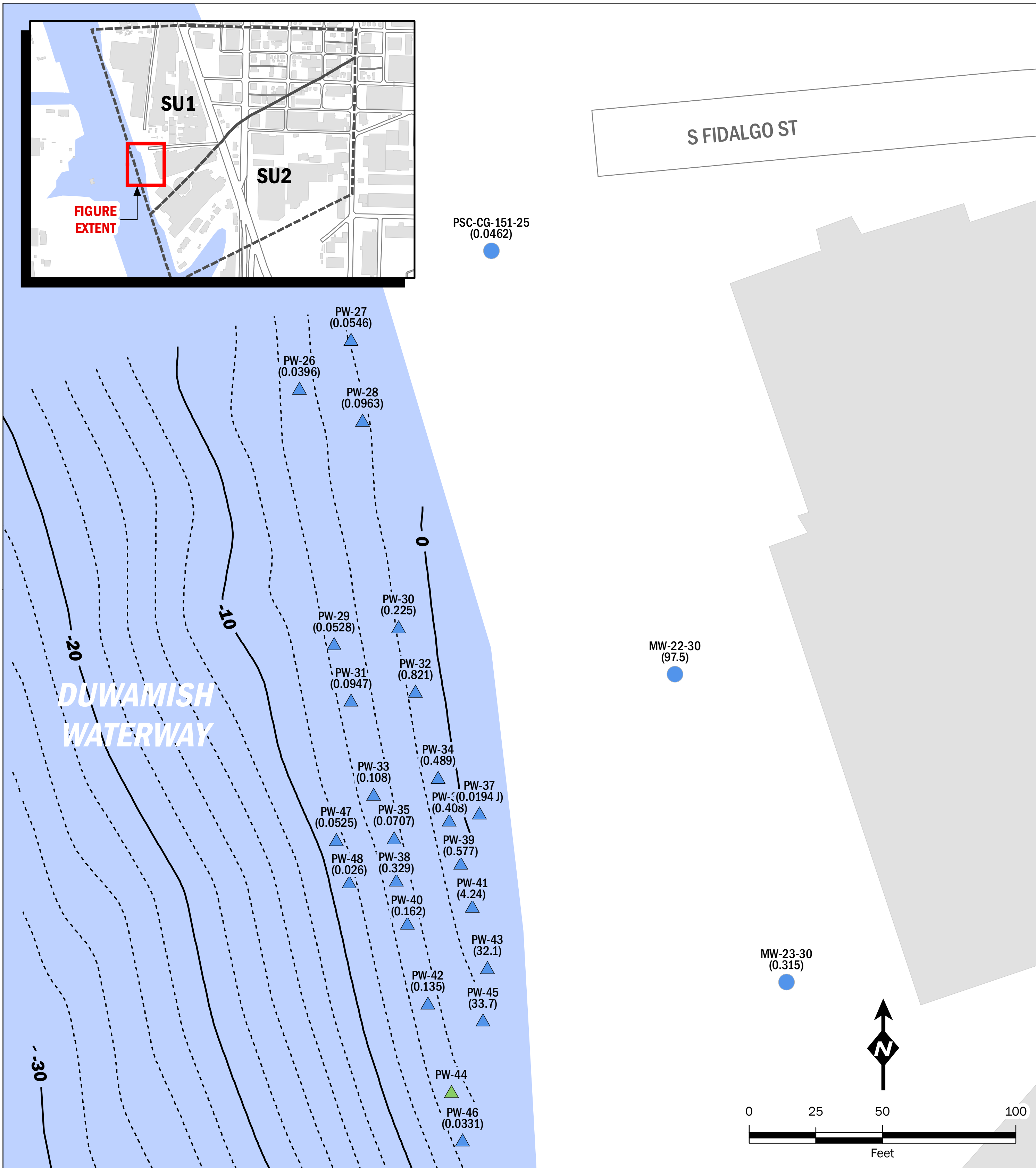
TCE in Porewater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK	3-5

GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS 3-5 TCE in Porewater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/8/2022 || User: nkochie || Print Date: 9/8/2022



GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS 3-6 DCE in Porewater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/8/2022 || User: nkochie || Print Date: 9/8/2022

Sample Locations:
- ▲ Porewater Sample Locations*
- ● Well (Groundwater Samples)*

Sample Location Symbol Color:
- Detected
- Not Detected

Feb, 2011 Bathymetric Elevation Contours, 2-ft. intervals (NAVD88)

**Porewater data from August 2020. Well data from August 2020.*

Notes:

-Porewater data from August 3, 2020. Well data from August 4, 2020.

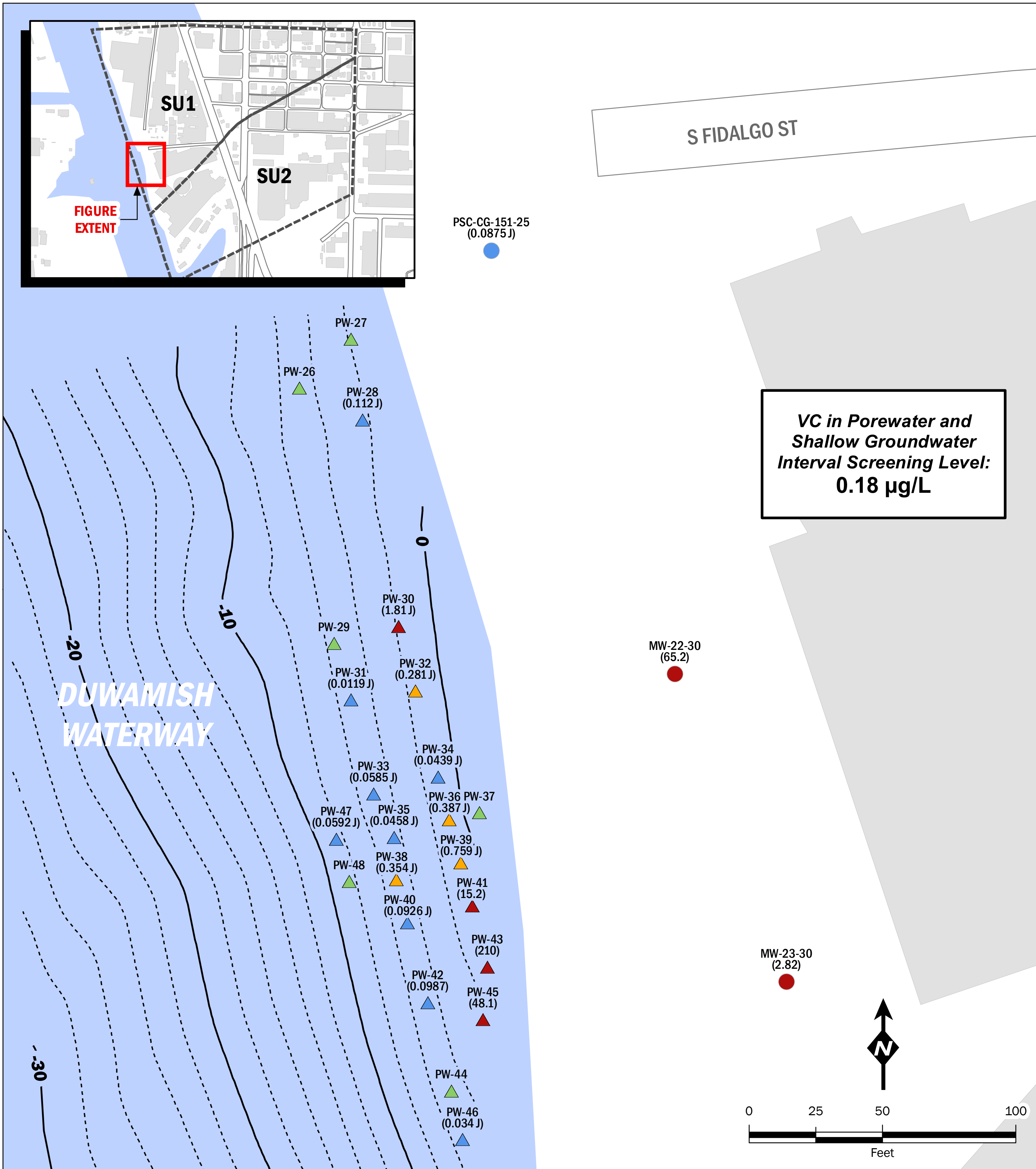
-Groundwater well data illustrated in this figure was collected using the same method as porewater data (passive diffusive bag samplers).

cis-DCE in Porewater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK	3-6



GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\3-7 VC in Porewater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/8/2022 || User: nkochie || Print Date: 9/8/2022

Sample Locations:

- ▲ Porewater Sample Locations*
- ● Well (Groundwater Samples)*

Sample Location Symbol Color:

- Detected at > 10x CUL
- Detected Above Screening Level
- Detected, No Exceedance
- Not Detected, No Exceedance

Feb, 2011 Bathymetric Elevation Contours, 2-ft. intervals (NAVD88)

Notes:

Porewater data from August 2020. Well data from August 2020.

-Porewater data from August 3, 2020. Well data from August 4, 2020.

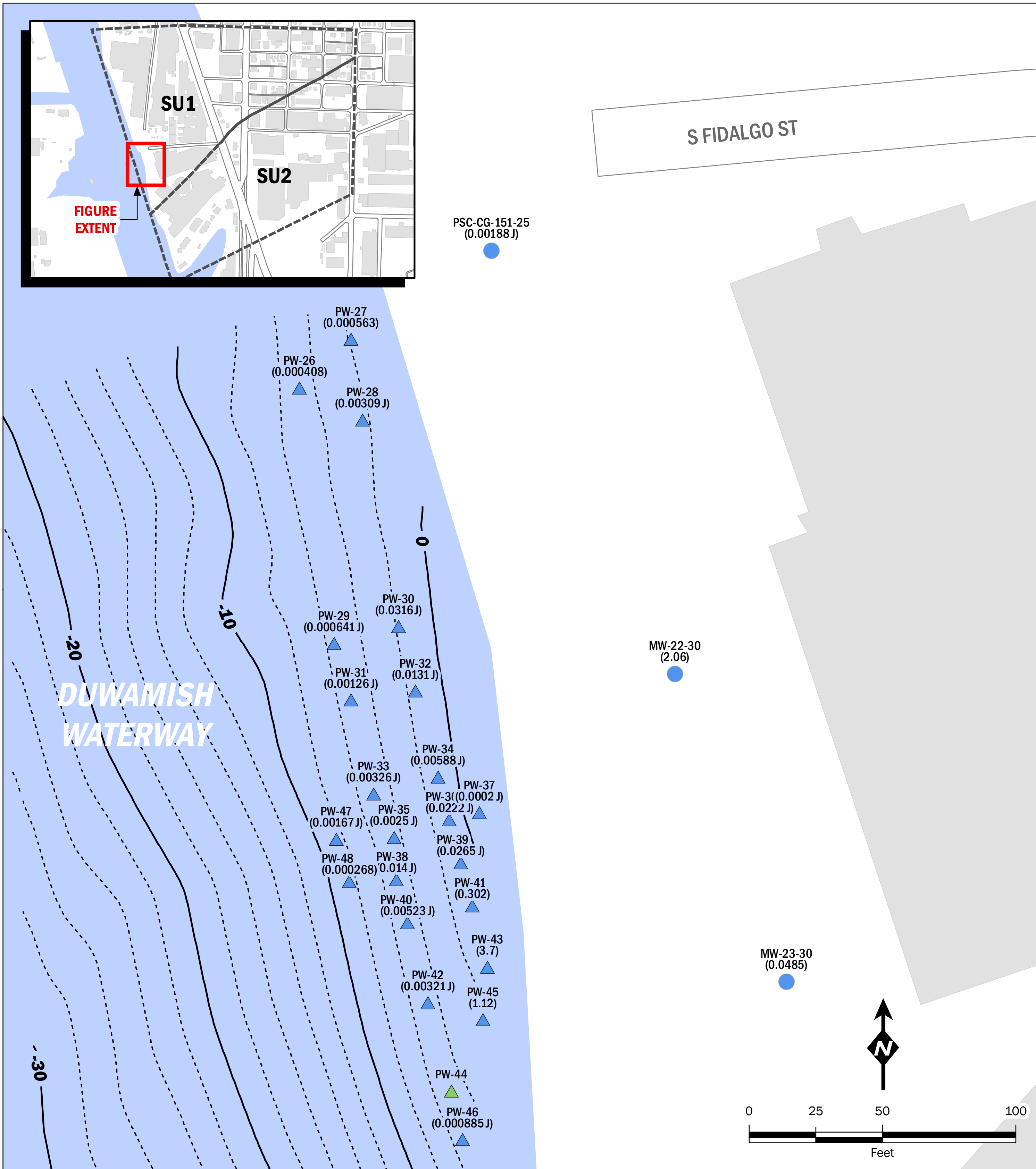
-Groundwater well data illustrated in this figure was collected using the same method as porewater data (passive diffusive bag samplers).

VC in Porewater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK	3-7



GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\3-8 Total Chlorinated Ethenes in Porewater.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/8/2022 || User: nkochie || Print Date: 9/8/2022

Sample Locations:

- Porewater Sample Locations*
- Well (Groundwater Samples)*

Sample Location Symbol Color:

- Detected
- Not Detected

Feb, 2011 Bathymetric Elevation Contours, 2-ft. intervals (NAVD88)

**Porewater data from August 2020. Well data from August 2020.*

Notes:

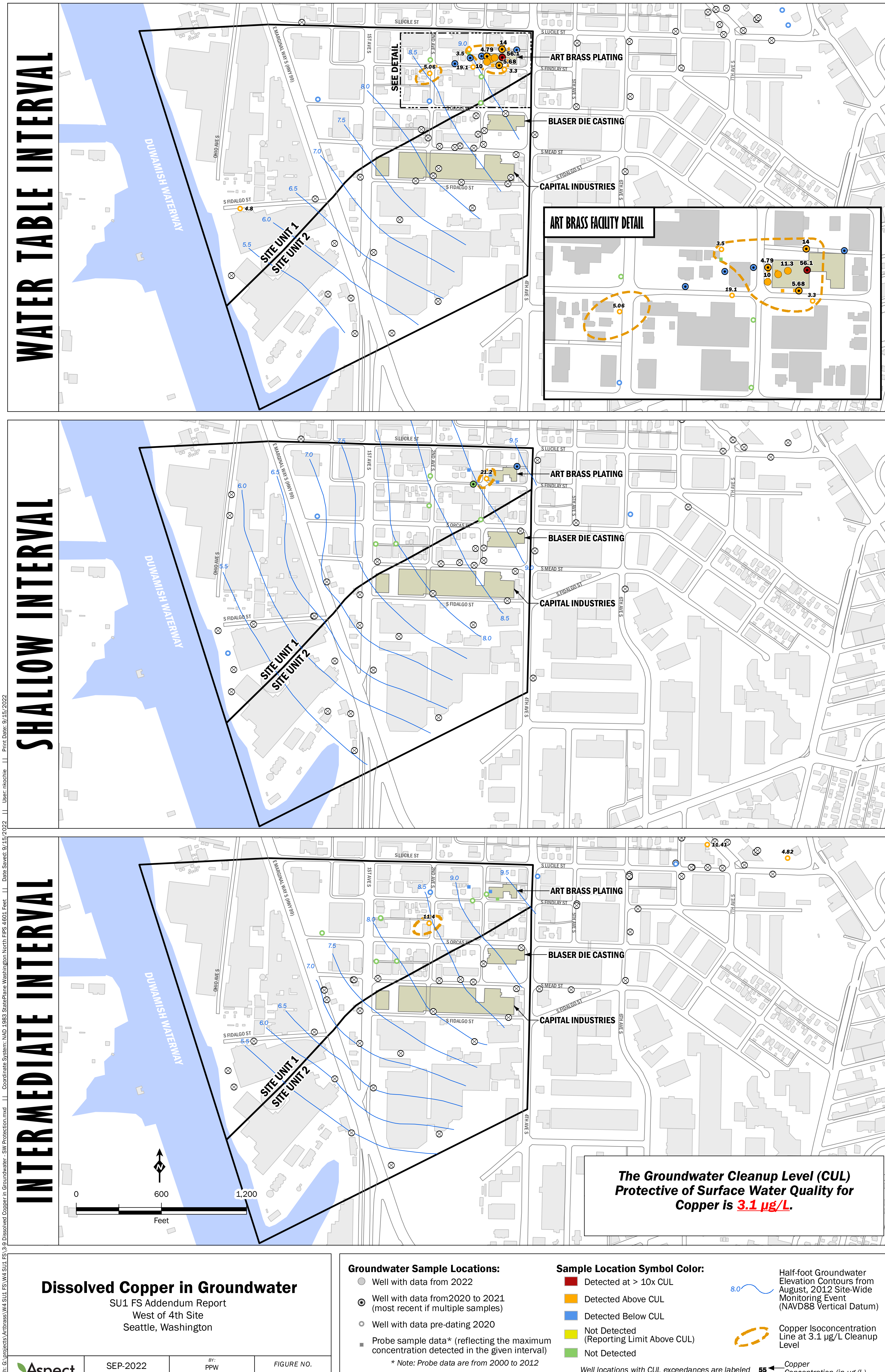
-Porewater data from August 3, 2020. Well data from August 4, 2020.

-Groundwater well data illustrated in this figure was collected using the same method as porewater data (passive diffusive bag samplers).

Total Chlorinated Ethenes in Porewater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING	SEP-2022	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REV BY: TDR / NLK	3-8



Dissolved Copper in Groundwater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK	3-9

Groundwater Sample Locations:

- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  - ** Note: Probe data are from 2000 to 2012*
- Well without data for analyte/interval

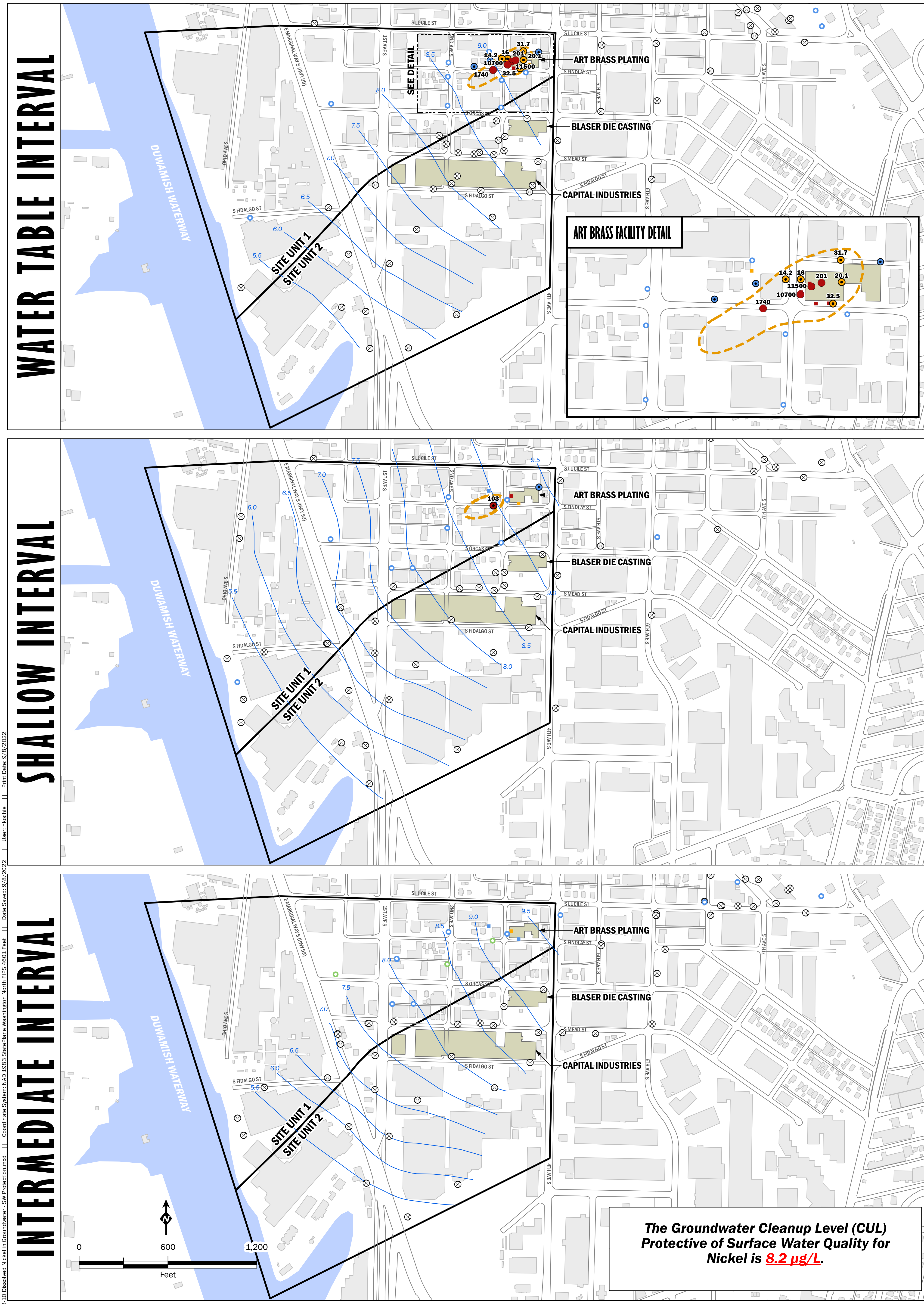
Sample Location Symbol Color:

- Detected at > 10x CUL
- Detected Above CUL
- Detected Below CUL
- Not Detected (Reporting Limit Above CUL)
- Not Detected

Well locations with CUL exceedances are labeled with the exceeding concentration: 55 Copper Concentration (in µg/L)

8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

Copper Isoconcentration Line at 3.1 µg/L Cleanup Level



Dissolved Nickel in Groundwater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING	SEP-2022	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REV BY: TDR / NLK	3-10

Groundwater Sample Locations:

- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  - ** Note: Probe data are from 2000 to 2012*
- Well without data for analyte/interval

Sample Location Symbol Color:

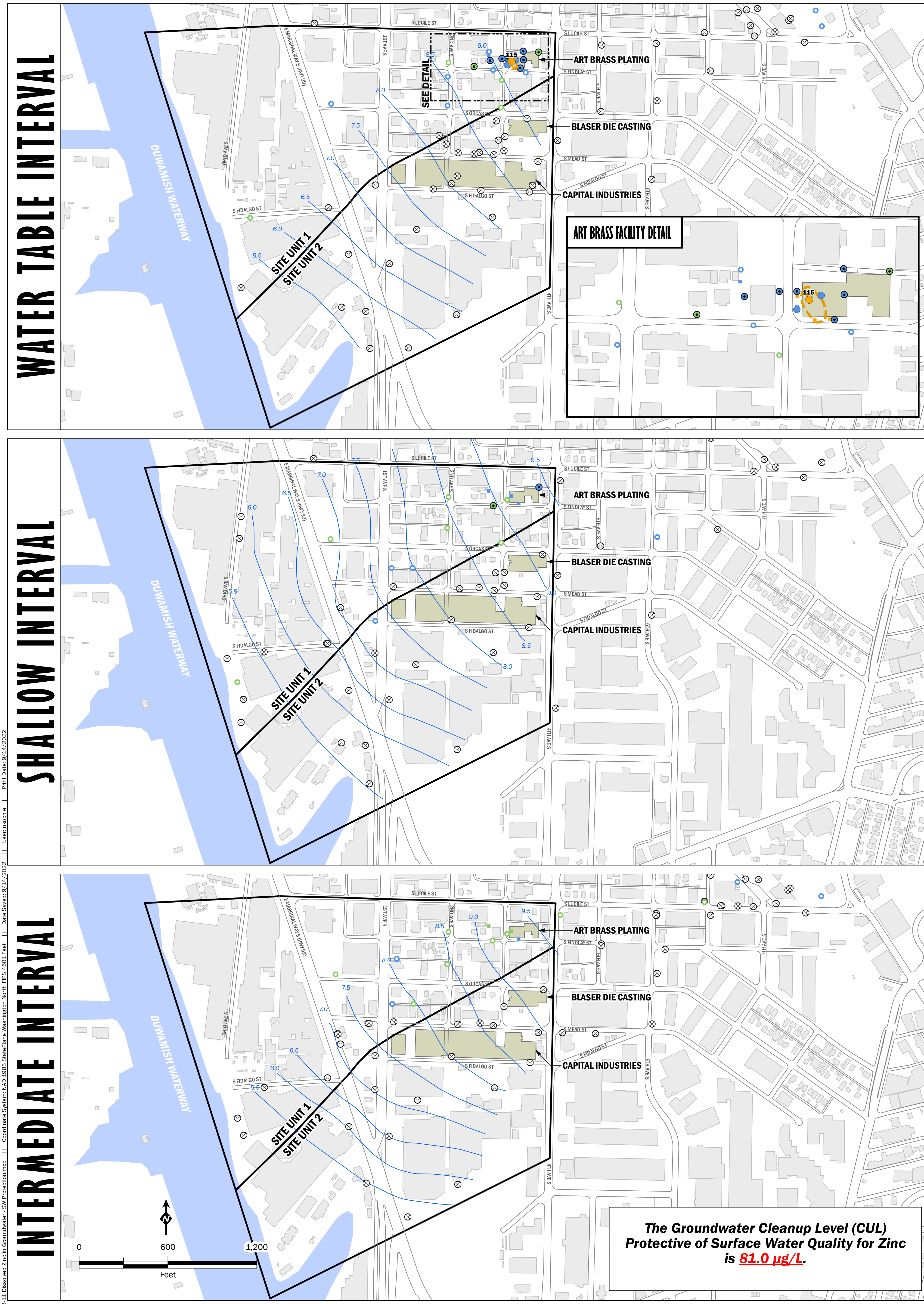
- Detected at > 10x CUL
- Detected Above CUL
- Detected Below CUL
- Not Detected (Reporting Limit Above CUL)
- Not Detected

Well locations with CUL exceedances are labeled with the exceeding concentration: 55 — *Nickel Concentration (in µg/L)*

8.0 — Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level

GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\3-10 Dissolved Nickel in Groundwater - SW Protection.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/8/2022 || User: nkochie || Print Date: 9/8/2022



Dissolved Zinc in Groundwater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING	SEP-2022	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REV BY: TDR / NLK	3-11

Groundwater Sample Locations:

- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  - * Note: Probe data are from 2000 to 2012
- Well without data for analyte/interval

Sample Location Symbol Color:

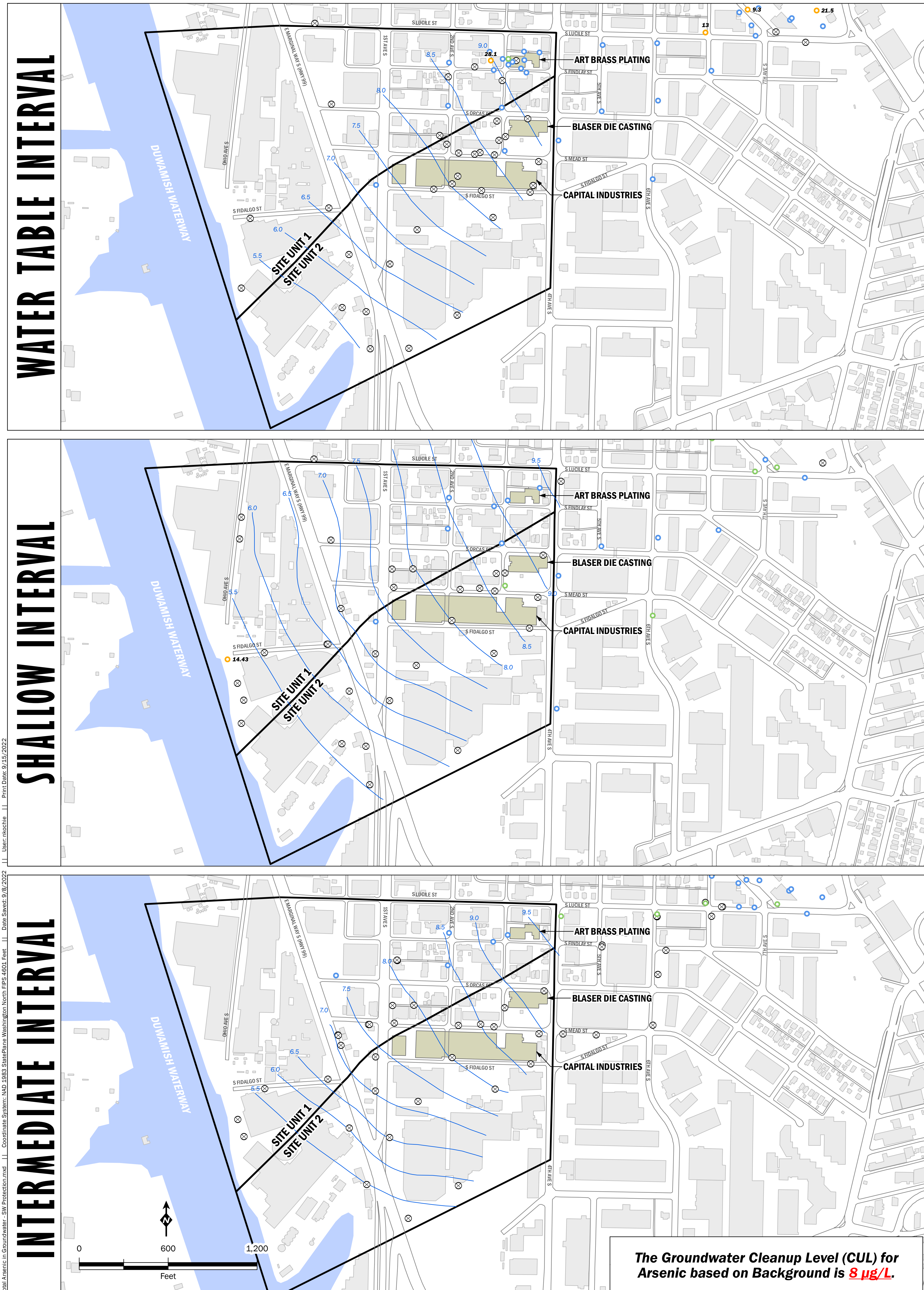
- Detected at > 10x CUL
- Detected Above CUL
- Detected Below CUL
- Not Detected (Reporting Limit Above CUL)
- Not Detected

Well locations with CUL exceedances are labeled with the exceeding concentration: 55 Zinc Concentration (in µg/L)

8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)

Zinc Isoconcentration Line at 81.0 µg/L Cleanup Level

GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\3-11 Dissolved Zinc in Groundwater - SW Protection.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/14/2022 || User: rkochie || Print Date: 9/14/2022



Total Arsenic in Groundwater

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022	BY: PPW		FIGURE NO.
PROJECT NO. 050067	REV BY: TDR / NLK		3-12

Groundwater Sample Locations:

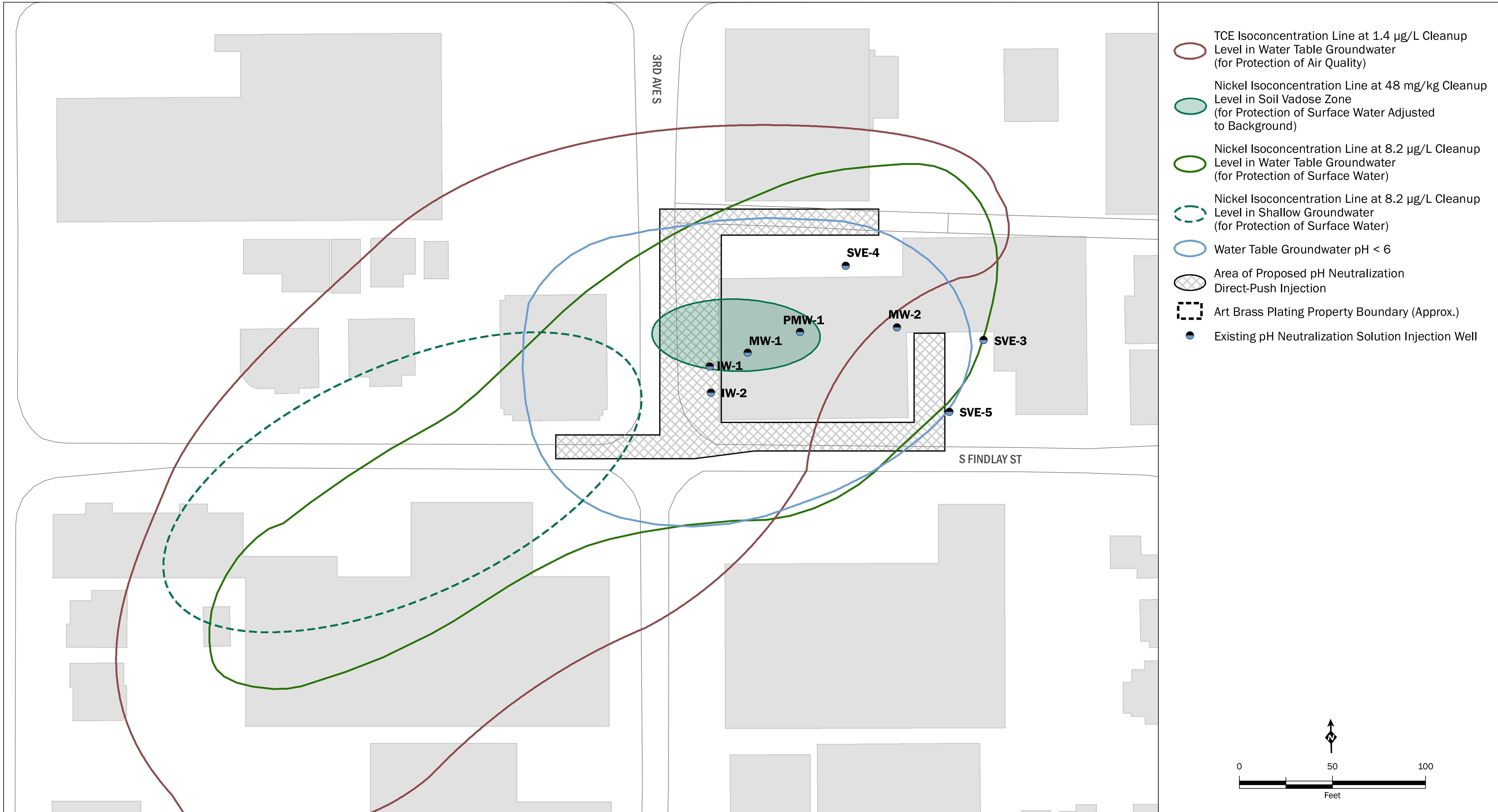
- Well with data from 2022
- Well with data from2020 to 2021 (most recent if multiple samples)
- Well with data pre-dating 2020
- Probe sample data* (reflecting the maximum concentration detected in the given interval)
  - * Note: Probe data are from 2000 to 2012
- Well without data for analyte/interval

Sample Location Symbol Color:

- Detected at > 10x CUL
- Detected Above CUL
- Detected Below CUL
- Not Detected (Reporting Limit Above CUL)
- Not Detected

Well locations with CUL exceedances are labeled with the exceeding concentration: 55 Arsenic Concentration (in µg/L)

8.0 Half-foot Groundwater Elevation Contours from August, 2012 Site-Wide Monitoring Event (NAVD88 Vertical Datum)



Remedial Design Concept - pH Adjustment Alternatives 2A and 2B

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

SEP-2022

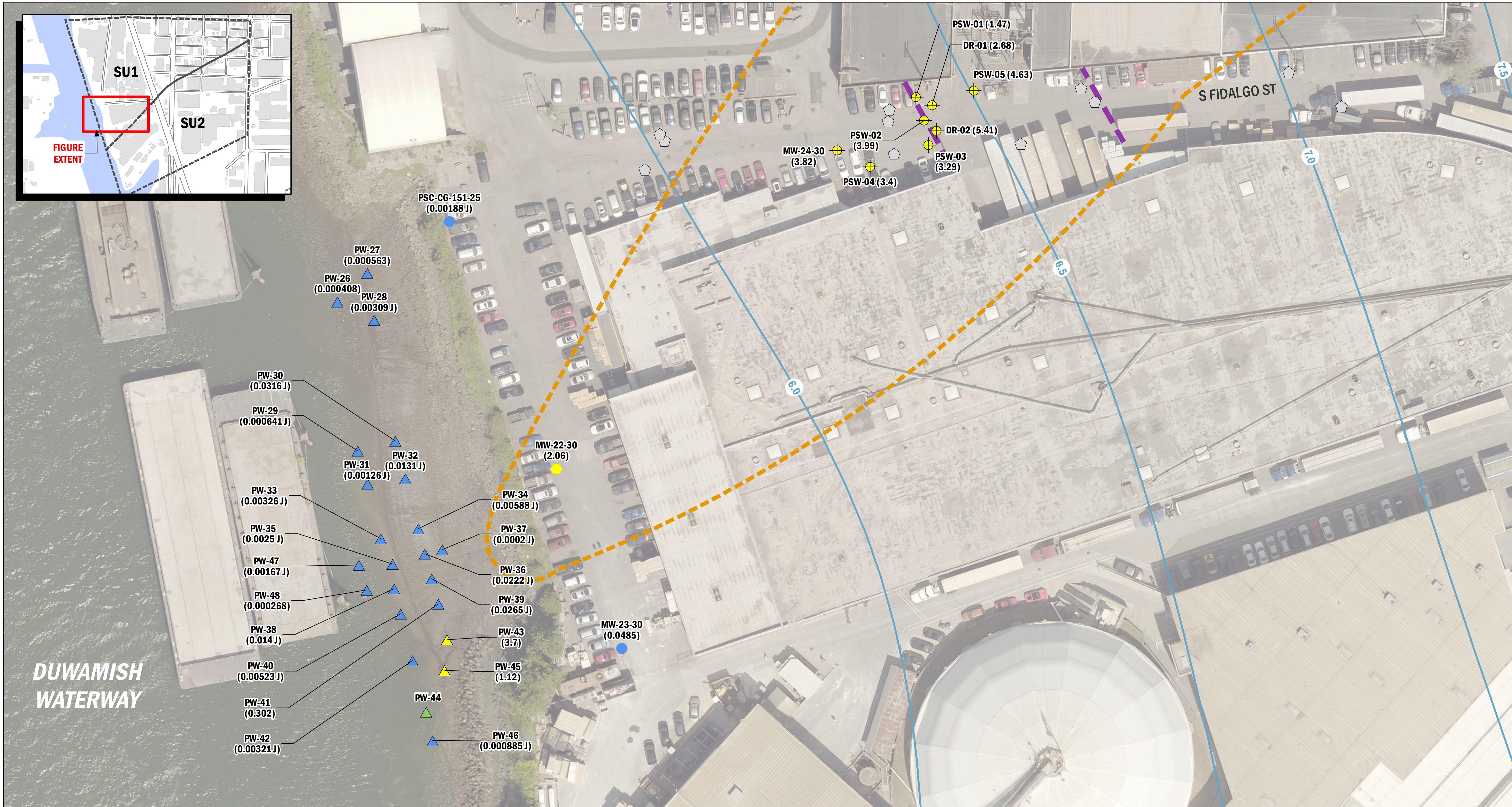
PROJECT NO. 050067

BY: PPW

REVISED BY: EAC / NLK

FIGURE NO. **5-1**

GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS\5-1 Remedial Design Concept - pH Adjustment.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/14/2022 || User: nkochie || Print Date: 9/14/2022



Sample Locations:
- Porewater Sample Locations*
- Well (Groundwater Samples)*
- Probe Location (2002 & 2005)
- Pilot Study Wells

*Porewater data from August 2020.
Well data from August 2020.

Sample Location Symbol Color:
- Detected, Total Chlorinated Ethenes Concentration Greater than 1 umol/L
- Detected
- Not Detected

9.0 0.5 ft Groundwater Elevation Contours†

†Contours based on January 2011 Tidal Study (Aspect, 2012).

TCE Isoconcentration Line at 0.7 µg/L Cleanup Level

ISCR/EAnB Treatment Transect

Notes:

- Total chlorinated ethenes data are from the Shallow Interval.
- Probe data collected between 2002 and 2005. Maximum concentration detected for Shallow Interval.
- Data from shoreline wells collected using the same method as porewater data (passive diffusion bag samplers).
- Data depicted for remaining wells collected as part of baseline groundwater monitoring for pilot study (10/4/2018, except MW-24-30 from 1/29/18).

0 60
Feet

N

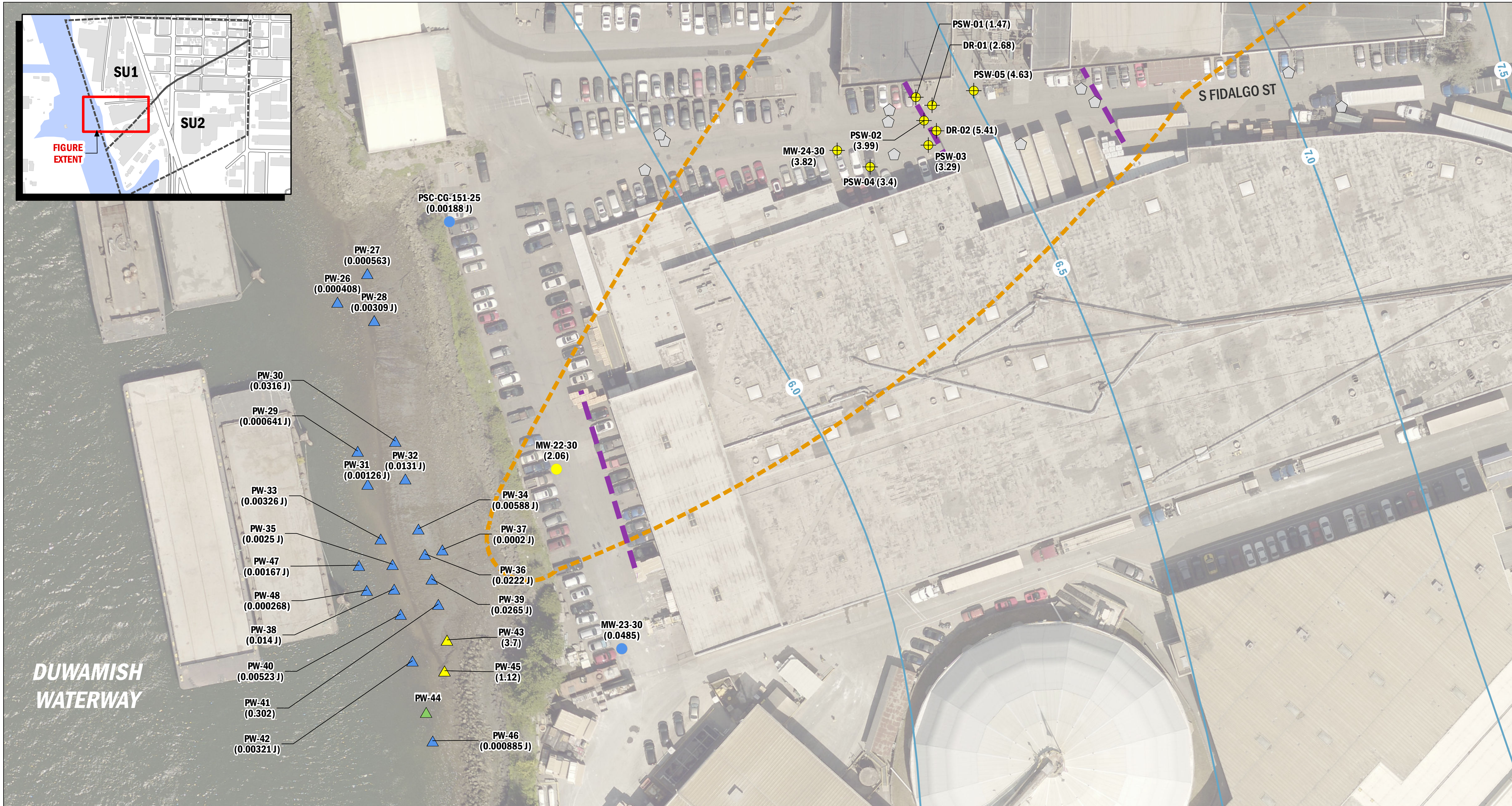
Remedial Design Concept in Downgradient Area—Alternative 2A

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

OCT-2022	BY: TDR	FIGURE NO.
PROJECT NO. 050067	REVISED BY: NLK	5-2

Basemap Layer Credits || EagleView Technologies, Inc.



GIS Path: G:\projects\Artbrass\W4 SU1 FS\W4 SU1 FS 5-3 Remedial Design Concept in Downgradient Area—Alternative 2B.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 10/24/2022 || User: nkoche || Print Date: 10/24/2022

Sample Locations:

- ▲ Porewater Sample Locations*
- ● Well (Groundwater Samples)*
- ⬟ Probe Location (2002 & 2005)
- ⊕ Pilot Study Wells

*Porewater data from August 2020.

Sample Location Symbol Color:

- Detected, Total Chlorinated Ethenes Concentration Greater than 1 umol/L
- Detected
- Not Detected
- 9.0 0.5 ft Groundwater Elevation Contours†

†Contours based on January 2011 Tidal Study (Aspect, 2012).

TCE Isoconcentration Line at 0.7 µg/L Cleanup Level

ISCR/EAnB Treatment Transect

Notes:

- Total chlorinated ethenes data are from the Shallow Interval.
- Probe data collected between 2002 and 2005. Maximum concentration detected for Shallow Interval.
- Data from shoreline wells collected using the same method as porewater data (passive diffusion bag samplers).
- Data depicted for remaining wells collected as part of baseline groundwater monitoring for pilot study (10/4/2018, except MW-24-30 from 1/29/18).

0 60
Feet

N

Remedial Design Concept in Downgradient Area—Alternative 2B

SU1 FS Addendum Report
West of 4th Site
Seattle, Washington

Aspect CONSULTING

OCT-2022	BY: TDR	FIGURE NO.
PROJECT NO. 050067	REVISED BY: NLK	5-3

Basemap Layer Credits || EagleView Technologies, Inc.

APPENDIX A

CVOC Pilot Study Completion Report

CVOC PILOT STUDY COMPLETION REPORT

West of Fourth - Site Unit 1

Prepared for: West of 4th Group

Project No. 050067 • December 2022

Aspect CONSULTING

earth + water

CVOC PILOT STUDY COMPLETION REPORT

West of Fourth - Site Unit 1

Prepared for: West of 4th Group

Project No. 050067 • December 2022

Aspect Consulting, LLC

12/14/2022

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Project Engineer
dmassey@aspectconsulting.com

Adam Griffin, PE
Associate Remediation Engineer
agriffin@aspectconsulting.com

V:\050067 Art Brass Plating\Feasibility Study Addendum\Final\App A CVOC Report\Completion Report\CVOCs Completion Report_Dec 2022.docx

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Acronyms

Aspect	Aspect Consulting, LLC
BETX	benzene, ethylbenzene, toluene and xylenes
CUL	Cleanup level
Ecology	Washington Department of Ecology
gpm	gallons per minute
mg/kg	milligrams/kilograms
mg/L	milligrams per liter
µg/L	micrograms per liter
MTCA	Model Toxics Control Act
NFA	No Further Action
PCE	tetrachloroethylene
RI/FS	Remedial Investigation/Feasibility Study
SAP	Sampling Analysis Plan
SVE	soil vapor extraction
TCE	trichloroethylene
TEF	toxic equivalency factor
VOC	volatile organic compound
WDNR	Washington Department of Natural Resources

1 Introduction

1.1 Purpose

The West of 4th (W4) Group Site Unit 1 (SU1) chlorinated volatile organic compounds (CVOC) Pilot Study Completion Report (Completion Report) has been prepared by Aspect Consulting, LLC (Aspect) on behalf of potentially liable persons (PLPs;[Art Brass Plating (ABP), Blaser Die Casting (BDC), Capital Industries (CI), and Burlington Environmental (BE)) identified by the Washington State Department of Ecology (Ecology) in Agreed Order (AO) No. DE10402 for the West of 4th (W4) Site (the Site). The AO requires the four PLPs (the W4 Group) to complete a Feasibility Study (FS) and prepare a Draft Cleanup Action Plan for the W4 Site. The W4 Site has been divided into two site units, Site Unit 1 (SU1; ABP and BE) and Site Unit 2 (SU2; BDC, CI, and BE), as described in the AO. Figure 1 shows the locations of the four PLPs' facilities and the SU1 and SU2 boundaries.

The SU1 FS (Aspect, 2016) developed and evaluated remedial alternatives to address contaminated media at SU1 in accordance with Washington Administrative Code (WAC) 173-340-350(8). Ecology did not agree with the preferred remedy identified in the SU1 FS (Ecology, 2016). Upon further discussion with Ecology, pilot testing of technologies was determined to be an appropriate step to reduce the uncertainties associated with treatment of CVOCs in downgradient groundwater and evaluate the ability of different treatment approaches, including *In- Situ* Chemical Reduction (ISCR) and Enhanced Anaerobic Biodegradation (EAnB), to achieve Remedial Action Objectives (RAOs).

Pilot testing was designed to assess the effectiveness and cost of using ISCR and EAnB to treat CVOCs in groundwater west of East Marginal Way. The First Amendment to the AO No. DE 15344, effective on November 20, 2017 (AO Amendment), identifies the pilot study scope of work and schedule of deliverables. After pilot study completion, the AO Amendment requires that the PLPs submit a SU1 Focused FS Report Addendum that selects the preferred cleanup action. The pilot study results will be used to revise and evaluate remedial alternatives presented in the SU1 FS and to define the preferred remedy, to be presented in the SU1 Focused FS Report Addendum (Aspect, 2021).

A Final CVOC Pilot Study Work Plan (Work Plan) describes pilot study activities proposed to evaluate the *in situ* treatment of the downgradient trichloroethene (TCE) Plume (Aspect, 2017). The Work Plan was approved by Ecology on January 11, 2018. The Work Plan presented the pilot study approach, including monitoring well installation and baseline groundwater monitoring before the final pilot study design. The pilot study location within the Site is shown on Figure 2 and the installed pilot study monitoring network is presented on Figure 3.

A Final CVOC Pilot Study Field Implementation Work Plan (FIWP) presents the baseline monitoring results, an updated Conceptual Site Model, and the final pilot study design (Aspect, 2018b). The FIWP was approved by Ecology on September 14, 2018.

A Work Plan for Monitoring Methane in Soil Gas (Addendum to the CVOC Pilot Study Field Implementation Work Plan; Methane Work Plan) was prepared to address elevated dissolved methane concentrations in groundwater prior to reagent injection through soil gas monitoring point installation and monitoring (Aspect, 2018a). The Methane Work Plan was approved by Ecology, July 11, 2018. A Work Plan for Additional Soil Gas Monitoring (Addendum to the CVOC Pilot Study Field Implementation Work Plan) outlines expanded soil gas methane monitoring and indoor air monitoring at adjacent buildings after increasing methane concentrations were encountered in groundwater and soil gas following reagent injection (Aspect, 2019; Ecology approval May 8, 2019).

This Completion Report includes a summary of two years of pilot testing activities and the pilot study conclusions. This Completion Report also presents a basis of design for this technology, to be used for refining and evaluating remedial alternatives in the SU1 FS Addendum. PLP document submittals and Ecology comment/approval letters are available online at http://clients.aspectconsulting.com/W4/.

1.2 Report Organization

This report is organized as follows:

- **Section 2** describes the approach and objectives of the pilot study.
- **Section 3** describes the reagent injection methods and monitoring. The discussion of reagent injections includes reagent selection, injection layout, injection methods, injection sequencing, injection point (IP) management, reagent dosing and batching, and applied conservative tracer application. The monitoring includes operational and performance monitoring, and also discusses contingency monitoring.
- **Section 4** presents the pilot study results, including reagent delivery and distribution, CVOC treatment, design parameters, downgradient performance, and secondary effects.
- **Section 5** discusses the effectiveness of the pilot study and whether a full-scale implementation is feasible.
- **Section 6** provides references used in the preparation of this report.

The text references tables and figures (attached) that support the text and illustrate the proposed pilot testing activities. Appendices to this report provide supporting information referenced within the text. These include operational monitoring logs and pressure transducer hydrographs.

2 Pilot Study Overview

2.1 Approach

The FIWP design consisted of an injection transect (oriented orthogonally) to groundwater flow in South Fidalgo Street (Figure 3). This orientation maximized the treatment downgradient of the injection transect (i.e., advection-controlled, physical flushing via a clean-water front generated within the reactive zone). The injection transect consisted of two injection lines of staggered direct-push (DP) points spaced 6 feet apart, and a total of 18 IPs. Injections targeted the contaminated mass flux in the Shallow Interval groundwater, which is defined by monitoring wells screened between 20 and 40 feet below ground surface (bgs).

The FIWP included a detailed discussion and comparison of the EAnB and ISCR technologies and concluded that both technologies were considered effective for the Downgradient TCE Plume Area.

Due to the baseline TCE concentrations in groundwater, a reagent with an ISCR component was selected in the FIWP for the final pilot test design. Additionally, a reagent that also has an EAnB component (organic carbon) would enhance the ongoing reductive dechlorination as indicated by the persistent cis-1,2 DCE and vinyl chloride concentrations, and confirmed complete with ethene/ethane baseline concentrations. The combined approach of ISCR and EAnB was implemented, using Peroxychem EHC ® Liquid Reagent (EHC Liquid), which includes a soluble iron compound and ELS™ (ELS) microemulsion.

2.2 Objectives

This pilot study was designed based on the following objectives:

1) **Evaluate the ability to deliver and distribute reagent in Shallow Interval groundwater.** This objective will be evaluated based on the ability to achieve targeted injection volumes and reagent dosing, observe reagent breakthrough, and establish a continuous reactive zone through an array of DP IPs. This objective also includes logistical considerations of access, a safe workspace in high-traffic areas, and utility locations.

2) **Reduce CVOC concentrations at rates greater than observed monitored natural attenuation (MNA) processes.** MNA processes are occurring at the Site and to evaluate effectiveness, post-injection CVOC trends at wells influenced by injections will be compared to trends in wells not influenced by injections.

3) **Estimate design parameters for implementing the technology.** This includes the longevity of the desired biogeochemical change and associated injection frequency required to maintain the reactive barrier. Other design parameters include radius of influence (ROI)/injection-volume relationship, injection-specific capacity (relationship of injection rate and water level increase), and injection-pressure thresholds.

4) **Evaluate performance downgradient of the reactive zone.** Downgradient of the reactive zone in the direction of the Waterway, CVOC concentrations will be reduced through physical flushing of pore spaces via a clean-water front. This will be evaluated using downgradient analytical monitoring and directly measuring groundwater flow rates using an applied, conservative tracer.

5) **Evaluate ability to manage secondary effects.** With both the EAnB and ISCR technologies, there are secondary effects inherent to the desired change in CVOC concentrations that should be expected and managed. These include the reductive dissolution of redox-sensitive metals, the generation and potential accumulation of methane, and potential short circuiting of injection solution. The final design includes management elements of a redox recovery zone, a buffer between buildings and IPs, and monitoring of these secondary effects.

3 Injection Methods and Monitoring

This section presents the injection methods and monitoring that were completed in accordance with the FIWP, and any deviations are described in detail below. This section also presents the monitoring data collected during the pilot test. Results are discussed in Section 4.

3.1 Reagent Injections

The reagent injections were implemented according to the FIWP on October 8, 2018 through October 12, 2018. Ecology site manager Ed Jones was on Site October 8, 2018, to observe the reagent injections.

3.1.1 Injection Layout

A reactive zone was created through an array of IPs targeting a continuous reactive zone in the Shallow Interval groundwater and spanning the width of right-of-way access, as shown on Figure 3. Two offset transects of nine IPs spaced 6 feet apart were used to create the reactive zone oriented orthogonally to the average groundwater flow direction in the Shallow Interval groundwater. A spacing of 9 feet between IP-7 and IP-8, and 11 feet between IP-16 and IP-17 was used to setback from the 6-inch-diameter sewer line that is approximately 4 feet deep.

3.1.2 Injection Methods

Injections were conducted as outlined in the FIWP using direct push tooling of a deployable 5-foot long screen. The injection volume of 500 gallons per IP was divided evenly between three depth intervals (approximately 167 gallons per interval). The three injection intervals are: 17.5 to 22.5 feet bgs, 22.5 to 27.5 feet bgs, and 27.5 to 32.5 feet bgs. The first location (IP-4) was inadvertently advanced using “bottom-up” methods; all subsequent locations were injected using “top-down” methods meaning that injections progressed from the shallowest to deepest interval. No substantial differences were observed in the results at IP-4 compared to the other locations that used the ‘top-down’ method. A total reagent injection volume of 9,051 gallons was achieved in the eighteen IPs in the injection transect.

To mitigate clogging that was indicated by reduced flow, up to 45 gallons of clean water was flushed through the injection lines after each IP was completed. The injections were performed by Cascade Drilling, and their injection logs are included in Appendix A. A photo log of the injections is included in Appendix B.

3.1.3 Injection Point Permitting and Abandonment

Injection points were abandoned with bentonite to ground surface after the injections were completed and in accordance with Washington State Administrative Code (WAC) 173-160-451. The injection wells were registered with Ecology’s underground injection control (UIC) program before the first injection event and automatically meet the non-endangerment standard and are rule-authorized. The injection points were registered with Ecology’s UIC program under permit number 34153, approved on September 28, 2018 (Appendix C).

3.1.4 Reagent Composition

The reagent mixture was prepared in 500-gallon batches consisting of 450 gallons of makeup water, 50 gallons of ELS microemulsion, and one 24.5-pound bag of EHC Liquid powder. The ELS microemulsion is pre-emulsified and 25 percent by volume, and the EHC Liquid is water soluble; therefore, both reagents were dissolved into water to inject.

Each 500-gallon batch was mixed for a minimum of 10 minutes before injections were commenced. The only deviation from the design presented in the FIWP was at IP-7, where an extra 50 gallons of injection solution were injected into the 17.5 to 22.5-foot interval.

3.1.5 Applied Conservative Tracer

The concentration of applied tracer (Rhodamine WT (RWT) from Ozark Underground Laboratory (OUL)) in the injection solution was 10 milligrams per liter (mg/L), per the FIWP. This required the addition of 18 grams of RWT per 500-gallon batch of injection reagent. OUL premeasured and prediluted this dosing to ease application and avoid measuring errors in the field during pilot testing.

Based on the concentration of the prediluted RWT in aqueous solution, 5 milliliters (mL) of RWT were to be added to each 500-gallon batch per IP. However, an implementation error resulted in 12 mL of RWT in the first three IP batches (IP-4, IP-10, and IP-12). This inconsistency in applied conservative tracer source strength did not impact pilot study objectives as discussed in Section 4.1.4.

3.2 Operational Monitoring

Operational monitoring was conducted during the pilot study reagent injections according to Section 5.2.1 of the FIWP. Injection parameters (flow rate, pressure, and injected volume) were monitored continuously and recorded at least once per depth interval at each IP. These injection monitoring logs are included in Appendix A. Operational monitoring results are provided in Table 1.

Two samples of the injection reagent were submitted to ARI for laboratory analysis of total organic carbon (TOC), dissolved iron, and RWT to measure the injection reagent dosing. The analytical results are provided in Table 2.

Manual water levels were measured at least twice daily. During the injections into IP-4 and IP-7, water levels were collected approximately every five minutes at the corresponding dose-response well (DR-01 and DR-02, respectively). Pressure transducers were deployed at DR-01 and PSW-04 on October 8, 2018 prior to starting the injections and set to log at 10-minute frequency through December 6, 2018. The pressure transducer readings are presented as groundwater elevation for this monitoring period in Appendix D.

Breakthrough monitoring was conducted at DR-01 and DR-02 during the initial injections at IP-4 and IP-7, respectively. Grab samples were collected at every 50 gallons injected and were compared to RWT standards for visual screening. Photos of the grab samples are included in Appendix B. A subset of the grab samples was then submitted to OUL for RWT analysis, including four samples from DR-01, and five samples from DR-

02. After reagent breakthrough had been confirmed by visual screening, one sample from each dose-response well was collected and submitted to ARI for analysis of TOC and dissolved iron. The breakthrough monitoring results are provided in Table 2.

3.3 Performance Monitoring

Performance monitoring was initiated at the end of the reagent injections to evaluate the objectives described in Section 2.2 and included both short-term and longer-term monitoring. Tables 3 and 4 show performance monitoring results for chlorinated solvents and dissolved gasses, as well as redox indictors, respectively. Time series plots of the performance monitoring data at each well are shown in Appendix E.

3.3.1 Short-term Monitoring

The following performance groundwater monitoring events were conducted according to Table 6 of the Final FIWP:

- Day 0 (elapsed post- reagent injection) on October 12, 2018
- Week 1 on October 19, 2018
- Week 2 on October 26, 2018
- Month 1 on November 9, 2018
- Month 2 on December 6, 2018
- Month 3 on January 4, 2019

3.3.2 Longer-term Monitoring

The following performance groundwater monitoring events were conducted according to Table 6 of the Final FIWP, with additional Month 15 and Month 18, and Month 22 events added per communications with Ecology:

- Month 6 on March 29, 2019
- Month 9 on June 26, 2019
- Month 12 on September 19, 2019
- Month 15 on December 19, 2019
- Month 18 on March 16, 2020
- Month 22 on August 4, 2020

Microbiological analysis with biotraps was completed at baseline and Month 6.

3.3.3 Soil Gas Monitoring

Methane concentrations in soil gas at SG-01, SG-02, and SG-03 were monitored during the Week 4, Months 3, 6, 9, 12, 15, and 18 performance monitoring events, following the methods provided in the Methane Work Plan (Aspect, 2018a).

3.4 Contingency Actions

The application of *in situ* remediation technologies requires the careful management of nontarget, secondary reactions and effects that require monitoring and contingency actions, if conditions warrant. The pilot study was designed at a scale to minimize the secondary effect footprint and to provide information necessary for full-scale design (see Pilot Study Objectives in Section 2.2). A Contingency Plan was included in the FIWP to outline actions to take during the pilot testing if monitoring results indicate a potential exposure risk.

The generation of methane during pilot test monitoring triggered the only contingency action during pilot testing. Methane monitoring to address this contingency condition is described below.

3.4.1 Methane Monitoring

During the Month 6 monitoring event, methane was detected in soil gas probes SG-01 and SG-02 at concentrations that exceeded the lower explosive limit (LEL) threshold of 5 percent, which was established as the contingency trigger in the FIWP. Ecology was immediately notified of this contingency condition and Aspect implemented the FIWP contingency action of indoor air monitoring in the adjacent buildings on April 5, 2019. Indoor air monitoring in buildings on the south and north sides of South Fidalgo Street. as well as methane monitoring in soil gas probes was initiated on April 5, 2019. Indoor air and soil gas were monitored weekly for methane through May 3, 2019.

On June 1, 2019, based on the persistence of methane in soil gas, three additional soil gas probes (SG-04S/D, SG-05, and SG-06) were installed in South Fidalgo Street per the FIWP Addendum (Aspect, 2019). The locations of these soil gas probes are shown on Figure 4. These additional probes were installed to better understand the mechanism of methane production and the potential accumulation in the vadose zone, and characterization of the aerial extent of methane. Soil gas and indoor air were monitored weekly from April 5 through May 3, 2019. Monthly soil gas and indoor air monitoring commenced in June 2019 in accordance with the FIWP Addendum and will continue until methane concentrations are below the LEL of 5 percent or return to baseline. As of September 25, 2020, four soil gas probes were above 5 percent methane.

No methane has been detected in indoor air of either building adjacent to the pilot test.

4 Results

This section presents the results of the pilot study, organized by the pilot study objectives presented in Section 2.2.

4.1 Reagent Delivery and Distribution

The following sections evaluate the first pilot study objective: the ability to deliver and distribute reagent in the subsurface.

4.1.1 Injection Rate, Volume, and Pressure

The average injection rate at each interval ranged from 5.4 to 16.7 gallons per minute (gpm) at sustained pressures of 15 to 44 pounds per square inch (psi). When higher pressures (above 25 psi) were necessary to achieve reasonable injection rates, the pressure was increased slowly and incrementally as described in the FIWP. There were no observations of reagent short-circuiting or daylighting that would have necessitated ceasing of injections. The injection operational monitoring data is included in Appendix A.

A total reagent injection volume of 9,051 gallons was distributed evenly among IP-1 through IP-18. An additional clean water injection volume of 618 gallons were necessary to keep the injection lines clear after each IP was completed.

4.1.2 Reagent Dosing

The measured concentrations of TOC in two separate batches of injection solution were 18,380 mg/L and 17,200 mg/L, or approximately 16 percent of the ELS microemulsion solution assuming a density of 8.4 lb/gal. (Table 1). The measured TOC concentration of 16 percent should be used as the basis for the full-scale design.

The dissolved iron concentration was 457 mg/L and 576 mg/L in each reagent batch sample. The RWT tracer was measured at 3,390 parts per billion (ppb) and 11,900 ppb in each reagent batch sample, of which the latter is comparable to the design concentration of 10,000 ppb. The difference in RWT concentrations may be attributed to variability in the reagent batches and did not affect the pilot test analysis.

4.1.3 Water Level Monitoring

Manual water levels are included in the water level monitoring logs included as Appendix A. The water level at DR-01 temporarily increased to a maximum of 1.15 feet during the injection at IP-4, and the water level at DR-02 increased to a maximum of 1.18 feet during the injection at IP-7. These water level increases were gradual, indicating that there was porous distribution, and no short circuiting or fracturing. The formation was able to accept the introduced volume of injection reagent without any significant change in groundwater elevation (i.e. mounding), and water levels receded rapidly once injections were not actively occurring.

Water level monitoring results from transducers deployed at DR-01 and PSW-04 are presented in Appendix B for two periods—the week of injections and for the entire monitoring period of October through December 2018. The effect of the tidal influence of the Duwamish Waterway on the water levels is clearly demonstrated in the short-term and long-term monitoring at DR-01 and PSW-04.

4.1.4 Breakthrough Monitoring

Breakthrough monitoring data is provided in Appendix B (visual monitoring) and Table 2 (analytical monitoring). Breakthrough of the injection solution at dose-response wells DR-01 and DR-02 was observed as visual identification of the fluorescent RWT tracer, after 50 gallons was injected into IP-4, and 234 gallons was injected into IP-7, respectively. The analytical results of the grab samples showed that the tracer was detected at maximum concentrations of 8,960 ppb in DR-01 and 10,500 ppb in DR-02. These measured tracer concentrations indicate that effectively 100 percent of the reagent solution (i.e., no significant dilution with groundwater) was arriving at these dose response monitoring wells approximately 2.5 feet away from the injection points. Field monitoring of visual screening of the tracer is presented in Appendix A. The results of the grab tracer samples analyzed for RWT and the post-breakthrough sample for TOC and dissolved iron are included in Table 1.

The tracer was observed by visual screening in the dose-response wells through the Month 15 monitoring period. However, the tracer was never visually identified at any of the downgradient performance monitoring wells. Downgradient samples were submitted to OUL from Week 2, Month 1, and Month 3, despite no visual confirmation. The results confirm that no RWT was present, except in PSW-03 (47.6 ppb) at Month 3. The arrival of TOC and dissolved iron at downgradient wells PSW-01, PSW-02 and PSW-03 during the same sampling events confirm the arrival of injection solution. It is likely that RWT was sorbed to the reagent or reactive in the aquifer sediments or groundwater. This effect was identified after the Month 1 monitoring, and tracer monitoring was discontinued at downgradient wells after Month 3.

4.2 CVOC Reduction Rates

An overall reduction in CVOC concentrations was noted at downgradient monitoring wells, as treatment proceeded both temporally through the degradation sequence and spatially as the clean water front moved downgradient. This was typically characterized as an initial drastic decrease in TCE, a subsequent decrease in cis-DCE while vinyl chloride increased, and finally a decrease in vinyl chloride as reductive dechlorination was completed. Treatment was initially seen at the dose-response wells, and then observed at the performance monitoring wells further downgradient. The pilot test results demonstrate a greater than 90 percent reduction in total CVOC mass beginning in Month 15 and a greater than 80 percent reduction 22 months after injections. The reduction in CVOC molar mass is shown in Figure 5. The trends in CVOC performance monitoring results are summarized as:

- **Upgradient**: There was no reduction in CVOC mass at the upgradient monitoring well, PSW-05 throughout the duration of the pilot study. Instead, there was an overall increase in CVOC molar mass by 53 percent at Month 15.
- **DR Wells (5 feet away from injection transect):** There was an overall decrease in CVOC molar mass at both DR-01 and DR-02, with a maximum of 94 percent and 98 percent, respectively, at Month 15. The reduction in mass at DR-01 began

to rebound and was down to 73 percent at Month 22, as the injection reagent is moved downgradient by groundwater flow.

- **PSW01, -02, and -03 Wells (15 feet away from injection transect):** The maximum reduction in CVOC molar mass seen at PSW-02 and PSW-03 was 99 percent and 100 percent, respectively, at Month 18. PSW-01 had a maximum CVOC molar mass reduction of 75 percent at Month 9; however, the percent mass reduction began to decrease until the measured CVOC molar mass at Month 18 exceeded the baseline mass. This is most likely because PSW-01 is located near the north end of the injection transect, and the transect was not quite orthogonal to the groundwater flow direction.
- **Downgradient Wells:** PSW-04 and MW-24-30 had maximum reductions in CVOC molar mass of 99 percent at Month 15 and 97 percent at Month 22, respectively. PSW-04 is located approximately 55 feet downgradient of the injection transect, and MW-24-30 is located approximately 75 feet downgradient.

A greater reduction in CVOC molar mass was seen at wells influenced by the reagent injections compared to wells that are only influenced by MNA processes. The baseline data from October 2018 indicates that the majority of the mass at each pilot test well was TCE and cis-1,2-DCE. The biogeochemical data from October 2018 show that natural attenuation processes were occurring prior to the pilot study injections. Reductive dechlorination was occurring, as demonstrated by the biodegradation byproducts present in the baseline data prior to the injections, but the total CVOC molar mass over the treatment area was relatively unchanged.

By nine months post-injection, the TCE molar mass downgradient of the injection transect had decreased to below detection levels[1], and the total CVOC molar mass in the pilot study area had decreased by 59 percent. The total CVOC molar mass continued to decrease rapidly over subsequent monitoring events. Pilot testing demonstrates that the engineered treatment results in 95 percent reduction in total CVOC mass in just 15 months over the pilot test footprint.

4.3 Downgradient Performance

The reactive zone is the area downgradient of the injection transect where there was an increase in the TOC concentration, which extended past MW-24-30. Downgradient of the reactive zone in the direction of the Waterway, CVOC concentrations are presumed to be reduced through physical flushing of pore spaces via a clean-water front. As discussed in Section 4.2, a maximum CVOC molar mass reduction of 99 percent was seen at both downgradient monitoring wells, PSW-04 and MW-24-30.

In lieu of downgradient breakthrough of applied tracer, the TOC transport velocity can be evaluated using downgradient analytical monitoring. This was derived from the date when there was TOC breakthrough at wells PSW-01, PSW-02, PSW-03, PSW-04, and MW-24-30. Because TOC is reactive, and the injection front is sorbing to soils, the TOC transport velocity will be lower than the seepage velocity. The estimated TOC transport

[1] Except at PSW-01, as explained above.

velocity of 0.52 to 0.98 feet per day (190 to 357 feet per year) are consistent with the Darcy's Law-derived average seepage velocity estimate of 0.9-1.9 feet per day from the FIWP as a reasonable design basis. These velocity calculations are shown in Table F-1 in Appendix F.

4.4 Secondary Effects

With both the EAnB and ISCR technologies, there are secondary effects inherent to the desired change in CVOC concentrations that need to be identified and managed. Potential secondary effects identified in the FIWP included change in pH, generation of methane, and water quality impacts due to mobilization of redox-sensitive metals or transport of fluorescent tracer. Methane generation and depressed pH were the most significant secondary effects observed during the performance monitoring. Each of these effects is discussed below.

4.4.1 pH Change

The fermentation of organic carbon and generation of volatile fatty acids decreased the pH at DR-01 and DR-02. The minimum pH at both DR-01 and DR-02 was 5.08 at Month 1. A pH of less than 5 can be toxic to biological processes, but the groundwater pH began to rebound during Month 2 and continued to increase at each successive monitoring event, showing that the aquifer buffered this temporary effect. The temporary change in pH did not have a significant long-term effect on the pilot study objectives and is important to understanding the aquifer's buffering capacity for any future injections of organic carbon.

4.4.2 Methane Generation

Methane generation and accumulation was another secondary effect of the pilot study. Dissolved methane concentrations in groundwater reached and exceeded solubility in groundwater (20 mg/L) in March 2019 at Month 6. As dissolved methane concentrations reached solubility, methane gas was released into the vadose zone underneath South Fidalgo Street and began to accumulate. This was reflected in the Month 6 soil gas concentrations, which exceeded the LEL of five percent, triggering the contingency actions described in Section 3.5.1. A maximum soil gas concentration of 48.8 percent methane was measured at SG-01 at in June 2019 (Table 5). The contingency indoor air monitoring confirmed that methane was not accumulating in either of the industrial buildings adjacent to the injection area.

Dissolved methane concentrations in groundwater decreased to almost baseline levels in September 2019, before increasing back to near-solubility concentrations in March 2020 at Month 18. By March 2020, TOC concentrations had returned to approximately baseline, which suggests that the reagent had been consumed and traveled downgradient. The increase in methane concentrations in March 2020 is therefore likely due to seasonal influences, and not caused by the injection reagent.

4.4.3 Water Quality Impacts

MW-24-30 was selected as the location for triggering water quality conditions that may warrant contingency action in the FIWP. These triggering water quality conditions included an increase in redox-sensitive metals (dissolved arsenic, barium and manganese) and fluorescent tracer concentrations. There were minimal, temporary increases of less than one order of magnitude of these redox sensitive metals at MW-24-30, which did not trigger any contingency action. There were also minor increases in redox-sensitive metals limited in spatial extent to the area immediately adjacent to the injection transect (DR-01, DR-02, PSW-01, PSW-02, and PSW-03). The fluorescent tracer was not detected at MW-24-30, as discussed in section 4.1.4.

In summary, secondary effects encountered during the pilot test were easily identified and managed through monitoring and contingency actions. Future reagent dosing should not exceed the pilot test design to minimize pH effects and methane production. A passive venting system is recommended for future full-scale implementation to manage the generation of methane.

4.5 Design Parameters

The subject pilot study objective in the FIWP is:

> **"Estimate design parameters for implementing the technology.** This includes the longevity of the desired biogeochemical change and associated injection frequency required to maintain the reactive barrier. Other design parameters include radius of influence (ROI)/injection-volume relationship, injection-specific capacity (relationship of injection rate and water level increase), and injection-pressure thresholds ."

The next step in the regulatory process is preparation of the FS Addendum to evaluate a focused set of remedial alternatives. The results of this pilot study provide a demonstration of the EAnB and ISCR technologies, and a basis of FS-level design of these technologies to support the FS Addendum. To support the FS Addendum, this pilot study objective is expanded and organized according to the following design parameter categories: Biogeochemical, Remediation Hydraulics, and Reagent Selection and Dosing, and Injection Transect Operations.

4.5.1 Biogeochemical

The pilot study results demonstrate a native biogeochemical environment that is capable of CVOC treatment and can be enhanced through injections. The pilot study results indicate both biological and chemical mechanisms of treatment.

Methane concentrations in groundwater and soil gas indicate that methane producing microorganisms (methanogens) are prolific in Shallow Interval groundwater in South Fidalgo Street. The engineering design to reduce methane generation, and to mitigate any accumulation is discussed in the physical design basis below.

The performance monitoring pilot results demonstrated a clear shift in groundwater redox conditions with TOC arrival, sulfate reduction, and methanogenesis (Table 6). The presence of TCE degradation products (e.g., cis-DCE, VC, and dissolved gases) verified the destruction of CVOCs. While the biotrap results indicated that there was an existing population of *dehalococcoides* bacteria prior to injections, the presence and activity of the microbiological community can be assessed by more cost-effective means that provide more insight into biogeochemical conditions. The EAnB and ISCR injections can operate with minimum performance monitoring of VOCs, dissolved gases, TOC, and sulfate in groundwater and should be adapted to any reagent selection, or performance monitoring results[2].

The performance monitoring indicates a significant treatment capacity with the EAnB technology. Biologically mediated reductive dechlorination has been demonstrated as highly effective at reducing CVOC mass at the site. The most recent results show that TOC has returned to baseline concentrations at the pilot test area wells. Sulfate reducing conditions remain at DR-01 and PSW-02 but are beginning to rebound at the other monitoring wells almost two years after the injections were completed.

4.5.2 Remediation Hydraulics

The Shallow Interval groundwater is readily amenable to accepting reagent injections, at non-fracturing pressures, and allowing porous distribution of reagent.

Direct-push injection were accomplished at pressures less than 45 psi, and monitoring indicates porous distribution. An injection rate of 10 gpm using a direct push injection screen of 5 feet is a reasonable assumption for design.

The target ROI of 3 feet was successfully achieved with an injection volume of 500 gallons per injection point. The assumed mobile porosity of 15 percent from the FIWP was appropriate and will be used for the final design.

4.5.3 Reagent Selection & Dosing

The EHC Liquid and ELS reagents selected for the pilot study were demonstrated to be highly effective for treatment of the CVOC plume in South Fidalgo Street by incorporating EAnB and ISCR components. However, the full-scale design requires adaptive dosing to manage secondary effects encountered during the pilot study. The actual TOC concentration in the pilot study ELS reagent was determined empirically to be 18,000 mg/L.

Reducing the TOC concentration to 75 percent of the actual pilot study concentration, or 13,000 mg/L, for the initial injection event will reduce TOC loading to the Shallow Interval, which will mitigate pH depression and methane generation. Subsequent injection events should be 50 percent of the pilot study TOC concentration, or 9,000 mg/L. The EHC Liquid dosing will be reduced proportionally for each event to maintain the vendor-recommended ratio of TOC to iron.

4.5.4 Injection Transect Operation

The pilot study design included a robust target vertical interval of 15 feet, to ensure a sufficient aquifer volume was influenced to evaluate the study. Historical data shows that the majority of the CVOC mass in soil and groundwater is in a relatively thin vertical interval between 21 and 25 feet bgs (Aspect, 2017). Based on the success of the pilot study injections, an optimized approach can be used for the final design, targeting the 10-foot Shallow Interval from 20 to 30 ft bgs. This reduction in the target vertical interval by 33 percent will also result in reduced methane production and ameliorate (but not eliminate) some of the secondary affects seen during the pilot study.

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[2] This minimum performance monitoring does not preclude the need for other associated analyses, such as soil gas and indoor air.

Methane accumulation will continue to be a consideration due to the physical conditions of the treatment area and the very active methanogen community. Passive venting wells may be appropriate for contingency mitigation and continued protection of indoor air of the adjacent buildings.

The pilot test has been monitored for 22 months, and there is still a significant reduction in CVOCs with limited rebound. The TOC design basis presented in the previous section is calibrated to a two-year target. However, biological-mediated CVOC treatment is greater than the TOC longevity, and assumed (based on data to date), to be at least 36 months. In addition, abiotic treatment may extend much longer than TOC. For the FS Addendum, the assumed initial injection frequency is recommended to be on an approximate three-year basis. However, it is likely that the injection frequency will be reduced with subsequent events. Actual injection frequency would be based on performance monitoring data and when further treatment is needed to achieve remedial action objectives.

For these subsequent injection events, the TOC concentration should be reduced to 50 percent of the pilot study TOC concentration, because of biomass buildup and endogenous recycling, which provides a sustained source of available carbon material.

5 Conclusions

The pilot study was effective in meeting the objectives described in the FIWP. The injection reagent was successfully delivered and distributed in the Shallow Interval groundwater. It was demonstrated that both EAnB and ISCR technologies are highly effective in treatment of CVOCs in Shallow Interval groundwater. The average total CVOC molar mass reduction was greater than 80 percent within the pilot test treatment area at 22 months post-injection. The pilot study has demonstrated that the secondary effects are minimal and manageable.

Design recommendations for full-scale implementation of this technology have been presented in this report. The results of the pilot study and the recommended design parameters from this Completion Report will be used to construct the alternatives in the FS Addendum.

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Limitations

Work for this project was performed for the West of 4th Group (Client), and this report was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

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TABLES

CVOC Pilot Study Completion Report

Table 1. Operational Monitoring

Project No. 050067, West of 4th - SU1, Seattle, Washington

		Injection Solution		DR-1				DR-2					
		Injection-1 10/9/2018 Injection-1	Injection-2 10/11/2018 Injection-2	DR-01 10/8/2018 DR-1-1	DR-01 10/8/2018 DR-1-5	DR-01 10/8/2018 DR-1-9	DR-01 10/9/2018 DR-1-100918	DR-02 10/10/2018 DR-2-3	DR-02 10/10/2018 DR-2-4	DR-02 10/10/2018 DR-2-5	DR-02 10/10/2018 DR-2-6	DR-02 10/10/2018 DR-2-9	DR-02 10/11/2018 DR-2-101118
Chemical Name	**Units**												
General Chemistry Parameters													
Total Organic Carbon	mg/L	**18380**	**17200**	--	--	--	**368.9**	--	--	--	--	--	**16200**
Redox-Sensitive Metals													
Iron (Dissolved)	ug/L	**457000**	**576000**	--	--	--	**28900**	--	--	--	--	--	**369000**
Fluorescent Tracer													
Rhodamine WT	ppb	**3390**	**11900**	**712**	**7720**	**8960**	**4010**	**4.51**	**383**	**5590**	**10500**	**24600**	**8540**

Notes:

Bold = detected

mg/L = milligrams per liter, ug/L = micrograms per liter, ppb = parts per billion

Qualifiers:

J = estimated

U = non-detect

Table 2. CVOC Pilot Study Performance Monitoring Results

Project No. 050067, West of 4th - SU1, Seattle, Washington

Dose Response Wells

Analyte	Unit	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01	DR-01
		01/29/2018	10/04/2018	10/12/2018	10/19/2018	10/26/2018	11/09/2018	12/06/2018	01/04/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019	08/04/2020
		Baseline	Baseline	Day 0	Day 7	Day 14	Day 28	Day 55	Day 84	Day 168	Day 257	Day 342	Day 433	Day 662
VOCs														
1,1,1-Trichloroethane	ug/L	< 1 U	< 0.20 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.02 U
1,1-Dichloroethane	ug/L	**1.17**	**1.32**	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.20 U	< 0.20 U	**0.27**	--
1,1-Dichloroethene	ug/L	< 1 U	**0.43**	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.20 U	< 0.20 U	< 0.20 U	**0.0173 J**
1,2-Dichloroethane (EDC)	ug/L	< 1 U	< 0.20 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.02 U
Chloroethane	ug/L	< 1 U	< 0.20 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.20 UJ	< 0.20 U	< 0.20 U	--
Tetrachloroethene (PCE)	ug/L	< 1 U	< 0.20 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.20 U	< 0.20 U	< 0.20 UJ	< 0.02 U
Trichloroethene (TCE)	ug/L	**53.7 J**	**60.1**	**53.7**	< 20.0 U	< 20.0 U	**24.2**	**85.6**	**23.9**	< 4.00 U	< 0.20 U	**0.07 J**	**0.11 J**	**0.0903**
cis-1,2-Dichloroethene (DCE)	ug/L	**201**	**191**	**132**	**50.7**	**37.7**	**114**	**167**	**88.7**	**82.3 J**	**26.8 J**	**10.0**	**3.50 J**	**0.589**
trans-1,2-Dichloroethene	ug/L	**4.72**	**4.50**	**3.09**	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	**0.45**	**0.21**	**0.13 J**	**0.0268**
Vinyl Chloride	ug/L	**13.5**	**12.8**	**3.51**	< 20.0 U	< 20.0 U	< 20.0 U	**13.1**	< 5 U	**7.01**	**13.4**	**7.53**	**6.93**	**15.0**
Total Chlorinated Ethenes	umoles/L	**2.74 J**	**2.68**	**1.86**	**0.523**	**0.389**	**1.36**	**2.58**	**1.10**	**0.961 J**	**0.495 J**	**0.226**	**0.149 J**	**0.247**
Dissolved Gases														
Ethane	ug/L	< 1.23 U	**6.15**	**3.03**	**1.44**	**1.73**	**2.91**	**5.39**	**1.92**	< 1.23 U	< 1.23 U	< 1.23 UJ	< 1.23 U	**11.9**
Ethene	ug/L	< 1.14 U	**1.29**	< 1.14 U	< 1.14 U	< 1.14 U	**1.50**	**2.12**	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 UJ	< 1.14 U	**57.5**
Methane	ug/L	**7210**	**5070**	**1040**	**5560**	**9870**	**4970**	**7990**	**17900**	**23000**	**9270**	**3980**	**4820**	**21300**
General Chemistry Parameters														
Chloride	mg/L	**18.7**	**16.1**	**12.6**	**15.7**	**26.0**	**51.5**	**14.3**	**17.3**	**30.1**	**16.8**	**17.1**	**15.1**	--
Nitrate as Nitrogen	mg/L	< 0.1 U	< 0.100 U	< 1.00 U	< 1.00 UJ	< 1.00 U	< 0.100 U	< 0.100 U	< 0.5 U	--	--	--	--	--
Nitrite as Nitrogen	mg/L	< 0.1 U	< 0.100 U	< 1.00 U	< 1.00 UJ	< 1.00 U	< 1.00 UJ	< 0.100 U	< 0.5 U	--	--	--	--	--
Sulfate	mg/L	**40.5**	**6.05**	**16.2**	**5.40**	**1.73**	< 5.00 U	< 0.100 U	**0.577**	< 1.00 U	**1.41**	**1.50**	**1.80**	< 2.00 U
Total Organic Carbon	mg/L	**18.2**	**5.86**	**7715**	**877.2**	**567.9**	**457.6**	**374.5**	**236.2**	**47.47**	**19.51**	**19.59**	**17.62**	**8.79**
Redox-Sensitive Parameters														
Arsenic (Dissolved)	ug/L	**1.61**	--	**2.74**	--	--	**0.591**	--	**0.84**	**2.28**	--	**2.15**	**1.10**	--
Barium (Dissolved)	ug/L	**18.8**	--	**30.3**	--	--	**9.03**	--	**5.87**	**6.89 J**	--	**8.64**	**8.18**	--
Iron (Dissolved)	ug/L	**5130 J**	**6790**	**195000**	**59400**	**46700**	**44600**	**43700**	**30900**	**27800**	**34400**	**28500**	**23500**	--
Manganese (Dissolved)	ug/L	**434**	--	**1630**	--	--	**572**	--	**570**	**442**	--	**523**	--	--
Fluorescent Tracer														
Eosine	ppb	< 0.0080 U	--	--	--	--	--	--	--	--	--	--	--	--
Fluorescein	ppb	< 0.0005 U	--	--	--	--	--	--	--	--	--	--	--	--
Rhodamine WT	ppb	< 0.0500 U	--	**2220**	**1370**	**1100**	**1320**	--	**748**	**383**	--	--	--	--
Sulforhodamine B	ppb	< 0.0400 U	--	--	--	--	--	--	--	--	--	--	--	--
Field Parameters														
Temperature	deg C	**14.1**	**17.8**	**17.2**	**17.4**	**17.8**	**16.8**	**15.9**	**15.3**	**14.2**	**18.7**	**19.4**	**15.7**	**18.4**
Specific Conductance	uS/cm	**530**	**431.9**	**1568**	**820**	**822**	**822**	**729**	**656**	**597.6**	**710**	**626**	**551.6**	**425.6**
Dissolved Oxygen	mg/L	**0.09**	**0.22**	**0.1**	**0.06**	**0.09**	**0.07**	**0.1**	**0.1**	**0.76**	**0.11**	**0.09**	**0.28**	**0.19**
pH	pH units	**6.62**	**7.1**	**5.97**	**5.29**	**5.28**	**5.08**	**5.31**	**5.77**	**5.82**	**6.32**	**6.21**	**6.1**	**6.11**
Oxidation Reduction Potential	mV	**-53.9**	**-62.8**	**-50.5**	**25.2**	**-179.7**	**-158.9**	**-24.2**	**-37.6**	**4.7**	**-111.2**	**-108.1**	**54.3**	**-13.7**
Turbidity	NTU	**20.1**	**3.3**	**100 E**	**616**	**489**	**218**	**78.8**	**43.1**	**11.3**	**18.9**	**41.1**	**23.5**	**6.96**
Iron, Ferrous, Fe+2	ppm	**2.5**	**6**	**3**	**2.5**	**4**	**3.5**	**4.5**	**6**	**0.5**	**7**	**5**	**1.5**	**2**

Analyte	Unit	DR-02	DR-02	DR-02	DR-02	DR-02	DR-02	DR-02	DR-02	DR-02	DR-02	DR-02	DR-02
		01/30/2018	10/04/2018	10/12/2018	10/19/2018	10/26/2018	11/09/2018	12/06/2018	01/03/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019
		Baseline	Baseline	Day 0	Day 7	Day 14	Day 28	Day 55	Day 83	Day 168	Day 257	Day 342	Day 433
VOCs													
1,1,1-Trichloroethane	ug/L	< 0.20 U	< 2.00 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.40 U	< 0.20 U	< 0.20 U
1,1-Dichloroethane	ug/L	**2.03**	**3.19**	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.40 U	**0.21**	**0.39**
1,1-Dichloroethene	ug/L	**0.53**	< 2.00 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	**5.13**	< 4.00 U	< 0.40 U	< 0.20 U	< 0.20 U
1,2-Dichloroethane (EDC)	ug/L	< 0.20 U	< 2.00 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.40 U	< 0.20 U	< 0.20 U
Chloroethane	ug/L	< 0.20 U	< 2.00 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.40 U	< 0.20 U	< 0.20 U
Tetrachloroethene (PCE)	ug/L	< 0.20 U	< 2.00 U	< 2.00 U	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	< 0.40 U	< 0.20 U	< 0.20 U
Trichloroethene (TCE)	ug/L	**382**	**387**	**211**	**90.2**	**152**	**266**	**358**	**277**	**7.45**	< 0.40 U	**0.08 J**	**0.06 J**
cis-1,2-Dichloroethene (DCE)	ug/L	**124**	**199**	**51.9**	**35.9**	**172**	**123**	**84.2**	**434**	**685**	**151**	**1.63**	**0.46**
trans-1,2-Dichloroethene	ug/L	**7.49**	**8.90**	**3.11**	< 20.0 U	< 20.0 U	< 20.0 U	< 10.0 U	**9.61**	**10.8**	**4.47**	< 0.20 U	**0.08 J**
Vinyl Chloride	ug/L	**9.47**	**19.9**	**2.49**	< 20.0 U	< 20.0 U	< 20.0 U	**10.8**	**22**	**17.6**	**102**	**33.1**	**5.48**
Total Chlorinated Ethenes	umoles/L	**4.42**	**5.41**	**2.22**	**1.06**	**2.93**	**3.29**	**3.76**	**7.09**	**7.52**	**3.24**	**0.547**	**0.0937**
Dissolved Gases													
Ethane	ug/L	**10.2**	**22.1**	**2.94**	**2.80**	**16.4**	**6.24**	**17.6**	**8.99**	< 1.23 U	< 1.23 U	< 1.23 UJ	< 1.23 U
Ethene	ug/L	< 1.14 U	**1.64**	< 1.14 U	< 1.14 U	**1.49**	**1.74**	**5.16**	**5.37**	**2.98**	**1.65**	< 1.14 UJ	**11.6**
Methane	ug/L	**1480**	**3520**	**759**	**927**	**3340**	**2400**	**3900**	**10800**	**17900**	**5560**	**7200 J**	**7820**
General Chemistry Parameters													
Chloride	mg/L	**14.6**	**18.7**	**12.7**	**16.0**	**38.0**	**20.9**	**15.9**	**18.6**	**62.1**	**25.9**	**18.8**	**16.9**
Nitrate as Nitrogen	mg/L	< 0.100 U	< 0.100 U	< 1.00 U	**1.18 J**	< 1.00 U	< 0.100 U	< 0.100 U	< 1 U	--	--	--	--
Nitrite as Nitrogen	mg/L	< 0.100 U	< 0.100 U	< 1.00 U	< 1.00 UJ	< 1.00 U	< 1.00 UJ	< 0.100 U	< 1 U	--	--	--	--
Sulfate	mg/L	**35.7**	**20.1**	**17.1**	**30.3**	**8.71**	**1.44**	**0.746**	< 0.5 U	**1.24**	**2.12**	**0.140**	**0.365**
Total Organic Carbon	mg/L	**5.96**	**5.86**	**10400**	**1724**	**561.4**	**367.6**	**408.2**	**293.4**	**72.82**	**40.86**	**23.35**	**14.42**
Redox-Sensitive Parameters													
Arsenic (Dissolved)	ug/L	**1.55**	--	**3.51**	--	--	**1.89**	--	**4.24**	**6.30**	--	**2.31**	**1.29**
Barium (Dissolved)	ug/L	**10.6**	--	**38.0**	--	--	**3.99**	--	**5.52**	**3.49**	--	**3.41**	**2.51**
Iron (Dissolved)	ug/L	**12300**	**11900**	**223000**	**84700**	**41100**	**58900**	**93700**	**72400**	**43900**	**37800**	**28400**	**19400**
Manganese (Dissolved)	ug/L	**573**	--	**3660**	--	--	**603**	--	**607**	**429**	--	**494**	--
Fluorescent Tracer													
Eosine	ppb	< 0.0080 U	--	--	--	--	--	--	--	--	--	--	--
Fluorescein	ppb	< 0.0005 U	--	--	--	--	--	--	--	--	--	--	--
Rhodamine WT	ppb	< 0.0500 U	--	**3220**	**2160**	**985**	**917**	--	**461**	**433**	--	--	--
Sulforhodamine B	ppb	< 0.0400 U	--	--	--	--	--	--	--	--	--	--	--
Field Parameters													
Temperature	deg C	**13.2**	**16.6**	**17**	**16.6**	**16.6**	**15.8**	**14.7**	**14.4**	**14.1**	**16.3**	**18.6**	**14.5**
Specific Conductance	uS/cm	**397.1**	**439.9**	**1810**	**1177**	**698**	**732**	**843**	**645**	**669**	**524.6**	**446.5**	**341.1**
Dissolved Oxygen	mg/L	**0.13**	**0.3**	**0.07**	**0.08**	**0.05**	**0.11**	**0.23**	**0.13**	**0.36**	**0.24**	**0.1**	**0.16**
pH	pH units	**6.67**	**6.85**	**6.16**	**5.46**	**5.31**	**5.08**	**5.21**	**5.2**	**5.7**	**5.85**	**6.06**	**5.99**
Oxidation Reduction Potential	mV	**-0.3**	**-13.5**	**-85.7**	**-25.1**	**-121**	**-143.7**	**5.5**	**20.4**	**-4.2**	**-54.1**	**-71.6**	**71.9**
Turbidity	NTU	**20.2**	**27.8**	**100 E**	**1100 E**	--	**81.7**	**15.4**	--	**12.7**	**28.6**	**25.1**	**23.1**
Iron, Ferrous, Fe+2	ppm	**6**	**3.5**	**2.5**	**2.5**	**3.5**	**3**	**4**	**6.5**	**1**	**0.5**	**0.5**	**2**

Notes:
Bold = detected

Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Table 2. CVOC Pilot Study Performance Monitoring Results

Project No. 050067, West of 4th - SU1, Seattle, Washington

					Downgradient Performance Wells					
		DR-02	DR-02	DR-02	MW-24	MW-24	MW-24	MW-24	MW-24	MW-24
		03/16/2020	03/20/2020	08/04/2020	01/31/2018	01/04/2019	03/29/2019	06/26/2019	09/20/2019	12/19/2019
Analyte	Unit	Day 521	Day 525	Day 662	Baseline	Day 84	Day 168	Day 257	Day 343	Day 433
VOCs										
1,1,1-Trichloroethane	ug/L	0.20 U	--	< 0.02 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
1,1-Dichloroethane	ug/L	**0.73**	--	--	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
1,1-Dichloroethene	ug/L	0.20 U	--	**0.0191 J**	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
1,2-Dichloroethane (EDC)	ug/L	0.20 U	--	< 0.02 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
Chloroethane	ug/L	0.20 U	--	--	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
Tetrachloroethene (PCE)	ug/L	0.23	--	< 0.02 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
Trichloroethene (TCE)	ug/L	**0.20 U**	--	**0.0692**	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	**0.47**
cis-1,2-Dichloroethene (DCE)	ug/L	**0.20 U**	--	**0.229**	**0.13 J**	< 0.2 U	< 0.20 U	< 0.20 U	**0.15 J**	**0.55**
trans-1,2-Dichloroethene	ug/L	0.06 J	--	**0.0207**	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	**0.06 J**
Vinyl Chloride	ug/L	**4.23**	--	**5.60**	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	**0.07 J**
Total Chlorinated Ethenes	umoles/L	**0.0705**	--	**0.0929**	**0.0013 J**	< 0.003 U	< 0.0032 U	< 0.0032 U	**0.002 J**	**0.0110 J**
Dissolved Gases										
Ethane	ug/L	--	1.63	**3.38**	< 1.23 U	**1.68**	**1.58**	< 1.23 U	< 1.23 U	< 1.23 U
Ethene	ug/L	--	**74.3**	**98.2**	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 U
Methane	ug/L	--	**19700**	**19500**	**11500**	**11200**	**8120**	**3030**	**2900**	**2960**
General Chemistry Parameters										
Chloride	mg/L	--	**14.5**	--	--	--	--	--	--	--
Nitrate as Nitrogen	mg/L	--	--	--	--	--	--	--	--	--
Nitrite as Nitrogen	mg/L	--	--	--	--	--	--	--	--	--
Sulfate	mg/L	--	**1.78**	**9.96**	--	--	--	--	--	--
Total Organic Carbon	mg/L	--	**8.24**	**6.47**	--	--	--	--	--	--
Redox-Sensitive Parameters										
Arsenic (Dissolved)	ug/L	--	--	--	--	--	--	--	--	--
Barium (Dissolved)	ug/L	--	--	--	--	--	--	--	--	--
Iron (Dissolved)	ug/L	--	--	--	--	--	--	--	--	--
Manganese (Dissolved)	ug/L	--	--	--	--	--	--	--	--	--
Fluorescent Tracer										
Eosine	ppb	--	--	--	--	--	--	--	--	--
Fluorescein	ppb	--	--	--	--	--	--	--	--	--
Rhodamine WT	ppb	--	--	--	--	--	--	--	--	--
Sulforhodamine B	ppb	--	--	--	--	--	--	--	--	--
Field Parameters										
Temperature	deg C	**14.6**	--	**17.6**	**11.6**	**13**	**11.4**	**18.9**	**21.5**	**13.2**
Specific Conductance	uS/cm	**429.2**	--	**412.3**	**642**	**720**	**724**	**804**	**762**	**732**
Dissolved Oxygen	mg/L	**0.2**	--	**0.27**	**0.1**	**0.16**	**0.16**	**0.28**	**0.09**	**0.17**
pH	pH units	**5.9**	--	**5.85**	**6.75**	**6.55**	**6.27**	**6.45**	**6.57**	**6.54**
Oxidation Reduction Potential	mV	**-57.7**	--	**29.1**	**-51**	**-40.9**	**33.8**	**-36.5**	**-71.4**	**88.4**
Turbidity	NTU	**11.3**	--	**9.77**	**13**	**13.4**	**3.06**	**9.84**	**10.9**	**29.1**
Iron, Ferrous, Fe+2	ppm	--	--	**5.5**	**1.75**	**3**	**0.5**	--	**1.5**	**1.5**

		Downgradient Performance Wells										
		MW-24-30	MW-24-30	MW-24-30	MW-24-30	MW-24-30	MW-24-30	MW-24-30	MW-24-30	MW-24-30	MW-24-30	MW-24-30
		01/29/2018	11/09/2018	12/06/2018	01/04/2019	03/29/2019	06/26/2019	09/20/2019	12/19/2019	03/16/2020	08/04/2020	
Analyte	Unit	Baseline	Day 28	Day 55	Day 84	Day 168	Day 257	Day 343	Day 433	Day 521	Day 662	
VOCs												
1,1,1-Trichloroethane	ug/L	< 1 U	< 0.20 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	< 0.02 U	
1,1-Dichloroethane	ug/L	**2**	**1.85**	**1.53**	**1.15**	**1.23**	**0.78**	**0.79**	**0.79**	**1.17**	--	
1,1-Dichloroethene	ug/L	**3.24**	**2.06**	**2.31**	**2.14**	< 0.20 U	< 0.20 U	**0.06 J**	**0.24**	**0.74**	**0.0381**	
1,2-Dichloroethane (EDC)	ug/L	< 1 U	< 0.20 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	< 0.02 U	
Chloroethane	ug/L	< 1 U	< 0.20 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	--	
Tetrachloroethene (PCE)	ug/L	< 1 U	< 0.20 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	< 0.02 U	
Trichloroethene (TCE)	ug/L	< 1 UJ	**0.23**	**0.28**	< 1 U	< 0.20 U	< 0.20 U	**0.14 J**	**0.23**	**0.40**	**0.0575**	
cis-1,2-Dichloroethene (DCE)	ug/L	**256**	**202**	**196**	**128**	**9.38**	**37.0**	**7.76**	**20.5**	**41.1**	**1.45**	
trans-1,2-Dichloroethene	ug/L	**9.85**	**8.24**	**8.89**	**7.94**	**1.55**	**1.21**	**0.85**	**0.70**	**1.66**	**0.408**	
Vinyl Chloride	ug/L	**65.1**	**43.5**	**41.6**	**40.5**	**55.5**	**20.8**	**8.17**	**32.1**	**43.5**	**6.95**	
Total Chlorinated Ethenes	umoles/L	**3.82**	**2.88**	**2.80**	**2.07**	**1.00**	**0.727**	**0.221**	**0.737**	**1.15**	**0.131**	
Dissolved Gases												
Ethane	ug/L	**13.6**	**12.9**	**9.31**	**11.8**	**7.88**	**3.43**	< 1.23 U	**1.66**	--	**7.56**	
Ethene	ug/L	**8.82**	**4.55**	**4.32**	**5.73**	**53.4**	**11.8**	**17.7**	**5.63**	--	**28.5**	
Methane	ug/L	**5700**	**5070**	**4750**	**7250**	**19700**	**10100**	**9780**	**4430**	--	**12500**	
General Chemistry Parameters												
Chloride	mg/L	**16.5**	**17.6**	**14.9**	**16.7**	**16.4**	**14.9**	**15.7**	**16.4**	--	--	
Nitrate as Nitrogen	mg/L	< 0.1 U	< 0.100 U	< 0.100 U	< 0.1 U	--	--	--	--	--	--	
Nitrite as Nitrogen	mg/L	< 0.1 U	< 1.00 UJ	< 0.100 U	< 0.1 U	--	--	--	--	--	--	
Sulfate	mg/L	**5.4**	**13.0**	**8.33**	**5.5**	**0.520**	**3.77**	**1.41**	**6.91**	--	**1.97**	
Total Organic Carbon	mg/L	**6.64**	**4.95**	**4.71**	**4.69**	**32.35**	**5.00**	**5.14**	**5.09**	--	**4.5**	
Redox-Sensitive Parameters												
Arsenic (Dissolved)	ug/L	**0.142**	--	--	--	**0.161 J**	--	**0.178 J**	**0.106 J**	--	--	
Barium (Dissolved)	ug/L	**1.63**	--	--	--	**3.29**	--	**1.66**	**2.22**	--	--	
Iron (Dissolved)	ug/L	**4620 J**	**5200**	**6020**	**5090**	**6590**	**5310**	**4700**	**5660**	--	--	
Manganese (Dissolved)	ug/L	**368**	--	--	--	**458**	--	**351**	--	--	--	
Fluorescent Tracer												
Eosine	ppb	< 0.0080 U	--	--	--	--	--	--	--	--	--	
Fluorescein	ppb	< 0.0005 U	--	--	--	--	--	--	--	--	--	
Rhodamine WT	ppb	< 0.0500 U	--	--	--	--	--	--	--	--	--	
Sulforhodamine B	ppb	< 0.0400 U	--	--	--	--	--	--	--	--	--	
Field Parameters												
Temperature	deg C	**13.9**	**15.7**	**15.2**	**15.5**	**14.8**	**17.4**	**17.6**	**15.3**	**15.6**	**17.2**	
Specific Conductance	uS/cm	**343**	**375.3**	**365.7**	**368.3**	**497.2**	**441.3**	**389.1**	**424.3**	**507.9**	**515.2**	
Dissolved Oxygen	mg/L	**0.13**	**0.16**	**0.15**	**0.14**	**0.13**	**0.45**	**0.1**	**3.31**	**0.12**	**0.88**	
pH	pH units	**6.61**	**6.57**	**6.68**	**6.69**	**6.58**	**6.63**	**6.72**	**6.47**	**6.7**	**6.33**	
Oxidation Reduction Potential	mV	**-69.9**	**-76.3**	**-51.2**	**-49.4**	**-26.4**	**-56**	**-74.1**	**53.6**	**16.3**	**44.4**	
Turbidity	NTU	**9.9**	**4.49**	**4.8**	**14.7**	**6.33**	**10.1**	**37.9**	**12.8**	**10**	**5.91**	
Iron, Ferrous, Fe+2	ppm	**6**	**1.5**	**3.5**	**3.5**	**5**	**2**	**1.5**	**4**	--	**1**	

		Downgradient Performance Wells						
		MW-24-50	MW-24-50	MW-24-50	MW-24-50	MW-24-50	MW-24-50	MW-24-50
		01/30/2018	12/06/2018	01/04/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019
Analyte	Unit	Baseline	Day 55	Day 84	Day 168	Day 257	Day 342	Day 433
VOCs								
1,1,1-Trichloroethane	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
1,1-Dichloroethane	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
1,1-Dichloroethene	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
1,2-Dichloroethane (EDC)	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
Chloroethane	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
Tetrachloroethene (PCE)	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
Trichloroethene (TCE)	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	**0.09 J**
cis-1,2-Dichloroethene (DCE)	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	**0.06 J**	**0.16 J**
trans-1,2-Dichloroethene	ug/L	< 0.20 U	< 0.20 U	< 0.2 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
Vinyl Chloride	ug/L	< 0.20 U	< 0.20 U	**0.34**	**0.32**	< 0.20 U	**0.15 J**	**0.20**
Total Chlorinated Ethenes	umoles/L	< 0.0032 U	< 0.0032 U	**0.0054**	**0.0051**	< 0.0032 U	**0.003 J**	**0.00554 J**
Dissolved Gases								
Ethane	ug/L	< 1.23 U	< 1.23 U	< 1.23 U	< 1.23 U	< 1.23 U	< 1.23 U	< 1.23 U
Ethene	ug/L	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 U
Methane	ug/L	**6290**	**15700**	**13500**	**18700**	**7800**	**5620**	**6510**
General Chemistry Parameters								
Chloride	mg/L	**11.1**	**31.1**	**32.3**	**32.9**	**32.7**	**28.2**	**34.6**
Nitrate as Nitrogen	mg/L	< 0.100 U	< 0.100 U	< 0.1 U	--	--	--	--
Nitrite as Nitrogen	mg/L	< 0.100 U	< 0.100 U	< 0.1 U	--	--	--	--
Sulfate	mg/L	**0.198**	< 0.100 U	< 0.1 U	< 0.100 U	< 0.100 U	< 0.100 U	**0.168**
Total Organic Carbon	mg/L	**4.10**	**7.05**	**7.11**	**7.26**	**7.43**	**7.79**	**9.22**
Redox-Sensitive Parameters								
Arsenic (Dissolved)	ug/L	**0.114 J**	--	--	**0.274**	--	**0.192 J**	**0.279**
Barium (Dissolved)	ug/L	--	--	--	**4.45**	--	**4.69**	**4.70**
Iron (Dissolved)	ug/L	**1260**	**743**	**790**	**823**	**799**	**836**	**892**
Manganese (Dissolved)	ug/L	**121**	--	--	**125**	--	**133**	--
Fluorescent Tracer								
Eosine	ppb	< 0.0080 U	--	--	--	--	--	--
Fluorescein	ppb	< 0.0005 U	--	--	--	--	--	--
Rhodamine WT	ppb	< 0.0500 U	--	--	--	--	--	--
Sulforhodamine B	ppb	< 0.0400 U	--	--	--	--	--	--
Field Parameters								
Temperature	deg C	**14.6**	**14.8**	**14.5**	**15.1**	**17**	**18**	**15.1**
Specific Conductance	uS/cm	**101.9**	**480.4**	**468.2**	**481.7**	**489.3**	**431**	**486.6**
Dissolved Oxygen	mg/L	**0.1**	**0.22**	**0.12**	**0.06**	**1.03**	**0.26**	**0.2**
pH	pH units	**6.21**	**7.49**	**7.45**	**7.46**	**7.31**	**7.37**	**7.35**
Oxidation Reduction Potential	mV	**-3.8**	**-109.1**	**-102.2**	**-107.4**	**-89.7**	**-129**	**53**
Turbidity	NTU	**1**	**6.82**	**1.66**	**0.45**	**8.03**	**11.3**	**20.2**
Iron, Ferrous, Fe+2	ppm	**1.5**	**1**	**0.5**	**1**	**0.5**	**0.5**	**1**

Notes:
Bold = detected

Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Table 2. CVOC Pilot Study Performance Monitoring Results
Project No. 050067, West of 4th - SU1, Seattle, Washington

		Downgradient Performance Wells																										
		PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-01	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02	PSW-02
		01/30/2018	10/04/2018	10/12/2018	10/19/2018	10/26/2018	11/09/2018	12/06/2018	01/03/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019	03/16/2020	03/20/2020	08/04/2020	01/30/2018	10/04/2018	10/12/2018	10/19/2018	10/26/2018	11/09/2018	12/06/2018	01/04/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019
Analyte	Unit	Baseline	Baseline	Day 0	Day 7	Day 14	Day 28	Day 55	Day 83	Day 168	Day 257	Day 342	Day 433	Day 521	Day 525	Day 662	Baseline	Baseline	Day 0	Day 7	Day 14	Day 28	Day 55	Day 84	Day 168	Day 257	Day 342	Day 433
VOCs																												
1,1,1-Trichloroethane	ug/L	< 0.20 U	< 1.00 U	--	--	< 0.20 U	< 1.00 U	< 0.20 U	< 0.4 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	--	--	< 1.00 U	< 1.00 U	< 0.20 U	< 1 U	< 1.00 U	< 0.20 U	< 0.20 U	< 0.20 U
1,1-Dichloroethane	ug/L	1.22	1.03	--	--	0.77	1.19	0.61	0.7	1.33	1.37	1.49	1.86	1.98	--	--	1.64	1.77	--	--	1.37	1.16	1.11	2.01	2.16	1.28	0.63	0.28
1,1-Dichloroethene	ug/L	1.42	1.18	--	--	0.95	1.02	0.68	0.43	0.70	< 0.20 U	1.46	1.57	5.62	--	7.15	0.55	< 1.00 U	--	--	< 1.00 U	< 1.00 U	0.26	< 1 U	< 1.00 U	< 0.20 U	< 0.20 U	< 0.20 U
1,2-Dichloroethane (EDC)	ug/L	< 0.20 U	< 1.00 U	--	--	< 0.20 U	< 1.00 U	< 0.20 U	< 0.4 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	--	--	< 1.00 U	< 1.00 U	< 0.20 U	< 1 U	< 1.00 U	< 0.20 U	< 0.20 U	< 0.20 U
Chloroethane	ug/L	< 0.20 U	< 1.00 U	--	--	< 0.20 U	< 1.00 U	< 0.20 U	< 0.4 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	--	--	< 0.20 U	< 1.00 U	--	--	< 1.00 U	< 1.00 U	< 0.20 U	< 1 U	< 1.00 U	< 0.20 U	< 0.20 U	< 0.20 U
Tetrachloroethene (PCE)	ug/L	< 0.20 U	< 1.00 U	--	--	< 0.20 U	< 1.00 U	< 0.20 U	< 0.4 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	--	--	< 1.00 U	< 1.00 U	< 0.20 U	< 1 U	< 1.00 U	< 0.20 U	< 0.20 U	< 0.20 U
Trichloroethene (TCE)	ug/L	20.0	33.0	--	--	15.5	22.5	< 0.20 U	< 0.4 U	1.61	< 0.20 U	5.96	8.20	62.0	--	38.9	45.1	33.8	--	--	23.1	2.71	0.25	< 1 U	< 1.00 U	< 0.20 U	< 0.20 U	< 0.20 U
cis-1,2-Dichloroethene (DCE)	ug/L	107	91.6	--	--	72.9	86.5	136	97.5	34.9	4.29	18.6	16.8	199	--	195	277	324	--	--	281	223	102	147	< 1.00 U	2.74	0.11 J	0.08 J
trans-1,2-Dichloroethene	ug/L	4.36	4.38	--	--	3.71	3.78	2.91	2.26	1.08	0.23	1.46	2.22	7.00	--	6.73	5.82	7.77	--	--	7.40	6.19	3.86	5.08	< 1.00 U	0.27	< 0.20 U	< 0.20 U
Vinyl Chloride	ug/L	16.0	13.8	--	--	15.2	18.0	22.5	40.4	73.7	20.1	47.2	43.6	40.3	--	48.2	16.5	19.8	--	--	33.3	43.4	75.7	100	102	40.6	5.58	0.77
Total Chlorinated Ethenes	umoles/L	1.57	1.47	--	--	1.16	1.40	1.80	1.68	1.57	0.369	1.02	0.972	3.3	--	3.22	3.53	3.99	--	--	3.69	3.08	2.30	3.57	1.63	0.681	0.090	0.0131 J
Dissolved Gases																												
Ethane	ug/L	10.9	7.04	--	--	8.85	8.92	5.71	4.66	9.45	4.41	3.39	5.32	--	16.3	12.5	8.70	10.9	--	--	7.23	3.11	8.11	10.8	7.91	1.94	< 1.23 U	< 1.23 U
Ethene	ug/L	< 1.14 U	2.29	--	--	5.33	3.65	< 1.14 U	1.63	30.7	31.1	10.4	17.7	--	8.06	5.08	< 1.14 U	1.80	--	--	3.30	1.88	2.66	2.54	54.0	14.3	25.8	23.3
Methane	ug/L	11200	8060	--	--	11000	8650	9500	9600	21700	9590	2850	2390	--	2790	5820	5110	5210	--	--	8290	4600	6860	5000	24400	10200	8320	20200
General Chemistry Parameters																												
Chloride	mg/L	18.8	14.8	--	--	15.8	17.9	14.3	14.9	15.8	13.9	17.4	16.6	--	15.2	--	16.8	16.1	--	--	16.4	20.6	15.8	17.1	17.2	14.3	16.9	15.3
Nitrate as Nitrogen	mg/L	< 0.100 U	< 0.100 U	--	--	< 1.00 U	< 0.100 U	< 0.100 U	< 0.1 U	--	--	--	--	--	--	--	< 0.100 U	< 0.100 U	--	--	< 1.00 U	< 0.100 U	< 0.100 U	< 0.1 U	--	--	--	--
Nitrite as Nitrogen	mg/L	< 0.100 U	< 0.100 U	--	--	< 1.00 U	< 1.00 UJ	< 0.100 U	< 0.1 U	--	--	--	--	--	--	--	< 0.100 U	< 0.100 U	--	--	< 1.00 U	< 0.200 R	< 0.100 U	< 0.1 U	--	--	--	--
Sulfate	mg/L	11.1	6.42	--	--	4.61	1.46	< 0.100 U	< 0.1 U	5.57	2.26	20.8	13.0	--	25.6	9.59	11.4	7.06	--	--	< 1.00 U	1.14	< 0.100 U	1.13	< 0.100 U	3.88	0.231	1.25
Total Organic Carbon	mg/L	6.51	5.26	--	--	4.61	110.7	68.21	20.12	12.04	5.57	4.61	4.59	--	4.64	4.71	6.29	5.81	--	--	23.79	110.8	52.09	15.37	25.25	6.09	8.84	8.85
Redox-Sensitive Parameters																												
Arsenic (Dissolved)	ug/L	1.23	--	--	--	--	--	--	--	0.330	--	0.147 J	0.171 J	--	--	--	1.85	--	--	--	--	--	--	--	0.697	--	0.421	0.610
Barium (Dissolved)	ug/L	5.65	--	--	--	--	--	--	--	2.55	--	1.65	1.71	--	--	--	15.4	--	--	--	--	--	--	--	8.81	--	5.99	5.48
Iron (Dissolved)	ug/L	8380	7530	--	--	6340	12300	13200	7270	7480	7070	6480	6430	--	--	--	1340	9330	--	--	7830	11900	11000	8880	11100	9520	12100	12200
Manganese (Dissolved)	ug/L	514	--	--	--	--	--	--	--	288	--	296	--	--	--	--	333	--	--	--	--	--	--	--	589	--	696	--
Fluorescent Tracer																												
Eosine	ppb	< 0.0080 U	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.0080 U	--	--	--	--	--	--	--	--	--	--	--
Fluorescein	ppb	< 0.0005 U	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.0005 U	--	--	--	--	--	--	--	--	--	--	--
Rhodamine WT	ppb	< 0.0500 U	--	--	--	--	< 0.05 U	--	< 0.05 U	--	--	--	--	--	--	--	< 0.0500 U	--	--	--	--	< 0.05 U	--	< 0.05 U	--	--	--	--
Sulforhodamine B	ppb	< 0.0400 U	--	--	--	--	--	--	--	--	--	--	--	--	--	--	< 0.0400 U	--	--	--	--	--	--	--	--	--	--	--
Field Parameters																												
Temperature	deg C	14.7	18.3	17.6	16.6	16.9	16	14.8	14.3	15.9	18.3	18.2	14.6	15.7	--	18.4	14	17	16.4	16.6	16.6	15	13.9	14.2	16.2	18.2	16.4	15.2
Specific Conductance	uS/cm	404	399.5	377.9	365.3	355.9	578.4	479.5	378.5	363.5	359.8	385.8	381.4	445	--	427.1	308.8	435.5	418.1	407.1	416.7	535.9	434	378.3	414.3	427.9	458.3	367.4
Dissolved Oxygen	mg/L	0.09	0.24	0.15	0.11	0.1	0.09	0.13	0.14	0.06	0.12	0.14	0.16	0.21	--	0.17	0.13	0.25	1.3	0.09	0.11	0.46	0.55	0.21	0.08	0.1	0.14	0.23
pH	pH units	6.62	6.93	6.64	6.25	6.62	6.45	6.48	6.42	6.42	6.48	6.66	6.61	6.4	--	6.85	6.76	7.01	6.6	6.47	6.66	6.44	6.59	6.59	6.36	6.35	6.19	6.1
Oxidation Reduction Potential	mV	-46.5	-40.4	-2.8	30.5	-60.6	-93.6	-61.2	-35.7	-36.5	-49.9	-141	23	-66.7	--	-41.4	-3.8	-1	-244	-51	-63.2	-62.5	-63.3	-57	-40.7	-60	-194.1	71.7
Turbidity	NTU	11	1.8	3.4	10.4	2.59	2.05	2.29	4	3.88	3.08	28.1	3.13	11.6	--	1.32	98	10.3	2.7	2.21	3.61	3.72	5.45	5.2	5.06	3.89	23.9	22.6
Iron, Ferrous, Fe+2	ppm	3	5.5	3	3	3.5	4	4.5	3	6	5.5	1.5	3.5	--	--	2	1.5	5.5	3	3	4	2	4.5	4.5	4.5	4	2.5	2

Notes:
Bold = detected

Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Table 2. CVOC Pilot Study Performance Monitoring Results

Project No. 050067, West of 4th - SU1, Seattle, Washington

Analyte	Unit	PSW-02	PSW-02	PSW-02	PSW-03	PSW-03	PSW-03	PSW-03	PSW-03	PSW-03	PSW-03	PSW-03	PSW-03
					Downgradient Performance Wells								
		03/16/2020	03/20/2020	08/04/2020	01/30/2018	10/04/2018	10/12/2018	10/19/2018	10/26/2018	11/09/2018	12/06/2018	01/03/2019	03/29/2019
		Day 521	Day 525	Day 662	Baseline	Baseline	Day 0	Day 7	Day 14	Day 28	Day 55	Day 83	Day 168
VOCs													
1,1,1-Trichloroethane	ug/L	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	--	--	< 1.00 U	< 0.20 U	< 0.20 U	< 1 U	< 1.00 U
1,1-Dichloroethane	ug/L	**0.45**	--	--	**2.19**	**2.04**	--	--	**1.87**	**0.98**	**1.16**	**3.14**	**1.81**
1,1-Dichloroethene	ug/L	0.20 U	--	< 0.02 U	**0.59**	< 1.00 U	--	--	< 1.00 U	**0.21**	**1.07**	**1.79**	**1.92**
1,2-Dichloroethane (EDC)	ug/L	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 UJ	--	--	< 1.00 U	< 0.20 U	< 0.20 U	< 1 U	< 1.00 U
Chloroethane	ug/L	0.20 U	--	--	< 0.20 U	< 1.00 U	--	--	< 1.00 U	< 0.20 U	< 0.20 U	< 1 U	< 1.00 U
Tetrachloroethene (PCE)	ug/L	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	--	--	< 1.00 U	< 0.20 U	< 0.20 U	< 1 U	< 1.00 U
Trichloroethene (TCE)	ug/L	**0.05 J**	--	**0.0198 J**	**328**	**166**	--	--	**232**	**82.4**	**0.65**	< 1 U	**75.5**
cis-1,2-Dichloroethene (DCE)	ug/L	**0.05 J**	--	**0.0543**	**130**	**137**	--	--	**141**	**71.2**	**232**	**419**	**271**
trans-1,2-Dichloroethene	ug/L	0.20 U	--	**0.0112 J**	**5.92**	**8.28**	--	--	**6.75**	**1.96**	**3.47**	**8.25**	**9.30**
Vinyl Chloride	ug/L	0.20 U	--	**0.0838**	**12.0**	**33.3**	--	--	**26.8**	**4.61**	**10.6**	**41.7**	**87.2**
Total Chlorinated Ethenes	umoles/L	**0.000896 J**	--	**0.00217 J**	**4.06**	**3.29**	--	--	**3.72**	**1.46**	**2.61**	**5.09**	**4.89**
Dissolved Gases													
Ethane	ug/L	--	2.60	**13.1**	**7.12**	**17.1**	--	--	**18.1**	**6.97**	**8.15**	**19**	**6.67**
Ethene	ug/L	--	**55.8**	**70.7**	< 1.14 U	**2.53**	--	--	**2.56**	< 1.14 U	< 1.14 U	**6.02**	**10.3**
Methane	ug/L	--	**20000**	**16100**	**1640**	**4690**	--	--	**6070**	**8040**	**3900**	**9560**	**25900**
General Chemistry Parameters													
Chloride	mg/L	--	**14.7**	--	**14.8**	**18.5**	--	--	**17.8**	**34.2**	**14.5**	**0.937**	**19.5**
Nitrate as Nitrogen	mg/L	--	--	--	< 0.100 U	< 0.100 U	--	--	< 1.00 U	< 0.100 U	< 0.100 U	< 0.1 U	--
Nitrite as Nitrogen	mg/L	--	--	--	< 0.100 U	< 0.100 U	--	--	< 1.00 U	< 0.200 R	< 0.100 U	< 0.1 U	--
Sulfate	mg/L	--	**0.188**	1 U	**26.3**	**29.9**	--	--	**12.0**	**0.198**	**0.124**	< 0.1 U	**19.5**
Total Organic Carbon	mg/L	--	**5.65**	**4.86**	**5.30**	**5.73**	--	--	**16.68**	**138.0**	**102.1**	**39.06**	**6.43**
Redox-Sensitive Parameters													
Arsenic (Dissolved)	ug/L	--	--	--	**0.613**	--	--	--	--	--	--	--	**0.173 J**
Barium (Dissolved)	ug/L	--	--	--	**5.82**	--	--	--	--	--	--	--	**1.57**
Iron (Dissolved)	ug/L	--	--	--	**8720**	**10800**	--	--	**9320**	**27100**	**13900**	**9040**	**9660**
Manganese (Dissolved)	ug/L	--	--	--	**352**	--	--	--	--	--	--	--	**267**
Fluorescent Tracer													
Eosine	ppb	--	--	--	< 0.0080 U	--	--	--	--	--	--	--	--
Fluorescein	ppb	--	--	--	< 0.0005 U	--	--	--	--	--	--	--	--
Rhodamine WT	ppb	--	--	--	< 0.0500 U	--	--	--	--	< 0.05 U	--	**47.6**	--
Sulforhodamine B	ppb	--	--	--	< 0.0400 U	--	--	--	--	--	--	--	--
Field Parameters													
Temperature	deg C	**15.3**	--	**19.2**	**13.9**	**16.4**	**16.6**	**16.2**	**16.8**	**15.6**	**14.9**	**15.2**	**14.4**
Specific Conductance	uS/cm	**349.1**	--	**385.3**	**374.2**	**482.1**	**463.2**	**462**	**463**	**777**	**562.2**	**372.4**	**457.5**
Dissolved Oxygen	mg/L	**0.23**	--	**0.19**	**0.16**	**0.27**	**0.14**	**0.08**	**0.1**	**0.08**	**0.33**	**0.09**	**0.17**
pH	pH units	**5.88**	--	**6.64**	**6.51**	**6.85**	**6.65**	**6.41**	**6.6**	**6.25**	**6.2**	**6.22**	**6.22**
Oxidation Reduction Potential	mV	**-39.1**	--	**-46.8**	**-40.9**	**-23.2**	**-9.5**	**-46**	**-65.5**	**-94.6**	**-12.4**	**-22.1**	**-14.2**
Turbidity	NTU	**21.5**	--	**6.07**	**13**	**4.12**	**6.5**	**5.21**	**7.76**	**5.36**	**4.21**	**12**	**3.8**
Iron, Ferrous, Fe+2	ppm	--	--	**4**	**2**	**3**	**3.5**	**3**	**3**	**2.5**	**4**	**5**	**1**

Analyte	Unit	PSW-03	PSW-03	PSW-03	PSW-03	PSW-03	PSW-03	PSW-04	PSW-04	PSW-04	PSW-04	PSW-04	PSW-04	PSW-04	PSW-04	PSW-04
		Downgradient Performance Wells														
		06/26/2019	09/19/2019	12/19/2019	03/16/2020	03/20/2020	08/04/2020	01/30/2018	10/04/2018	12/06/2018	01/03/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019	08/04/2020
		Day 257	Day 342	Day 433	Day 521	Day 525	Day 662	Baseline	Baseline	Day 55	Day 83	Day 168	Day 257	Day 342	Day 433	Day 662
VOCs																
1,1,1-Trichloroethane	ug/L	< 2.00 U	< 0.20 U	< 0.20 U	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U
1,1-Dichloroethane	ug/L	< 2.00 U	**1.05**	**0.73**	**0.76**	--	--	**0.92**	**1.40**	**1.58**	**1.12**	**1.59**	**0.70**	**0.95**	**0.64**	--
1,1-Dichloroethene	ug/L	< 2.00 U	< 0.20 U	< 0.20 U	0.20 U	--	**0.0203**	**0.55**	< 1.00 U	**0.75**	< 1 U	< 0.20 U	< 0.20 U	**0.11 J**	< 0.20 U	**4.24**
1,2-Dichloroethane (EDC)	ug/L	< 2.00 U	< 0.20 U	< 0.20 U	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.02 U
Chloroethane	ug/L	< 2.00 U	**0.46 J**	< 0.20 U	0.20 U	--	--	< 0.20 U	< 1.00 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	--
Tetrachloroethene (PCE)	ug/L	< 2.00 U	< 0.20 U	< 0.20 U	0.20 U	--	< 0.02 U	< 0.20 U	< 1.00 U	< 0.20 U	< 1 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.20 U	< 0.02 U
Trichloroethene (TCE)	ug/L	< 2.00 U	< 0.20 U	< 0.20 U	**0.15 J**	--	**0.0546**	**124**	**63.6**	**49.9**	**4**	< 0.20 U	< 0.20 U	**0.15 J**	< 0.20 U	**8.56**
cis-1,2-Dichloroethene (DCE)	ug/L	**105**	**4.21**	**0.05 J**	**0.13 J**	--	**0.0729**	**158**	**230**	**204**	**253**	**0.42**	**31.7**	**31.3**	**0.13 J**	**118**
trans-1,2-Dichloroethene	ug/L	**2.90**	**0.15 J**	< 0.20 U	0.20 U	--	**0.0132 J**	**6.15**	**9.70**	**6.83**	**7.77**	< 0.20 U	**0.85**	**0.93**	**0.10 J**	**3.63**
Vinyl Chloride	ug/L	**184**	**57.9**	**2.29**	**2.75**	--	**8.04**	**27.4**	**25.9**	**18.9**	**107**	**58.4**	**26.9**	**26.8**	**2.89**	**54.0**
Total Chlorinated Ethenes	umoles/L	**4.05**	**0.971**	**0.0372**	**0.0465**	--	**0.130**	**3.08**	**3.40**	**2.86**	**4.43**	**0.938**	**0.766**	**0.764**	**0.0486**	**2.23**
Dissolved Gases																
Ethane	ug/L	< 1.23 U	< 1.23 U	< 1.23 U	--	**2.84**	**13.3**	**6.93**	**8.61**	**8.67**	**4.68**	**6.87**	**1.65**	< 1.23 U	< 1.23 U	**8.37**
Ethene	ug/L	**18.3**	**33.5**	**12.1**	--	**79.5**	**117**	< 1.14 U	**5.67**	**4.26**	**6.15**	**87.1**	**8.42**	**10.7**	**18.9**	**24.7**
Methane	ug/L	**14400**	**10100**	**6800**	--	**16600**	**13000**	**5660**	**7250**	**8150**	**5960**	**23100**	**15300**	**8980**	**7190**	**13600**
General Chemistry Parameters																
Chloride	mg/L	**17.6**	**18.7**	**16.4**	--	**14.3**	--	**17.0**	**16.4**	**15.8**	**15.9**	**20.8**	**14.6**	**16.1**	**15.3**	--
Nitrate as Nitrogen	mg/L	--	--	--	--	--	--	< 0.100 U	< 0.100 U	< 0.100 U	< 0.1 U	--	--	--	--	--
Nitrite as Nitrogen	mg/L	--	--	--	--	--	--	< 0.100 U	< 0.100 U	< 0.100 U	**0.123**	--	--	--	--	--
Sulfate	mg/L	**3.27**	**0.155**	**0.109**	--	**3.37**	**10.8**	**31.5**	**6.95**	**4.91**	**0.384**	**1.73**	**6.00**	**3.41**	**0.326**	**8.96**
Total Organic Carbon	mg/L	**12.58**	**6.32**	**6.97**	--	**6.51**	**4.73**	**8.31**	**8.02**	**6.50**	**119.2**	**48.41**	**16.57**	**6.59**	**7.17**	**5.2**
Redox-Sensitive Parameters																
Arsenic (Dissolved)	ug/L	--	**0.581**	**0.202**	--	--	--	**2.29**	--	--	--	**0.382**	--	**0.248**	**0.366**	--
Barium (Dissolved)	ug/L	--	**2.17**	**1.63**	--	--	--	**9.89**	--	--	--	**6.93**	--	**7.02**	**8.21**	--
Iron (Dissolved)	ug/L	**12100**	**10400**	**10900**	--	--	--	**4700**	**7740**	**6000**	**12700**	**9640**	**7050**	**8120**	**11500**	--
Manganese (Dissolved)	ug/L	--	**460**	--	--	--	--	**320**	--	--	--	**600**	--	**460**	--	--
Fluorescent Tracer																
Eosine	ppb	--	--	--	--	--	--	< 0.0080 U	--	--	--	--	--	--	--	--
Fluorescein	ppb	--	--	--	--	--	--	< 0.0005 U	--	--	--	--	--	--	--	--
Rhodamine WT	ppb	--	--	--	--	--	--	< 0.0500 U	--	--	--	--	--	--	--	--
Sulforhodamine B	ppb	--	--	--	--	--	--	< 0.0400 U	--	--	--	--	--	--	--	--
Field Parameters																
Temperature	deg C	**17.8**	**17.3**	**15.1**	**14.4**	--	**17.1**	**14.6**	**17**	**14.8**	**14.7**	**14.3**	**18.2**	**18.7**	**14.7**	**17.3**
Specific Conductance	uS/cm	**461.6**	**429.6**	**350.3**	**463.6**	--	**410.9**	**424**	**445.3**	**448.2**	**696**	**575.6**	**517.9**	**519.2**	**561.6**	**441.3**
Dissolved Oxygen	mg/L	**0.17**	**0.18**	**0.35**	**0.69**	--	**0.21**	**0.1**	**0.26**	**0.12**	**0.12**	**0.1**	**0.28**	**0.07**	**0.1**	**0.27**
pH	pH units	**6.13**	**6.15**	**6.15**	**6.08**	--	**6.12**	**6.76**	**7.01**	**6.77**	**6.58**	**6.33**	**6.47**	**6.51**	**6.28**	**6.01**
Oxidation Reduction Potential	mV	**-2.7**	**-66.3**	**61.4**	**-38.8**	--	**-12.3**	**-65.3**	**-42.4**	**-65.9**	**-58.3**	**11.5**	**-80.4**	**-92.3**	**36.6**	**10.1**
Turbidity	NTU	**6.56**	**54.2**	**30.3**	**43.6**	--	**24.4**	**26**	**6.35**	**2.89**	**19**	**1.66**	**9.55**	**10.3**	**4.31**	**3.5**
Iron, Ferrous, Fe+2	ppm	**6.5**	**0.5**	**2**	--	--	**1.5**	**2**	**3.5**	**4.5**	**4.5**	**2**	**1**	**1**	**3.5**	**0.5**

Notes:
Bold = detected

Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Table 2. CVOC Pilot Study Performance Monitoring Results

Project No. 050067, West of 4th - SU1, Seattle, Washington

Analyte	Unit	Upgradient Monitoring Well								Control Well
		PSW-05	PSW-05	PSW-05	PSW-05	PSW-05	PSW-05	PSW-05	PSW-05	PSC-CG-142-40
		01/30/2018	10/04/2018	11/09/2018	01/03/2019	03/29/2019	06/26/2019	09/20/2019	12/19/2019	01/29/2018
		Baseline	Baseline	Day 28	Day 83	Day 168	Day 257	Day 343	Day 433	Baseline
VOCs										
1,1,1-Trichloroethane	ug/L	< 0.20 U	< 1.00 U	< 1.00 U	< 1 U	< 1.00 U	< 1.00 U	< 1.00 U	< 2.00 U	< 0.2 U
1,1-Dichloroethane	ug/L	**0.76**	**3.53**	**4.56**	**1.73**	**2.66**	**2.81**	< 1.00 U	**2.23**	< 0.2 U
1,1-Dichloroethene	ug/L	**0.29**	< 1.00 U	**3.17**	**1.9**	**1.94**	**2.29**	**3.47**	**2.17**	< 0.2 U
1,2-Dichloroethane (EDC)	ug/L	< 0.20 U	< 1.00 U	< 1.00 U	< 1 U	< 1.00 U	< 1.00 U	< 1.00 U	< 2.00 U	< 0.2 U
Chloroethane	ug/L	< 0.20 U	< 1.00 U	< 1.00 U	< 1 U	< 1.00 U	< 1.00 U	< 1.00 U	< 2.00 U	< 0.2 U
Tetrachloroethene (PCE)	ug/L	< 0.20 U	< 1.00 U	< 1.00 U	< 1 U	< 1.00 U	< 1.00 U	< 1.00 U	< 2.00 U	< 0.2 U
Trichloroethene (TCE)	ug/L	**264**	**301**	**381**	**242**	**396**	**444**	**479**	**344**	< 0.2 UJ
cis-1,2-Dichloroethene (DCE)	ug/L	**63.3**	**181**	**364**	**245**	**335**	**433**	**472**	**355**	**0.27**
trans-1,2-Dichloroethene	ug/L	**5.05**	**9.21**	**17.5**	**10.7**	**14.4**	**14.1**	**18.1**	**15.4**	< 0.2 U
Vinyl Chloride	ug/L	**6.61**	**23.7**	**49.3**	**25**	**25.1**	**37.9**	**46.4**	**40.6**	< 0.2 U
Total Chlorinated Ethenes	umoles/L	**2.82**	**4.63**	**7.65**	**4.90**	**7.04**	**8.62**	**9.48**	**7.110**	**0.0028**
Dissolved Gases										
Ethane	ug/L	< 1.23 U	**28.4**	**16.3**	**10.1**	**12.2**	**5.52**	**7.10**	**6.88**	< 1.23 U
Ethene	ug/L	< 1.14 U	**2.23**	**4.60**	< 1.14 U	**3.30**	**1.62**	< 1.14 U	**1.52**	< 1.14 U
Methane	ug/L	**1680**	**3180**	**3930**	**2130**	**4700**	**1190**	**1920**	**1870**	**4810**
General Chemistry Parameters										
Chloride	mg/L	**14.7**	**18.9**	**16.3**	**16.6**	**17.6**	**15.5**	**16.7**	**15.5**	**15.3**
Nitrate as Nitrogen	mg/L	< 0.100 U	< 0.100 U	< 0.100 U	< 0.1 U	--	--	--	--	< 0.1 U
Nitrite as Nitrogen	mg/L	< 0.100 U	< 0.100 U	< 2.00 UJ	< 0.1 U	--	--	--	--	< 0.1 U
Sulfate	mg/L	**16.3**	**25.3**	**35.0**	**25.2**	**25.0**	**17.4**	**24.8**	**21.2**	**0.578**
Total Organic Carbon	mg/L	**6.76**	**6.70**	**4.98**	**4.84**	**4.53**	**4.87**	**4.58**	**5.13**	**4.89**
Redox-Sensitive Parameters										
Arsenic (Dissolved)	ug/L	**1.11**	--	--	--	**0.150 J**	--	--	**0.140 J**	**0.372**
Barium (Dissolved)	ug/L	**12.4**	--	--	--	**3.01**	--	--	**2.89**	**7.63**
Iron (Dissolved)	ug/L	**14000**	**10300**	**9420**	**10900**	**9390**	**9900**	**8070**	**8920**	**2280 J**
Manganese (Dissolved)	ug/L	**566**	--	--	--	**339**	--	--	--	**333**
Fluorescent Tracer										
Eosine	ppb	< 0.0080 U	--	--	--	--	--	--	--	--
Fluorescein	ppb	< 0.0005 U	--	--	--	--	--	--	--	--
Rhodamine WT	ppb	< 0.0500 U	--	--	--	--	--	--	--	--
Sulforhodamine B	ppb	< 0.0400 U	--	--	--	--	--	--	--	--
Field Parameters										
Temperature	deg C	**13.5**	**17**	**15.5**	**14.9**	**15.3**	**16.7**	**17.7**	**14.8**	**14**
Specific Conductance	uS/cm	**419.1**	**460.2**	**411.5**	**445.9**	**392.1**	**386.3**	**383.9**	**370.5**	**330**
Dissolved Oxygen	mg/L	**0.13**	**0.29**	**0.11**	**0.13**	**0.1**	**0.12**	**0.12**	**0.19**	**0.13**
pH	pH units	**6.5**	**7.04**	**6.42**	**6.57**	**6.38**	**6.42**	**6.64**	**6.56**	**6.87**
Oxidation Reduction Potential	mV	**-35**	**-3.3**	**-91.6**	**-39.5**	**18.3**	**3.3**	**-89.7**	**27.4**	**-96.8**
Turbidity	NTU	**12**	**4.42**	**6.52**	**8**	**4.22**	**6.68**	**11.6**	**4.33**	**3.3**
Iron, Ferrous, Fe+2	ppm	**2**	**5.5**	**1.5**	**4**	**1**	**3.5**	**3.5**	**4.5**	**3.5**

Notes:
Bold = detected

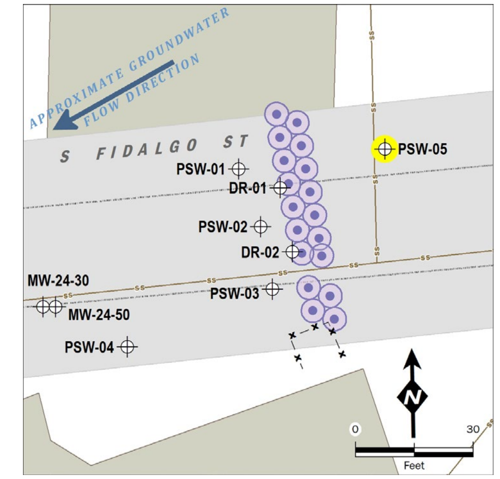
Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Table 3. Performance Monitoring Results - Chlorinated VOCs and Dissolved Gases

Project No. 050067, West of 4th - SU1, Seattle, Washington

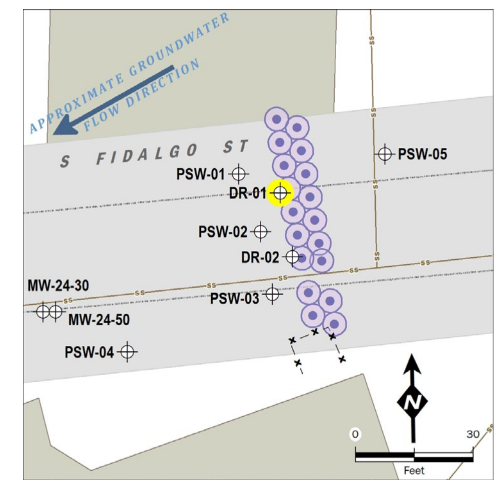
PSW-05 *(Upgradient Monitoring Well)*

		Baseline		*Performance Monitoring*										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/03/2019**	**03/29/2019**	**06/26/2019**	**09/20/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	36	NS	91	176	265	351	441	NS	NS	NS
VOCs														
TCE	ug/L	**264**	**301**	--	**381**	--	**242**	**396**	**444**	**479**	**344**	--	--	--
cis-DCE	ug/L	**63.3**	**181**	--	**364**	--	**245**	**335**	**433**	**472**	**355**	--	--	--
trans-DCE	ug/L	**5.05**	**9.21**	--	**17.5**	--	**10.7**	**14.4**	**14.1**	**18.1**	**15.4**	--	--	--
VC	ug/L	**6.61**	**23.7**	--	**49.3**	--	**25**	**25.1**	**37.9**	**46.4**	**40.6**	--	--	--
Dissolved Gases														
Ethane	ug/L	< 1.23 U	**28.4**	--	**16.3**	--	**10.1**	**12.2**	**5.52**	**7.10**	**6.88**	--	--	--
Ethene	ug/L	< 1.14 U	**2.23**	--	**4.60**	--	< 1.14 U	**3.30**	**1.62**	< 1.14 U	**1.52**	--	--	--



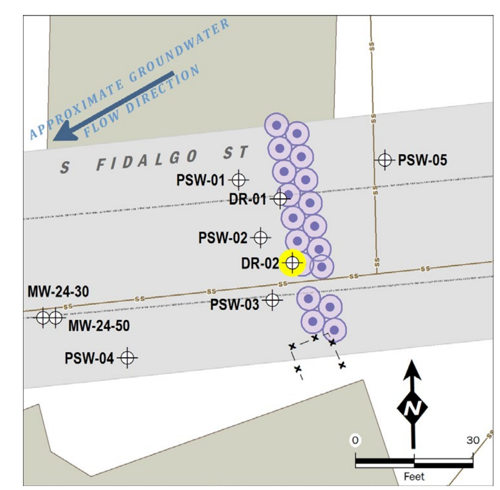
DR-01 *(Dose Response Monitoring Well)*

		Baseline		*Performance Monitoring*										
		01/29/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/04/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-248	0	8	36	63	92	176	265	350	441	NS	NS	670
VOCs														
TCE	ug/L	**53.7 J**	**60.1**	**53.7**	**24.2**	**85.6**	**23.9**	< 4.00 U	< 0.20 U	**0.07 J**	**0.11 J**	--	--	**0.0903**
cis-DCE	ug/L	**201**	**191**	**132**	**114**	**167**	**88.7**	**82.3 J**	**26.8 J**	**10.0**	**3.50 J**	--	--	**0.589**
trans-DCE	ug/L	**4.72**	**4.50**	**3.09**	< 20.0 U	< 10.0 U	< 5 U	< 4.00 U	**0.45**	**0.21**	**0.13 J**	--	--	**0.0268**
VC	ug/L	**13.5**	**12.8**	**3.51**	< 20.0 U	**13.1**	< 5 U	**7.01**	**13.4**	**7.53**	**6.93**	--	--	**15**
Dissolved Gases														
Ethane	ug/L	< 1.23 U	**6.15**	**3.03**	**2.91**	**5.39**	**1.92**	< 1.23 U	< 1.23 U	< 1.23 UJ	< 1.23 U	--	--	**11.9**
Ethene	ug/L	< 1.14 U	**1.29**	< 1.14 U	**1.50**	**2.12**	< 1.14 U	< 1.14 U	< 1.14 U	< 1.14 UJ	< 1.14 U	--	--	**57.5**



DR-02 *(Dose Response Monitoring Well)*

		Baseline		*Performance Monitoring*										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/03/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	8	36	63	91	176	265	350	441	529	533	670
VOCs														
TCE	ug/L	**382**	**387**	**211**	**266**	**358**	**277**	**7.45**	< 0.40 U	**0.08 J**	**0.06 J**	**0.06 J**	--	**0.0692**
cis-DCE	ug/L	**124**	**199**	**51.9**	**123**	**84.2**	**434**	**685**	**151**	**1.63**	**0.46**	**0.23**	--	**0.229**
trans-DCE	ug/L	**7.49**	**8.90**	**3.11**	< 20.0 U	< 10.0 U	**9.61**	**10.8**	**4.47**	< 0.20 U	**0.08 J**	< 0.20 U	--	**0.0207**
VC	ug/L	**9.47**	**19.9**	**2.49**	< 20.0 U	**10.8**	**22**	**17.6**	**102**	**33.1**	**5.48**	**4.23**	--	**5.6**
Dissolved Gases														
Ethane	ug/L	**10.2**	**22.1**	**2.94**	**6.24**	**17.6**	**8.99**	< 1.23 U	< 1.23 U	< 1.23 UJ	< 1.23 U	--	**1.63**	**3.38**
Ethene	ug/L	< 1.14 U	**1.64**	< 1.14 U	**1.74**	**5.16**	**5.37**	**2.98**	**1.65**	< 1.14 UJ	**11.6**	--	**74.3**	**98.2**



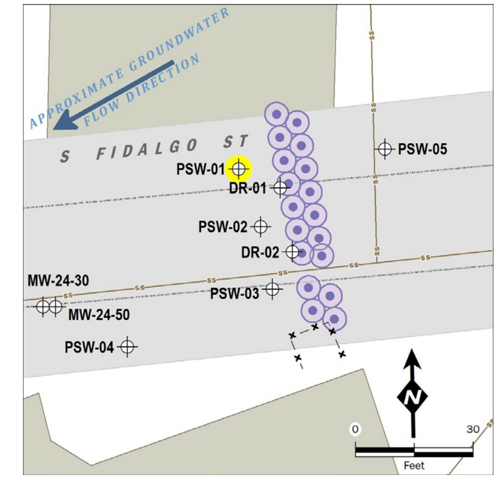
Data Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Notes:
TCE = Trichloroethene
cis-DCE = cis-1,2-Dichloroethene
trans-DCE = trans-1,2-Dichloroethene
VC = Vinyl Chloride
NS = Not Sampled

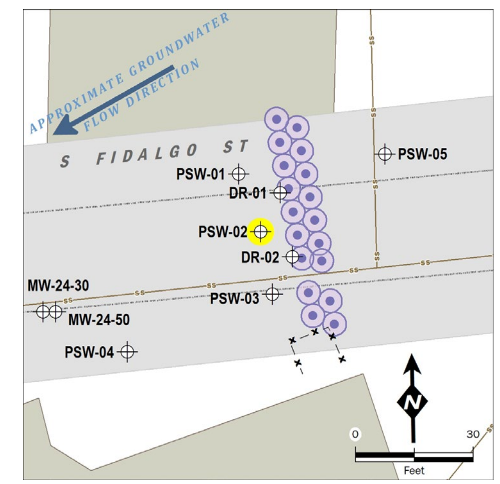
Table 3. Performance Monitoring Results - Chlorinated VOCs and Dissolved Gases

Project No. 050067, West of 4th - SU1, Seattle, Washington

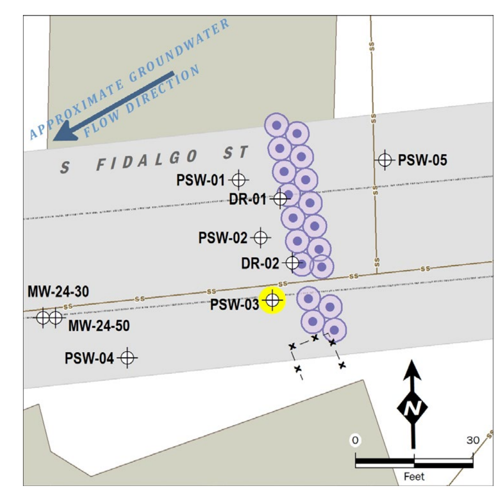
		PSW-01 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/03/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	36	63	91	176	265	350	441	529	533	670
VOCs														
TCE	ug/L	**20.0**	**33.0**	--	**22.5**	< 0.20 U	< 0.4 U	**1.61**	< 0.20 U	**5.96**	**8.20**	**62.0**	--	**38.9**
cis-DCE	ug/L	**107**	**91.6**	--	**86.5**	**136**	**97.5**	**34.9**	**4.29**	**18.6**	**16.8**	**199**	--	**195**
trans-DCE	ug/L	**4.36**	**4.38**	--	**3.78**	**2.91**	**2.26**	**1.08**	**0.23**	**1.46**	**2.22**	**7.00**	--	**6.73**
VC	ug/L	**16.0**	**13.8**	--	**18.0**	**22.5**	**40.4**	**73.7**	**20.1**	**47.2**	**43.6**	**40.3**	--	**48.2**
Dissolved Gases														
Ethane	ug/L	**10.9**	**7.04**	--	**8.92**	**5.71**	**4.66**	**9.45**	**4.41**	**3.39**	**5.32**	--	**16.3**	**12.5**
Ethene	ug/L	< 1.14 U	**2.29**	--	**3.65**	< 1.14 U	**1.63**	**30.7**	**31.1**	**10.4**	**17.7**	--	**8.06**	**5.08**



		PSW-02 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/04/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	36	63	92	176	265	350	441	529	533	670
VOCs														
TCE	ug/L	**45.1**	**33.8**	--	**2.71**	**0.25**	< 1 U	< 1.00 U	< 0.20 U	< 0.20 U	< 0.20 U	**0.05 J**	--	**0.0198 J**
cis-DCE	ug/L	**277**	**324**	--	**223**	**102**	**147**	< 1.00 U	**2.74**	**0.11 J**	**0.08 J**	**0.05 J**	--	**0.0543**
trans-DCE	ug/L	**5.82**	**7.77**	--	**6.19**	**3.86**	**5.08**	< 1.00 U	**0.27**	< 0.20 U	< 0.20 U	< 0.20 U	--	**0.0112 J**
VC	ug/L	**16.5**	**19.8**	--	**43.4**	**75.7**	**100**	**102**	**40.6**	**5.58**	**0.77**	< 0.20 U	--	**0.0838**
Dissolved Gases														
Ethane	ug/L	**8.70**	**10.9**	--	**3.11**	**8.11**	**10.8**	**7.91**	**1.94**	< 1.23 U	< 1.23 U	--	**2.60**	**13.1**
Ethene	ug/L	< 1.14 U	**1.80**	--	**1.88**	**2.66**	**2.54**	**54.0**	**14.3**	**25.8**	**23.3**	--	**55.8**	**70.7**



		PSW-03 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/03/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	36	63	91	176	265	350	441	529	533	670
VOCs														
TCE	ug/L	**328**	**166**	--	**82.4**	**0.65**	< 1 U	**75.5**	< 2.00 U	< 0.20 U	< 0.20 U	**0.15 J**	--	**0.0546**
cis-DCE	ug/L	**130**	**137**	--	**71.2**	**232**	**419**	**271**	**105**	**4.21**	**0.05 J**	**0.13 J**	--	**0.0729**
trans-DCE	ug/L	**5.92**	**8.28**	--	**1.96**	**3.47**	**8.25**	**9.30**	**2.90**	**0.15 J**	< 0.20 U	< 0.20 U	--	**0.0132 J**
VC	ug/L	**12.0**	**33.3**	--	**4.61**	**10.6**	**41.7**	**87.2**	**184**	**57.9**	**2.29**	**2.75**	--	**8.04**
Dissolved Gases														
Ethane	ug/L	**7.12**	**17.1**	--	**6.97**	**8.15**	**19**	**6.67**	< 1.23 U	< 1.23 U	< 1.23 U	--	**2.84**	**13.3**
Ethene	ug/L	< 1.14 U	**2.53**	--	< 1.14 U	< 1.14 U	**6.02**	**10.3**	**18.3**	**33.5**	**12.1**	--	**79.5**	**117**



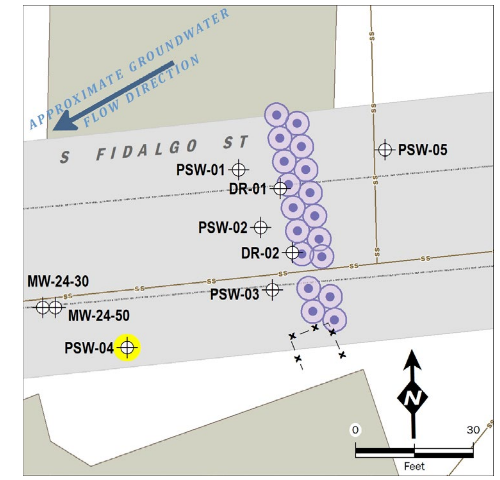
Data Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Notes:
TCE = Trichloroethene
cis-DCE = cis-1,2-Dichloroethene
trans-DCE = trans-1,2-Dichloroethene
VC = Vinyl Chloride
NS = Not Sampled

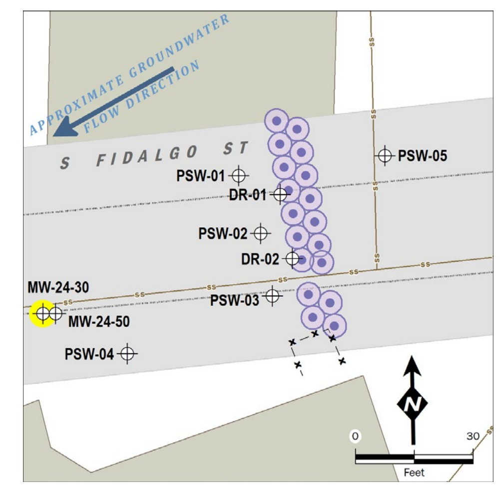
Table 3. Performance Monitoring Results - Chlorinated VOCs and Dissolved Gases

Project No. 050067, West of 4th - SU1, Seattle, Washington

		PSW-04 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/03/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	NS	63	91	176	265	350	441	NS	NS	670
VOCs														
TCE	ug/L	**124**	**63.6**	--	--	**49.9**	**4**	< 0.20 U	< 0.20 U	**0.15 J**	< 0.20 U	--	--	**8.56**
cis-DCE	ug/L	**158**	**230**	--	--	**204**	**253**	**0.42**	**31.7**	**31.3**	**0.13 J**	--	--	**118**
trans-DCE	ug/L	**6.15**	**9.70**	--	--	**6.83**	**7.77**	< 0.20 U	**0.85**	**0.93**	**0.10 J**	--	--	**3.63**
VC	ug/L	**27.4**	**25.9**	--	--	**18.9**	**107**	**58.4**	**26.9**	**26.8**	**2.89**	--	--	**54**
Dissolved Gases														
Ethane	ug/L	**6.93**	**8.61**	--	--	**8.67**	**4.68**	**6.87**	**1.65**	< 1.23 U	< 1.23 U	--	--	**8.37**
Ethene	ug/L	< 1.14 U	**5.67**	--	--	**4.26**	**6.15**	**87.1**	**8.42**	**10.7**	**18.9**	--	--	**24.7**



		MW-24-30 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/29/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/04/2019**	**03/29/2019**	**06/26/2019**	**09/20/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-248	NS	NS	36	63	92	176	265	351	441	529	NS	670
VOCs														
TCE	ug/L	< 1 UJ	--	--	**0.23**	**0.28**	< 1 U	< 0.20 U	< 0.20 U	**0.14 J**	**0.23**	**0.40**	--	**0.0575**
cis-DCE	ug/L	**256**	--	--	**202**	**196**	**128**	**9.38**	**37.0**	**7.76**	**20.5**	**41.1**	--	**1.45**
trans-DCE	ug/L	**9.85**	--	--	**8.24**	**8.89**	**7.94**	**1.55**	**1.21**	**0.85**	**0.70**	**1.66**	--	**0.408**
VC	ug/L	**65.1**	--	--	**43.5**	**41.6**	**40.5**	**55.5**	**20.8**	**8.17**	**32.1**	**43.5**	--	**6.95**
Dissolved Gases														
Ethane	ug/L	**13.6**	--	--	**12.9**	**9.31**	**11.8**	**7.88**	**3.43**	< 1.23 U	**1.66**	--	--	**7.56**
Ethene	ug/L	**8.82**	--	--	**4.55**	**4.32**	**5.73**	**53.4**	**11.8**	17.7	**5.63**	--	--	**28.5**



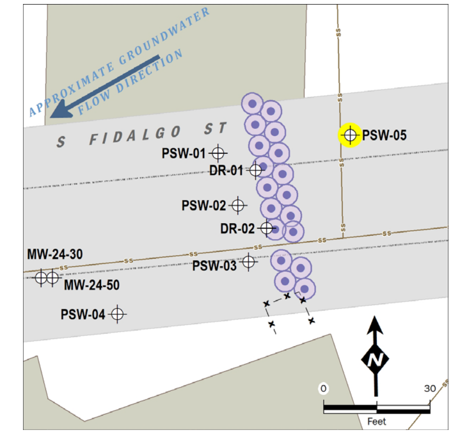
Data Qualifiers:
J = estimated
U = non-detect
UJ = estimated, non-detect
E = exceeded calibration range
R = rejected, do not use

Notes:
TCE = Trichloroethene
cis-DCE = cis-1,2-Dichloroethene
trans-DCE = trans-1,2-Dichloroethene
VC = Vinyl Chloride
NS = Not Sampled

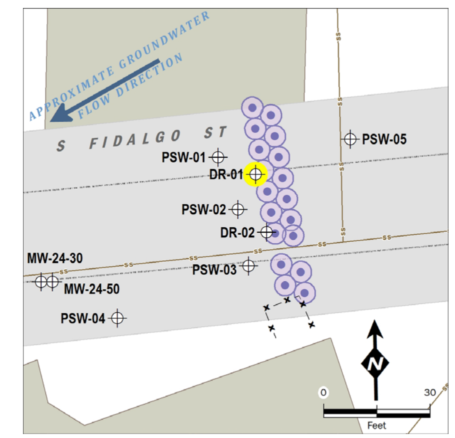
Table 4. Performance Monitoring Results - Redox Indicators

Project No. 050067, West of 4th - SU1, Seattle, Washington

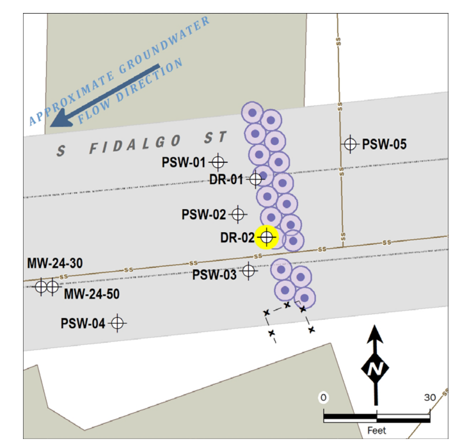
		PSW-05 *(Upgradient Monitoring Well)*												
		Baseline		**Performance Monitoring**										
		01/30/2018	10/04/2018	10/12/2018	11/09/2018	12/06/2018	01/03/2019	03/29/2019	06/26/2019	09/20/2019	12/19/2019	03/16/2020	03/20/2020	8/4/2020
Days Elapsed		-247	0	NS	36	NS	91	176	265	351	441	NS	NS	NS
Redox Indicators														
TOC	mg/L	**6.76**	**6.70**	--	**4.98**	--	**4.84**	**4.53**	**4.87**	**4.58**	**5.13**	--	--	--
Methane	ug/L	**1680**	**3180**	--	**3930**	--	**2130**	**4700**	**1190**	**1920**	**1870**	--	--	--
Sulfate	mg/L	**16.3**	**25.3**	--	**35.0**	--	**25.2**	**25.0**	**17.4**	**24.8**	**21.2**	--	--	--



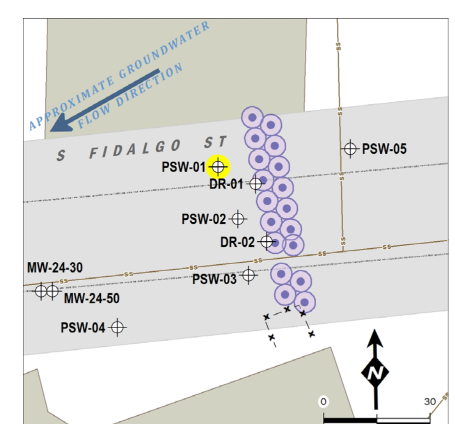
		DR-01 *(Dose Response Monitoring Well)*												
		Baseline		**Performance Monitoring**										
		01/29/2018	10/04/2018	10/12/2018	11/09/2018	12/06/2018	01/04/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019	03/16/2020	03/20/2020	8/4/2020
Days Elapsed		-248	0	8	36	63	92	176	265	350	441	NS	NS	670
Redox Indicators														
TOC	mg/L	**18.2**	**5.86**	**7715**	**457.6**	**374.5**	**236.2**	**47.47**	**19.51**	**19.59**	**17.62**	--	--	**8.79**
Methane	ug/L	**7210**	**5070**	**1040**	**4970**	**7990**	**17900**	**23000**	**9270**	**3980**	**4820**	--	--	**21300**
Sulfate	mg/L	**40.5**	**6.05**	**16.2**	< 5.00 U	< 0.100 U	**0.577**	< 1.00 U	**1.41**	**1.50**	**1.80**	--	--	< 2.00 U



		DR-02 *(Dose Response Monitoring Well)*												
		Baseline		**Performance Monitoring**										
		01/30/2018	10/04/2018	10/12/2018	11/09/2018	12/06/2018	01/03/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019	03/16/2020	03/20/2020	8/4/2020
Days Elapsed		-247	0	8	36	63	91	176	265	350	441	NS	533	670
Redox Indicators														
TOC	mg/L	**5.96**	**5.86**	**10400**	**367.6**	**408.2**	**293.4**	**72.82**	**40.86**	**23.35**	**14.42**	--	**8.24**	**6.47**
Methane	ug/L	**1480**	**3520**	**759**	**2400**	**3900**	**10800**	**17900**	**5560**	**7200 J**	**7820**	--	**19700**	**19500**
Sulfate	mg/L	**35.7**	**20.1**	**17.1**	**1.44**	**0.746**	< 0.5 U	**1.24**	**2.12**	**0.140**	**0.365**	--	**1.78**	**9.96**



		PSW-01 *(Downgradient Performance Monitoring Well)*												
		Baseline		**Performance Monitoring**										
		01/30/2018	10/04/2018	10/12/2018	11/09/2018	12/06/2018	01/03/2019	03/29/2019	06/26/2019	09/19/2019	12/19/2019	03/16/2020	03/20/2020	8/4/2020
Days Elapsed		-247	0	NS	36	63	91	176	265	350	441	NS	533	670
Redox Indicators														
TOC	mg/L	**6.51**	**5.26**	--	**110.7**	**68.21**	**20.12**	**12.04**	**5.57**	**4.61**	**4.59**	--	**4.64**	**4.71**
Methane	ug/L	**11200**	**8060**	--	**8650**	**9500**	**9600**	**21700**	**9590**	**2850**	**2390**	--	**2790**	**5820**
Sulfate	mg/L	**11.1**	**6.42**	--	**1.46**	< 0.100 U	< 0.1 U	**5.57**	**2.26**	**20.8**	**13.0**	--	**25.6**	**9.59**

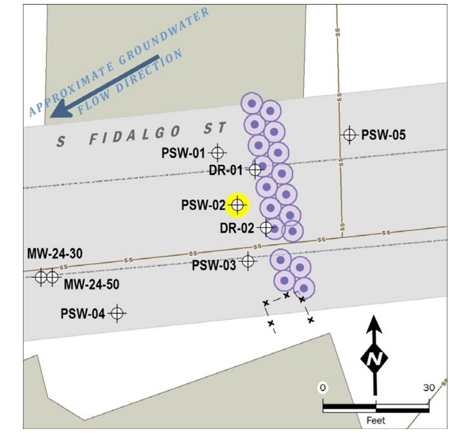


Notes:
TOC - Total Organic Carbon
J = estimated
U = non-detect
NS = Not Sampled
Additional performance monitoring events occurred one and two weeks-post injection but not included on this figure due to space limitations.

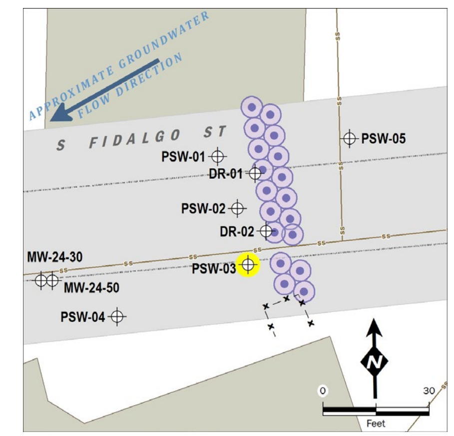
Table 4. Performance Monitoring Results - Redox Indicators

Project No. 050067, West of 4th - SU1, Seattle, Washington

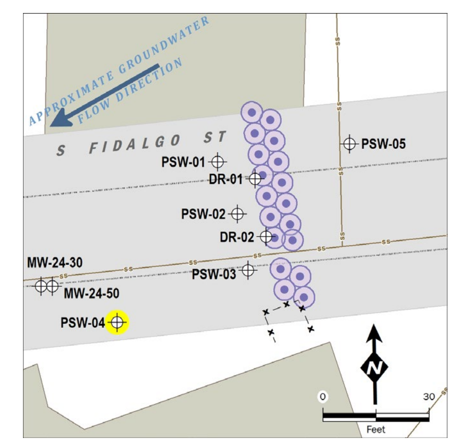
		PSW-02 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/04/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	36	63	92	176	265	350	441	NS	533	670
Redox Indicators														
TOC	mg/L	**6.29**	**5.81**	--	**110.8**	**52.09**	**15.37**	**25.25**	**6.09**	**8.84**	**8.85**	--	**5.65**	**4.86**
Methane	ug/L	**5110**	**5210**	--	**4600**	**6860**	**5000**	**24400**	**10200**	**8320**	**20200**	--	**20000**	**16100**
Sulfate	mg/L	**11.4**	**7.06**	--	**1.14**	< 0.100 U	**1.13**	< 0.100 U	**3.88**	**0.231**	**1.25**	--	**0.188**	< 1.00 U



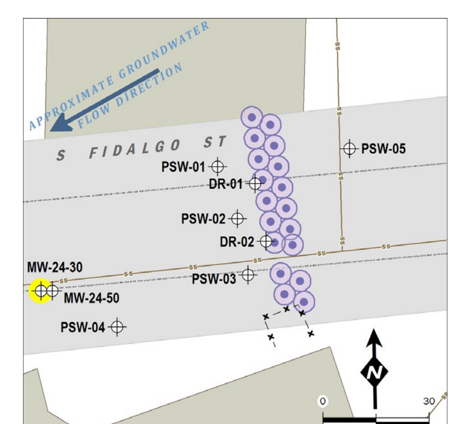
		PSW-03 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/03/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	36	63	91	176	265	350	441	NS	533	670
Redox Indicators														
TOC	mg/L	**5.30**	**5.73**	--	**138.0**	**102.1**	**39.06**	**6.43**	**12.58**	**6.32**	**6.97**	--	**6.51**	**4.73**
Methane	ug/L	**1640**	**4690**	--	**8040**	**3900**	**9560**	**25900**	**14400**	**10100**	**6800**	--	**16600**	**13000**
Sulfate	mg/L	**26.3**	**29.9**	--	**0.198**	**0.124**	< 0.1 U	**19.5**	**3.27**	**0.155**	**0.109**	--	**3.37**	**10.80**



		PSW-04 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/30/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/03/2019**	**03/29/2019**	**06/26/2019**	**09/19/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-247	0	NS	NS	63	91	176	265	350	441	NS	NS	670
Redox Indicators														
TOC	mg/L	**8.31**	**8.02**	--	--	**6.50**	**119.2**	**48.41**	**16.57**	**6.59**	**7.17**	--	--	**5.2**
Methane	ug/L	**5660**	**7250**	--	--	**8150**	**5960**	**23100**	**15300**	**8980**	**7190**	--	--	**13600**
Sulfate	mg/L	**31.5**	**6.95**	--	--	**4.91**	**0.384**	**1.73**	**6.00**	**3.41**	**0.326**	--	--	**8.96**



		MW-24-30 *(Downgradient Performance Monitoring Well)*												
		Baseline		***Performance Monitoring***										
		01/29/2018	**10/04/2018**	**10/12/2018**	**11/09/2018**	**12/06/2018**	**01/04/2019**	**03/29/2019**	**06/26/2019**	**09/20/2019**	**12/19/2019**	**03/16/2020**	**03/20/2020**	**8/4/2020**
Days Elapsed		-248	NS	NS	36	63	92	176	265	351	441	NS	NS	670
Redox Indicators														
TOC	mg/L	**6.64**	--	--	**4.95**	**4.71**	**4.69**	**32.35**	**5.00**	**5.14**	**5.09**	--	--	**4.5**
Methane	ug/L	**5700**	--	--	**5070**	**4750**	**7250**	**19700**	**10100**	**9780**	**4430**	--	--	**12500**
Sulfate	mg/L	**5.4**	--	--	**13.0**	**8.33**	**5.5**	**0.520**	**3.77**	**1.41**	**6.91**	--	--	**1.97**



Notes:
TOC - Total Organic Carbon
J = estimated
U = non-detect
NS = Not Sampled
Additional performance monitoring events occurred one and two weeks-post injection but not included on this figure due to space limitations.

Table 5. Soil Gas Monitoring Results

Project No. 050067, West of 4th - SU1, Seattle, WA

Date	Days Post-Injection	SG-01			SG-02			SG-03			SG-04S			SG-04D			SG-05			SG-06		
		CH_4 (%volume)	CO_2 (%volume)	O_2 (%volume)	CH_4 (%volume)	CO_2 (%volume)	O_2 (%volume)	CH_4 (%volume)	CO_2 (%volume)	O_2 (%volume)	CH_4 (%volume)	CO_2 (%volume)	O_2 (%volume)	CH_4 (%volume)	CO_2 (%volume)	O_2 (%volume)	CH_4 (%volume)	CO_2 (%volume)	O_2 (%volume)	CH_4 (%volume)	CO_2 (%volume)	O_2 (%volume)
7/18/2018	Baseline	0	15.5	1.3	0	15.5	2	9.4	12.5	0.6												
8/13/2018	Baseline	0	16.7	1.2	0	16.2	1.9	9.2	12.9	0.5												
11/21/2018	Day 40	0	11.6	4.4	0	12	2	9.3	10.2	0												
3/29/2019	Day 168	22	11.9	0	18.6	10.9	0	8.5	8.7	0												
4/5/2019	Day 175	26.7	12.5	-	22.5	11.6	-	9	9.4	-	Probes SG-04S, SG-04D, SG-05, and SG-06 were installed on June 1, 2019											
4/12/2019	Day 182	28.7	12.3	0	25.3	11.8	0	8.7	9.3	0												
4/19/2019	Day 189	31.1	12.2	0	28.5	11.7	0	8.8	9.2	0												
4/26/2019	Day 196	34.6	12.1	0	30.5	11.7	0	8.8	9.2	0												
5/3/2019	Day 203	37.1	12.8	0	31.5	12.3	0	9.2	9.7	0												
6/1/2019	Day 232	47.8	13.7	0	37.1	13.4	0	10.0	10.5	0	3.3	9.5	3.6	5.3	12.1	0	8.1	11.2	0	7.0	7.2	10.4
6/7/2019	Day 238	48.4	13.6	0	39.4	13.6	0	10.6	11.3	0	2.7	11.1	2..7	5.2	13.3	0	8.9	12.7	0	15.7	14.3	0
6/26/2019	Day 257	48.8	15.1	0	41.5	15.3	0	10.3	12.2	0	4.9	14.1	0	6.1	14.4	0	9.7	14.1	0	17.7	15.7	0
7/26/2019	Day 287	44.1	14.2	0	44.9	13.6	0	10.4	12.3	0	7.5	13.6	0	8.6	13.6	0	10.7	14	0	17.8	15	0
8/23/2019	Day 315	42.7	16.1	0	46.2	14.7	0	10.8	13.1	0	8.6	14.4	0	9.4	14.5	0	10.6	15.5	0	17.5	16.4	0
9/23/2019	Day 346	36.6	15.5	0	43.8	13.9	0	11.3	12.5	0	11.6	14	0	11.6	14	0	9.1	15.1	0	15.8	15.3	0
10/25/2019	Day 378	32.2	15	0	40.9	13.7	0	12.2	12.4	0	14.2	14.3	0	14.1	14.4	0	7.4	15.4	0	14.6	16	0
11/22/2019	Day 406	27.1	14.7	0	37.7	13.2	0	11.5	11.8	0	11.2	14.4	0	12.2	14.5	0	3.8	15.6	0	12.8	15.8	0
12/20/2019	Day 434	21.7	13.6	0	34.4	12.3	0	10.5	10.6	0	12.3	13.4	0	12.9	13.5	0	0.6	13.7	0	9.1	14.2	0
1/28/2020	Day 473	16.7	12	0	27.8	11	0	9.8	8.8	0	10.4	11.4	0	10.7	11.6	0	0	11	3.1	5.2	11.7	0
2/28/2020	Day 504	15.1	13.4	0	23.5	11.6	0	8.5	9.1	0	5.9	13.2	0	6.8	13	0	0.1	11.9	1	5.9	12.1	0
3/20/2020	Day 525	13.1	12.5	0	21.5	10.5	0.2	9.1	8.3	0	4.2	11.8	0	2.9	11.9	0	0	10.5	3.2	8.2	11.2	0
4/24/2020	Day 560	12.3	15.6	0	19.3	13.4	0	9	10.8	0	2.5	14.6	0	3.1	14.7	0	0	13.4	0.3	8.6	14	0
5/27/2020	Day 593	11	16.2	0	18.6	14.8	0	9.9	11.2	0	3.3	15.4	0	3.5	15.4	0	0	13.6	1.6	7.8	14.7	0
6/26/2020	Day 623	11.4	16.7	0	16.8	15.8	0	11.8	11.9	0	3.6	16	0	4	15.9	0	0	14.9	0	9.6	15.2	0
7/24/2020	Day 651	9.5	19.1	0	13.1	17.3	0	11	13.2	0	1.4	16.9	0	1.8	17	0	0	16.9	0.1	9.2	16.6	0
8/19/2020	Day 677	9.3	19.1	0	11.6	17.3	0	11.2	12.8	0.8	0.6	14.4	2.6	0.6	8.8	10.3	0	12.1	6.7	9.4	15	1.7
9/25/2020	Day 714	7.7	17	0	5.6	10.3	7.4	10	12	0	0	14	0.3	0	14.4	0	0	13.5	3.2	8.7	15.1	0

Notes:

- = O_2 sensor not operational

Table 6. Microbiological Results

Project No. 050067, West of 4th - SU1, Seattle, Washington

Analyte	Units	DR-01 02/28/2018 DR-1-022818	DR-01 03/29/2019 DR-1-032919	MW-24-30 02/28/2018 MW-24-30-022818	MW-24-30 03/29/2019 MW-24-30-032919P	PSC-CG-142-40 02/28/2018 PSC-CG-142-40-022818	PSC-CG-142-40 03/29/2019 PSC-CG-142-40-032919
CENSUS							
Dehalococcoides (DHC)	cells/bead	**32.9**	25 U	25 U	**3380**	**5.20 J**	**27.3**
PLFA							
Anaerobic metal reducers (BrMonos)	%	0 U	**0.89**	0 U	**0.52**	0 U	0 U
Decreased Permeability	ratio trans/cis	**0.213**	**0.147**	**0.177**	**0.0545**	0 U	0 U
Eukaryotes (polyenoics)	%	**1.16**	**8.14**	**1.43**	0 U	**0.7**	**25.1**
Firmicutes (TerBrSats)	%	**12.8**	**7.56**	0 U	**5.03**	**0.77**	0 U
Normal Saturated (Nsats)	%	**16.5**	**34.4**	**22.7**	**26.8**	**26.0**	**46.2**
Proteobacteria (Monos)	%	**65.3**	**48.4**	**75.9**	**67.7**	**72.6**	**28.7**
Slowed Growth	ratio cy/cis	**0.111**	**0.411**	**0.226**	**0.116**	**0.328**	**0.520**
SRB/Actinomycetes (MidBrSats)	%	**4.24**	**0.65**	0 U	0 U	0 U	0 U
Total Biomass	cells/bead	**3.88E+05**	**1.90E+06**	**9.25E+04**	**4.55E+05**	**1.30E+05**	**8.72E+04**

Notes:

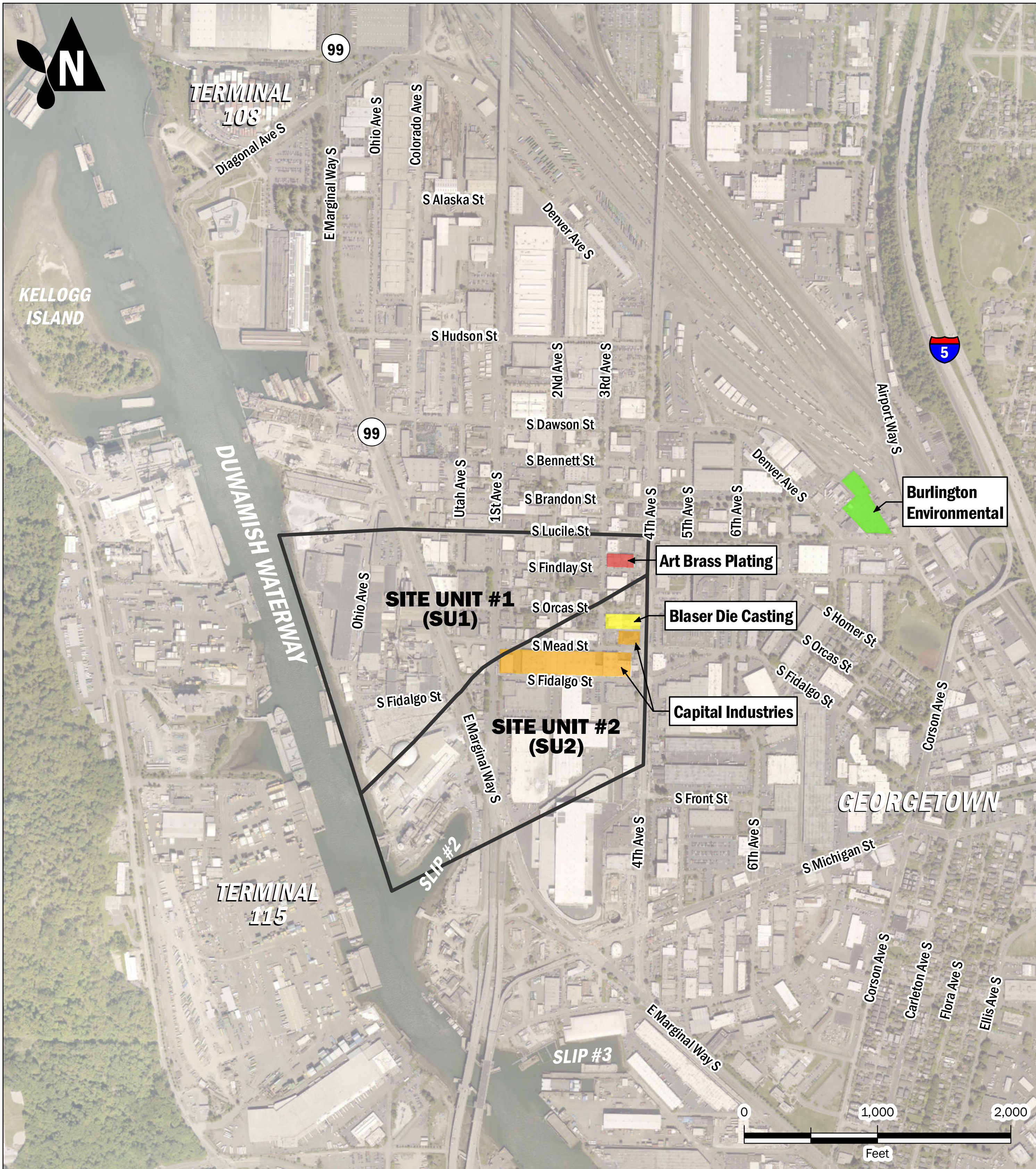
J - Analyte was positively identified below the reporting limit. The reported result is an estimate.

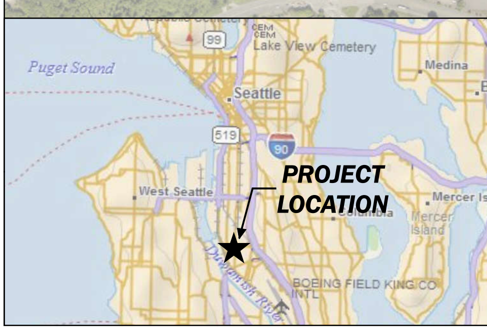
U - Analyte was not detected at or above the reported result.

Bold = detected

FIGURES

CVOC Pilot Study Completion Report



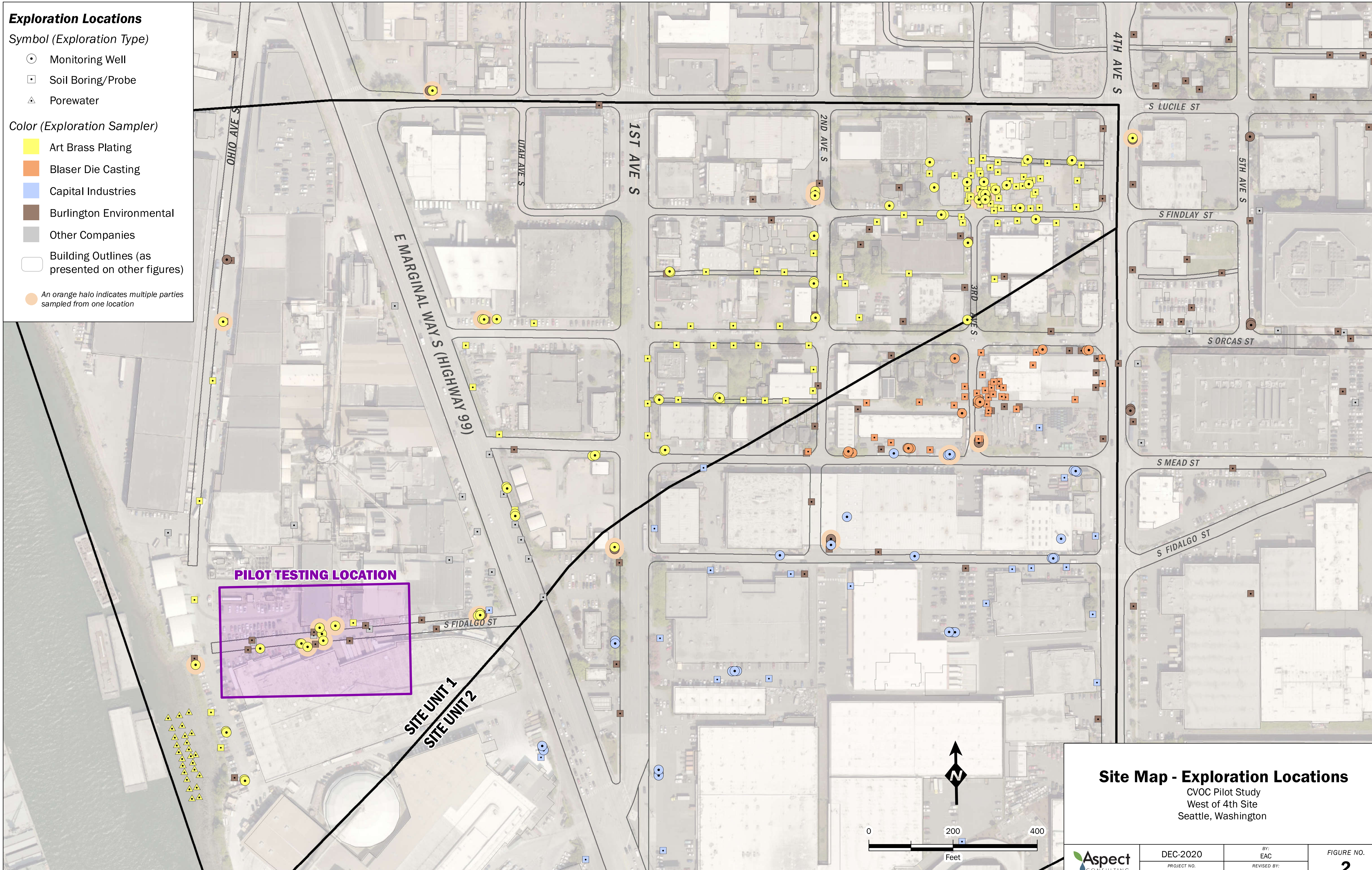


Site Diagram

CVOC Pilot Study
West of 4th Site
Seattle, Washington

Aspect CONSULTING	DEC-2020	BY: PPW	FIGURE: 1
	PROJECT NO. 050067	REVISED BY: EAC	

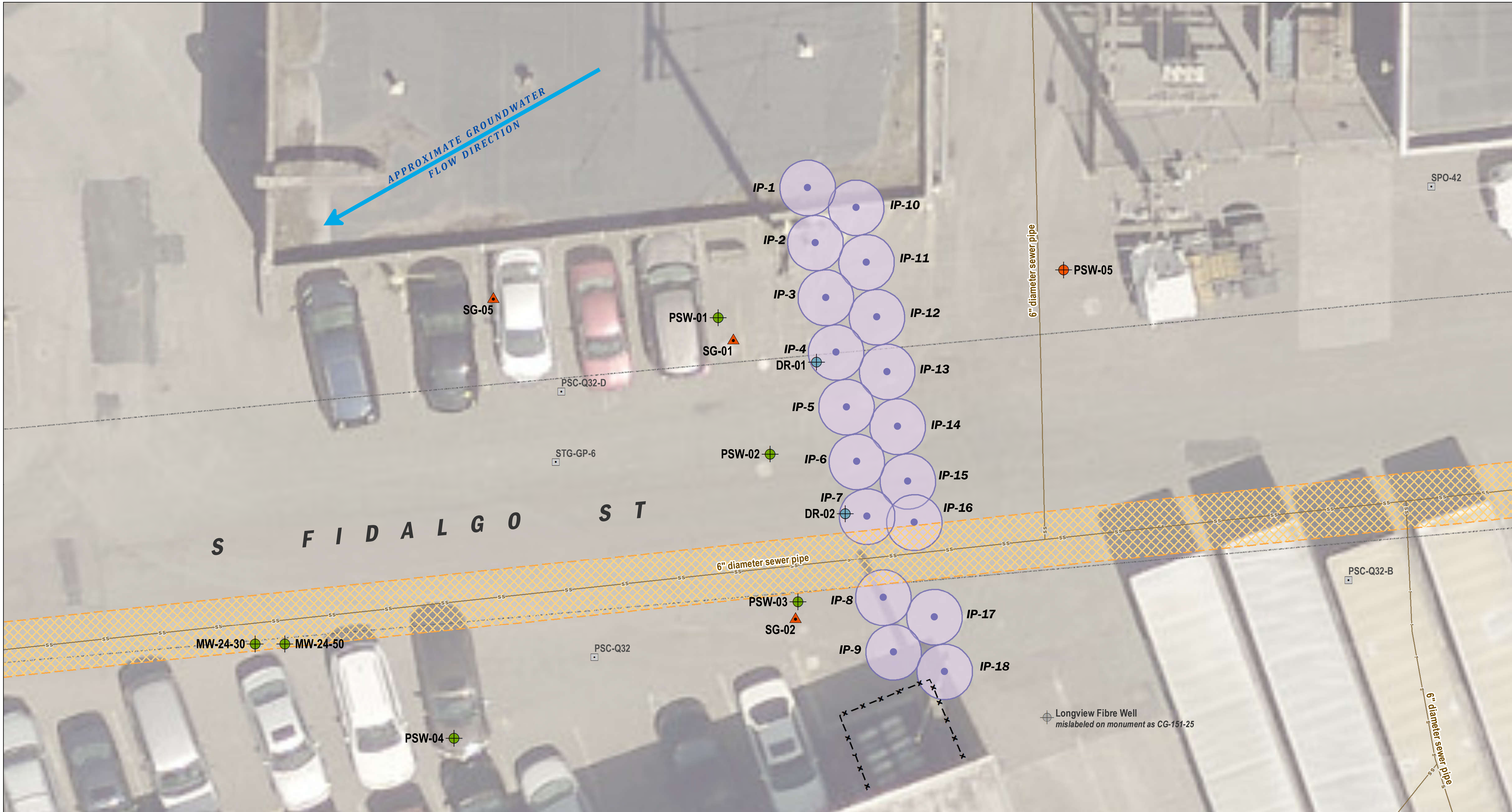
GIS Path: T:\projects_8\Artbrass\W4 SU1 FS\CVOCs Completion Report\01 Site Diagram.mxd || Coordinate System: NAD83 HARN Washington North || Date Saved: 2020-12-30 || User: trulien || Print Date: 2020-12-30



Site Map - Exploration Locations

CVOC Pilot Study
West of 4th Site
Seattle, Washington

Aspect CONSULTING	DEC-2020	BY: EAC	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: DIM / EAC	2



Pilot Test Monitoring Locations

- Dose-response Monitoring Well
- Downgradient Performance Monitoring Well
- Upgradient Monitoring Well
- Soil Gas Monitoring Point
- Direct Push Injection Point
- Target Radius of Influence
- Sewer Pipe Buffer
- Temporary Soil Boring/Probe
- Longview Fibre Well
- Road Edge
- Fenced Area

N

0 10 20

Feet

CVOC Pilot Testing Well Layout

CVOC Pilot Study
West of 4th Site
Seattle, Washington

Aspect CONSULTING	DEC-2020	BY: EAC	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: DIM / RAP / SCC	3

GIS Path: T:\projects_8\Artbrass\W4 SU1 FS\CVOCs Completion Report\03 CVOC Pilot Testing Well Layout.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 2020-12-30 || User: trulien || Print Date: 2020-12-30

Pilot Test Monitoring Locations

- Soil Gas Monitoring Point
- Dose-response Monitoring Well
- Downgradient Performance Monitoring Well
- Upgradient Monitoring Well
- Direct Push Injection Point
- Target Radius of Influence
- Temporary Soil Boring/Probe
- Control Monitoring Well
- Building
- Road Edge
- King County Parcel Boundary

Note: All locations are approximate.

N

0 15 30

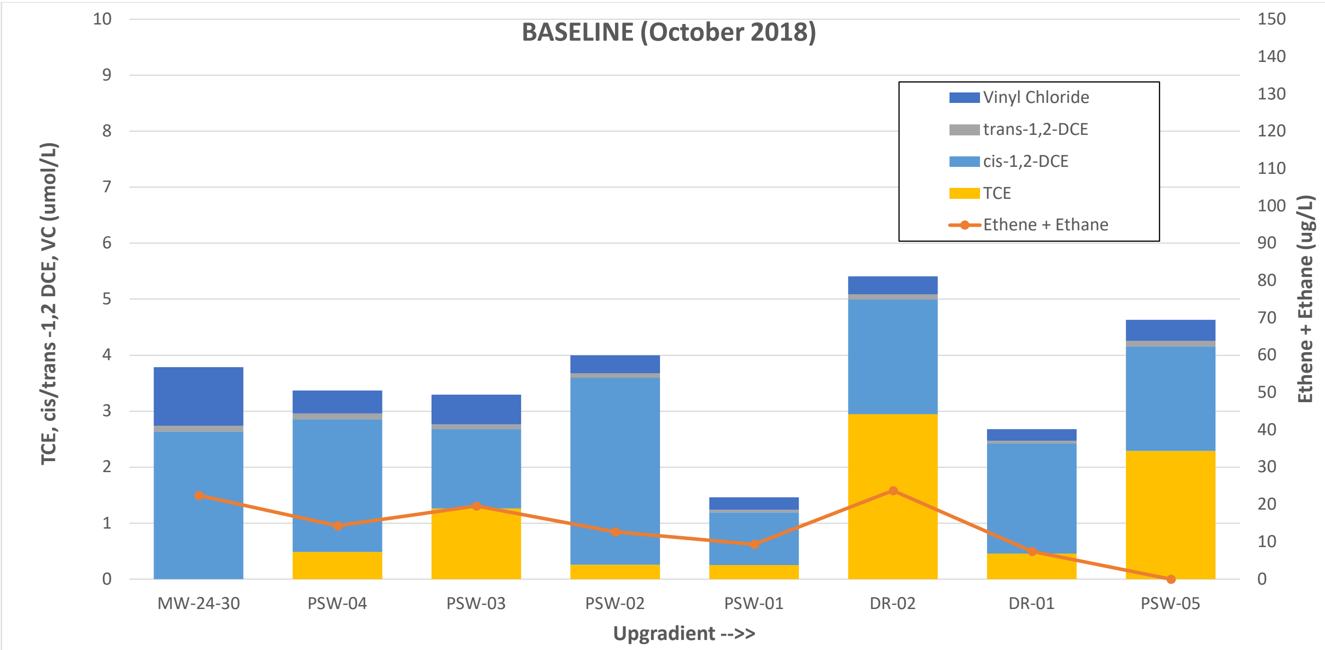
Feet

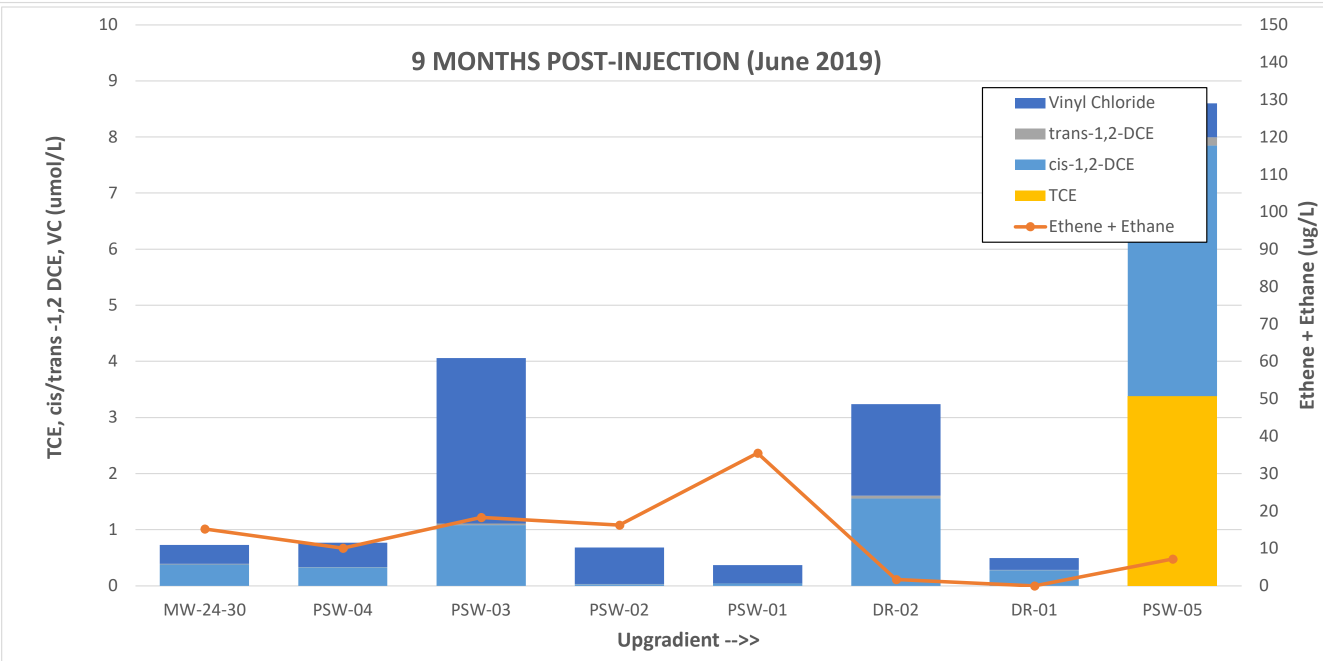
Soil Gas Monitoring Locations

CVOC Pilot Study
West of 4th Site
Seattle, Washington

Aspect CONSULTING	DEC-2020	BY: EAC	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: ACG/SCC	4

GIS Path: T:\projects_8\Artbrass\W4 SU1 FS\CVOCs Completion Report\04 Soil Gas Monitoring Locations.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 2020-12-30 || User: trulien || Print Date: 2020-12-30





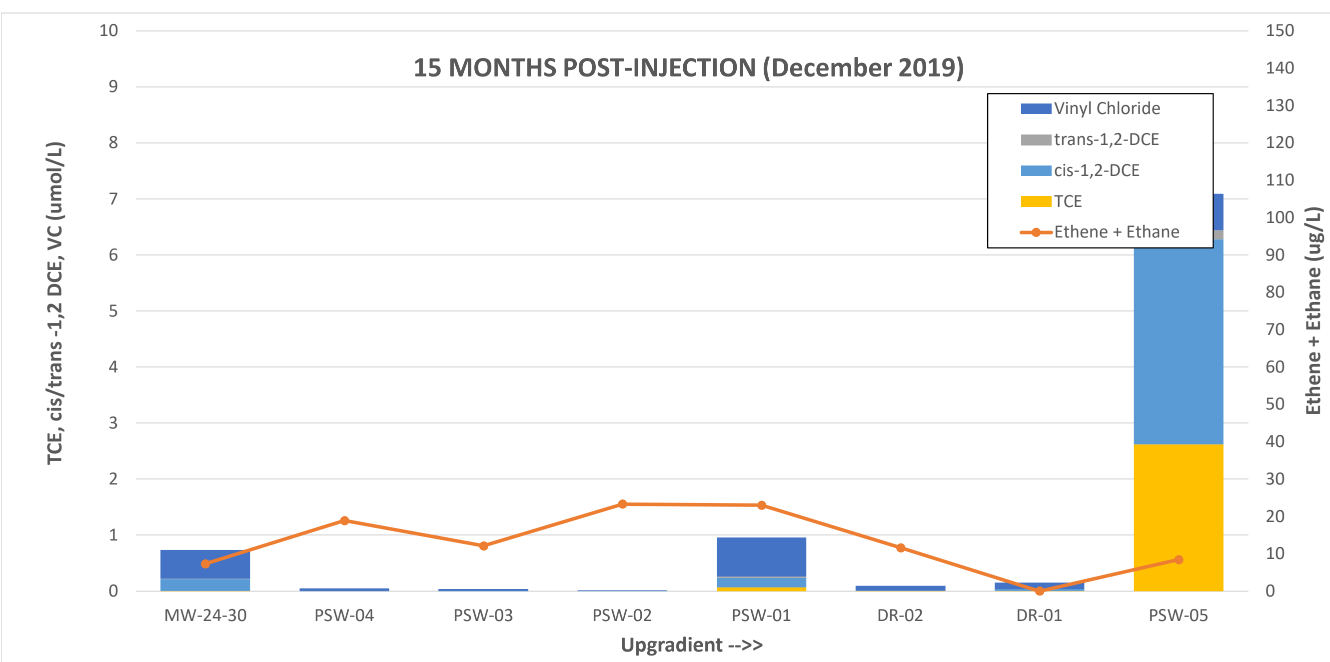


Figure 5
Total CVOC Molar Mass
West of 4th Site - SU1, Seattle, WA

APPENDIX A

of CVOC Pilot Study Completion Report

Injection Log

INJECTION FIELD LOG

PROJECT NUMBER/NAME: 0

LEAD OPERATOR: 0
SCOPE OF WORK: 0

INJECTION APPROACH: 0

Well ID	Start Date	Start Time	End Date	End Time	Injection Interval			Initial Pressure (PSI)	Sustained Pressure (PSI)	Average Flow Rate (GPM)	% Solution #1	#2	#3	Water (Gallons)	% Solution Injected (Gallons)	Flush Water Injected (Gal)	Total Injected (Gal)	Day Lighting	Field Notes
IP-4	10/8/2018	1:09 PM	10/8/2018	1:25 PM	27.5	to	32.5	25	25	6.3	0.0	0.0	12.0	100.0	100.0	0.0	100.0		Dyed water test. Cored asphalt and hand cleared to 5' with 2.25" hand auger. Replaced upper 5' of boring with 3/8" bentonite chips to seal annulus before installing injection tooling. Filled injection tooling with potable water during advancement to minimize potential heave. Started injecting at slowest rate and gradually increased volume to see potential GPM without exceeding 25 PSI cap. Pressure slowly declined as GPM increased. @ 25 GLs injected- 6 GPM @ 22 PSI - @ 50 GLs 7 GPM @ 25 PSI, @ 75 GLs 7.1 GPM @ 25 PSI. On this Injection point we worked from the lowest interval up to minimze fine sediments from entering and clogging injection screen. This method allows for a seemless injection flow eliminating the need to stop and advance tooling.
	10/8/2018	2:20 PM	10/8/2018	2:50 PM	27.5	to	32.5	25	24	5.6	15.0	7.0	12.0	135.0	167.0	0.0	167.0		Injection point closest to DR-1. Initial pressure 45 PSI, encountered partial clogging of injection screen due to fine sediment that surged inside screen. Pressure dropped back down once clog was expelled. Readings similar to dyed water test. Did not encounter any clogs after initial start up
	10/8/2018	2:50 PM	10/8/2018	3:19 PM	22.5	to	27.5	23	25	5.8	15.0	7.0	12.0	135.0	167.0	0.0	167.0		Similar flows and pressures as lower interval
	10/8/2018	3:28 PM	10/8/2018	3:57 PM	17.5	to	22.5	24	26	5.8	15.0	7.0	12.0	135.0	167.0	25.0	192.0		Similar flows and pressures as mid interval. Spoke with client and will attempt a top down approach on next injection point, if we encounter clogged we will switch back to the bottom up injection approach.
										TOTALS	**45.0**	**21.0**	**48.0**	**505.0**	**601.0**	**25.0**	**626**		
IP-10	10/9/2018	9:29 AM	10/9/2018	9:58 AM	17.5	to	22.5	20	30	5.8	16.6	8.2	12.0	150.0	167.0	0.0	167.0		Will use top down injection method going forward.
	10/9/2018	10:15 AM	10/9/2018	10:40 AM	22.5	to	27.5	34	34	6.7	16.6	8.2	12.0	150.0	167.0	0.0	167.0		
	10/9/2018	11:04 AM	10/9/2018	11:28 AM	27.5	to	32.5	26	25	7.0	16.6	8.2	5.0	150.0	167.0	0.0	167.0		Noticed Rhodamine (Dye) at current batching of 12 ML per batch would not be enough to finish all points. Brough to clients attention, adjusted volume to 5 ML per tank from this point forward.
										TOTALS	**49.8**	**24.6**	**29.0**	**450.0**	**501.0**	**0.0**	**501**		
IP-12	10/9/2018	9:29 AM	10/9/2018	9:58 AM	17.5	to	22.5	27	35	5.8	16.6	8.2	12.0	150.0	167.0	0.0	167.0		
	10/9/2018	10:15 AM	10/9/2018	10:40 AM	22.5	to	27.5	32	34	6.7	16.6	8.2	12.0	150.0	167.0	0.0	167.0		
	10/9/2018	11:04 AM	10/9/2018	11:28 AM	27.5	to	32.5	36	36	7.0	16.6	8.2	5.0	150.0	167.0	0.0	167.0		Noticed Rhodamine (Dye) at current batching of 12 ML per batch would not be enough to finish all points. Brough to clients attention, adjusted volume to 5 ML per tank from this point forward.
										TOTALS	**49.8**	**24.6**	**29.0**	**450.0**	**501.0**	**0.0**	**501**		
IP-11	10/9/2018	1:32 PM	10/9/2018	2:03 PM	17.5	to	22.5	29	40	5.4	16.6	8.2	5.0	150.0	167.0	0.0	167.0		
	10/9/2018	2:11 PM	10/9/2018	2:41 PM	22.5	to	27.5	39	43	5.6	16.6	8.2	5.0	150.0	167.0	0.0	167.0		Placed a small amount of EHC into bucket with water to time breakdown. Water turned dark brown but there was still a fair amount of solids at the bottom of the bucket. (2 hours time)
	10/9/2018	3:03 PM	10/9/2018	3:33 PM	27.5	to	32.5	30	41	5.6	16.6	8.2	5.0	150.0	167.0	25.0	192.0		Using additional flush water to clear EHC heavies from injection line to minimize clogging of inner inj. Screen.
										TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**25.0**	**526**		
IP-1	10/9/2018	1:32 PM	10/9/2018	2:03 PM	17.5	to	22.5	22	41	5.4	16.6	8.2	5.0	150.0	167.0	0.0	167.0		
	10/9/2018	2:11 PM	10/9/2018	2:41 PM	22.5	to	27.5	40	41	5.6	16.6	8.2	5.0	150.0	167.0	0.0	167.0		Noticed clogging from EHC in injection tooling. Was able to remove clog with higher pressure
	10/9/2018	3:03 PM	10/9/2018	3:33 PM	27.5	to	32.5	31	34	5.6	16.6	8.2	5.0	150.0	167.0	25.0	192.0		Will flush after each interval to clear EHC from injection line
										TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**25.0**	**526**		
IP-13	10/9/2018	1:32 PM	10/9/2018	2:03 PM	17.5	to	22.5	24	43	5.4	16.6	8.2	5.0	150.0	167.0	0.0	167.0		Pressure rising due to clogging (EHC), Removed clog with high pressure, Pressure gauge decreased to normal pressure
	10/9/2018	2:11 PM	10/9/2018	2:41 PM	22.5	to	27.5	35	37	5.6	16.6	8.2	5.0	150.0	167.0	0.0	167.0		
	10/9/2018	3:03 PM	10/9/2018	3:33 PM	27.5	to	32.5	32	36	5.6	16.6	8.2	5.0	150.0	167.0	25.0	192.0		Will flush after each interval to clear EHC from injection line
										TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**25.0**	**526**		
IP-14	10/9/2018	4:09 PM	10/9/2018	4:25 PM	17.5	to	22.5	32	41	11.2	16.6	8.2	5.0	150.0	167.0	12.5	179.5		Flushng system after each interval seems to work well for preventing clogs
	10/9/2018	4:35 PM	10/9/2018	4:51 PM	22.5	to	27.5	41	44	10.4	16.6	8.2	5.0	150.0	167.0	12.5	179.5		Pressure rising due to clogging (EHC), Removed clog with high pressure, Pressure gauge decreased to normal pressure
	10/9/2018	4:59 PM	10/9/2018	5:12 PM	27.5	to	32.5	40	44	12.8	16.6	8.2	5.0	150.0	167.0	12.5	179.5		
										TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**37.5**	**539**		
IP-2	[illegible]	[illegible]	10/10/2018	10:02 AM	17.5	to	22.5	26	31	6.7	16.6	8.2	5.0	150.0	167.0	15.0	182.0		

CASCADE
DRILLING | TECHNICAL SERVICES

INJECTION FIELD LOG

PROJECT NUMBER/NAME: 0

LEAD OPERATOR: 0
SCOPE OF WORK: 0

INJECTION APPROACH: 0

Well ID	Start Date	Start Time	End Date	End Time	Injection Interval	Initial Pressure (PSI)	Sustained Pressure (PSI)	Average Flow Rate (GPM)	% Solution #1	% Solution #2	% Solution #3	% Solution Water (Gallons)	% Solution Injected (Gallons)	Flush Water Injected (Gal)	Total Injected (Gal)	Day Lighting	Field Notes
	10/10/2018	10:26 AM	10/10/2018	10:55 AM	22.5 to 27.5	30	27	5.8	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Noticed screens still partially clogging with EHC heavies during injection. Will add 10 minutes to mixing time to allow for better EHC breakdown
	10/10/2018	11:22 AM	10/10/2018	11:46 AM	27.5 to 32.5	22	29	7.0	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-3	10/10/2018	9:35 AM	10/10/2018	10:02 AM	17.5 to 22.5	24	29	6.7	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Pressure rising due to clogging (EHC), Removed clog with high pressure, Pressure gauge decreased to normal pressure
	10/10/2018	10:26 AM	10/10/2018	10:55 AM	22.5 to 27.5	24	26	5.8	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Noticed screens still partially clogging with EHC heavies during injection. Will add 10 minutes to mixing time to allow for better EHC breakdown
	10/10/2018	11:22 AM	10/10/2018	11:46 AM	27.5 to 32.5	21	27	7.0	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-5	10/10/2018	9:35 AM	10/10/2018	10:02 AM	17.5 to 22.5	14	15	6.7	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Pressure rising due to clogging (EHC), Removed clog with high pressure, Pressure gauge decreased to normal pressure
	10/10/2018	10:26 AM	10/10/2018	10:55 AM	22.5 to 27.5	14	16	5.8	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Noticed screens still partially clogging with EHC heavies during injection. Will add 10 minutes to mixing time to allow for better EHC breakdown
	10/10/2018	11:22 AM	10/10/2018	11:46 AM	27.5 to 32.5	37	41	7.0	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-7	10/10/2018	4:16 PM	10/10/2018	4:30 PM	17.5 to 22.5	35	35	14.3	21.5	10.6	6.5	180.0	200.0	0.0	200.0		Injection point closest to DR-2, Injected 50 Gls too much into interval
	10/10/2018	4:40 PM	10/10/2018	4:50 PM	22.5 to 27.5	34	32	16.7	11.7	5.8	3.5	150.0	167.0	15.0	182.0		Added 50 GLs of water to tank to bring volume from 117 GLs (solution) to 167 GLs. Noticed pink coloration in monitoring well during this interval.
	10/10/2018	4:54 PM	10/10/2018	5:05 PM	27.5 to 32.5	41	44	15.2	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**480.0**	**534.0**	**30.0**	**564**		
IP-6	10/11/2018	8:40 AM	10/11/2018	9:00 AM	17.5 to 22.5	31	34	9.1	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Screen partially clogged, flushed with water to clear before starting injection
	10/11/2018	9:29 AM	10/11/2018	9:46 AM	22.5 to 27.5	37	42	10.7	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Screen partially clogged, pulled up 2 " and screen cleared.
	10/11/2018	10:09 AM	10/11/2018	10:28 AM	27.5 to 32.5	26	26	8.8	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-15	10/11/2018	8:40 AM	10/11/2018	9:00 AM	17.5 to 22.5	30	35	9.1	16.6	8.2	5.0	150.0	167.0	15.0	182.0		Allowing more time for Iron compound to mix to decrease potential injection tool clogging.
	10/11/2018	9:29 AM	10/11/2018	9:46 AM	22.5 to 27.5	35	43	10.7	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/11/2018	10:09 AM	10/11/2018	10:28 AM	27.5 to 32.5	29	30	8.8	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-9	10/11/2018	11:59 AM	10/11/2018	12:21 PM	17.5 to 22.5	41	46	8.3	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/11/2018	12:38 PM	10/11/2018	12:56 PM	22.5 to 27.5	24	25	10.1	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/11/2018	1:16 PM	10/11/2018	1:34 PM	27.5 to 32.5	34	29	9.3	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-16	10/11/2018	11:59 AM	10/11/2018	12:21 PM	17.5 to 22.5	41	48	8.3	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/11/2018	12:38 PM	10/11/2018	12:56 PM	22.5 to 27.5	40	41	10.1	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/11/2018	1:16 PM	10/11/2018	1:34 PM	27.5 to 32.5	33	27	9.3	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-17	10/11/2018	2:48 PM	10/11/2018	3:07 PM	17.5 to 22.5	33	40	9.6	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/11/2018	3:31 PM	10/11/2018	3:50 PM	22.5 to 27.5	41	44	9.6	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/11/2018	4:07 PM	10/11/2018	4:26 PM	27.5 to 32.5	32	30	8.8	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
								TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		
IP-18	10/11/2018	2:48 PM	10/11/2018	3:07 PM	17.5 to 22.5	34	32	9.6	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	[illegible]	[illegible]	10/11/2018	3:50 PM	22.5 to 27.5	33	35	9.6	16.6	8.2	5.0	150.0	167.0	15.0	182.0		

INJECTION FIELD LOG

PROJECT NUMBER/NAME: 0

LEAD OPERATOR: 0
SCOPE OF WORK: 0

INJECTION APPROACH: 0

Well ID	Start Date	Start Time	End Date	End Time	Injection Interval			Initial Pressure (PSI)	Sustained Pressure (PSI)	Average Flow Rate (GPM)	% Solution #1	% Solution #2	% Solution #3	% Solution Water (Gallons)	% Solution Injected (Gallons)	Flush Water Injected (Gal)	Total Injected (Gal)	Day Lighting	Field Notes
	10/11/2018	4:07 PM	10/11/2018	4:26 PM	27.5	to	32.5	26	25	8.8	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
										TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		

Well ID	Start Date	Start Time	End Date	End Time	Injection Interval			Initial Pressure (PSI)	Sustained Pressure (PSI)	Average Flow Rate (GPM)	% Solution #1	% Solution #2	% Solution #3	% Solution Water (Gallons)	% Solution Injected (Gallons)	Flush Water Injected (Gal)	Total Injected (Gal)	Day Lighting	Field Notes
IP-8	10/12/2018	8:24 AM	10/12/2018	8:36 AM	17.5	to	22.5	36	36	15.2	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/12/2018	9:01 AM	10/12/2018	9:15 AM	22.5	to	27.5	35	36	13.0	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
	10/12/2018	9:20 AM	10/12/2018	9:35 AM	27.5	to	32.5	37	37	11.1	16.6	8.2	5.0	150.0	167.0	15.0	182.0		
										TOTALS	**49.8**	**24.6**	**15.0**	**450.0**	**501.0**	**45.0**	**546**		

CASCADE
DRILLING | TECHNICAL SERVICES

Tracer Monitoring Log
Art Brass Plating 050067

Field Staff: DJM
Date: 10/8/18

Date	Time	Well	Total Volume Injected (gal) (cumulative)	Sample ID	Rhodamine WT visible?	Visual Screening (Estimated Dilution)	Analytical for Bromide (Y or N?)	
10/5/18 [illegible]	1300	DR-1	0	—				30
[illegible]	1428	DR-1	50	DR-1-1	Y	3X	—	
	1435	DR-1	100	DR-1-2	Y	3x	cloudier	
	1443	DR-1	107	DR-1-3	Y	3X		
	1455	DR-1	50	DR-1-4	Y	3X		25
	1500	DR-1	100	DR-1-5	Y	3X		
	1510	DR-1	107	DR-1-6	Y	3x		
	1525	DR-1	50	DR-1-7	Y	3X		20
	1535	DR-1	100	DR-1-8	Y	3X		
	1545	DR-1	150	DR-1-9	Y	3X		
~~10/9/18~~	~~0925~~	~~DR-1~~	~~67~~	~~DR-1-10~~	~~Y~~	~~3X~~	~~cloudy~~	
	~~0935~~	~~DR-1~~	~~117~~	~~DR-1-11~~	~~Y~~	~~3X~~		
	~~0945~~	~~DR-1~~	~~167~~	~~DR-1-12~~	~~Y~~	~~3X~~		
	~~1010~~	~~DR-1~~	~~67~~	~~DR-1-13~~	~~Y~~	~~3x~~		
	~~1020~~	~~DR-1~~	~~117~~	~~DR-1-14~~	~~Y~~	~~3x~~		
	~~1030~~	~~DR-1~~	~~167~~	~~DR-1-15~~	~~Y~~	~~3x~~		
10/10/18	1610	DR-2	67	DR-2-1	N	—		
	1615	DR-2	117	DR-2-2	N	—		
	1620		167	DR-2-3	N	—		
	1635		67	DR-2-4	Y	20x		
	1640		117	DR-2-5	Y	2x		
	1645		167	DR-2-6	Y	1x		
	1650		67	DR-2-7	Y	1x		
	1655		117	DR-2-8	Y	1x		
	1700		167	DR-2-9	Y	1x		
10/11/18	1610	FP-17/18	167	DR-2-101118	Y	1x		

Injection Monitoring Log

Art Brass Plating 050067

Field Staff: DJM

Date: 10/8/18

Page 1 of 2

	Injection Point - (Depth)	Date	Time	Injection Rate (gpm)	Injection Pressure (psig)	Cumulative Injected Volume (gal)	ul
30	IP-4-~~32.5~~	10/8/18	1300	~2.6	25	0	7.90
	IP-4-~~32.5~~		1305	3.6	24		
	IP-4-~~32.5~~		1306	6	25	25	
			1309	7	25	50	
			1313	7	25	75	
			1317	7	25	100	
	IP-4-~~32.5~~		1420	2	40	35	purge
	IP-4-~~32.5~~		1430	4.5	24	100	
	IP-4-~~32.5~~		1443	4.5	24	167	
25	IP-4-~~22.5~~		1450	4.7	24	50	
	IP-4-~~22.5~~		1500	4.7	24	100	
	IP-4-25		1510	4.7	24	167	
	IP-4-20		1525	4.8	24	50	
	IP-4-20		1535	4.8	24	100	
	IP-4-20		1545	4.8	24	150	
	IP-10/12-20	10/9/18	0925	5	20/35	67	IP 10/12
			~~1000~~ 1015		26/32	100	
			~~1015~~ 1100		20/38	167	
	IP-11/-1/-13		1332		29/22/24	67	
	11		1411		39/40/45	107	
	IP-14		1609		32/41	67	
	IP-14		1635		41/44	117	
20	IP-2	10/10/18	0935	~5	26	67	
	IP-3		0935	~5	24	167	
	IP-5		0935	~5	14	117	
25	IP-2		1026		30	117	
	IP-3		1026		24	117	
	IP-5		1026		14	117	
30	IP-2		1122	~5	14	167	
	IP-3		1122		14		
	IP-5		1122		37		
20	IP-6		0840	~5	31/34	67	0900
	IP-15		0840		20/35	117	0900
25	IP-6		0927		37/42	167	0946
	IP-15		0927		35/43	67	0946
30	IP-6		1009		26/26	117	1028
	IP-15		1009		29/30	167	1028

Notes

gpm = gallons per minute

psig = pounds per square inch, gage

gal = gallons

Injection Monitoring Log

Art Brass Plating 050067

Field Staff: DJM
Date: 10/11/18

Injection Point - (Depth)	Date	Time	Injection Rate (gpm)	Injection Pressure (psig)	Cumulative Injected Volume (gal)	
IP-9	10/11/18	1159	~5	41/46	67	1221
IP-16		1159		41/48	67	↓
IP-9		1238		24/25	117	1256
IP-16		1238		40/41	167	↓
IP-9		1316		34/29	167	1334
IP-16		1316		33/27	167	↓
IP-17		1448	~5	33/40	67	1507
IP-18		1448		34/32	67	1507
IP-17		1531		41/44	117	1550
IP-18		1531		33/35	117	1550
IP-17		1607		32/30	167	1626
IP-18		1607		26/25	167	1626
IP-8	10/12/18	0824	5	36/36	67	0836
IP-8		0901		35/36	117	0915
IP-8		0920		37/37	167	0935

Notes

gpm = gallons per minute

psig = pounds per square inch, gage

gal = gallons

Field Staff: DJM
Date: 10/8/18
Page 1 of 2

Water Level Monitoring Log

Art Brass Plating 050067

Injection Well	Date	Time	Injection Location	Water Level (ft bTOC)	
DR-1 ~~IP-4~~	10/8/18	1300	IP-4-30	7.90	clean water
DR-1	10/8/18	1305	IP-4	7.58	
DR-1		1306	IP-4	7.41	
DR-1		1309	IP-4	7.38	
DR-1		1313	IP-4	7.35	
DR-1		1317	IP-4	7.76	reagent
DR-1		1420	IP-4	7.34	
DR-1		1428	IP-4	7.13	
DR-1		1435	IP-4	7.07	
DR-1		1443	IP-4	7.19	
DR-1		1450	IP-4-25	7.12	
DR-1		1500	IP-4-25	7.05	
DR-1		1510	IP-4-25	7.00	
DR-1		1525	IP-4-20	6.92	
DR-1		1535	IP-4-20	6.86	
DR-1		1545	IP-4-20	6.75	
PSW-2		1600	—	6.67	
PSW-1			—	7.08	
PSW-5			—	7.08	
DR-2			—	6.81	
PSW-3			—	6.98	
PSW-2	10/9/18	0730	pre-injection	6.01	
PSW-1				6.45	
DR-1				6.41	
PSW-4				6.41	
PSW-3				6.43	
DR-2				6.25	
DR-1		0920	pre-inject	6.44	
DR-1		0925	inject@	6.21	IP-10/12-20
DR-1		0935	IP-10/12-20	6.21	
DR-1		0945	IP-10/12-20	6.26	
DR-1		1010	IP-10/12-25	6.46	
DR-1		1020	"	6.49	
DR-1		1030	"	6.51	
DR-1		1125	—	6.96	
PSW-1		1130	—	7.54	
PSW-2			—	7.18	
PSW-3			—	7.65	
DR-2			—	7.43	
PSW-4			—	7.83	
DR-1		1445	IP-13/1/1	7.38	
PSW-1		1500		7.50	
PSW-2				7.08	
PSW-4				7.72	
PSW-3				7.50	
DR-2				7.15	

Water Level Monitoring Log

Art Brass Plating 050067

Field Staff: DJM
Date: 10/10/18
Page 2 of 2

Injection Well	Date	Time	Injection Location	Water Level (ft bTOC)
PSW-2	10/10/18	0900	—	6.21
DR-1			—	6.35
PSW-4			—	6.65
PSW-3			—	6.64
DR-2			—	6.44
DR-2	10/10/18	1555	—	7.31
PSW-3			—	7.51
PSW-2			—	7.08
PSW-1			—	7.47
DR-1			—	7.18
PSW-4			—	7.54
DR-2		1610	IP-7-20	6.70
DR-2		1615	IP-7-20	6.63
		1620	IP-7-20	6.61
		1635	IP-7-25	6.29
		1640	"	6.25
		1650	IP-7-30	6.22
		1655		6.17
		1700		6.13
PSW-3		1705	—	6.97
PSW-2			—	6.57
DR-1			—	6.71
PSW-1			—	6.98
PSW-4			—	6.98
PSW-1	10/11/18	0800	—	6.91
DR-1			—	6.60
PSW-2			—	6.45
PSW-3			—	6.83
DR-2			—	6.62
PSW-1		1305	IP-16/-9	7.37
DR-1			IP-16/-9	7.02
PSW-2			IP-16/-9	6.78
PSW-1			IP-16/-9	7.09
DR-2			IP-16/-9	6.61
DR-2		1610	IP-17/18	6.87
DR-1				6.09
PSW-1				7.30
PSW-2				6.84
PSW-3				7.29
PSW-1	10/12/18	0800	—	7.22
DR-1			—	6.92
PSW-2			—	6.78
PSW-3			—	7.17
DR-2			—	6.97

PSW-1 is covered by truck

PSW-4 covered by truck

APPENDIX B
of CVOC Pilot Study Completion Report
Photo Log

Photograph 1. Cascade's equipment layout for direct push injections.

Photograph 2. Batch mixing set-up.

Photograph 3. Injection reagent during mixing.

Photograph 4. Grab samples from dose-response wells during injections, showing visual identification of fluorescent tracer.

APPENDIX C

of CVOC Pilot Study Completion Report

UIC Permitting

DEPARTMENT OF ECOLOGY State of Washington

Underground Injection Control

Automatically Meet the Nonendangerment Standard

For Class V wells that automatically meet the non endangerment standard in accordance with WAC 173-218-100.

Registration Status

Site Number: 34153
Authorization Status: Pending
Comments:

Facility/Site Information

Facility Name: Art Brass Plating
Address: 5516 3rd Ave S
PO Box/Suite/Building:
City: Seattle
State: WA **ZIP:** 98108
Phone: 206-767-4443
County: King
Facility Site ID:

Contact Information

Well Owner
Name: Mike Merryfield
Organization: Art Brass Plating
Address: 5516 3rd Ave S
PO Box/Suite/Building:
City: Seattle
State: WA **ZIP:** 98108
E-mail:
Phone: 206-767-4443

Property Owner
Name: City Seattle
Organization: Seattle City DOT
Address: 700 5th Ave S
PO Box/Suite/Building: PO Box 34996, Suite 2300
City: Seattle
State: WA **ZIP:** 98108
E-mail:
Phone: 206-684-7623

Technical Contact
Name: Adam Griffin
Organization: Aspect Consulting, LLC
Address: 350 Madison Avenue N
PO Box:
City: Bainbridge Island
State: WA **ZIP:** 98110
E-mail: agriffin@aspectconsulting.com
Phone: 206-780-7746

Main Well Information

Well Name	UIC Well Type From Section C (1-12)	Construction Date	EPA Well Type	Status	Depth of UIC Well (ft.)	Latitude	Longitude
IP-18	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990	-122.337170
IP-17	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990	-122.337170
IP-16	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990	-122.337170
IP-15	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990	-122.337170
IP-14	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990	-122.337170
IP-13	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990	-122.337170
IP-12	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990	-122.337170

IP-11	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-10	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-09	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-08	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-07	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-06	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-05	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-04	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-03	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-02	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170
IP-01	12	10/8/2018	5B6 - Aquifer remediation	Proposed	33	47.549990 -122.337170

Main Well Information (continued)

Well Name	Permit Type	Permit ID	Permit Issuer
IP-18	MTCA	47779679	Ed Jones
IP-17	MTCA	47779679	Ed Jones
IP-16	MTCA	47779679	Ed Jones
IP-15	MTCA	47779679	Ed Jones
IP-14	MTCA	47779679	Ed Jones
IP-13	MTCA	47779679	Ed Jones
IP-12	MTCA	47779679	Ed Jones
IP-11	MTCA	47779679	Ed Jones
IP-10	MTCA	47779679	Ed Jones
IP-09	MTCA	47779679	Ed Jones
IP-08	MTCA	47779679	Ed Jones
IP-07	MTCA	47779679	Ed Jones
IP-06	MTCA	47779679	Ed Jones
IP-05	MTCA	47779679	Ed Jones
IP-04	MTCA	47779679	Ed Jones
IP-03	MTCA	47779679	Ed Jones
IP-02	MTCA	47779679	Ed Jones
IP-01	MTCA	47779679	Ed Jones

Ecology Home | UIC Home | Contact Us | Data Disclaimer | Privacy Policy

UIC Version: 2.5.2
User: adamgriffin10

UIC Registration Signature Page

Site Number/ID: 34153

I hereby certify that the information contained in the above referenced registration is true and correct to the best of my knowledge.

ADAM GRIFFIN
Name of legally authorized representative

SENIOR ENGINEER / ASPECT CONSULTING, LLC
Title

Signature of legally authorized representative

9/28/18
Date

Please return this signed and dated signature page, along with any required documentation, to:

Washington State Department of Ecology
ATTN: UIC Coordinator, Water Quality Program
P.O. Box 47600
Olympia, WA 98504-7600

- or -

Fax to: (360) 407-6426

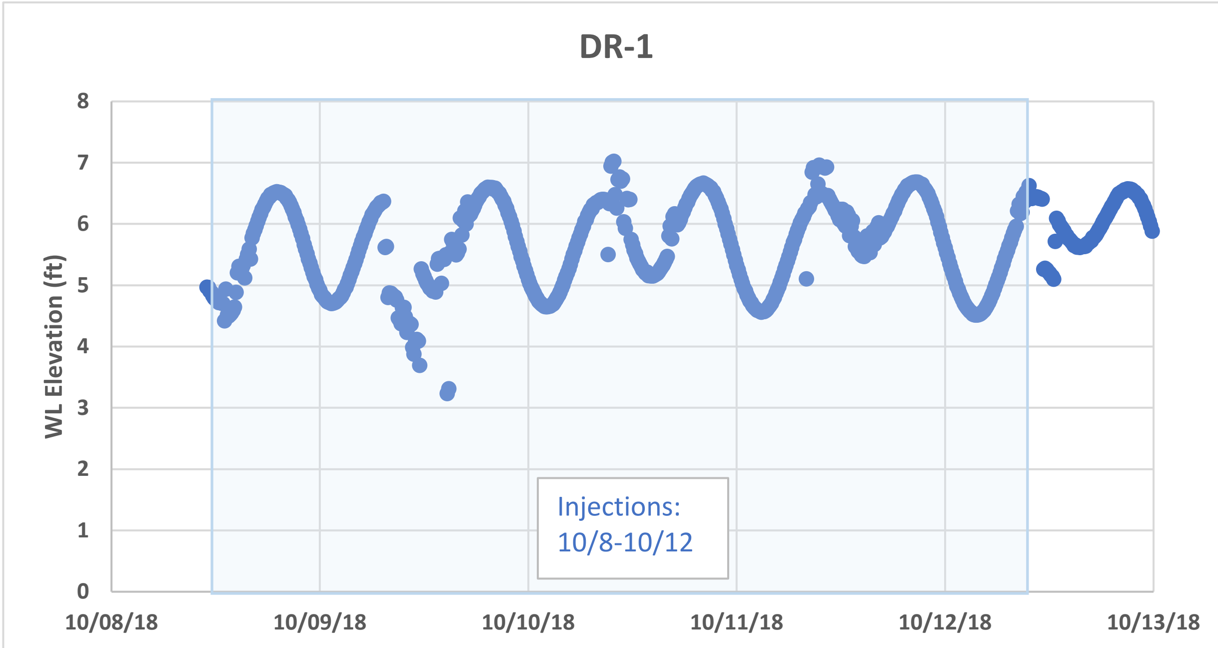
- or -

Scan and email to: maha461@ecy.wa.gov

APPENDIX D

of CVOC Pilot Study Completion Report

Pressure Transducer – Hydrographs



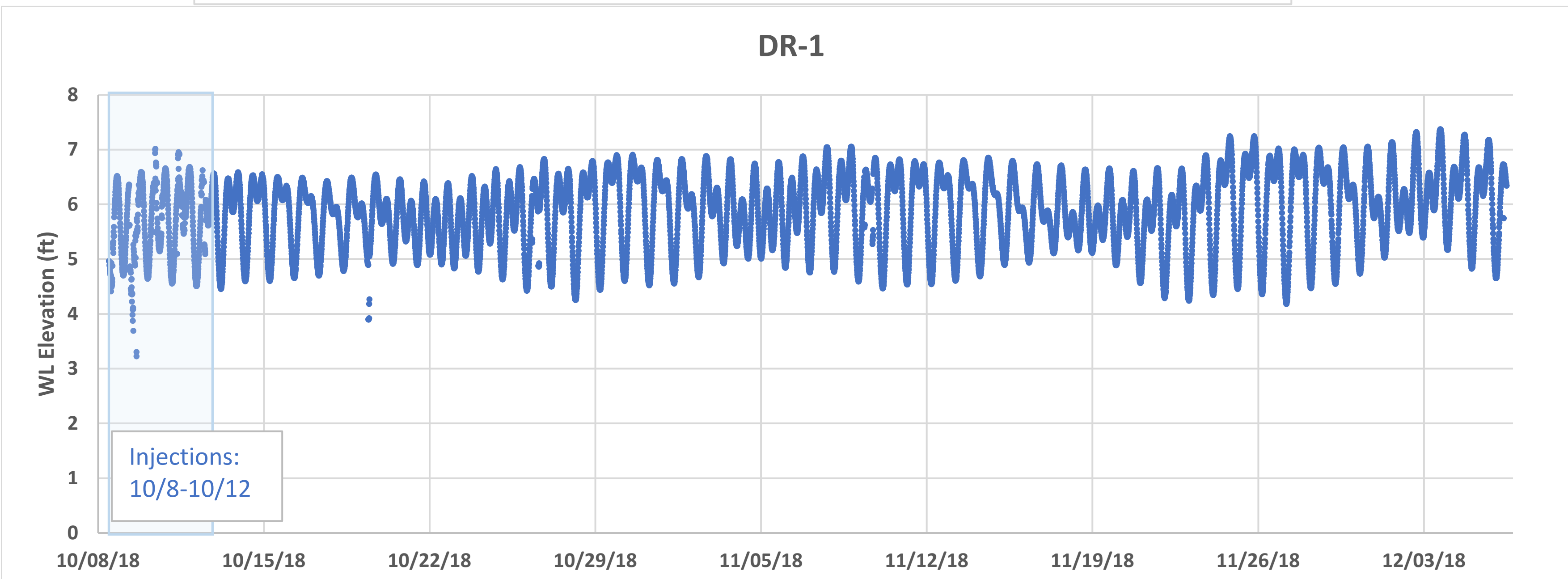
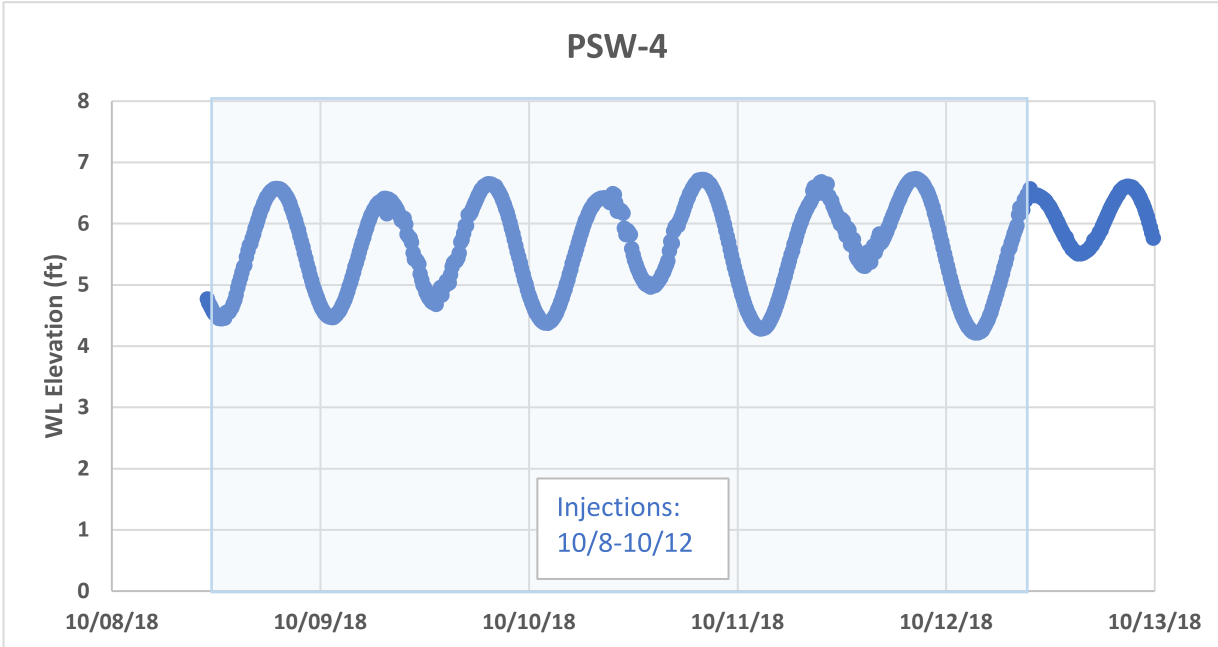
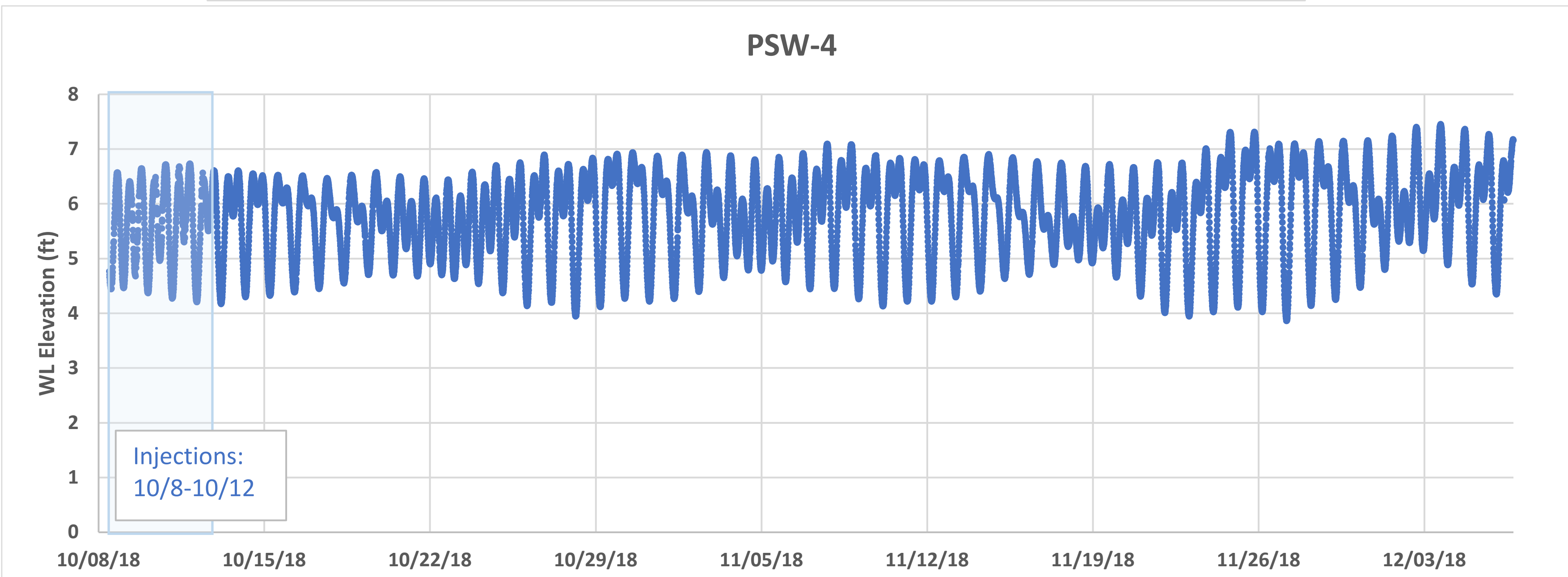


Figure D.1
Hydrographs for DR-1
CVOCs Completion Report





Aspect Consulting
1/5/2021
V:\050067 Art Brass Plating\Feasibility Study Addendum\App A CVOC Report\Completion Report\Appendices\AppD_Hydrographs\AppD_Hydrographs

Figure D.2
Hydrographs for PSW-4
CVOCs Completion Report

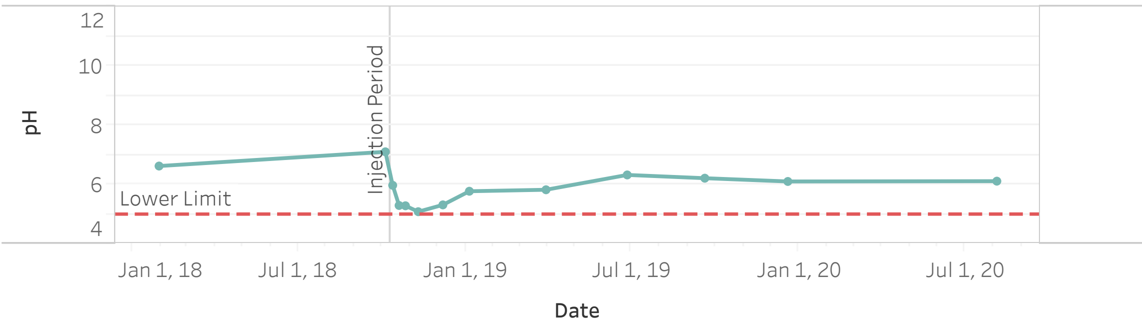
APPENDIX E
of CVOC Pilot Study Completion Report

Performance Evaluation Summary Sheets

Performance Monitoring Workbook

Well
DR-1

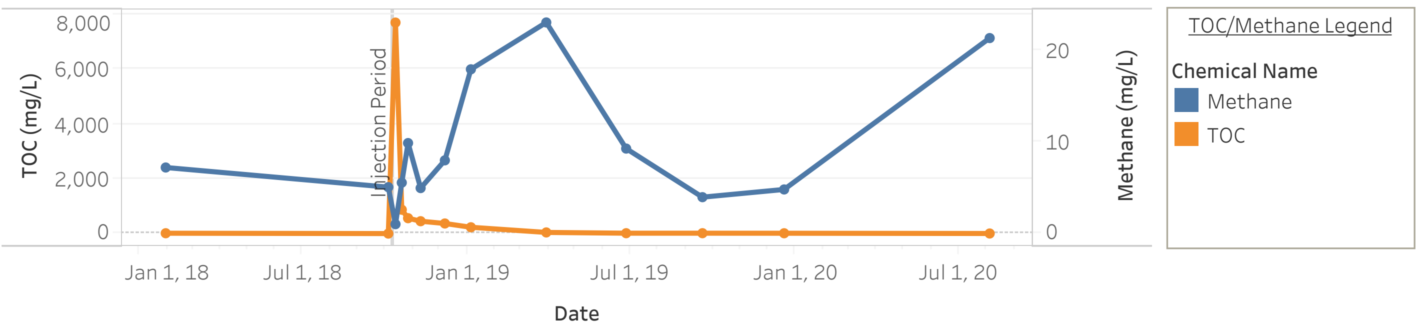
pH



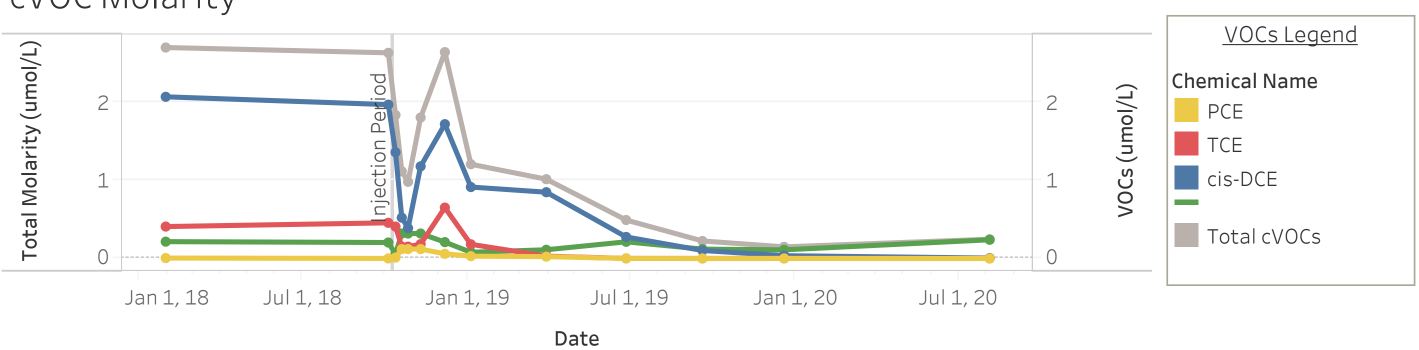
Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



cVOC Molarity



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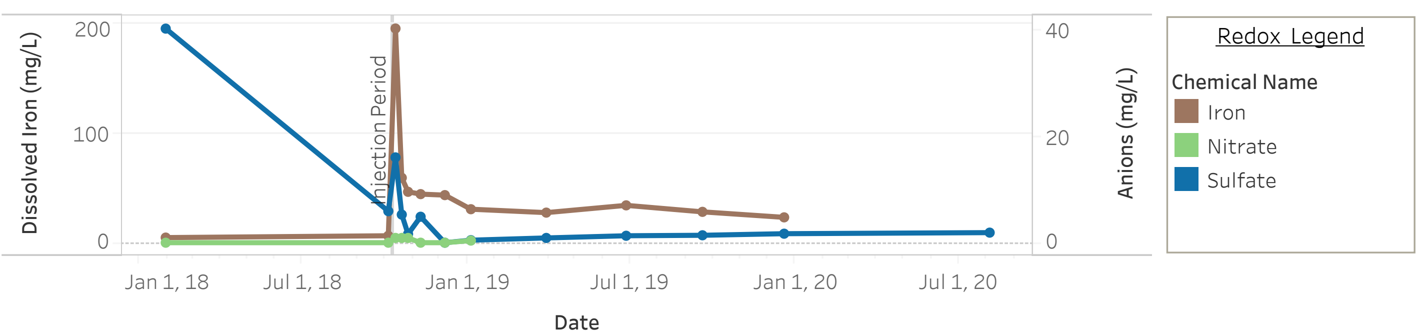
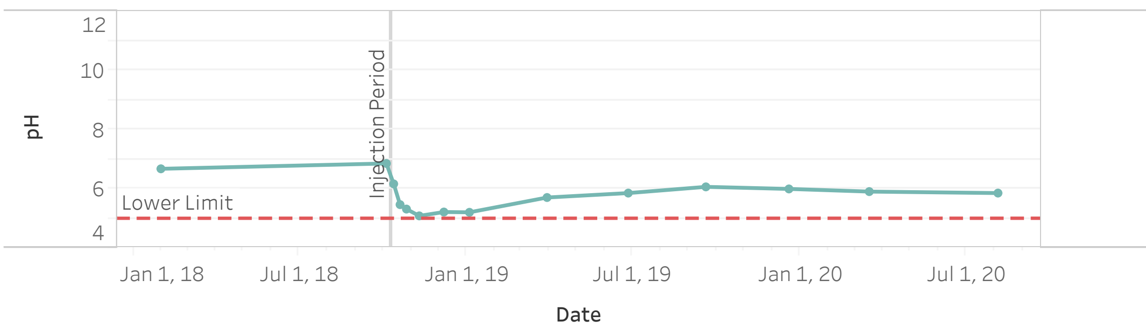


Performance Monitoring Workbook

Well
DR-2

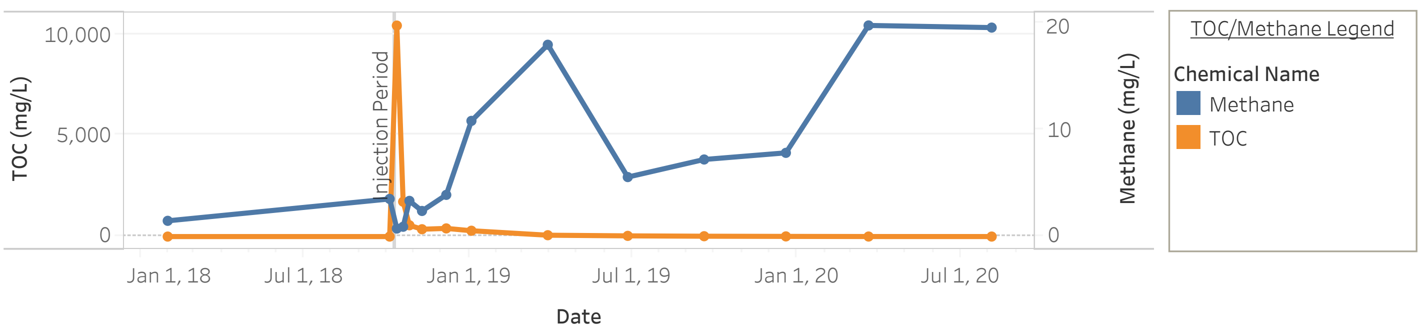
pH



Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



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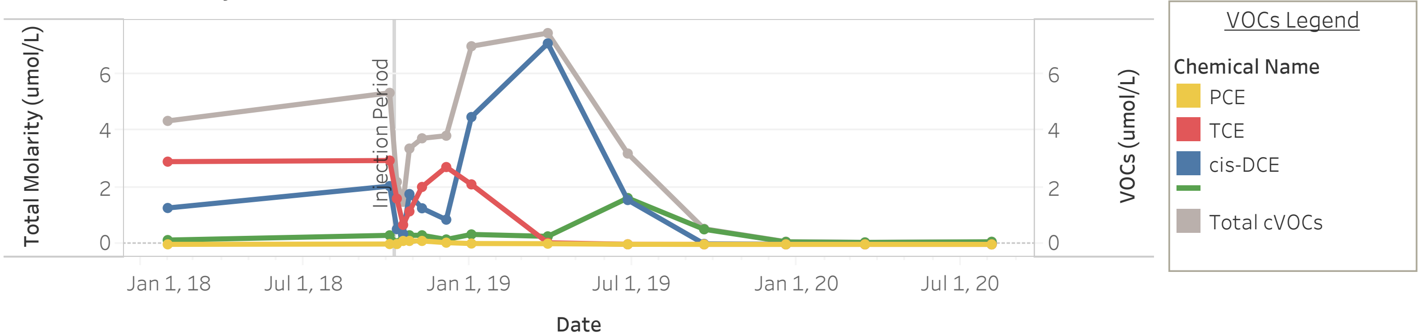

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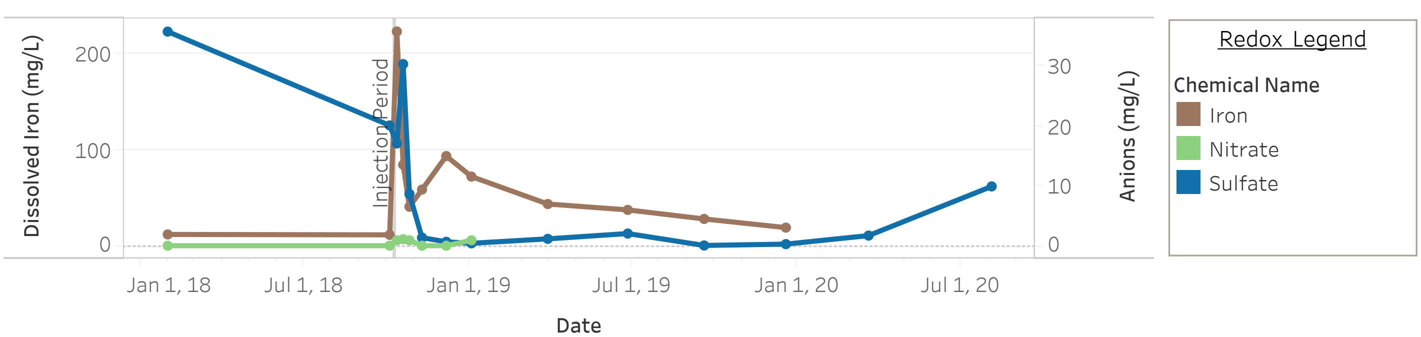
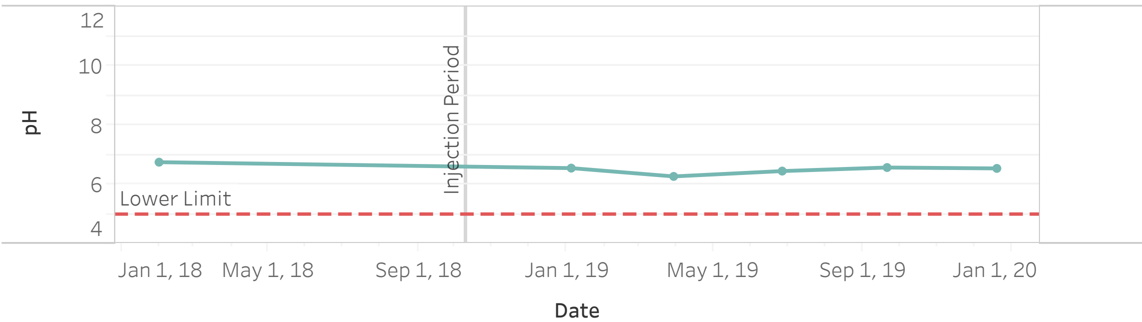


Performance Monitoring Workbook

Well
MW-24

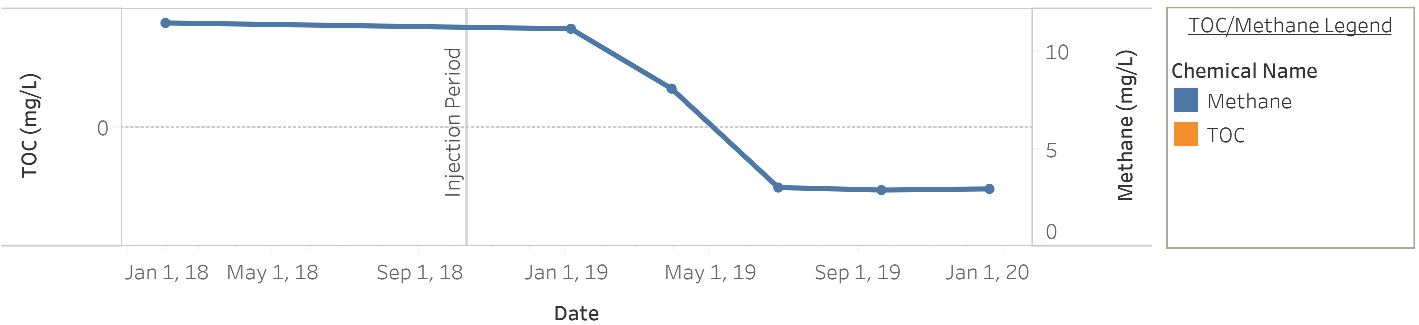
pH



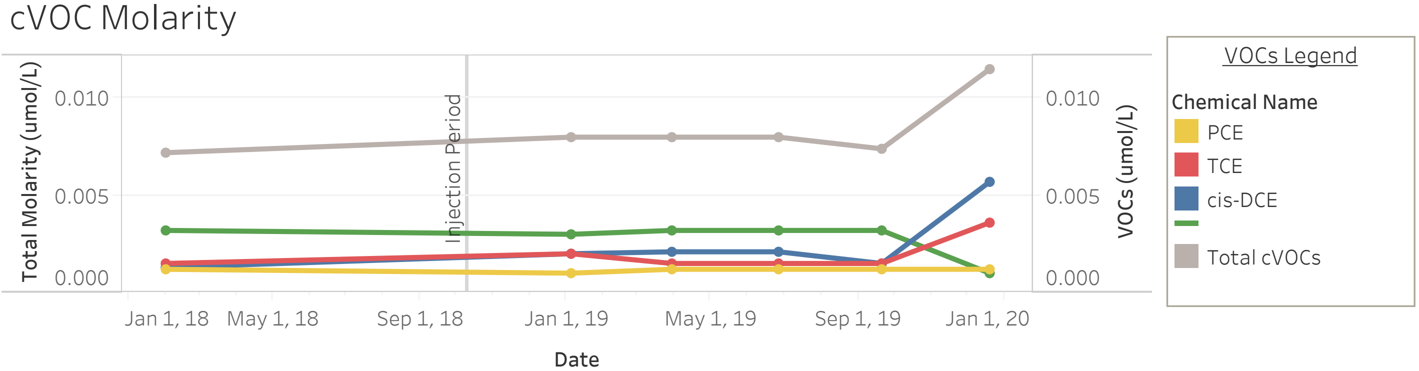
Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



cVOC Molarity



Redox Indicators

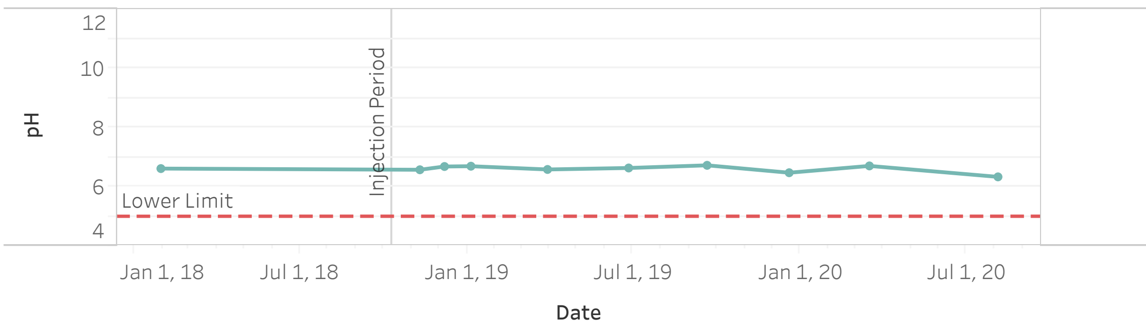
Redox Legend

Chemical Name

Performance Monitoring Workbook

Well
MW-24-30

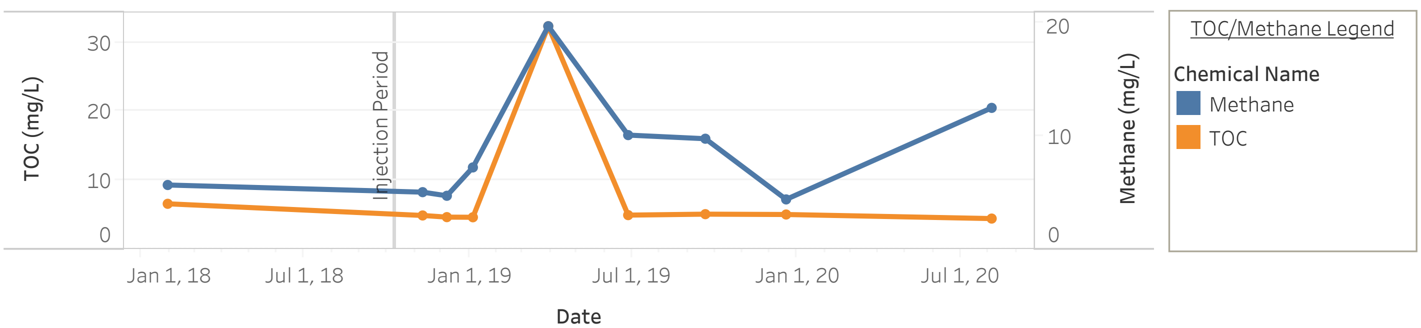
pH



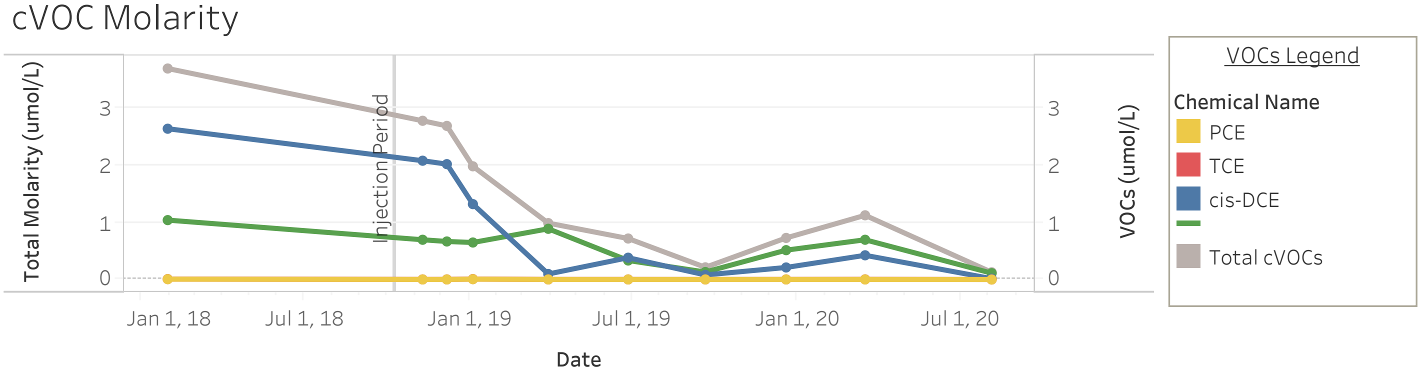
Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



cVOC Molarity



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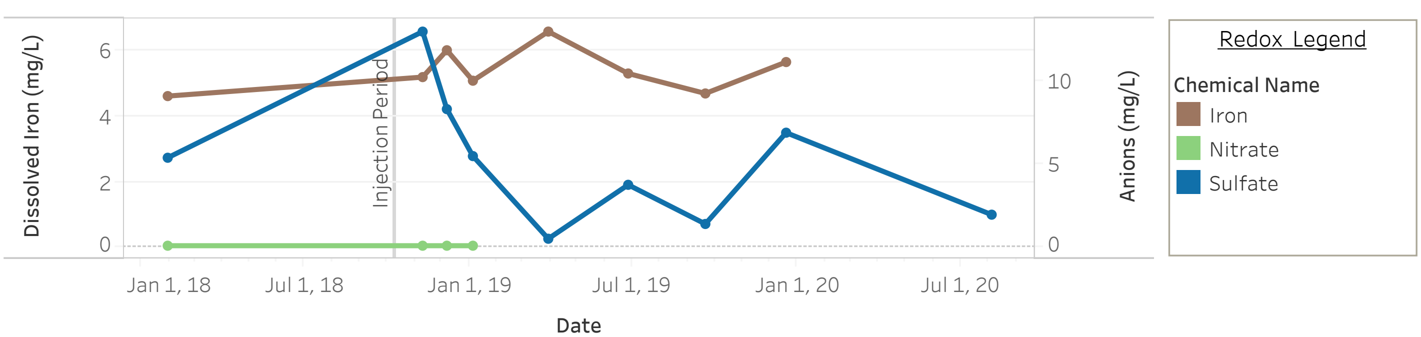
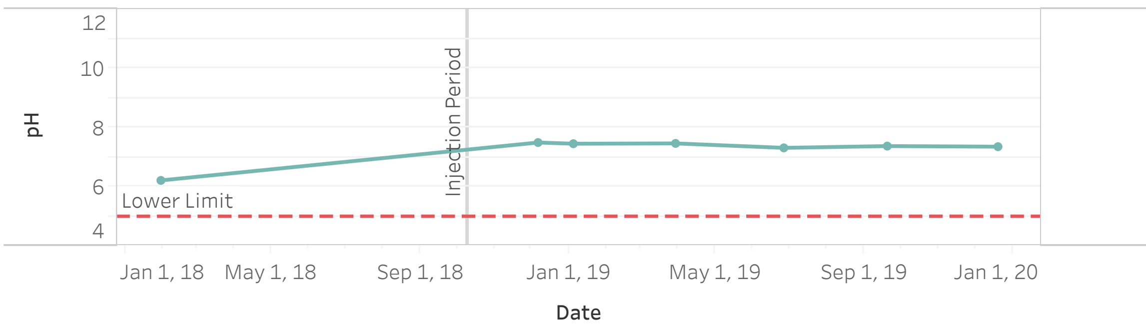


Performance Monitoring Workbook

Well
MW-24-50

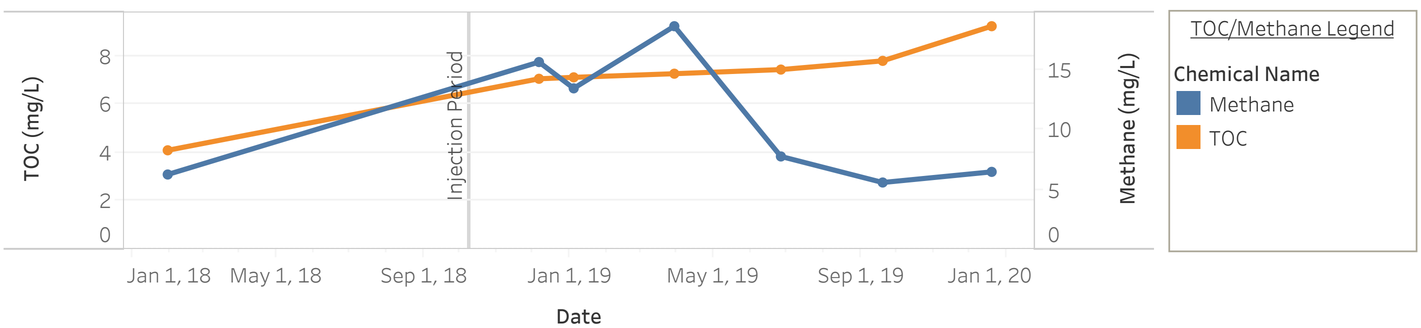
pH



Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



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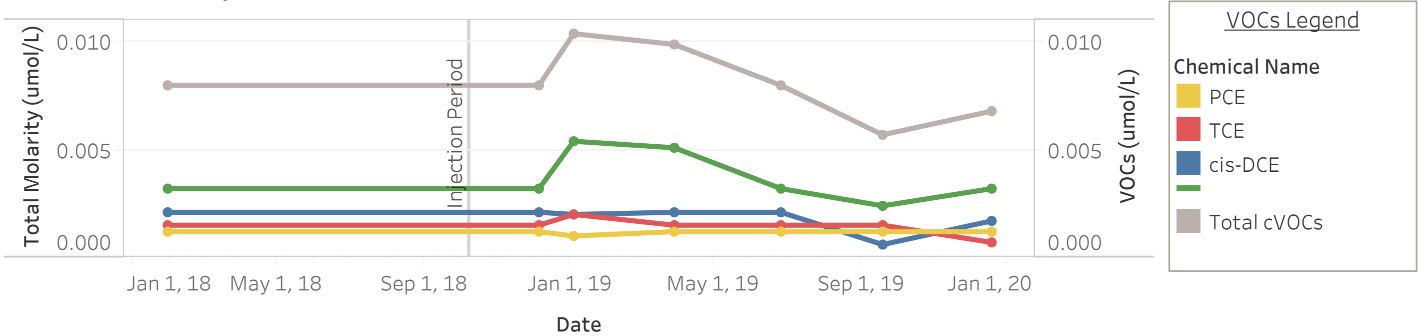

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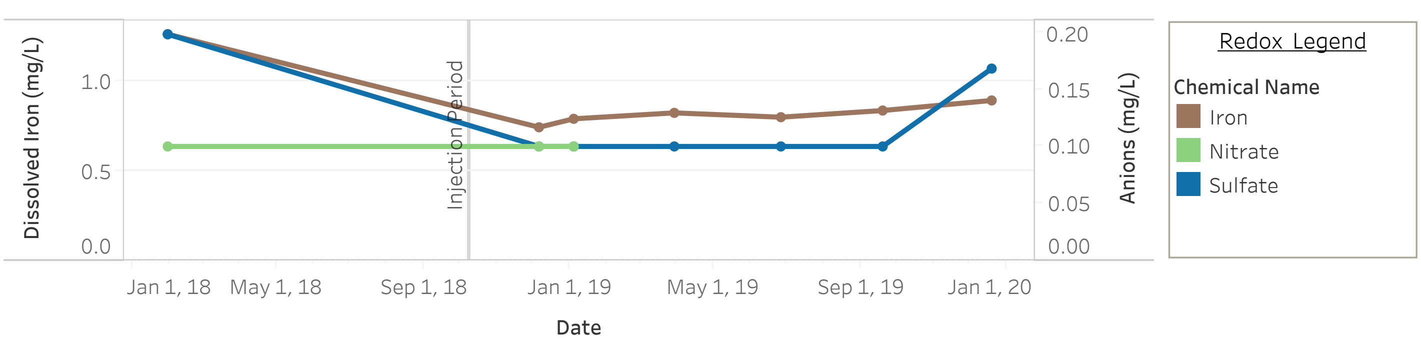
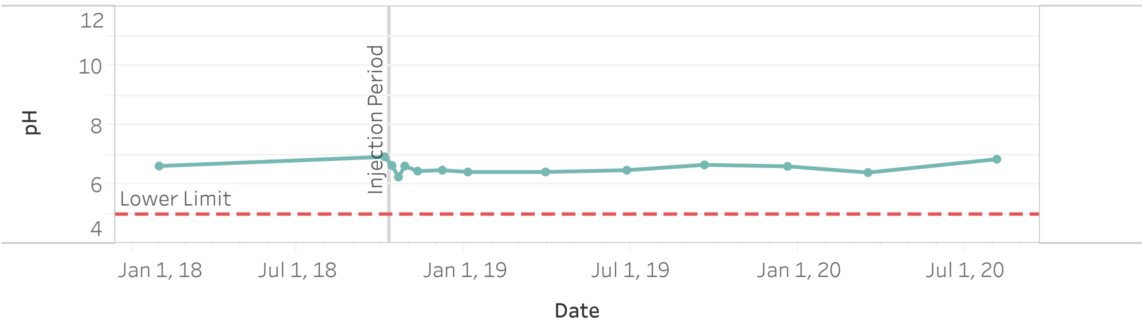


Performance Monitoring Workbook

Well
PSW-1

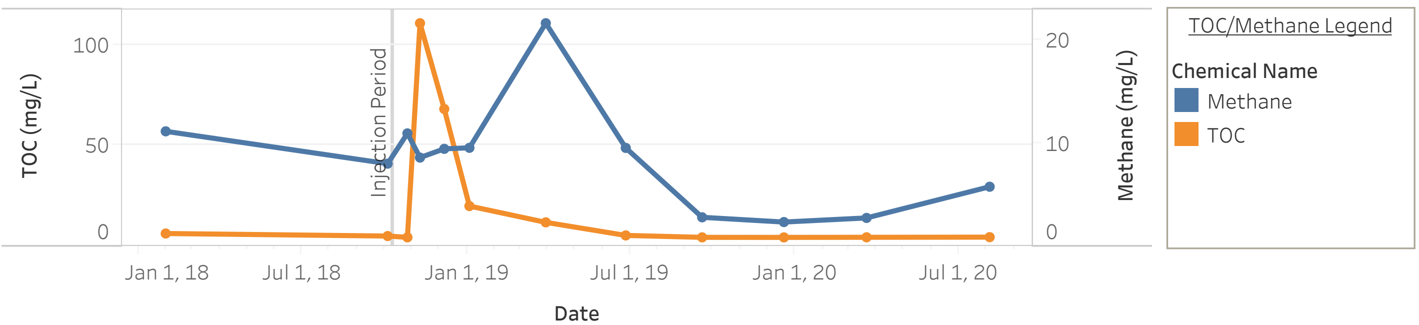
pH



Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



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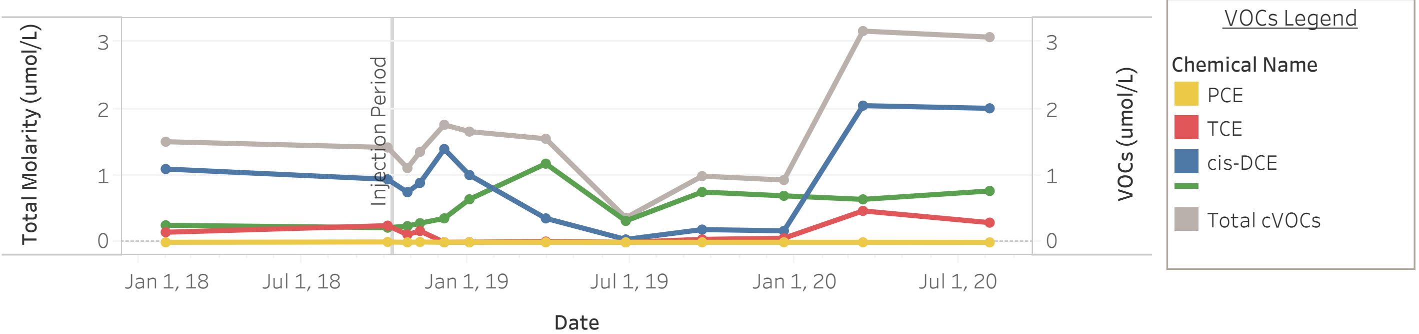

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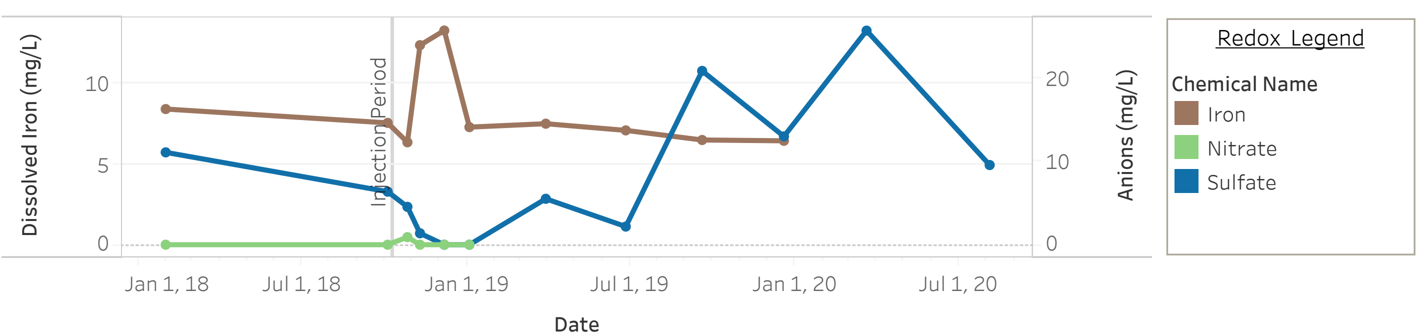
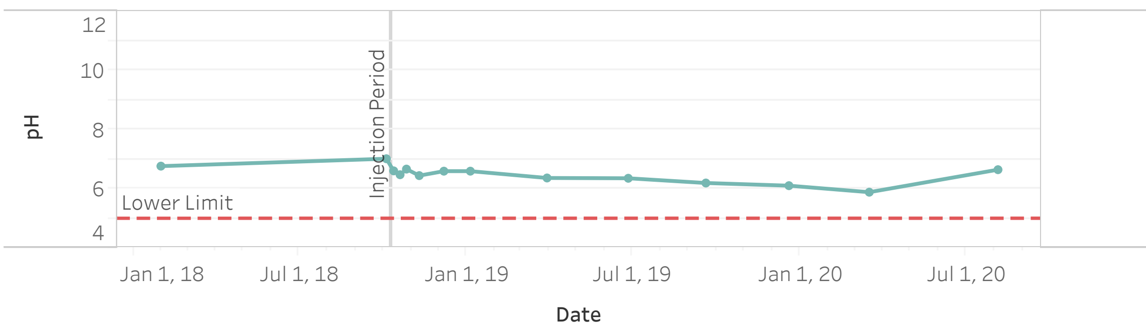


Performance Monitoring Workbook

Well
PSW-2

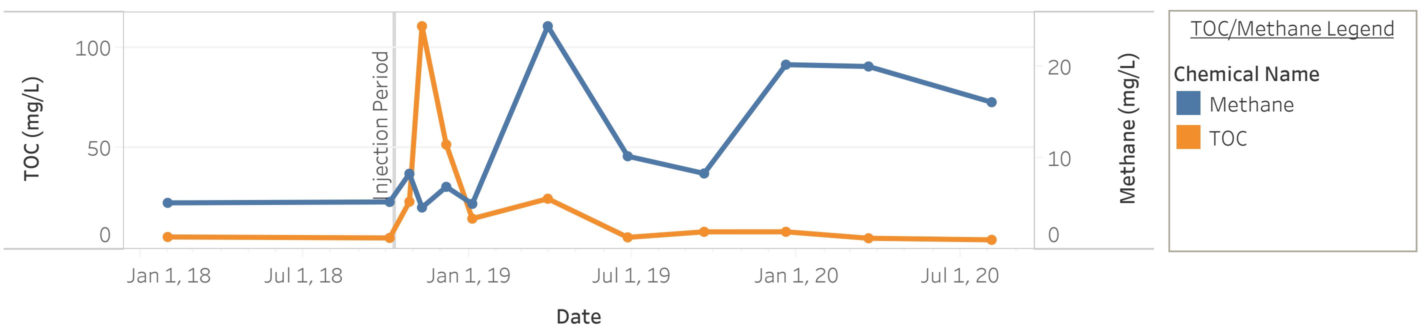
pH



Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



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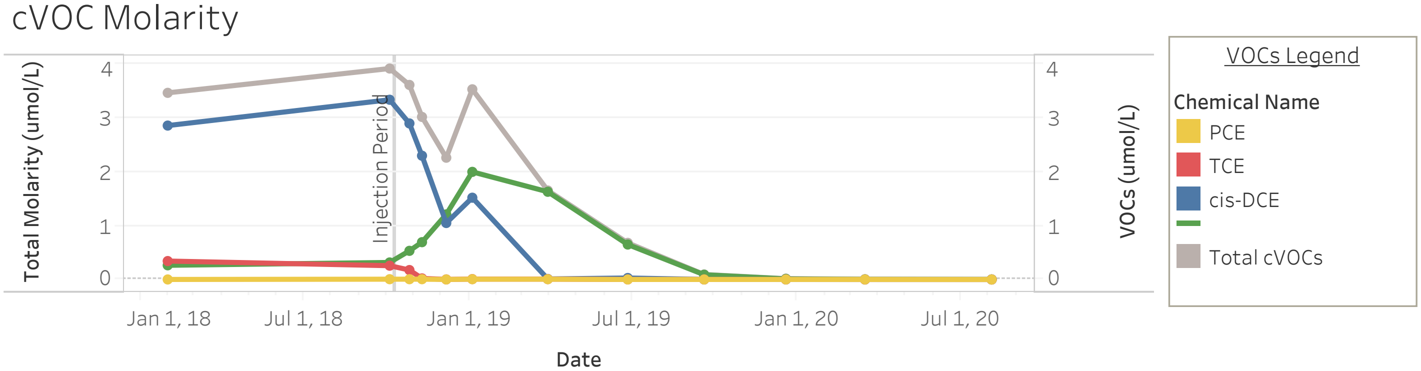

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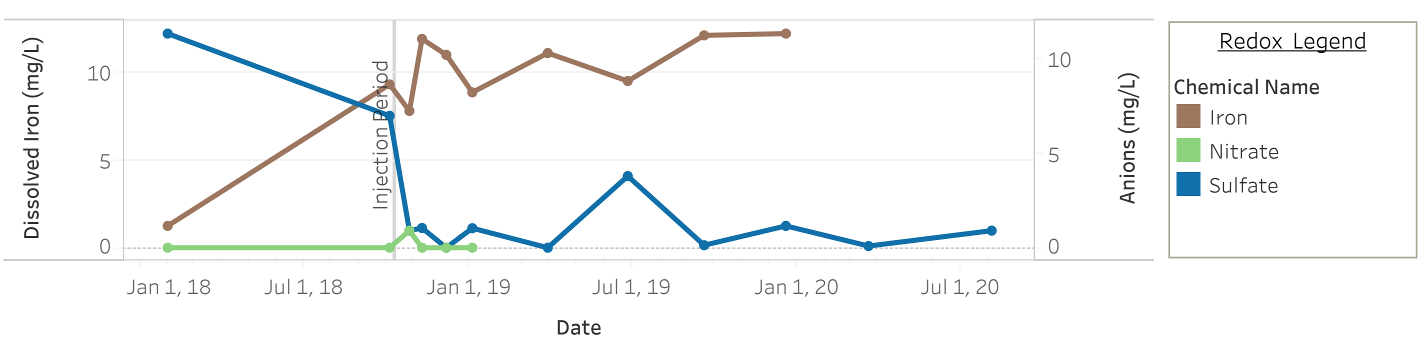
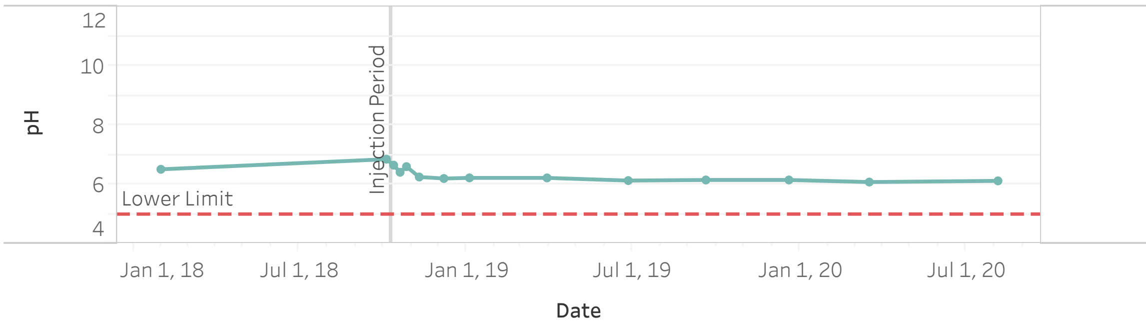


Performance Monitoring Workbook

Well
PSW-3

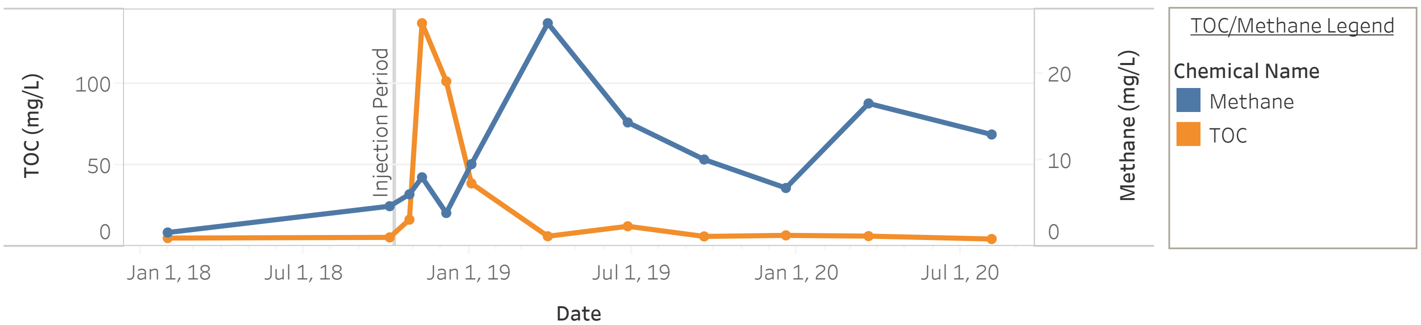
pH



Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



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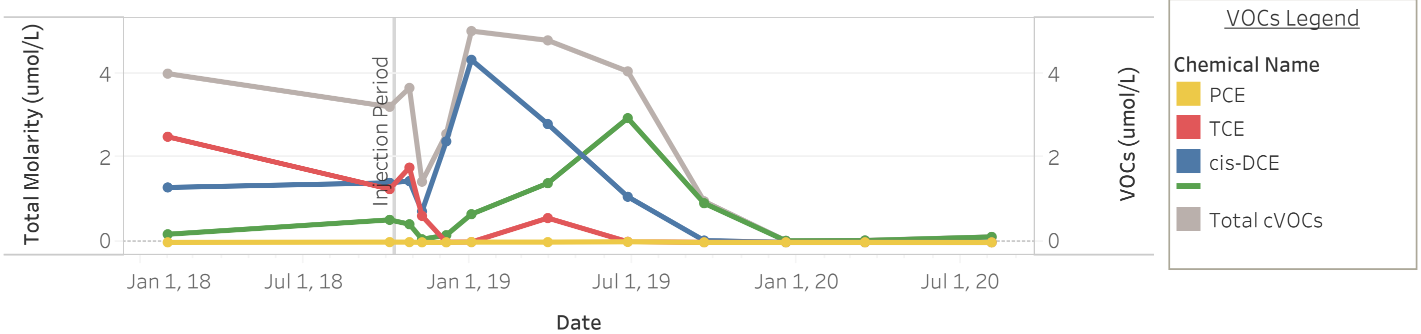

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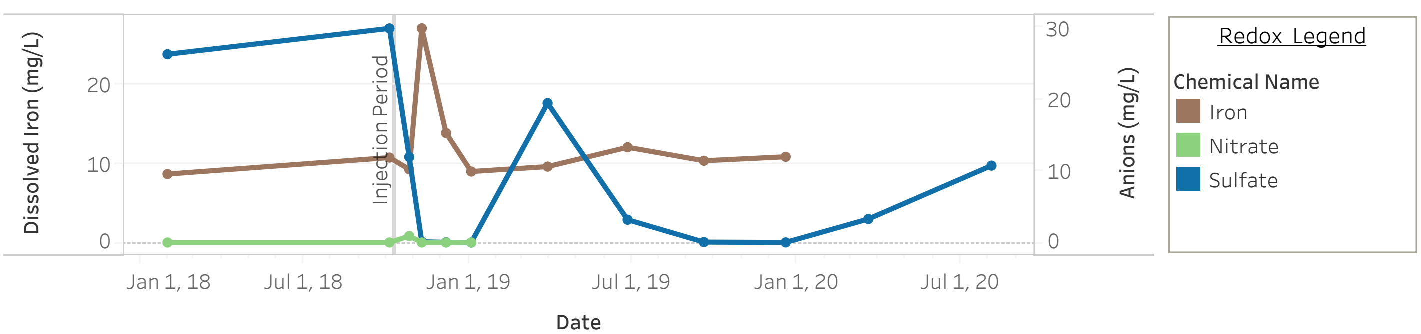
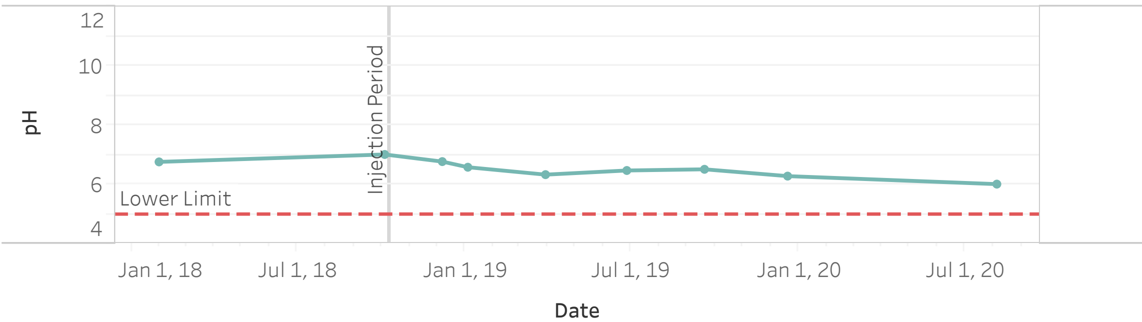


Performance Monitoring Workbook

Well
PSW-4

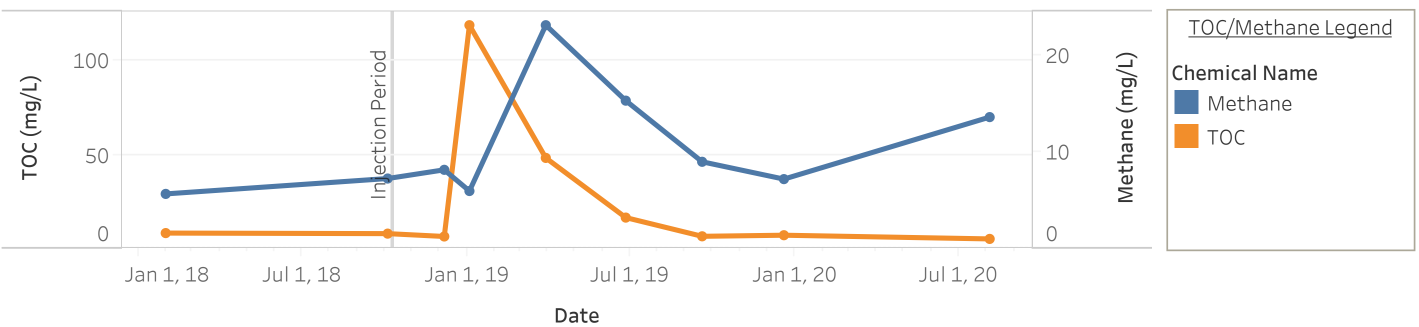
pH



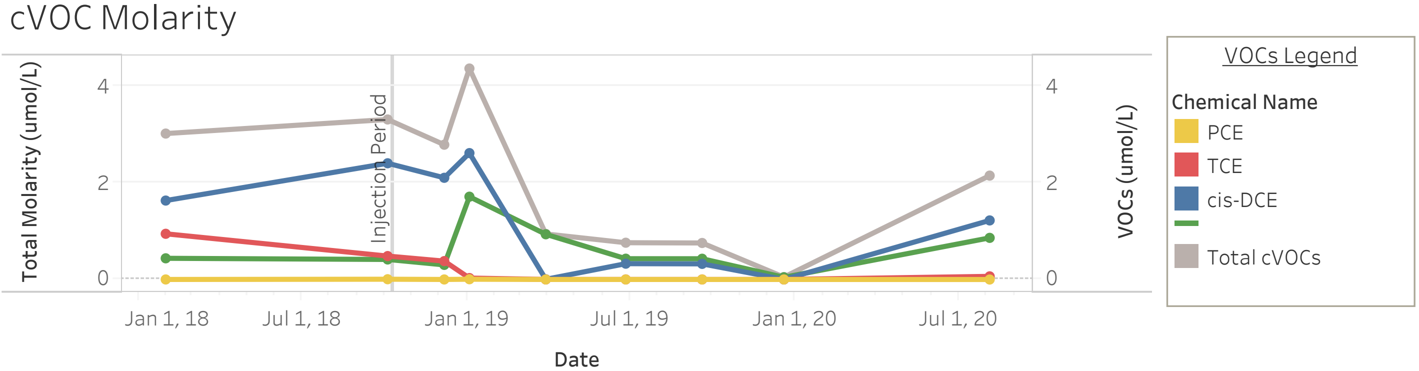
Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



cVOC Molarity



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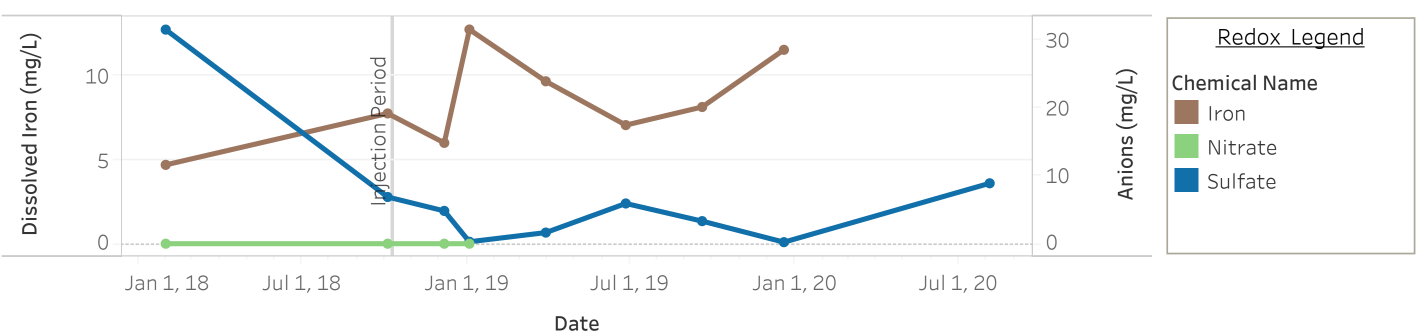
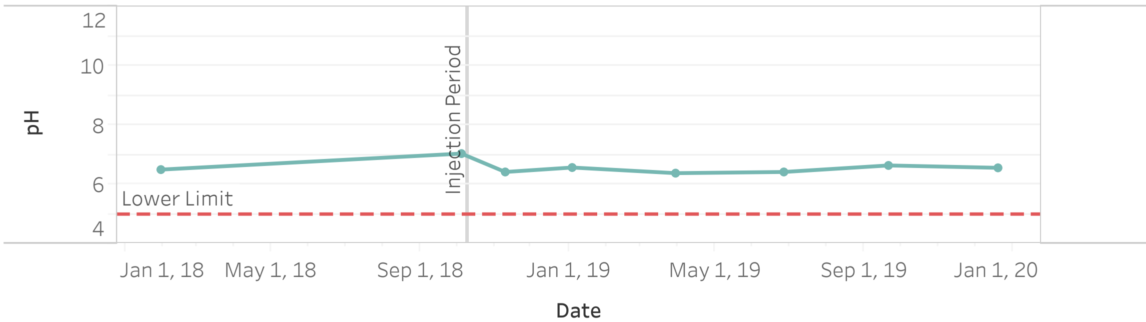


Performance Monitoring Workbook

Well
PSW-5

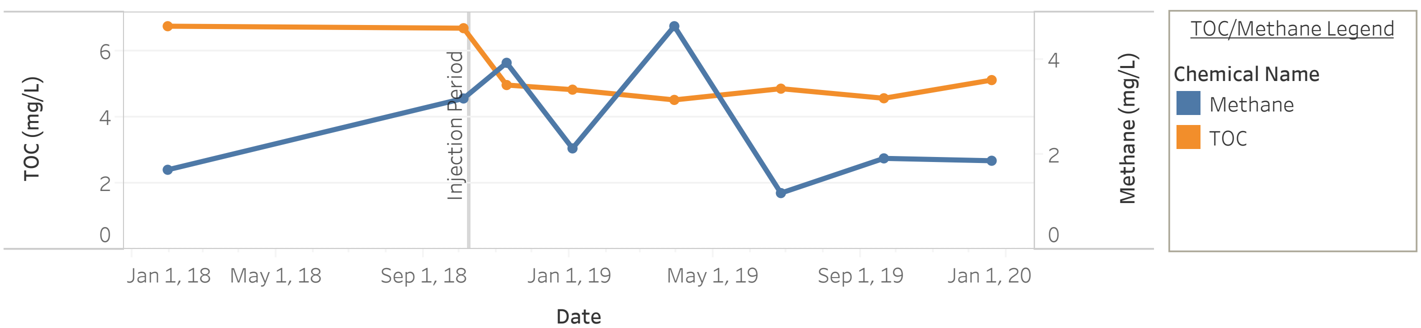
pH



Injection Start
10/8/2018

Injection End
10/11/2018

TOC and Methane



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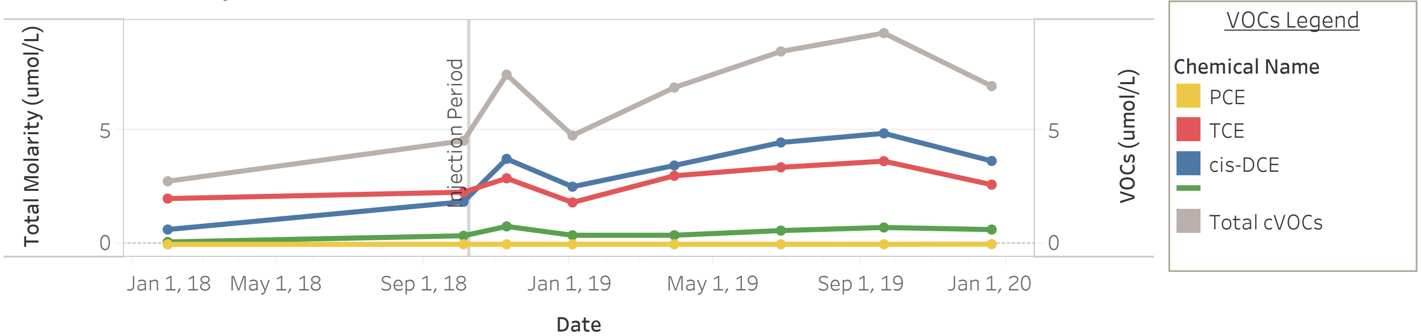

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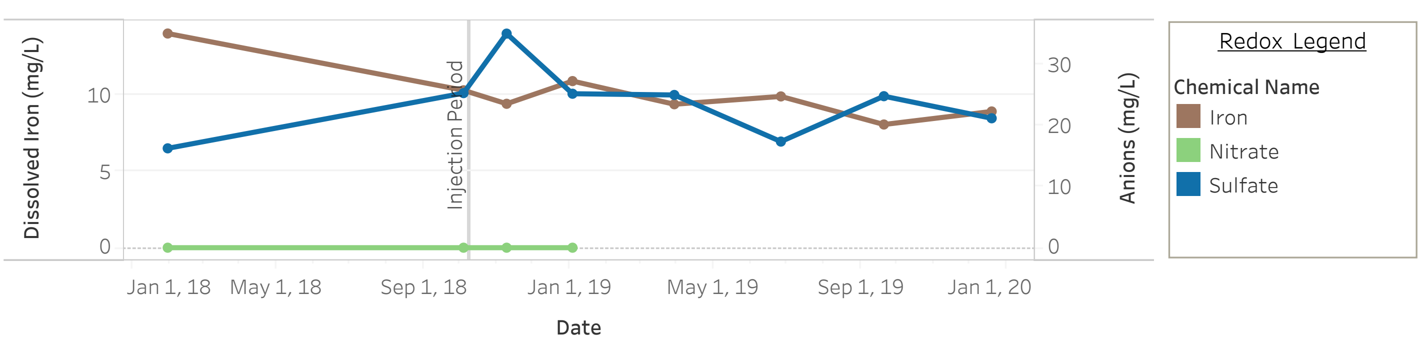

APPENDIX F

of CVOC Pilot Study Completion Report

Seepage Velocity and Flushing Calculations

Table F-1. Velocity Calculations

Project No. 050067, Seattle, Washington

	TOC Transport Velocity Estimate [1,2]		Average Seepage Velocity[3]	
ft/day	0.52	0.98	0.90	1.90
ft/year	190	357	329	694

Notes:

1. Range in values is based on dates of monitoring events between which the change was observed.
2. Increase in TOC at downgradient wells was used to determine GW Flow Velocity.
3. This is the estimated velocity derived from Darcy's Law in the Pilot Test Work Plan (Aspect, 2017).

APPENDIX B

Metals Immobilization Pilot Study Completion Report

IN SITU METALS IMMOBILIZATION - PILOT STUDY COMPLETION REPORT

West of 4th Site - Site Unit 1

Prepared for: West of 4th Group

Project No. 050067 ● December 2022 FINAL

earth + water

Aspect CONSULTING

Aspect CONSULTING

IN SITU METALS IMMOBILIZATION - PILOT STUDY COMPLETION REPORT

West of 4th Site - Site Unit 1

Prepared for: West of 4th Group

Project No. 050067 ● December 2022 FINAL

Aspect Consulting, LLC

12/14/2022

Delia Massey, PE
Project Engineer
dmassey@aspectconsulting.com

Adam Griffin, PE
Associate Remediation Engineer
agriffin@aspectconsulting.com

V:\050067 Art Brass Plating\Feasibility Study Addendum\Final Dec 2022\App B Metals Report\Metals Completion Report.docx

Contents

List of Tables

List of Figures

List of Appendices

Acronyms

ABP	Art Brass Plating
Aspect	Aspect Consulting, LLC
BETX	benzene, ethylbenzene, toluene and xylenes
CUL	Cleanup level
Ecology	Washington Department of Ecology
gpm	gallons per minute
mg/kg	milligrams/kilograms
mg/L	milligrams per liter
µg/L	micrograms per liter
MTCA	Model Toxics Control Act
NFA	No Further Action
PCE	tetrachloroethylene
RI/FS	Remedial Investigation/Feasibility Study
SAP	Sampling Analysis Plan
SVE	soil vapor extraction
TCE	trichloroethylene
TEF	toxic equivalency factor
VOC	volatile organic compound
WDNR	Washington Department of Natural Resources

1 Introduction

1.1 Purpose

This *In Situ* Metals Immobilization – Pilot Study Completion Report (Completion Report) for the West of 4th (W4) Site, Site Unit 1 (SU1) has been prepared by Aspect Consulting, LLC (Aspect) on behalf of potentially liable persons (PLPs; Art Brass Plating (ABP), Blaser Die Casting (BDC), Capital Industries (CI), and Burlington Environmental (BE)), identified by the Washington State Department of Ecology (Ecology) in Agreed Order (AO) No. DE10402 for the W4 Site (the Site). The AO requires the four PLPs (the W4 Group) to complete a feasibility study (FS) and prepare a draft cleanup action plan (DCAP) for the Site.

The W4 Site has been divided into two site units, Site Unit 1 (SU1; ABP and BE) and Site Unit 2 (SU2; BDC, CI and BE), as described in the AO. Figure 1 shows the locations of the four PLPs' facilities, and the SU1 and SU2 boundaries.

The SU1 FS (Aspect, 2016) developed and evaluated remedial alternatives to address contaminated media at SU1 in accordance with Washington Administrative Code (WAC) 173-340-350(8). Ecology did not agree with the preferred remedy identified for chlorinated volatile organic compounds (CVOCs) in the SU1 FS (Ecology, 2016). Upon further discussion with Ecology, pilot testing of technologies was determined to be an appropriate step to reduce the uncertainties associated with treatment of CVOCs in downgradient groundwater. In November 2017, the AO was amended to delay submittal of the DCAP to allow for completion of pilot testing and preparation of an addendum to the FS to refine the evaluation of remedial alternatives (SU1 FS Addendum; Aspect, 2021).

The use of pH neutralization to immobilize dissolved metals in SU1 groundwater was included in seven of the nine remedial alternatives evaluated in the SU1 FS. Because submittal of the DCAP was delayed to provide time for CVOC pilot studies, a pH neutralization pilot test was conducted concurrent with the CVOC pilot test to evaluate the effectiveness of potential amendments and better define the remedy in the CAP. As discussed in the SU1 FS, pilot testing of pH neutralization is necessary for full-scale design and will reduce uncertainty in performance and cost of the technology.

The Final *In Situ* Metals Immobilization – Pilot Testing Work Plan (Work Plan) describes pilot study activities proposed to evaluate the *in situ* pH neutralization of plating metals in Water Table Interval groundwater (Aspect, 2017). Ecology approved the Work Plan on January 11, 2018. The Work Plan presented the pilot study activities in three phases:

- Phase I – Field Data Collection
- Phase II – Bench-Scale Pilot Testing
- Phase III – Field-Scale Pilot Testing

The Final *In Situ* Metals Immobilization – Pilot Study Field Implementation Work Plan (FIWP) provided the results of Phases I and II, and the Phase III design of the field-scale pilot test (Aspect, 2018; Ecology approval August 14, 2018). The injection design in the FIWP was implemented in September 2018. The pilot testing well layout is shown on Figure 2.

In July 2019, Aspect prepared the *In Situ* Metals Immobilization – Pilot Study Field Implementation Work Plan Addendum (FIWP Addendum), which presented six months of performance monitoring results after the injection event (Aspect, 2019). The performance monitoring data demonstrated that density-driven flow of injected reagent[1] were occurring, which prevented achieving pilot test objectives with the design parameters implemented in the September 2018 injection event. The FIWP Addendum also presented plans for a second injection event with adapted reagent design and performance monitoring; Ecology approved the FIWP Addendum on July 17, 2019.

This Completion Report includes a summary of the first and second injection events, the pilot test performance monitoring results, and conclusions including recommendations for a full-scale design basis, to be used for remedial alternative refinement in the SU1 FS Addendum. PLP document submittals and Ecology comment/approval letters are available online at http://clients.aspectconsulting.com/W4/.

1.2 Report Organization

This report is organized as follows:

- **Section 2** describes the approach and objectives of the pilot study.
- **Section 3** describes the reagent injection methods and monitoring. The discussion of reagent injections includes injection methods and reagent dosing and batching. The discussion of monitoring includes operational and performance monitoring.
- **Section 4** presents the results of the pilot study, including attenuation of dissolved metals, reagent delivery and distribution, permanence of metals immobilization, and design parameters.
- **Section 5** discusses the effectiveness of the pilot study and whether a full-scale implementation is feasible.
- **Section 6** provides references used in the preparation of this report.

The text references tables and figures (attached) that support the text and illustrate the proposed pilot testing activities. Appendices to this report provide supporting information references within the text.

[1] Vertical flow due to solution density gradients occurs in the groundwater system (density-driven flow). Pilot test results confirm it is a design consideration for delivery and distribution of reagents. The potential for vertical flow in the Water Table interval is high because of the high permeability of the alluvial aquifer and the lack of lower-permeability bedding below target interval that would prevent vertical flow.

2 Pilot Study Overview

2.1 Approach

The SU1 FS selected pH neutralization as part of the final remedy to immobilize dissolved plating metals in groundwater. As discussed in the Revised Technology Screening Memo (PGG, 2015), raising the groundwater pH to more-neutral conditions (i.e., around pH 7) can induce precipitation of metals from groundwater and sorption to soil. Pilot testing was recommended in the SU1 FS to evaluate treatment performance and better understand effects on groundwater chemistry.

The pilot test activities were completed in three phases:

- **Phase I (field data collection).** Phase I included monitoring and injection well installation, soil sampling, and groundwater sampling.
- **Phase II (bench-scale pilot testing).** Phase II included soil and groundwater sample processing, titration batch testing, and treatment batch testing with Site soil and groundwater and three alkaline reagents.
- **Phase III (field-scale pilot testing).** Two injection events and a total performance monitoring period of 6 months post-injection.

The results of Phase I and Phase II are summarized in the FIWP and are not repeated in this Completion Report. The results of the Phase III activities are the subject of this Completion Report.

2.2 Objectives

Pilot testing was conducted to assess the effectiveness and cost of an *in situ* pH-adjustment to immobilize plating metals in ABP source area groundwater. The pilot study was designed based on the following objectives:

1. **Reduce dissolved plating-metals concentrations in groundwater.** Acidic groundwater and associated plating-metals concentrations are naturally attenuating. The bench-scale pilot testing confirmed that a pH increase can enhance this attenuation. The field-scale pilot testing evaluates the ability to enhance attenuation through an engineered *in situ* pH neutralization. The objective is evaluated based on the performance monitoring.
2. **Evaluate the ability to deliver and distribute reagent in Water Table Interval groundwater using permanent injection wells.** This objective is evaluated based on the ability to achieve targeted injection volumes, reagent breakthrough, and pH adjustment at monitoring wells.
3. **Evaluate the permanence of the pH adjustment and immobilization of plating metals.** The field-scale pilot test targeted a small portion of the aquifer with acidic pH and, therefore, once the acidity neutralizes all alkaline reagent, it is expected that the groundwater pH will decrease as acidic groundwater from upgradient returns to the area influenced by injections. Therefore, this objective is evaluated by measuring

where the groundwater pH stabilizes and the permanence of plating metals immobilization through the longer-term monitoring.

4. **Estimate design parameters for scaling the technology.** The parameters determined from pilot testing will support design of a full-scale application capable of neutralizing a significant portion of the acidity and significantly enhancing plating metals attenuation. The following parameters have been refined based on the field-scale pilot testing results:

    a. Reagent Dosing: The ability of the 0.1 Molar (M) sodium bicarbonate and 0.1 M sodium hydroxide injection reagent to achieve the target pH of 8 at the dose-response monitoring well. Determining reagent dosing for full-scale application will need to balance the treatment capacity with the reagent density.

    b. The injected volume/radius of influence (ROI) relationship: The actual injection volume of the reagent required to achieve the breakthrough of tracer at the dose-response monitoring well. Tracer breakthrough is estimated based on the method of moments method which calculates the center of mass of the breakthrough curve (Payne et al., 2008). This relationship derives a field-measured mobile porosity.

    c. Achievable injection rates and corresponding injection-pressure relationship as determined by the operational monitoring.

3 Injection Methods and Monitoring

This section presents the methods and field observations from the Phase III field-scale pilot testing.

3.1 First Injection Event (September 2018)

The initial injection event was completed on September 18 through September 20, 2018, following the methods outlined in the FIWP. A brief discussion of both the methods, field observations, and initial findings are provided below.

3.1.1 Reagent Injections

A total of 9,940 gallons of 1.0 M sodium bicarbonate solution was delivered to injection wells IW-01 (5,072 gallons) and IW-02 (4,867 gallons). Injections were completed at one well at a time such that the corresponding dose-response well could be monitored for breakthrough. Injections were completed using gravity flow from the solution head in a 6,5000-gallon tank, and no pump head was required. The injection locations are shown on Figure 4.

The injection wells were registered with Ecology's underground injection control (UIC) program before the first injection event and automatically meet the non-endangerment standard and are rule-authorized (Site #34114).

3.1.2 Operational Monitoring

Operational monitoring of the reagent injections was conducted as described in the FIWP. Operational parameters (flow rate, pressure, and injected volume) were collected approximately every 500 gallons injected and are provided in Table 1. The flow rate ranged from to 13.3 gallons per minute (gpm) to 1 gpm with an average of 8.2 gpm. The observed flow rate was proportional to the solution head in the tank. The injection pressure was 0.5 pounds per square inch gauge (psig) or lower.

Dose-response parameters (pH, specific conductance, and sodium concentration) were monitored for every 500 gallons injected and are shown in Table 2. Select samples collected during breakthrough monitoring were submitted for sodium analysis (as a conservative tracer of injection solution) and laboratory analytical results from these samples are also included in Table 2.

Breakthrough was indicated by a sharp increase in specific conductance and an increase in pH. Injections were conducted at IW-2 first, and breakthrough was noted at dose-response well PSW-07 after 4,370 gallons injected into IW-2. A pH of 7.21 and a normalized sodium concentration[2] of 21.3 percent was observed at the peak breakthrough at PSW-7. There was an 0.43-foot increase in the water level at PSW-7 during the injection at IW-2.

Injections were conducted at IW-1 once injections at IW-2 were complete. At PSW-6, breakthrough was observed after 3,420 gallons were injected into IW-1. A pH of 7.6 and

[2] The normalized sodium concentration was calculated by dividing the measured concentration of the sample by the sodium concentration of the injection reagent.

a normalized sodium concentration of 32.1 percent was observed at peak breakthrough at PSW-6. There was an 0.48-foot increase in the water level at PSW-6 during the injection at IW-1.

Additionally, a breakthrough of up to 87.1 percent normalized sodium concentration was observed at Shallow Interval monitoring well MW-03-30. This observation was the first indication of the density-driven flow effect.

3.1.3 Performance Monitoring

Two baseline performance monitoring events were completed on February 1, 2018 and September 14, 2018, prior to reagent injections. Day 0 performance monitoring was completed on September 21, 2018, and Week 1 performance monitoring on September 27, 2018. Subsequent performance monitoring events on Week 2, Week 4, Month 2, Month 3, and Month 6 were completed as planned according to the schedule, locations, and analytes outlined in the FIWP. All performance monitoring results are provided in Table 3. Baseline monitoring data, including pH and dissolved metals concentrations used to develop the pilot test design, is provided on Figures 3 and 4.

The results indicate an initial increase in the pH at the injection wells and performance monitoring wells from pH 4 to 5 up to around 7, below the target of 8.0. A modest and temporary reduction in dissolved nickel concentration was observed at injection wells and dose-response monitoring wells.

By Month 3, the acidic groundwater with high dissolved metals concentrations from the upgradient source returned to the pilot test area. This demonstrated that the maximum pH adjustment and corresponding geochemical changes had occurred within three months after injection.

The 1.0 M sodium bicarbonate reagent migrated below the target treatment zone of 10 to 20 feet below ground surface (Water Table Interval), based on the magnitude of the specific conductivity, sodium, and pH response at MW-03-30 at 20 to 30 feet below ground surface (Shallow Interval). These observations confirmed the density-driven flow effect.

Because the target pH in the target vertical treatment interval was not met, the pilot test objectives were not achieved. Therefore, a second injection event with a lower density reagent solution was designed and implemented to meet pilot test objectives defined in the FIWP. The second injection reagent dosing was balanced with the density gradient between the reagent and groundwater to reduce potential density-driven vertical flow.

3.2 Second Injection Event (August 2019)

The second injection event was completed on August 5 through August 8, 2019, following the pilot study design approved by Ecology in the FIWP Addendum. The methodology for the second injection event is described below. The monitoring results are provided in section 4.

3.2.1 Reagent Design

Sodium bicarbonate was selected for the initial injections because it is a weak base that acts as a buffer and will maintain a pH of about 8.3, is stable, readily available, and has no special handling requirements. However, the 1.0 M sodium bicarbonate solution was not capable of achieving the desired pH adjustment in the Water Table interval due to observed density-driven flow effect described in section 3.1.3. The reagent design was adapted to include a strong base, sodium hydroxide, in the reagent solution to target the same pH of 8 at a significantly lower reagent solution density. The addition of sodium hydroxide as a strong base achieved a higher pH at a lower molar strength and thus lower density and less potential for density-driven flow. The strong base was buffered by sodium bicarbonate in solution.

The second injection event used a solution of 0.1 M sodium bicarbonate and 0.1 M sodium hydroxide and is referred to hereafter as the “reagent.”

Injections of a mixture of 0.1 M sodium bicarbonate and 0.1 M sodium hydroxide were completed on August 5 through August 8, 2019. The reagent was received in 275-gallon totes as a concentrate of 1.0 M sodium bicarbonate and 1.0 M sodium hydroxide from Silver Fern Chemical, Inc in Seattle, WA, and was diluted into 2,750-gallon batches with tap water from the ABP facility. Photos of the injection setup are included in Appendix A.

3.2.2 Reagent Injections

A total injection volume of 20,300 gallons into IW-1 (10,000 gallons) and IW-2 (10,300 gallons) was measured using a flow totalizer. Injections were completed using gravity flow from the solution head in the 4,900-gallon tank, and no pump head was required. Well locations are shown on Figure 4. Injections were completed at one well at a time such that the corresponding dose-response well could be monitored for breakthrough.

3.2.3 Operational Monitoring

Operational parameters (flow rate, pressure, and injected volume) were monitored at least every 500 gallons injected and are provided in Table 4. The flow rate ranged from 45.7 gpm to 10.5 gpm and varied based on the solution head in the tank. This increased injection flow rate compared to the first injection event can be attributed to a pipe diameter modification. During the first injection event, 1-inch-diameter piping had been used with a 1-inch diameter totalizer. During this second injection event, 2-inch-diameter piping and a 2-inch-diameter totalizer were used, allowing for a faster flow rate. The injection pressure was <0.1psig.

Dose-response parameters (pH, specific conductance, and sodium concentration) were monitored approximately every 500 gallons injected and are shown in Table 5. Select samples collected during breakthrough monitoring were submitted for sodium analysis (as a conservative tracer of injection solution) and laboratory analytical results from these samples are also included in Table 5. The breakthrough monitoring results are presented as relative cumulative volume injected in Appendix B.

3.2.4 Performance Monitoring

Performance monitoring was conducted in accordance with Table 5 of the FIWP Addendum. Results are provided in Table 6. The monitoring schedule was as follows:

Short-term monitoring:

- Pre-injection baseline monitoring on August 2, 2019

- Day 0 monitoring on August 9, 2019
- Week 1 monitoring on August 16, 2019
- Week 2 monitoring on August 22, 2019
- Week 4 monitoring on September 6, 2019
- Month 2 monitoring on October 9, 2019
- Month 3 monitoring on November 15, 2019

Long-term monitoring:

- Month 6 monitoring on February 5, 2020

4 Results

The results of the second injection event are summarized below according to the pilot study objectives presented in section 2.2.

4.1 Attenuation of Dissolved Metals

Acidic groundwater and associated dissolved plating metals concentrations in groundwater are naturally attenuating. The second field-scale pilot test injections demonstrated the ability to enhance attenuation through an engineered *in situ* pH neutralization. An analysis of pH and dissolved plating metals concentrations throughout the pilot test are discussed below. Time series data of dissolved nickel, pH, and alkalinity at dose-response monitoring wells PSW-6 and PSW-7 are shown on Figure 5. Performance monitoring data is provided in Table 6.

At PSW-06, the pH increased to 10.02 at the Day 0 post-injection monitoring event and remained above pH 9.0 through Month 3. Dissolved nickel concentrations began to decrease after one-week post-injection and decreased to a minimum of 51 ug/L at Month 3, a reduction of 94 percent relative to baseline, before slightly increasing at Month 6.

At PSW-07, the pH increased to 9.98 at the Day 0 post-injection monitoring event and remained above pH 9.0 through Month 3. Dissolved nickel concentrations began to decrease after one-week post-injection and decreased to a minimum of 116 ug/L, a reduction of 94 percent relative to baseline, at Month 6.

This increase in pH at both dose-response monitoring wells confirmed the pH neutralization in the Water Table Interval via the alkaline reagent injections. The decrease in dissolved nickel concentrations of over 90 percent demonstrates the effectiveness of the engineered *in situ* pH neutralization to immobilize dissolved-phase plating metals.

A temporary increase in dissolved copper was also observed due to dissolution and mobilization caused by the large initial increase in pH at IW-1, IW-2, PSW-06, PSW-07, and MW-3-30. Dissolved copper concentrations remained slightly above baseline at Month 6 but continued to decrease as the pH stabilizes. This secondary effect will need to be considered and managed by dosing in the full-scale application design.

4.2 Reagent Delivery and Distribution

The ability to deliver and distribute the reagent was evaluated by the ability to achieve targeted injection volumes, reagent breakthrough, and pH adjustment at monitoring wells.

- **Injection rate, volume, and pressure.** The design injection volume of 20,000 gallons was achieved with a total injection volume of 20,300 gallons. An injection rate up to 40 gpm was observed under gravity flow, significantly greater than the assumed flow rate of 10 gpm.

  The injection pressure remained at <0.1 psi. The water level at PSW-6 increased by a maximum of 1.02 feet during the injection at IW-1, and the water level at PSW-7 increased by a maximum of 1.65 feet during the injection at IW-2. The water level remained below nearby utilities in South Findlay Street, notably a sewer line that is approximately 3.4 feet bgs. This demonstrates that the permeable aquifer can easily accept 20,000 gallons of injected reagent solution without significant mounding that would result in impacts to utilities or daylighting.

- **Dose-response monitoring.** Breakthrough of the injection solution at the dose-response wells PSW-6 and PSW-7 was observed as a sharp increase in specific conductance, and an increase in pH after 2,754 gallons injected into IW-1, and 3,480 gallons injected into IW-2, respectively. The dose-response monitoring data is shown in Table 5. A pH of 10.65 and a normalized sodium concentration of 89.4 percent was observed at peak breakthrough at PSW-6. A pH of 10.63 and a normalized sodium concentration of 88.9 percent was observed at the peak breakthrough at PSW-7. Breakthrough curves at PSW-6 and PSW-7 are shown on Figure B-1 in Appendix B.

The operational monitoring and dose-response monitoring results confirm that the reagent was effectively delivered and distributed to the Water Table Interval. Although there was evidence of density-driven flow, it was delayed and less pronounced compared to the first injection event. During breakthrough monitoring for the second injection event, there were smaller increases in pH and specific conductivity at MW-3-30, and during performance monitoring, an increase in pH and specific conductivity above baseline was not observed until two weeks post-injection. Therefore, a balance between dosing and density was achieved during the second injection event, and the bulk of the reagent remained in the targeted 10- to 20-foot interval.

4.3 Permanence of Metals Immobilization

The permanence of the pH adjustment and metals immobilization is evaluated based on groundwater pH and dissolved plating metals concentrations after washout of the injection solution during the longer-term monitoring. As described in Section 4.1, the initial *in situ* pH adjustment is supported by the increased pH and alkalinity at dose-response monitoring wells PSW-06 and PSW-07. The pH stabilized at approximately 9.75 through Month 3, during which there was a steady decrease in dissolved nickel concentrations. As of Month 6, the adjusted pH decreased to 7.55 and 6.8 at the injection wells (IW-01 and IW-02, respectively), and to 7.16 and 7.47 at monitoring wells PSW-06 and PSW-07, respectively, but remained above 9.4 at MW-3-30.

The return of pH to near baseline levels at IW-01 and IW-02 and an increase in dissolved metals concentrations indicates that acidic groundwater with high dissolved metals concentrations from the upgradient source is returning to the pilot test area. At the dose-response wells (PSW-06 and PSW-07), the pH had decreased to neutral at Month 6, but, the dissolved nickel concentrations remained at least 90 percent below baseline. The metals immobilization at the dose-response wells was effective even as pH returned to neutral.

4.4 Design Parameters

Based on the results of the pilot test, the following design parameters and considerations are recommended for full-scale implementation of the technology:

- **The reagent dosing required to achieve target pH.** The pilot test dosing of 0.1 M sodium bicarbonate and 0.1 M sodium hydroxide met and exceeded the target pH of 8, while also balancing the density of the injection reagent. The addition of a strong base (sodium hydroxide) allowed achievement of a higher pH at a lower molar strength and thus lower density and less potential for density-driven flow. While there was some vertical migration of the injection reagent at MW-3-30, the sustained pH adjustment in the dose-response monitoring wells indicates that the majority of the injection reagent remained in the Water Table Interval.

  However, while the strong base was somewhat managed by the buffering capacity of sodium bicarbonate in solution, the initial drastic increase in pH (>10) created a secondary effect of metals mobilization. Therefore, the concentration of sodium hydroxide should be reduced in future injections. The reagent dosing for full-scale treatment is recommended to be 0.1 M sodium bicarbonate and 0.05 M sodium hydroxide, to reduce the amount of strong base and mitigate any metals mobilization due to high pH.

- **The injected volume/ROI relationship.** The actual injection volume of the reagent required to achieve the breakthrough of tracer at the dose-response monitoring well was calculated from the pilot test operational monitoring data. Tracer breakthrough was estimated based on the method of moments method which calculates the center of mass of the breakthrough curve (Payne et al., 2008). These breakthrough curves are shown on Figure B-1 in Appendix B.

  Based on this relationship, the field-measured mobile porosity is 20 percent, greater than the 15 percent assumed in the design. The center of mass of the breakthrough curves for both PSW-06 and PSW-07 was approximately 5,000 gallons, which is the basis for injection volume at the full-scale design. Based on this injection volume, the target ROI for full-scale implementation would be 10 feet, smaller than the 12-foot target ROI of the pilot test. The ROI would be subject to change depending on the final injection volume.

- **Achievable injection rates and corresponding injection-pressure relationship.** The maximum injection rate for the 4-inch diameter injection wells during the second injection event was 45.7 gpm with an average above the predicted rate of 10 gpm, and the injection pressure remained at <0.1 psi, indicating a high injection specific capacity within the Water Table interval. The limiting factors to the injection rate are the diameter of the injection piping and the solution head in the tank. The highly permeable alluvial aquifer with low anisotropy allows for high injection rates and low pressures.

- **Injection Infrastructure.** The pilot test was successfully completed with permanent injection wells, and reagent delivery and distribution objectives were achieved. The pilot test data showed that very high injection rates (up to 47 gpm) can be accomplished with just the tank head. Based on these injection rates and the observed distribution, direct push delivery would be possible for the full-scale implementation and could be more cost effective depending on the area targeted and if more than one injection is needed.

5 Conclusions

The pilot study was successfully implemented as planned in the FIWP and the FIWP Addendum. Although the first injection event did not meet pilot study objectives as described in Section 3, the redesigned approach to pH neutralization for the second injection event was successful. The pilot study objectives were achieved and provide the basis of design for full-scale implementation of the *in situ* metals immobilization. The attenuation of dissolved metals was demonstrated through a decrease in nickel concentrations during the performance monitoring data. The reagent was delivered and distributed uniformly and targeted the Water Table Interval. The metals immobilization was shown to last through at least six months post-injection at the dose-response monitoring wells when the pH had returned to neutral, confirming the permanence of this treatment.

Sufficient data was collected during the pilot study to provide design parameters and recommendations for full-scale implementation.

6 References

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Limitations

Work for this project was performed for the West of 4th Group (Client), and this report was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.

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TABLES

In-Situ Metals Immobilization – Pilot Study Completion Report

Table 1. Operational Monitoring - First Injection Event

Project No. 050067, Art Brass Plating, Seattle, Washington

Active Injection Well	Date	Time	Injection Rate (gpm)	Injection Pressure (psig)	Cumulative Injected Volume (gal)	Volume injected per well (gal)
IW-2	9/18/2018	9:54	10.7	0.5	621	621
IW-2	9/18/2018	10:06	10.5	0.5	838	838
IW-2	9/18/2018	10:19	10.3	0.5	1012	1012
IW-2	9/18/2018	10:43	10.3	0.5	1200	1200
IW-2	9/18/2018	10:54	10.5	0.5	1313	1313
IW-2	9/18/2018	11:05	10.3	0.5	1420	1420
IW-2	9/18/2018	11:16	10	0.5	1535	1535
IW-2	9/18/2018	11:41	11.5	0.5	1672	1672
IW-2	9/18/2018	11:52	11.5	0.5	1830	1830
IW-2	9/18/2018	12:04	11.5	0.5	1956	1956
IW-2	9/18/2018	13:08	11.3	0.5	2284	2284
IW-2	9/18/2018	13:19	11	0.5	2392	2392
IW-2	9/18/2018	13:30	10.5	0.5	2483	2483
IW-2	9/18/2018	13:40	8.1	0.5	2500	2500
IW-2	9/18/2018	13:52	9.8	0.5	2602	2602
IW-2	9/18/2018	14:04	9.4	0.5	2716	2716
IW-2	9/18/2018	14:15	9	0.5	2812	2812
IW-2	9/18/2018	14:26	8.8	0.5	2916	2916
IW-2	9/18/2018	14:36	8.7	0.5	3002	3002
IW-2	9/18/2018	14:47	8.6	0.5	3094	3094
IW-2	9/18/2018	14:58	8.6	0.5	3199	3199
IW-2	9/18/2018	15:09	8.1	0.5	3273	3273
IW-2	9/18/2018	15:20	8.1	0.5	3379	3379
IW-2	9/18/2018	15:31	8	0	3470	3470
IW-2	9/18/2018	16:10	7.5	0	3722	3722
IW-2	9/18/2018	16:22	6.7	0	3816	3816
IW-2	9/18/2018	16:33	6.7	0	3875	3875
IW-2	9/18/2018	16:45	6.7	0	3954	3954
IW-2	9/18/2018	18:01	4.8	0	4370	4370
IW-2	9/18/2018	18:13	4.6	0	4430	4430
IW-2	9/18/2018	18:23	4.4	0	4480	4480
IW-2	9/19/2018	10:21	1.81	0	4798	4798
IW-2	9/19/2018	10:32	1.62	0	4803	4803
IW-2	9/19/2018	10:42	1.33	0	4828	4828
IW-2	9/19/2018	10:54	1	0	4834	4834
IW-2	9/19/2018	10:59	NC	NC	4867	4867
IW-1	9/19/2018	13:58	13.3	0	5378	511
IW-1	9/19/2018	14:09	13.3	0	5537	670
IW-1	9/19/2018	14:20	13	0	5660	793
IW-1	9/19/2018	14:31	12.6	0	5800	933
IW-1	9/19/2018	14:42	12.5	0	5931	1064
IW-1	9/19/2018	14:52	11.4	0	6052	1185
IW-1	9/19/2018	15:05	11.4	0	6213	1346
IW-1	9/19/2018	15:15	11.4	0	6338	1471
IW-1	9/19/2018	15:26	10.9	0	6452	1585
IW-1	9/19/2018	15:55	10.4	0	6766	1899
IW-1	9/19/2018	16:06	10.3	0	6881	2014
IW-1	9/19/2018	16:17	10	0	7001	2134
IW-1	9/19/2018	16:47	9.68	0	7299	2432
IW-1	9/19/2018	16:58	9.38	0	7393	2526
IW-1	9/19/2018	17:08	9.38	0	7490	2623
IW-1	9/19/2018	17:44	8.4	0	7818	2951
IW-1	9/19/2018	17:55	8.22	0	7893	3026
IW-1	9/19/2018	18:06	8.11	0	7993	3126
IW-1	9/19/2018	18:44	7.43	0	8283	3416
IW-1	9/19/2018	18:55	7.06	0	8379	3512
IW-1	9/19/2018	19:06	6.97	0	8442	3575
IW-1	9/19/2018	19:47	6.32	0	8721	3854
IW-1	9/19/2018	19:58	5.83	0	8793	3926
IW-1	9/19/2018	20:10	5.61	0	8860	3993
IW-1	9/20/2018	9:44	4.8	0	9241	4374
IW-1	9/20/2018	9:54	4.71	0	9290	4423
IW-1	9/20/2018	10:04	4.51	0	9332	4465
IW-1	9/20/2018	12:26	2	0	9798	4931
IW-1	9/20/2018	12:37	1.94	0	9808	4941
IW-1	9/20/2018	12:49	1.71	0	9829	4962
IW-1	9/20/2018	14:50	NC	NC	9940	5072

Notes:

NC - Not collected

Table 2. Dose-Response Monitoring - First Injection Event
Project No. 050067, Art Brass Plating, Seattle, Washington

Monitoring Well Location	Active Injection Well	Date	Time	WL (ft BTOC)	pH	Specific Conductance (us/cm)	Na Concentration (mg/L)	Normalized Na Concentration (%)	Analytical Sample Name
	IW-2	9/18/2018	18:40	NA	8.29	55363	24,300		Injection-1
	IW-1	9/19/2018	20:20	NA	8.34	55168	24,600		Injection-2
MW-3	IW-2	9/18/2018	10:19	6.87	4.26	568.1			
MW-3	IW-2	9/18/2018	10:24	6.87	4.16	581	39.3	0.2%	MW-3-091818-1
MW-3	IW-2	9/18/2018	11:16	5.85	4.33	512			
MW-3	IW-2	9/18/2018	11:21	5.85	4.16	507.3			MW-3-091818-2
MW-3	IW-2	9/18/2018	12:04	5.84	4.33	484			
MW-3	IW-2	9/18/2018	12:09	5.83	4.14	507.2			MW-3-091818-3
MW-3	IW-2	9/18/2018	13:40	5.91	4.33	479.6			
MW-3	IW-2	9/18/2018	13:45	5.91	4.12	491.1			MW-3-091818-4
MW-3	IW-2	9/18/2018	14:15	5.91	4.21	506.8			
MW-3	IW-2	9/18/2018	14:20	5.92	4.49	544.7	75	0.3%	MW-3-091818-5
MW-3	IW-2	9/18/2018	14:58	5.96	NC	NC			
MW-3	IW-2	9/18/2018	15:03	5.98	6.16	3351	879	3.6%	MW-3-091818-6
MW-3	IW-2	9/18/2018	15:31	6.01	6.56	7396			
MW-3	IW-2	9/18/2018	15:36	6.02	6.42	5193	1290	5.3%	MW-3-091818-7
MW-3	IW-2	9/18/2018	16:45	6.12	6.86	12677			
MW-3	IW-2	9/18/2018	16:50	6.14	6.54	6284	1680	6.9%	MW-3-091818-8
MW-3	IW-2	9/18/2018	18:23	6.25	6.33	4140			
MW-3	IW-2	9/18/2018	18:28	6.26	6.3	3705			MW-3-091818-9
MW-3	IW-2	9/19/2018	10:54	6.4	6.07	1496			
MW-3	IW-2	9/19/2018	10:59	6.42	5.4	870			MW-3-091818-10
MW-3	IW-1	9/19/2018	14:20	5.91	NC	NC			
MW-3	IW-1	9/19/2018	14:25	5.91	5	763			MW-3-091818-11
MW-3	IW-1	9/19/2018	14:52	5.91	6.72	1872			
MW-3	IW-1	9/19/2018	14:57	5.91	5.12	823			MW-3-091818-12
MW-3	IW-1	9/19/2018	15:26	5.92	6.39	1965			
MW-3	IW-1	9/19/2018	15:31	5.93	5.14	855	62.4	0.3%	MW-3-091818-13
MW-3	IW-1	9/19/2018	16:17	5.96	5.83	1257			
MW-3	IW-1	9/19/2018	16:21	5.97	5.15	916			MW-3-091818-14
MW-3	IW-1	9/19/2018	17:08	6.01	6.36	2006			
MW-3	IW-1	9/19/2018	17:13	6.02	5.29	879			MW-3-091818-15
MW-3	IW-1	9/19/2018	18:06	6.07	6.69	2058			
MW-3	IW-1	9/19/2018	18:11	6.09	5.44	840			MW-3-091818-16
MW-3	IW-1	9/19/2018	19:06	6.13	6.43	1473			
MW-3	IW-1	9/19/2018	19:11	6.15	5.62	796	79.5	0.3%	MW-3-091818-17
MW-3	IW-1	9/19/2018	20:10	6.21	6.72	1979			
MW-3	IW-1	9/19/2018	20:15	6.22	5.73	830			MW-3-091818-18
MW-3	IW-1	9/20/2018	10:04	6.23	6.6	1852			
MW-3	IW-1	9/20/2018	10:09	6.24	5.55	747			MW-3-091818-19
MW-3	IW-1	9/20/2018	12:49	6.35	6.36	1472			
MW-3	IW-1	9/20/2018	12:59	6.35	5.51	741			MW-3-091818-20
MW-3-30	IW-2	9/18/2018	10:06	5.87	6.29	503.3			
MW-3-30	IW-2	9/18/2018	10:12	5.85	6.47	518	33	0.1%	MW-3-30-091818-1
MW-3-30	IW-2	9/18/2018	11:05	5.83	6.34	483.2			
MW-3-30	IW-2	9/18/2018	11:10	5.84	6.34	458.3			MW-3-30-091818-2
MW-3-30	IW-2	9/18/2018	11:52	5.85	6.24	434.3			
MW-3-30	IW-2	9/18/2018	11:57	5.85	6.25	426.2			MW-3-30-091818-3
MW-3-30	IW-2	9/18/2018	13:30	5.9	6.21	409.4			
MW-3-30	IW-2	9/18/2018	13:35	5.87	6.1	403.3	24	0.1%	MW-3-30-091818-4
MW-3-30	IW-2	9/18/2018	14:04	6.84	6.09	389.7			
MW-3-30	IW-2	9/18/2018	14:09	6.85	6.1	390			MW-3-30-091818-5
MW-3-30	IW-2	9/18/2018	14:47	5.87	6.05	376.6			
MW-3-30	IW-2	9/18/2018	14:52	5.88	6.06	382.5			MW-3-30-091818-6
MW-3-30	IW-2	9/18/2018	15:20	5.9	6.11	381.5			
MW-3-30	IW-2	9/18/2018	15:25	5.91	6.05	377.8			MW-3-30-091818-7
MW-3-30	IW-2	9/18/2018	16:33	5.96	6.03	382.2			
MW-3-30	IW-2	9/18/2018	16:38	5.99	5.92	376.9	21.6	0.1%	MW-3-30-091818-8
MW-3-30	IW-2	9/18/2018	18:13	6.05	5.95	599			
MW-3-30	IW-2	9/18/2018	18:18	6.08	5.95	623			MW-3-30-091818-9
MW-3-30	IW-2	9/19/2018	10:42	6.33	8.16	46344			
MW-3-30	IW-2	9/19/2018	10:47	6.35	8.17	48968	21300	87.1%	MW-3-30-091818-10
MW-3-30	IW-1	9/19/2018	14:09	5.87	8.14	47333			
MW-3-30	IW-1	9/19/2018	14:14	5.87	8.11	46678			MW-3-30-091818-11
MW-3-30	IW-1	9/19/2018	14:42	5.84	8.12	46013			
MW-3-30	IW-1	9/19/2018	14:47	5.85	8.09	45491			MW-3-30-091818-12
MW-3-30	IW-1	9/19/2018	15:15	5.83	8.09	44406			
MW-3-30	IW-1	9/19/2018	15:20	5.84	8.07	44209			MW-3-30-091818-13
MW-3-30	IW-1	9/19/2018	16:06	5.86	8.09	43756			
MW-3-30	IW-1	9/19/2018	16:11	5.87	8.02	42702	17700	72.4%	MW-3-30-091818-14
MW-3-30	IW-1	9/19/2018	16:58	5.89	8.01	41338			
MW-3-30	IW-1	9/19/2018	17:03	5.92	7.98	41147			MW-3-30-091818-15
MW-3-30	IW-1	9/19/2018	17:55	5.94	8.02	41308			
MW-3-30	IW-1	9/19/2018	18:00	5.96	7.97	41130			MW-3-30-091818-16
MW-3-30	IW-1	9/19/2018	18:55	5.99	8.09	44554			
MW-3-30	IW-1	9/19/2018	19:00	6.01	8.05	43807			MW-3-30-091818-17
MW-3-30	IW-1	9/19/2018	19:58	6.06	8.13	46617			
MW-3-30	IW-1	9/19/2018	20:03	6.08	8.07	45092			MW-3-30-091818-18
MW-3-30	IW-1	9/20/2018	9:54	6.11	7.99	45793			
MW-3-30	IW-1	9/20/2018	9:59	6.11	7.85	44096	19000	77.7%	MW-3-30-091818-19
MW-3-30	IW-1	9/20/2018	12:37	6.21	7.91	44977			
MW-3-30	IW-1	9/20/2018	12:42	6.22	7.74	41885			MW-3-30-091818-20
PSW-6	IW-1	9/19/2018	13:58	5.54	5.12	554.1			
PSW-6	IW-1	9/19/2018	14:03	5.54	5.23	460	25	0.1%	PSW-6-091818-11
PSW-6	IW-1	9/19/2018	14:31	5.52	5.56	547.4			
PSW-6	IW-1	9/19/2018	14:36	5.52	5.18	550.7			PSW-6-091818-12
PSW-6	IW-1	9/19/2018	15:05	5.53	5.63	538.7			
PSW-6	IW-1	9/19/2018	15:10	5.54	5.34	497			PSW-6-091818-13
PSW-6	IW-1	9/19/2018	15:55	5.57	5.68	508.8			

Table 2. Dose-Response Monitoring - First Injection Event
Project No. 050067, Art Brass Plating, Seattle, Washington

Monitoring Well Location	Active Injection Well	Date	Time	WL (ft BTOC)	pH	Specific Conductance (us/cm)	Na Concentration (mg/L)	Normalized Na Concentration (%)	Analytical Sample Name
PSW-6	IW-1	9/19/2018	16:00	5.57	5.7	521.2			PSW-6-091818-14
PSW-6	IW-1	9/19/2018	16:47	5.62	5.84	510.2			
PSW-6	IW-1	9/19/2018	16:52	5.62	5.71	481.6			PSW-6-091818-15
PSW-6	IW-1	9/19/2018	17:44	5.68	5.94	526.6			
PSW-6	IW-1	9/19/2018	17:49	5.69	5.67	469	26	0.1%	PSW-6-091818-16
PSW-6	IW-1	9/19/2018	18:44	5.76	NC	NC			
PSW-6	IW-1	9/19/2018	18:49	5.77	7.17	9046	3220	13.2%	PSW-6-091818-17
PSW-6	IW-1	9/19/2018	19:47	5.84	7.4	20867			
PSW-6	IW-1	9/19/2018	19:52	5.85	7.38	20400	7010	28.7%	PSW-6-091818-18
PSW-6	IW-1	9/20/2018	9:44	5.89	7.52	23083			
PSW-6	IW-1	9/20/2018	9:49	5.9	7.57	22226	7840	32.1%	PSW-6-091818-19
PSW-6	IW-1	9/20/2018	12:26	6.01	7.61	25630			
PSW-6	IW-1	9/20/2018	12:31	6.02	7.6	24621			PSW-6-091818-20
PSW-7	IW-2	9/18/2018	9:54	5.81	4.67	300.4			
PSW-7	IW-2	9/18/2018	10:01	5.74	4.67	289	15	0.1%	PSW-7-091818-1
PSW-7	IW-2	9/18/2018	10:54	5.74	4.85	288.6			
PSW-7	IW-2	9/18/2018	10:59	5.74	4.8	283.7			PSW-7-091818-2
PSW-7	IW-2	9/18/2018	11:41	5.81	4.86	301			
PSW-7	IW-2	9/18/2018	11:46	5.78	4.87	284.8			PSW-7-091818-3
PSW-7	IW-2	9/18/2018	13:19	5.89	4.97	287			
PSW-7	IW-2	9/18/2018	13:24	5.84	4.93	285.5			PSW-7-091818-4
PSW-7	IW-2	9/18/2018	13:52	5.78	4.97	294			
PSW-7	IW-2	9/18/2018	13:57	5.78	4.9	289.1			PSW-7-091818-5
PSW-7	IW-2	9/18/2018	14:36	5.81	4.97	291			
PSW-7	IW-2	9/18/2018	14:41	5.82	4.95	292.5	16.5	0.1%	PSW-7-091818-6
PSW-7	IW-2	9/18/2018	15:09	5.84	5.03	394.2			
PSW-7	IW-2	9/18/2018	15:14	5.86	4.89	357.9			PSW-7-091818-7
PSW-7	IW-2	9/18/2018	16:22	5.92	4.83	384.8			
PSW-7	IW-2	9/18/2018	16:27	5.94	4.77	401.5	23.2	0.1%	PSW-7-091818-8
PSW-7	IW-2	9/18/2018	18:01	6.05	6.21	3248			
PSW-7	IW-2	9/18/2018	18:06	6.07	6.28	3536	783	3.2%	PSW-7-091818-9
PSW-7	IW-2	9/19/2018	10:32	6.24	7.18	15726			
PSW-7	IW-2	9/19/2018	10:37	6.24	7.21	16380	5210	21.3%	PSW-7-091818-10
PSW-8	IW-2	9/18/2018	10:43	5.9	4.78	412.8			
PSW-8	IW-2	9/18/2018	10:48	5.9	4.79	377.2	17.7	0.1%	PSW-8-091818-2
PSW-8	IW-2	9/18/2018	13:08	6.13	4.98	381.1			
PSW-8	IW-2	9/18/2018	13:13	6.06	5.19	341.8			PSW-8-091818-4
PSW-8	IW-2	9/18/2018	14:26	5.95	5.26	341.7			
PSW-8	IW-2	9/18/2018	14:31	5.95	5.09	335.7			PSW-8-091818-6
PSW-8	IW-2	9/18/2018	16:10	6.02	5.51	441.5			
PSW-8	IW-2	9/18/2018	16:15	6.03	5.36	408.6			PSW-8-091818-8
PSW-8	IW-2	9/19/2018	10:21	6.27	5.55	338.9			
PSW-8	IW-2	9/19/2018	10:26	6.27	5.52	322.6			PSW-8-091818-9

Notes:

NC - Not collected

Normalized Na Concentration was calculated by dividing the measured sodium concentration at a well by the average of the injection solution sodium concentration.

Table 3. Performance Monitoring - First Injection Event

Project No. 050067-014M-01, Art Brass Plating, Seattle, Washington

		Water Table Interval															
		Injection Wells															
		IW-01								IW-02							
		02/01/2018	09/21/2018	09/27/2018	10/05/2018	10/19/2018	11/15/2018	12/13/2018	03/08/2019	02/01/2018	09/21/2018	09/27/2018	10/05/2018	10/19/2018	11/15/2018	12/13/2018	03/08/2019
Analyte	Units	Baseline	Day 0	Day 6	Day 14	Day 28	Day 55	Day 83	Day 168	Baseline	Day 0	Day 6	Day 14	Day 28	Day 55	Day 83	Day 168
Plating Metals (Dissolved)																	
Cadmium	ug/L	**0.176**	< 0.200 U	--	--	< 0.500 U	--	< 0.100 U	< 0.100 U	**0.139**	< 0.200 U	--	--	< 0.500 U	--	**0.182**	**0.180**
Copper	ug/L	**23.1**	**7.94**	--	--	**3.96**	--	< 0.500 U	< 0.500 U	**10.2**	**11.8**	--	--	**4.31**	--	**2.03**	**1.28**
Nickel	ug/L	**2370**	**48.4**	--	--	**14.8**	--	**1610**	**3110**	**4570**	**217**	--	--	**280**	--	**13300**	**12700**
Zinc	ug/L	**34.1**	< 8.00 U	--	--	< 20.0 UJ	--	**5.36**	**6.38**	**35.8**	< 8.00 U	--	--	< 20.0 UJ	--	**16.9**	**24.4**
Redox-Sensitive Metals (Dissolved)																	
Arsenic	mg/L	< 0.0500 U	**0.0109 J**	--	--	**0.0093 J**	--	**0.0064 J**	< 0.0500 U	**0.0054 J**	< 0.100 U	--	--	**0.0068 J**	--	< 0.0500 U	< 0.0500 U
Barium	mg/L	**0.0287**	**0.0033 J**	--	--	**0.0027 J**	--	**0.0019 J**	**0.0056**	**0.0265**	**0.0053 J**	--	--	**0.0018 J**	--	**0.0044**	**0.0069**
Manganese	mg/L	**0.561**	**0.0080**	--	--	**0.0268**	--	**0.293**	**0.390**	**0.469**	**0.0158**	--	--	**0.0307**	--	**0.398**	**0.535**
General Chemistry Parameters																	
Aluminum	mg/L	**0.433**	**0.220**	--	--	**0.187**	--	**0.0484 J**	**0.0636**	**0.313**	**0.234**	--	--	**0.103**	--	**0.111**	**0.270**
Calcium	mg/L	**28.2**	**0.428**	--	--	**0.324**	--	**6.26**	**14.9**	**20.5**	**0.978**	--	--	**0.657**	--	**18.3**	**22.6**
Iron	mg/L	**3.05**	**0.181**	--	--	**2.95**	--	**1.57**	**1.27**	**5.79**	**0.179**	--	--	**1.37**	--	**0.480**	**0.537**
Magnesium	mg/L	**9.53**	**0.186**	--	--	**0.0745**	--	**3.58**	**5.36**	**6.28**	**0.213**	--	--	**0.222**	--	**5.87**	**6.45**
Potassium	mg/L	**8.65**	**0.742 J**	--	--	**0.978**	--	**1.64**	**3.76**	**6.12**	**1.34**	--	--	**0.550**	--	**2.63**	**4.36**
Sodium	mg/L	**33.8**	**964**	**445**	**252**	**220**	**161**	**118**	**70.1**	**38.8**	**969**	**310**	**178**	**167**	**138**	**114**	**85.6**
Acidity	ug/L	**20000**	< 10000 U	--	--	< 10000 U	--	< 10000 U	< 10000 U	**24000**	< 10000 U	--	--	< 10000 U	--	< 10000 U	< 10000 U
Alkalinity, Total	mg/L	**4.45**	**1670**	--	--	**184**	--	**71.7**	**43.3**	**3.64**	**1750**	--	--	**160**	--	**56.9**	**13.6**
Chloride	mg/L	**33.7**	**44.2**	--	--	**40.0**	--	**28.1**	**31.9**	**19.3**	**27.3**	--	--	**28.5**	--	**40.0**	**39.1**
Sulfate	mg/L	**143**	**113**	--	--	**207**	--	**205**	**204 J**	**145**	**59.9**	--	--	**125**	--	**245**	**332 J**
Total Organic Carbon	mg/L	**1.88**	**7.17**	--	--	**5.12**	--	**1.53**	**1.33**	**1.97**	**15.95**	--	--	**4.29**	--	**1.86**	**1.65**
Field Parameters																	
Temperature	deg C	**13.9**	**20.3**	**18.7**	**17.5**	**17.3**	**17.1**	**14.8**	**12**	**14.3**	**19.4**	**18.1**	**16.6**	**17.5**	**17**	**14.6**	**13**
Specific Conductance	uS/cm	**377.1**	**3460**	**1510**	**998**	**838**	**618**	**1054**	**460.5**	**376**	**3473**	**1107**	**717**	**687**	**576.9**	**552.5**	**626.2**
Dissolved Oxygen	mg/L	**0.3**	**0.22**	**0.14**	**0.12**	**0.13**	**0.13**	**0.12**	**0.14**	**0.26**	**0.14**	**0.15**	**0.12**	**0.1**	**0.19**	**0.25**	**0.2**
pH	pH units	**5.25**	**7.24**	**7.15**	**6.85**	**6.6**	**6.18**	**5.73**	**5.45**	**5.19**	**7.19**	**6.65**	**6.61**	**6.64**	**6.15**	**5.94**	**5.4**
Oxidation Reduction Potential	mV	**179.7**	**27.4**	**14.8**	**-32**	**-18.1**	**15.6**	**66.8**	**81.6**	**182.2**	**57.7**	**36.9**	**-8.1**	**-97.2**	**53.9**	**82.4**	**111.7**
Turbidity	NTU	**37**	**3.78**	**8**	**8.4**	**8.21**	**4.42**	**25.1**	**48.1**	**10**	**4.89**	**5.59**	**3.4**	**2.96**	**4.9**	**3.73**	**45.2**

Notes:

J - Analyte was positively identified. The reported result is an estimate.
U - Analyte was not detected at or above the reported limit.

Table 3. Performance Monitoring - First Injection Event

Project No. 050067-014M-01, Art Brass Plating, Seattle, Washington

		Water Table Interval																	
		Performance Monitoring Wells																	
		MW-03									PSW-06								
		01/29/2018	09/14/2018	09/21/2018	09/27/2018	10/05/2018	10/19/2018	11/15/2018	12/13/2018	03/08/2019	02/01/2018	09/14/2018	09/21/2018	09/27/2018	10/05/2018	10/19/2018	11/15/2018	12/13/2018	03/08/2019
Analyte	**Units**	**Baseline**	**Baseline**	**Day 0**	**Day 6**	**Day 14**	**Day 28**	**Day 55**	**Day 83**	**Day 168**	**Baseline**	**Baseline**	**Day 0**	**Day 6**	**Day 14**	**Day 28**	**Day 55**	**Day 83**	**Day 168**
Plating Metals (Dissolved)																			
Cadmium	ug/L	0.216	0.262	< 0.500 U	< 1.00 U	0.264	< 1.00 U	0.308	0.243	0.262	0.171	0.238	< 0.200 U	< 0.500 U	< 0.100 U	< 0.500 U	< 0.1 U	< 0.100 U	0.123
Copper	ug/L	15.5	27.0	10.8	15.8	17.3	14.7	23.1	19.5	16.4	1.06	9.59	3.17	3.22	3.85	23.8	19.2	7.39	3.09
Nickel	ug/L	11400	23800	13900	17300	20800	15800	12300	18700	15300	4600	6730	3050	4520	3760	1780	1890	2780	4410
Zinc	ug/L	46.6	--	46.8	57.8	52.8	57.0 J	77.1	57.1	60.6	50.2	--	44.9	46.4	20.6	< 20.0 UJ	12.2	20.1	30.0
Redox-Sensitive Metals (Dissolved)																			
Arsenic	mg/L	0.0060 J	0.0094 J	< 0.0500 U	0.0066 J	0.0058 J	--	0.0088 J	< 0.0500 U	0.0051 J	0.0059 J	0.0072 J	0.0095 J	0.0093 J	0.0093 J	0.0102 J	0.0081 J	0.0059 J	0.0071 J
Barium	mg/L	0.0084	0.0075	0.0055	0.0060	0.0078	--	0.0085	0.0085	0.0096	0.0487	0.0143	0.0169	0.0120	0.0111	0.0082	0.005	0.0103	0.0083
Manganese	mg/L	0.356	0.463	0.393	0.431	0.440	--	0.572	0.502	0.390	0.906	0.735	0.708	0.534	0.292	0.104	0.105	0.198	0.341
General Chemistry Parameters																			
Aluminum	mg/L	1.25	1.83	0.738	1.06	1.23	1.14	2.15	1.77	1.14	0.794	1.35	0.568	0.521	0.245	0.354	0.332	0.304	0.328
Calcium	mg/L	26.0	32.6	25.9	28.5	30.0	28.4	40.4	32.9	29.2	44.5	41.1	36.7	32.3	20.6	7.84	7.02	12.7	20.2
Iron	mg/L	0.0791	0.584	0.391	0.292	0.285	0.491	0.536	0.555	0.0854	6.37	3.90	5.45	1.14	0.514	0.378	0.234	0.803	0.494
Magnesium	mg/L	7.14	7.84	7.09	7.53	7.18	7.09	9.66	8.32	7.40	14.8	13.1	13.8	11.1	6.35	2.30	2.06	4.12	6.64
Potassium	mg/L	6.79	9.52	8.73	8.60	8.40	8.74	9.57	8.61	7.68	12.5	13.2	13.1	11.5	10.4	6.67	5.27	6.88	6.78
Sodium	mg/L	37.0	67.5	67.7	56.0	57.6	55.0	54.6	49.2	58.3	54.3	62.6	174	84.8	263	223	165	116	82.1
Acidity	ug/L	26000	28000	24000	< 10000 U	12000	32000	< 10000 U	< 10000 U	< 10000 U	130000	8000 J	< 10000 U	< 10000 U	< 10000 U	< 10000 U	< 10000 U	< 10000 U	< 10000 U
Alkalinity, Total	mg/L	< 1.00 U	< 1.00 U	20.1	< 1.00 U	< 1.00 U	< 1.00 U	< 1 U	< 1.00 U	< 1.00 U	6.68	5.47	252	83.5	487	339	232	99.5	52.9
Chloride	mg/L	23.7	42.1	33.7	--	39.8	39.2	47.5	40.1	40.5	49.6	45.4	37.5	--	30.4	24.7	22	26.8	31.9
Sulfate	mg/L	163	267	200	--	208	184	277 J	207	318 J	247	253	201	--	140	106	131 J	170	260 J
Total Organic Carbon	mg/L	1.88	2.36	1.57	1.63	1.66	1.56	1.57	1.51	2.21	1.70	1.71	2.10	1.74	4.04	5.28	3.98	2.14	1.78
Field Parameters																			
Temperature	deg C	13.6	18.1	18.2	18.4	17.5	18	17.3	16.2	13	14.7	17.6	18.3	18.6	18	18.2	17.3	16.2	13.6
Specific Conductance	uS/cm	320	793	588	480.9	546.7	565.2	646	465.5	585.1	593	797	1072	568.3	1108	873	677	1064	557.6
Dissolved Oxygen	mg/L	2.67	0.25	0.15	0.21	0.09	0.15	0.38	0.87	0.65	0.14	0.3	0.09	0.18	0.1	0.12	0.19	0.13	0.17
pH	pH units	4.87	4.04	4.88	4.62	4.46	4.58	4.27	4.48	4.76	5.27	4.66	6	5.62	6.74	6.9	6.78	5.88	5.73
Oxidation Reduction Potential	mV	93.9	190.1	136.4	135.5	159.5	261.9	120.4	108.7	93.5	174.5	152.3	65.6	74.1	32	-7.1	88.9	88.9	83.2
Turbidity	NTU	41.9	56.3	6.22	7.06	5.7	5.46	2.72	5	10.2	7	8.2	1.61	1.8	1.6	7.78	4.92	4.16	28.7

Notes:

J - Analyte was positively identified. The reported result is an estimate.
U - Analyte was not detected at or above the reported limit.

Table 3. Performance Monitoring - First Injection Event

Project No. 050067-014M-01, Art Brass Plating, Seattle, Washington

		Water Table Interval																	
		Performance Monitoring Wells																	
		PSW-07									PSW-08								
		02/01/2018	09/14/2018	09/21/2018	09/27/2018	10/05/2018	10/19/2018	11/15/2018	12/13/2018	03/08/2019	02/01/2018	09/14/2018	09/21/2018	09/27/2018	10/05/2018	10/19/2018	11/15/2018	12/13/2018	03/08/2019
Analyte	Units	Baseline	Baseline	Day 0	Day 6	Day 14	Day 28	Day 55	Day 83	Day 168	Baseline	Baseline	Day 0	Day 6	Day 14	Day 28	Day 55	Day 83	Day 168
Plating Metals (Dissolved)																			
Cadmium	ug/L	**0.251**	< 0.100 U	< 0.500 U	< 0.200 U	**0.111**	< 0.500 U	< 0.1 U	**0.112**	**0.130**	**0.223**	**0.174**	< 0.500 U	< 0.500 U	**0.139**	< 0.500 U	**0.124**	**0.247**	**0.114**
Copper	ug/L	**2.55**	**2.63**	< 2.50 U	**1.87**	**3.20**	**3.04**	**3.88**	**6.19**	**5.95**	**3.25**	**7.49**	< 2.50 U	**4.47**	**6.78**	**7.45**	**6.56**	**7.28**	**5.17**
Nickel	ug/L	**8850**	**3670**	**6030**	**7570**	**8880**	**4900**	**3460**	**8350**	**7590**	**7510**	**6910**	**604**	**4720**	**5870**	**5860**	**5130**	**5400**	**2820**
Zinc	ug/L	**52.4**	--	**51.6**	**33.1**	**29.1**	**75.8 J**	**12.3**	**21.7**	**22.2**	**54.8**	--	< 20.0 U	**47.9**	**54.0**	**56.7 J**	**51**	**51.2**	**41.0**
Redox-Sensitive Metals (Dissolved)																			
Arsenic	mg/L	**0.0058 J**	**0.0066 J**	**0.0109 J**	**0.0064 J**	**0.0064 J**	**0.0050 J**	**0.0063 J**	< 0.0500 U	**0.0049 J**	< 0.0500 U	< 0.0500 U	< 0.0500 U	**0.0049 J**	**0.0067 J**	**0.0083 J**	**0.0061 J**	< 0.0500 U	< 0.0500 U
Barium	mg/L	**0.0319**	**0.0077**	**0.0112**	**0.0068**	**0.0088**	**0.0053**	**0.003**	**0.0049**	**0.0047**	**0.0359**	**0.0076**	**0.0065**	**0.0080**	**0.0078**	**0.0086**	**0.0083**	**0.0081**	**0.0082**
Manganese	mg/L	**0.596**	**0.379**	**0.540**	**0.365**	**0.360**	**0.167**	**0.0937**	**0.214**	**0.229**	**0.601**	**0.449**	**0.418**	**0.427**	**0.409**	**0.418**	**0.471**	**0.420**	**0.266**
General Chemistry Parameters																			
Aluminum	mg/L	**0.838**	**0.702**	**0.648**	**0.430**	**0.398**	**0.231**	**0.256**	**0.394**	**0.482**	**0.869**	**1.23**	**0.371**	**0.698**	**1.02**	**1.10**	**1.04**	**1.06**	**0.643**
Calcium	mg/L	**30.0**	**18.2**	**25.7**	**21.2**	**22.2**	**10.4**	**6.46**	**14.2**	**14.9**	**30.5**	**24.5**	**15.0**	**19.3**	**21.3**	**21.4**	**22.2**	**22.3**	**13.9**
Iron	mg/L	**6.30**	**6.68**	**6.85**	**2.68**	**2.08**	**1.50**	**1.15**	**1.26**	**1.44**	**4.73**	**3.83**	**8.72**	**5.45**	**3.79**	**3.76**	**6.63**	**2.52**	**1.75**
Magnesium	mg/L	**8.93**	**5.97**	**9.47**	**7.04**	**6.71**	**3.01**	**1.71**	**3.58**	**4.11**	**9.13**	**7.37**	**5.79**	**6.34**	**6.07**	**6.40**	**6.96**	**6.61**	**4.01**
Potassium	mg/L	**7.98**	**6.01**	**7.81**	**8.10**	**8.94**	**7.45**	**5.01**	**5.51**	**5.96**	**8.33**	**7.95**	**6.53**	**6.67**	**7.38**	**8.34**	**8.69**	**9.28**	**8.77**
Sodium	mg/L	**46.8**	**24.3**	**86.5**	**139**	**301**	**289**	**169**	**130**	**105**	**38.4**	**28.9**	**18.4**	**21.7**	**27.5**	**30.6**	**36**	**46.0**	**82.3**
Acidity	ug/L	**20000**	**18000**	< 10000 U	< 10000 U	< 10000 U	< 10000 U	< 10000 U	< 10000 U	**19300**	**80000**	**20000**	**20000**	**4000 J**	**4000 J**	**20000**	**32000**	< 10000 U	< 10000 U
Alkalinity, Total	mg/L	< 1.00 U	**3.65**	**68.1**	**265**	**447**	**439**	**256**	**118**	**62.0**	< 1.00 U	< 1.00 U	**22.6**	**4.89**	< 1.00 U	< 1.00 U	< 1 U	**1.63**	< 1.00 U
Chloride	mg/L	**27.6**	**22.0**	**30.7**	--	**35.7**	**27.8**	**27.3**	**34.0**	**35.1**	**32.9**	**25.0**	**10.9**	--	**26.7**	**27.2**	**25.5**	**32.9**	**34.7**
Sulfate	mg/L	**215**	**96.3**	**173**	--	**205**	**156**	**144 J**	**192**	**215 J**	**188**	**151**	**71.3**	--	**123**	**119**	**153 J**	**160**	**309 J**
Total Organic Carbon	mg/L	**1.60**	**1.63**	**1.79**	**2.56**	**2.72**	**3.00**	**2.7**	**2.06**	**2.24**	**1.43**	**1.25**	**1.76**	**1.75**	**1.63**	**1.51**	**1.73**	**1.43**	**1.42**
Field Parameters																			
Temperature	deg C	**14.4**	**17.5**	**18.1**	**18.6**	**17.8**	**18.4**	**17.4**	**16.3**	**13.4**	**14.7**	**18.3**	**17.1**	**17.9**	**17**	**18.1**	**17.8**	**16.6**	**14.2**
Specific Conductance	uS/cm	**495.6**	**336.4**	**633**	**801**	**1066**	**1191**	**724**	**493.9**	**554.4**	**436.1**	**451.6**	**280.1**	**292.3**	**335.9**	**384.9**	**372.9**	**805**	**548.4**
Dissolved Oxygen	mg/L	**0.16**	**0.25**	**0.1**	**0.17**	**0.07**	**0.1**	**0.18**	**0.3**	**0.14**	**0.11**	**0.23**	**0.07**	**0.018**	**0.09**	**0.21**	**0.18**	**0.14**	**0.08**
pH	pH units	**4.97**	**4.54**	**5.15**	**6.05**	**6.17**	**6.69**	**6.39**	**5.84**	**5.46**	**4.94**	**4.16**	**4.94**	**4.98**	**4.65**	**4.7**	**4.74**	**4.74**	**4.35**
Oxidation Reduction Potential	mV	**205.1**	**172.6**	**95.6**	**82.3**	**82.1**	**13**	**69.7**	**155.7**	**58.6**	**245.4**	**269**	**148.7**	**99.4**	**113.5**	**240**	**83.7**	**101.8**	**82.6**
Turbidity	NTU	**3**	**18.2**	**2.44**	**1.85**	**0.7**	**1.7**	**1.97**	**4.95**	**26.6**	**11**	**8.39**	**1.99**	**4.37**	**0**	**0.55**	**1.4**	**7.85**	**1.16**

Notes:

J - Analyte was positively identified. The reported result is an estimate.
U - Analyte was not detected at or above the reported limit.

Table 3. Performance Monitoring - First Injection Event

Project No. 050067-014M-01, Art Brass Plating, Seattle, Washington

		Water Table Interval							Shallow GW Interval					
		Downgradient Well			Upgradient Well				Performance Monitoring Well					
		MW-08			MW-01				MW-03-30					
		01/31/2018	12/13/2018	03/08/2019	01/31/2018	10/19/2018	12/13/2018	03/08/2019	01/31/2018	09/21/2018	10/19/2018	11/15/2018	12/13/2018	03/08/2019
Analyte	**Units**	**Baseline**	**Day 83**	**Day 168**	**Baseline**	**Day 28**	**Day 83**	**Day 168**	**Baseline**	**Day 0**	**Day 28**	**Day 55**	**Day 83**	**Day 168**
Plating Metals (Dissolved)														
Cadmium	ug/L	< 0.100 U	< 0.100 U	**0.128**	**0.456**	< 1.00 U	**0.334**	**0.361**	< 0.100 U	< 1.00 U	< 0.500 U	< 0.1 U	< 0.100 U	< 0.100 U
Copper	ug/L	**1.72**	**1.04**	**1.71**	**16.2**	**17.5**	**17.2**	**13.5**	< 0.500 U	**5.75**	< 2.50 U	**13.8**	**12.2**	**12.5**
Nickel	ug/L	**6740**	**5360**	**6100**	**18600**	**18900**	**17100**	**15500**	**4.62**	**93.8**	**14.4**	**11**	**12.2**	**20.4**
Zinc	ug/L	**7.56**	**8.01**	**10.2**	**44.4**	**70.4 J**	**60.0**	**91.6**	< 4.00 U	< 40.0 U	< 20.0 UJ	< 4 U	< 4.00 U	< 4.00 U
Redox-Sensitive Metals (Dissolved)														
Arsenic	mg/L	--	--	--	--	**0.0089 J**	--	--	--	--	--	--	--	--
Barium	mg/L	--	--	--	--	**0.0119**	--	--	--	--	--	--	--	--
Manganese	mg/L	--	--	--	--	**0.635**	--	--	--	--	--	--	--	--
General Chemistry Parameters														
Aluminum	mg/L	**0.0418 J**	**0.0427 J**	**0.0320 J**	**0.823**	**1.90**	**1.73**	**0.717**	< 0.0500 U	**0.250 U**	**0.0440 J**	**0.136**	**0.129**	**0.126**
Calcium	mg/L	**51.1**	**32.2**	**43.4**	**20.2**	**39.7**	**38.5**	**24.1**	**14.4**	**48.3**	**12.8**	**16.7**	**21.5**	**8.85**
Iron	mg/L	**3.54**	**10.0**	**6.87**	**0.413**	**2.61**	**2.54**	**0.102**	**8.68**	**8.96**	**6.67**	**4.5**	**4.97**	**1.55**
Magnesium	mg/L	**13.1**	**9.24**	**12.0**	**6.76**	**12.0**	**11.7**	**7.48**	**20.9**	**130**	**5.30**	**5.84**	**4.03**	**3.45**
Potassium	mg/L	**11.1**	**9.00**	**8.77**	**9.20**	**10.9**	**11.1**	**8.91**	**7.22**	**142**	**12.2**	**6.98**	**4.36**	**4.84**
Sodium	mg/L	**41.5**	**31.2**	**30.5**	**75.9**	**60.1**	**70.3**	**87.7**	**30.1**	**14800**	**1020**	**506**	**176**	**368**
Acidity	ug/L	< 10000 U	< 10000 U	**17300**	**40000**	**18000**	< 10000 U	< 10000 U	< 10000 U	< 10000 U	< 10000 U	**16000**	< 10000 U	< 10000 U
Alkalinity, Total	mg/L	**58.7**	**60.0**	**54.7**	< 1.00 U	< 1.00 U	< 1.00 U	< 1.00 U	**158**	**30300**	**1920**	**806**	**333**	**734**
Chloride	mg/L	**33.5**	**22.2**	**39.1**	**49.2**	**42.8**	**99.9**	**40.0**	**22.2**	**8.90**	**22.1**	**21.6**	**25.4**	**32.0**
Sulfate	mg/L	**187**	**139**	**229 J**	**219**	**289**	**317**	**334 J**	**18.6**	**195**	**58.0**	**64.6 J**	**68.7**	**91.8 J**
Total Organic Carbon	mg/L	**1.99**	**1.42**	**1.63**	**1.91**	**1.83**	**1.71**	**3.30**	**3.96**	**39.12**	**6.82**	**5.46**	**5.24**	**5.88**
Field Parameters														
Temperature	deg C	**13.4**	**15.3**	**12.3**	**17.2**	**18.5**	**17.6**	**15.8**	**14.8**	**17.8**	**17.4**	**16.6**	**15.4**	**14.7**
Specific Conductance	uS/cm	**502**	**297.5**	**541.1**	**520**	**770**	**620**	**688**	**271.6**	**35209**	**3452**	**2289**	**1400**	**1348**
Dissolved Oxygen	mg/L	**0.27**	**0.15**	**0.2**	**0.66**	**0.28**	**0.35**	**3.2**	**0.1**	**0.02**	**0.08**	**0.1**	**0.1**	**0.1**
pH	pH units	**6.24**	**5.93**	**5.9**	**4.18**	**3.82**	**3.99**	**4.75**	**6.33**	**7.67**	**6.95**	**7.23**	**6.98**	**7.33**
Oxidation Reduction Potential	mV	**61.4**	**83.3**	**91.7**	**266.9**	**80.4**	**146.6**	**137.4**	**29.6**	**-93.7**	**-64.4**	**-55.9**	**-67.3**	**36.1**
Turbidity	NTU	**6**	**2.4**	**2.26**	**13**	**6.06**	**2.3**	**10**	**8**	**2.73**	**8.32**	**4.57**	**8.59**	**12**

Notes:

J - Analyte was positively identified. The reported result is an estimate.
U - Analyte was not detected at or above the reported limit.

Table 4. Operational Monitoring - Second Injection Event

Project No. 050067-014L-01, Art Brass Plating, Seattle, Washington

Active Injection Well	Date	Time	Injection Rate (gpm)	Injection Pressure (psig)	Cumulative Injected Volume (gal)	Volume Injected Per Well (gal)
IW-2	8/5/2019	9:30	43	0	0	0
IW-2	8/5/2019	10:30	25.5	0	2,139	2,139
IW-2	8/5/2019	11:20	0	0	2,722	2,722
IW-2	8/5/2019	14:35	45.7	0	2,722	2,722
IW-2	8/5/2019	14:47	44.5	0	3,222	3,222
IW-2	8/5/2019	15:00	0	0	3,480	3,480
IW-2	8/5/2019	15:35	20.3	0	3,722	3,722
IW-2	8/5/2019	15:45	19.6	0	3,978	3,978
IW-2	8/5/2019	16:00	0	0	4,228	4,228
IW-2	8/5/2019	16:32	19	0	4,496	4,496
IW-2	8/5/2019	16:45	18.6	0	4,746	4,746
IW-2	8/5/2019	17:00	16.6	0	4,996	4,996
IW-2	8/5/2019	17:17	10.9	0	5,261	5,261
IW-2	8/5/2019	17:35	15.4	0	5,472	5,472
IW-2	8/5/2019	17:50	17.8	0	5,722	5,722
IW-2	8/5/2019	17:57	0	0	5,767	5,767
IW-2	8/6/2019	8:35	18.6	0	5,767	5,767
IW-2	8/6/2019	9:00	16.9	0	6239	6239
IW-2	8/6/2019	9:25	21.5	0	6800	6800
IW-2	8/6/2019	9:50	18.6	0	7306	7306
IW-2	8/6/2019	10:15	21.2	0	7784	7784
IW-2	8/6/2019	10:55	12.5	0	8314	8314
IW-2	8/6/2019	11:18	0	0	8722	8722
IW-2	8/6/2019	13:45	23.2	0	8722	8722
IW-2	8/6/2019	13:50	22.7	0	8834	8834
IW-2	8/6/2019	14:10	21.1	0	9269	9269
IW-2	8/6/2019	14:35	19.9	0	9789	9789
IW-2	8/6/2019	14:48	0	0	10,000	10,000
Switch from IW-2 to IW-1						
IW-1	8/6/2019	15:30	23.5	0	10,000	0
IW-1	8/6/2019	15:55	19.6	0	10,550	550
IW-1	8/6/2019	16:20	16.7	0	10,994	994
IW-1	8/6/2019	16:45	12.5	0	11,354	1,354
IW-1	8/6/2019	17:30	0	0	11,694	1,694
IW-1	8/7/2019	8:47	21.1	0	11,694	1694
IW-1	8/7/2019	9:00	19.9	0	11,969	1969
IW-1	8/7/2019	9:20	20.2	0	12,369	2369
IW-1	8/7/2019	9:40	19.1	0	12,754	2754
IW-1	8/7/2019	9:50	22	0	12,964	2964
IW-1	8/7/2019	10:05	19.8	0	13,279	3279
IW-1	8/7/2019	10:17	19	0	13,504	3504
IW-1	8/7/2019	10:30	18.3	0	13,754	3754
IW-1	8/7/2019	10:46	15.1	0	14,004	4004
IW-1	8/7/2019	11:05	11.2	0	14,262	4262
IW-1	8/7/2019	11:30	0	0	14,447	4447
IW-1	8/7/2019	13:43	20.4	0	14,447	4447
IW-1	8/7/2019	14:00	19.5	0	14,664	4664
IW-1	8/7/2019	14:12	18.6	0	15,000	5000
IW-1	8/7/2019	14:25	17.6	0	15,254	5254
IW-1	8/7/2019	14:40	21	0	15,564	5564
IW-1	8/7/2019	14:52	19.5	0	15,754	5754
IW-1	8/7/2019	15:05	19.3	0	16,004	6004
IW-1	8/7/2019	15:20	16.5	0	16,259	6259
IW-1	8/7/2019	15:35	18.6	0	16,504	6504
IW-1	8/7/2019	15:50	17.5	0	16,764	6764
IW-1	8/7/2019	16:05	14.3	0	17,004	7004
IW-1	8/7/2019	16:25	10.5	0	17,459	7459
IW-1	8/7/2019	16:55	0	0	17,459	7459
IW-1	8/8/2019	8:30	20.2	0	17,459	7459
IW-1	8/8/2019	8:55	18.2	0	17,979	7979
IW-1	8/8/2019	9:25	19.2	0	18,469	8469
IW-1	8/8/2019	9:50	20.6	0	18,974	8974
IW-1	8/8/2019	10:15	17.6	0	19,459	9459
IW-1	8/8/2019	10:50	12.6	0	20,000	10000
IW-1	8/8/2019	11:20	0	0	20,300	10300

Table 5. Dose-Response Monitoring - Second Injection Event

Project No. 050067-014L-01, Art Brass Plating, Seattle, Washington

Monitoring Well Location	Active Injection Well	Date	Time	Water Level (ft BTOC)	pH	Specific Conductance (us/cm)	Na Concentration (mg/L)	Normalized Na Concentration (%)	Analytical Sample Name	Notes
Injection-1	--	8/5/2019	18:05	--	11.44	13635	3850	89.8	Injection-1	Pre-Injection
Injection-2	--	8/8/2019	8:50	--	11.66	15661	4720	110.2	Injection-2	Pre-Injection
MW-3	IW-2	8/5/2019	15:15	6.25	8	2402				
MW-3	IW-2	8/5/2019	15:20	--	9.51	3126				
MW-3	IW-2	8/5/2019	16:10	6.29	7.31	2939				
MW-3	IW-2	8/5/2019	16:15	--	7.64	2950				
MW-3	IW-2	8/5/2019	17:27	5.83	9.7	6329				
MW-3	IW-2	8/5/2019	17:30	--	10	7900				
MW-3	--	8/6/2019	7:50	6.61	9.77	8685				Pre-Injection
MW-3	--	8/6/2019	7:55	--	9.37	7760				Pre-Injection
MW-3	IW-2	8/6/2019	9:15	5.13	10.14	10896				
MW-3	IW-2	8/6/2019	9:18	--	10.56	11355				
MW-3	IW-2	8/6/2019	9:40	5.2	10.31	11231				
MW-3	IW-2	8/6/2019	9:43	--	10.76	12075				
MW-3	IW-2	8/6/2019	10:05	5.38	10.51	12330				
MW-3	IW-2	8/6/2019	10:07	--	10.88	12800				
MW-3	IW-2	8/6/2019	10:30	5.28	10.92	13099				
MW-3	IW-2	8/6/2019	10:33	--	10.9	12906				
MW-3	IW-2	8/6/2019	10:55	5.55	10.77	13075				
MW-3	IW-2	8/6/2019	10:58	--	10.92	12961				
MW-3	IW-2	8/6/2019	14:27	5.15	10.86	14263				
MW-3	IW-2	8/6/2019	14:30	--	11.37	14698				
MW-3	IW-2	8/6/2019	15:07	6.42	9.82	5355				
MW-3	IW-2	8/6/2019	15:10	--	10.12	6850				
MW-3	--	8/8/2019	8:00	--	9.31	7700				Post-Injection
MW-3	--	8/8/2019	8:03	6.58	9.35	7075				Post-Injection
MW-3-30	IW-2	8/5/2019	15:05	6	6.42	737				
MW-3-30	IW-2	8/5/2019	15:10	--	5.95	412				
MW-3-30	IW-2	8/5/2019	16:05	6.13	6.03	420				
MW-3-30	IW-2	8/5/2019	16:10	--	6.07	401				
MW-3-30	IW-2	8/5/2019	17:11	5.75	6.18	414				
MW-3-30	IW-2	8/5/2019	17:15	--	6.15	394				
MW-3-30	--	8/6/2019	7:40	6.5	6.03	590				Pre-Injection
MW-3-30	--	8/6/2019	7:45	--	6.52	900				Pre-Injection
MW-3-30	IW-2	8/6/2019	9:10	5.65	6.31	562				
MW-3-30	IW-2	8/6/2019	9:13	--	5.92	419				
MW-3-30	IW-2	8/6/2019	9:35	5.62	5.9	421				
MW-3-30	IW-2	8/6/2019	9:38	--	5.73	434				
MW-3-30	IW-2	8/6/2019	10:00	5.65	5.89	453				
MW-3-30	IW-2	8/6/2019	10:03	--	5.66	486				
MW-3-30	IW-2	8/6/2019	10:25	5.65	6	539				
MW-3-30	IW-2	8/6/2019	10:28	--	5.67	346				
MW-3-30	IW-2	8/6/2019	10:50	5.7	6.00	580				
MW-3-30	IW-2	8/6/2019	10:53	--	5.56	587				
MW-3-30	IW-2	8/6/2019	13:52	5.89	5.75	715				
MW-3-30	IW-2	8/6/2019	13:55	--	5.51	795				
MW-3-30	IW-2	8/6/2019	14:22	5.68	5.82	978				
MW-3-30	IW-2	8/6/2019	14:25	--	5.76	978				
MW-3-30	IW-2	8/6/2019	15:02	6.22	5.82	1218				
MW-3-30	IW-2	8/6/2019	15:05	--	5.79	1211				
MW-3-30	IW-1	8/7/2019	9:58	5.6	5.72	1223				
MW-3-30	IW-1	8/7/2019	10:00	--	5.82	1325				
MW-3-30	IW-1	8/7/2019	10:52	5.81	6	1304				
MW-3-30	IW-1	8/7/2019	10:55	--	5.95	1135				
MW-3-30	IW-1	8/7/2019	13:52	5.9	6.12	1135				
MW-3-30	IW-1	8/7/2019	13:55	--	5.78	970				
MW-3-30	IW-1	8/7/2019	14:20	5.88	6.16	965				
MW-3-30	IW-1	8/7/2019	14:23	--	5.96	922				
MW-3-30	IW-1	8/7/2019	14:47	5.68	6.6	978				
MW-3-30	IW-1	8/7/2019	14:50	--	6.35	885				
MW-3-30	IW-1	8/7/2019	15:12	5.72	6.44	823				
MW-3-30	IW-1	8/7/2019	15:15	--	6.14	809				
MW-3-30	IW-1	8/7/2019	15:43	5.73	7.52	950				
MW-3-30	IW-1	8/7/2019	15:48	--	6.4	763				
MW-3-30	IW-1	8/7/2019	16:14	5.84	7.27	943				
MW-3-30	IW-1	8/7/2019	16:17	--	6.29	731				
MW-3-30	--	8/8/2019	7:55	--	6.78	1215				Pre-Injection
MW-3-30	--	8/8/2019	7:58	6.48	6.5	1082				Pre-Injection
MW-3-30	IW-1	8/8/2019	9:13	5.78	6.88	892				
MW-3-30	IW-1	8/8/2019	9:15	--	6.93	760				
MW-3-30	IW-1	8/8/2019	9:35	5.73	7.74	950				
MW-3-30	IW-1	8/8/2019	9:38	--	6.76	965				
MW-3-30	IW-1	8/8/2019	10:05	5.63	8.05	995				
MW-3-30	IW-1	8/8/2019	10:10	--	6.32	629				
MW-3-30	IW-1	8/8/2019	10:27	5.74	7.54	880				
MW-3-30	IW-1	8/8/2019	10:30	--	6.62	708				
MW-3-30	--	8/8/2019	11:40	6.14	7.54	764				Post-Injection
MW-3-30	--	8/8/2019	11:43	--	6.83	697				Post-Injection
PSW-6	IW-2	8/6/2019	8:10	6.23	--	--				
PSW-6	IW-1	8/6/2019	16:20	5.38	7.21	535				
PSW-6	IW-1	8/6/2019	16:25	--	5.83	457	61.8	1.4	PSW-6-080619-1	
PSW-6	IW-1	8/7/2019	9:01	5.49	5.93	426				
PSW-6	IW-1	8/7/2019	9:05	--	5.51	418			PSW-6-080719-2	
PSW-6	IW-1	8/7/2019	9:40	5.33	5.66	585				
PSW-6	IW-1	8/7/2019	9:43	--	5.7	683			--	
PSW-6	IW-1	8/7/2019	9:52	5.23	5.73	826				
PSW-6	IW-1	8/7/2019	9:55	--	5.77	853	143	3.3	PSW-6-080719-3	
PSW-6	IW-1	8/7/2019	10:05	5.25	6.09	1098				
PSW-6	IW-1	8/7/2019	10:10	--	6.07	1132			PSW-6-080719-4	
PSW-6	IW-1	8/7/2019	10:18	5.28	7.14	1724				

Table 5. Dose-Response Monitoring - Second Injection Event

Project No. 050067-014L-01, Art Brass Plating, Seattle, Washington

Monitoring Well Location	Active Injection Well	Date	Time	Water Level (ft BTOC)	pH	Specific Conductance (us/cm)	Na Concentration (mg/L)	Normalized Na Concentration (%)	Analytical Sample Name	Notes
PSW-6	IW-1	8/7/2019	10:20	--	6.49	1556			PSW-6-080719-5	
PSW-6	IW-1	8/7/2019	10:32	5.33	6.36	1791				
PSW-6	IW-1	8/7/2019	10:35	--	6.32	1883			PSW-6-080719-6	
PSW-6	IW-1	8/7/2019	10:46	5.42	6.45	2121				
PSW-6	IW-1	8/7/2019	10:50	--	6.53	2378	544	12.7	PSW-6-080719-7	
PSW-6	IW-1	8/7/2019	11:05	5.59	6.72	2900				
PSW-6	IW-1	8/7/2019	11:10	--	6.82	3161			PSW-6-080719-8	
PSW-6	IW-1	8/7/2019	13:45	5.7	7.53	3611				
PSW-6	IW-1	8/7/2019	13:50	--	6.81	3230			PSW-6-080719-9	
PSW-6	IW-1	8/7/2019	14:00	5.46	6.97	3918				
PSW-6	IW-1	8/7/2019	14:05	--	6.65	3622			PSW-6-080719-10	
PSW-6	IW-1	8/7/2019	14:12	5.42	8.19	4992				
PSW-6	IW-1	8/7/2019	14:15	--	7.41	4467	1190	27.8	PSW-6-080719-11	
PSW-6	IW-1	8/7/2019	14:27	5.54	8.2	5193				
PSW-6	IW-1	8/7/2019	14:30	--	8.38	5256			PSW-6-080719-12	
PSW-6	IW-1	8/7/2019	14:40	5.3	9.12	6000				
PSW-6	IW-1	8/7/2019	14:45	--	9.12	6081			PSW-6-080719-13	
PSW-6	IW-1	8/7/2019	14:52	5.29	9.25	6783				
PSW-6	IW-1	8/7/2019	14:55	--	9.35	6734			PSW-6-080719-14	
PSW-6	IW-1	8/7/2019	15:05	5.33	9.64	7562				
PSW-6	IW-1	8/7/2019	15:10	--	9.61	7635			PSW-6-080719-15	
PSW-6	IW-1	8/7/2019	15:22	5.4	9.5	8218				
PSW-6	IW-1	8/7/2019	15:25	--	9.72	8583	2490	58.1	PSW-6-080719-16	
PSW-6	IW-1	8/7/2019	15:36	5.38	9.86	9216				
PSW-6	IW-1	8/7/2019	15:40	--	9.88	9260			PSW-6-080719-17	
PSW-6	IW-1	8/7/2019	15:50	5.36	9.9	9600				
PSW-6	IW-1	8/7/2019	15:55	--	10.09	9965			PSW-6-080719-18	
PSW-6	IW-1	8/7/2019	16:07	5.5	9.95	10525				
PSW-6	IW-1	8/7/2019	16:12	--	10.05	10640				
PSW-6	IW-1	8/7/2019	16:26	5.63	9.96	10760				
PSW-6	IW-1	8/7/2019	16:30	--	10.06	11088	3230	75.4	PSW-6-080719-19	
PSW-6	--	8/8/2019	8:12	--	9.88	9300				Pre-Injection
PSW-6	--	8/8/2019	8:13	6.25	9.88	9136				Pre-Injection
PSW-6	IW-1	8/8/2019	9:00	5.46	10.16	9631				
PSW-6	IW-1	8/8/2019	9:05	--	10.13	9819			PSW-6-080819-20	
PSW-6	IW-1	8/8/2019	9:26	5.38	9.96	10390				
PSW-6	IW-1	8/8/2019	9:30	--	10.22	10915				
PSW-6	IW-1	8/8/2019	9:52	5.27	10.29	11719				
PSW-6	IW-1	8/8/2019	9:55	--	10.36	11960	3390	79.1	PSW-6-080819-21	
PSW-6	IW-1	8/8/2019	10:16	5.39	10.42	12373				
PSW-6	IW-1	8/8/2019	10:20	--	10.53	12625				
PSW-6	--	8/8/2019	11:25	5.83	10.47	13200				Post-Injection
PSW-6	--	8/8/2019	11:30	--	10.65	13995	3830	89.4	PSW-6-080819-22	Post-Injection
PSW-7	IW-2	8/5/2019	10:30	6.4	5	6.05				
PSW-7	IW-2	8/5/2019	10:35	5.02	4.63	623	64.2	1.5	PSW-7-080519-1	
PSW-7	IW-2	8/5/2019	11:20	6.19	5.13	669				
PSW-7	IW-2	8/5/2019	11:25	6.19	5.09	674			PSW-7-080519-2	
PSW-7	IW-2	8/5/2019	14:48	4.75	5.18	742				
PSW-7	IW-2	8/5/2019	14:52	--	5.23	813			PSW-7-080519-3	
PSW-7	IW-2	8/5/2019	15:20	6.23	5.75	923				
PSW-7	IW-2	8/5/2019	15:25	--	5.53	900	127	3.0	PSW-7-080519-4	
PSW-7	IW-2	8/5/2019	15:38	5.52	6.03	1384				
PSW-7	IW-2	8/5/2019	15:42	--	5.99	1497			PSW-7-080519-5	
PSW-7	IW-2	8/5/2019	15:53	5.45	6.38	2145				
PSW-7	IW-2	8/5/2019	15:55	--	6.33	2105			PSW-7-080519-6	
PSW-7	IW-2	8/5/2019	16:15	6.19	6.56	2657				
PSW-7	IW-2	8/5/2019	16:20	5.8	6.55	2681	565	13.2	PSW-7-080519-7	
PSW-7	IW-2	8/5/2019	16:33	5.55	6.8	3793				
PSW-7	IW-2	8/5/2019	16:35	--	6.81	3824			PSW-7-080519-8	
PSW-7	IW-2	8/5/2019	16:45	5.5	7.03	4092				
PSW-7	IW-2	8/5/2019	16:47	--	7.09	4259			PSW-7-080519-9	
PSW-7	IW-2	8/5/2019	17:00	5.52	7.25	4800				
PSW-7	IW-2	8/5/2019	17:05	--	7.47	5075	1320	30.8	PSW-7-080519-10	
PSW-7	IW-2	8/5/2019	17:17	5.69	8.28	5864				
PSW-7	IW-2	8/5/2019	17:20	--	8.4	5857			PSW-7-080519-11	
PSW-7	IW-2	8/5/2019	17:37	5.62	9.4	7200				
PSW-7	IW-2	8/5/2019	17:40	--	9.38	7247			PSW-7-080519-12	
PSW-7	IW-2	8/5/2019	17:52	5.52	9.39	7530				
PSW-7	IW-2	8/5/2019	17:55	--	9.35	7955	2120	49.5	PSW-7-080519-13	
PSW-7	--	8/6/2019	7:30	6.42	8.12	6222				Pre-Injection
PSW-7	--	8/6/2019	7:35	--	8.16	6218				Pre-Injection
PSW-7	IW-2	8/6/2019	8:55	5.7	8.95	6671				
PSW-7	IW-2	8/6/2019	9:00	--	8.99	6795			PSW-7-080619-14	
PSW-7	IW-2	8/6/2019	9:20	5.38	9.54	8346				
PSW-7	IW-2	8/6/2019	9:25	--	9.66	8709			PSW-7-080619-15	
PSW-7	IW-2	8/6/2019	9:45	5.4	10.03	10280				
PSW-7	IW-2	8/6/2019	9:50	--	10.03	10364			PSW-7-080619-16	
PSW-7	IW-2	8/6/2019	10:15	5.39	10.2	11139				
PSW-7	IW-2	8/6/2019	10:20	--	10.2	11278	3410	79.6	PSW-7-080619-17	
PSW-7	IW-2	8/6/2019	10:37	5.45	10.32	11370				
PSW-7	IW-2	8/6/2019	10:40	--	10.33	11322			PSW-7-080619-18	
PSW-7	IW-2	8/6/2019	14:11	5.41	10.1	11505				
PSW-7	IW-2	8/6/2019	14:15	--	10.47	11850	3540	82.6	PSW-7-080619-19	
PSW-7	IW-2	8/6/2019	14:50	5.9	10.66	12765				
PSW-7	IW-2	8/6/2019	14:55	--	10.63	12635	3810	88.9	PSW-7-080619-20	
PSW-7	IW-1	8/7/2019	10:12	5.7	10.02	10722				
PSW-7	IW-1	8/7/2019	10:15	--	10	10725				
PSW-7	IW-1	8/7/2019	11:12	5.92	9.91	10345				
PSW-7	IW-1	8/7/2019	11:15	--	9.97	10577				
PSW-7	IW-1	8/7/2019	14:07	5.82	9.82	10750				

Table 5. Dose-Response Monitoring - Second Injection Event

Project No. 050067-014L-01, Art Brass Plating, Seattle, Washington

Monitoring Well Location	Active Injection Well	Date	Time	Water Level (ft BTOC)	pH	Specific Conductance (us/cm)	Na Concentration (mg/L)	Normalized Na Concentration (%)	Analytical Sample Name	Notes
PSW-7	IW-1	8/7/2019	14:10	--	9.91	10787				
PSW-7	IW-1	8/7/2019	14:32	5.77	9.86	10788				
PSW-7	IW-1	8/7/2019	14:35	--	9.93	10836				
PSW-7	IW-1	8/7/2019	14:59	5.72	9.92	10844				
PSW-7	IW-1	8/7/2019	15:02	--	9.88	10522				
PSW-7	IW-1	8/7/2019	15:30	5.75	9.84	10300				
PSW-7	IW-1	8/7/2019	15:33	--	9.81	10084				
PSW-7	IW-1	8/7/2019	15:59	5.75	9.88	10195				
PSW-7	IW-1	8/7/2019	16:02	--	9.86	10180				
PSW-7	IW-1	8/7/2019	16:32	5.95	9.85	10425				
PSW-7	IW-1	8/7/2019	16:35	--	9.84	10380				
PSW-7	--	8/8/2019	7:50	--	9.6	9810				Post-Injection
PSW-7	--	8/8/2019	7:53	6.43	9.82	9997				Post-Injection
PSW-7	IW-1	8/8/2019	9:07	5.81	9.85	10240				
PSW-7	IW-1	8/8/2019	9:10	--	9.86	10293				
PSW-7	IW-1	8/8/2019	9:30	5.75	9.92	10350				
PSW-7	IW-1	8/8/2019	9:33	--	9.9	10330				
PSW-7	IW-1	8/8/2019	9:59	5.67	9.86	9863				
PSW-7	IW-1	8/8/2019	10:02	--	9.82	9720				
PSW-7	IW-1	8/8/2019	10:21	5.73	9.95	9838				
PSW-7	IW-1	8/8/2019	10:24	--	9.92	9777				
PSW-7	--	8/8/2019	11:33	6.1	9.96	10107				Post-Injection
PSW-7	--	8/8/2019	11:36	--	9.97	10180				Post-Injection
PSW-8	IW-2	8/5/2019	15:00	5.96	4.94	456				
PSW-8	IW-2	8/5/2019	15:05	--	4.61	457				
PSW-8	IW-2	8/5/2019	16:00	5.72	5.12	502				
PSW-8	IW-2	8/5/2019	16:05	--	4.76	487				
PSW-8	IW-2	8/5/2019	17:07	5.78	5.85	644				
PSW-8	IW-2	8/5/2019	17:10	--	5.22	546				
PSW-8	--	8/6/2019	7:35	6.47	6.82	780				Pre-Injection
PSW-8	--	8/6/2019	7:40	--	6.26	551				Pre-Injection
PSW-8	IW-2	8/6/2019	9:05	5.79	7.25	667				
PSW-8	IW-2	8/6/2019	9:08	--	6.01	470				
PSW-8	IW-2	8/6/2019	9:30	5.66	7.19	750				
PSW-8	IW-2	8/6/2019	9:33	--	5.31	517				
PSW-8	IW-2	8/6/2019	9:55	5.69	5.77	655				
PSW-8	IW-2	8/6/2019	9:58	--	5.3	533				
PSW-8	IW-2	8/6/2019	10:20	5.64	7.72	882				
PSW-8	IW-2	8/6/2019	10:23	--	5.41	690				
PSW-8	IW-2	8/6/2019	10:45	5.73	6.82	894				
PSW-8	IW-2	8/6/2019	10:48	--	5.64	719				
PSW-8	IW-2	8/6/2019	13:48	6.13	6.92	732				
PSW-8	IW-2	8/6/2019	13:50	--	6.26	588				
PSW-8	IW-2	8/6/2019	14:18	5.72	6.84	760				
PSW-8	IW-2	8/6/2019	14:20	--	5.77	615				
PSW-8	IW-2	8/6/2019	14:57	5.14	7.34	800				
PSW-8	IW-2	8/6/2019	15:00	--	5.67	568				
PSW-8	--	8/8/2019	7:42	6.46	5.87	507				Post-Injection
PSW-8	--	8/8/2019	7:45	--	5.83	507				Post-Injection

Notes:

Select samples from PSW-6 and PSW-7 were analyzed for Na.

Normalized Na Concentration was calculated by dividing the measured sodium concentration at a well by the average of the injection solution sodium concentration.

Table 6. Metals Pilot Test Performance Monitoring

Project No. 050067, Art Brass Plating, Seattle, Washington

		Water Table Interval															
		Injection Well															
		IW-01								IW-02							
		08/02/2019	08/09/2019	08/16/2019	08/22/2019	09/06/2019	10/09/2019	11/15/2019	02/05/2020	08/02/2019	08/09/2019	08/16/2019	08/22/2019	09/06/2019	10/09/2019	11/15/2019	02/05/2020
Analyte	**Unit**	**Baseline**	**Day 0**	**Day 7**	**Day 13**	**Day 28**	**Day 61**	**Day 98**	**Day 180**	**Baseline**	**Day 0**	**Day 7**	**Day 13**	**Day 28**	**Day 61**	**Day 98**	**Day 180**
Plating Metal (Dissolved)																	
Cadmium	ug/L	< 0.100 U	--	< 2.00 U	--	< 0.500 U	< 0.100 U	< 0.100 U	< 0.100 U	**0.130**	--	< 2.00 U	--	< 0.500 U	< 0.200 U	**0.150**	**0.134**
Copper	ug/L	< 0.500 U	--	**353**	--	**94.5**	**29.0**	**11.8**	**7.13**	< 0.500 U	--	**507**	--	**138**	**41.3**	**19.4**	**8.19**
Nickel	ug/L	**438**	--	**431**	--	**132**	**48.3**	**205**	**1360**	**4800**	--	**1280**	--	**526**	**143**	**194**	**3860**
Zinc	ug/L	**4.65**	--	< 80.0 U	--	< 20.0 U	**5.66**	**4.37**	**6.24**	**25.0**	--	< 80.0 U	--	**20.7**	< 8.00 U	**5.99**	**6.33**
Redox-Sensitive Metals (Dissolved)																	
Arsenic	mg/L	--	--	**0.0617 J**	--	< 2.50 U	< 1.00 U	< 0.250 U	**0.0284 J**	--	--	**0.0781 J**	--	< 2.50 U	< 1.00 U	**0.0301 J**	< 0.250 U
Barium	mg/L	--	--	**0.0092 J**	--	< 0.150 U	**0.0238 J**	**0.0080 J**	**0.0152**	--	--	**0.0107 J**	--	< 0.150 U	< 0.0600 U	**0.0181**	**0.0125 J**
Manganese	mg/L	--	--	**0.0210**	--	< 0.0500 U	**0.0101 J**	**0.0697**	**0.216**	--	--	**0.0254**	--	**0.0314 J**	**0.0090 J**	**0.0202**	**0.119**
General Chemistry Parameters																	
Aluminum	mg/L	**0.0564**	--	**0.492**	--	**0.802 J**	**1.11**	**0.271**	**0.185 J**	**0.323**	--	**0.549**	--	**0.981 J**	**0.456 J**	**0.270**	**0.116 J**
Calcium	mg/L	**6.84**	--	**2.41**	--	**2.09 J**	**3.66**	**28.3**	**34.4**	**18.5**	--	**3.72**	--	**3.12**	**3.55**	**24.0**	**25.7**
Iron	mg/L	**6.93**	--	**0.478**	--	**0.654 U**	**0.276 J**	**0.270**	**0.360**	**11.5**	--	**1.07**	--	**0.963 U**	**0.678 J**	**0.416**	**0.398**
Magnesium	mg/L	**2.00**	--	**1.09**	--	< 2.50 U	**0.917 J**	**5.48**	**6.93**	**5.58**	--	**1.48**	--	**0.991 J**	**0.530 J**	**2.74**	**5.60**
Potassium	mg/L	**1.41**	--	**2.64**	--	< 25.0 U	**1.40 U**	**1.06 J**	**1.64 J**	**3.35**	--	**3.56**	--	< 25.0 U	< 10.0 U	**0.902 J**	**1.54 J**
Sodium	mg/L	**49.2**	--	**2000**	--	**354**	**300**	**221**	**160**	**48.5**	--	**2040**	--	**380**	**282**	**222**	**158**
Alkalinity, Total	mg/L	**33.3**	--	**4560**	--	**658**	**447**	**354**	**266**	< 1.00 U	--	**4420**	--	**223**	**449**	**349**	**204**
Total Organic Carbon	mg/L	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Field Parameters																	
Temperature	deg C	**17**	**21.9**	**21.1**	**19.1**	**18.7**	**17.7**	**16.8**	**13.2**	**16.9**	**21**	**20.2**	**20.3**	**18.5**	**16.9**	**16.9**	**14.4**
Specific Conductance	uS/cm	**322**	**11804**	**7231**	**3141**	**1735**	**1293**	**1059**	**793**	**459.3**	**5675**	**7096**	**3327**	**1854**	**1179**	**1019**	**812**
Dissolved Oxygen	mg/L	**0.17**	**1.27**	**0.05**	**0.1**	**0.06**	**0.25**	**0.13**	**0.19**	**0.15**	**1.04**	**0.09**	**0.05**	**0.05**	**0.12**	**0.08**	**0.27**
pH	pH units	**5.57**	**11.23**	**10.35**	**10**	**9.98**	**9.73**	**8.67**	**7.55**	**5.31**	**10.99**	**10.18**	**9.92**	**9.82**	**9.67**	**8.87**	**6.8**
Oxidation Reduction Potential	mV	**4.9**	**14.5**	**108.2**	**55**	**55**	**73.5**	**27.8**	**31.7**	**133.7**	**67.4**	**58.6**	**37.3**	**39.1**	**33.5**	**27.9**	**101.4**
Turbidity	NTU	**59.3**	**10.6**	--	**18**	**17**	**12.2**	**9.21**	**9.16**	**44.5**	**15.1**	--	**10.1**	**11.7**	**11.9**	**10.3**	**24**

Notes:

J - Analyte was positively identified. The reported result is an estimate.

U - Analyte was not detected at or above the reported limit.

UJ - Analyte not detected and the reporting limit is an estimate.

Table 6. Metals Pilot Test Performance Monitoring

Project No. 050067, Art Brass Plating, Seattle, Washington

		Water Table Interval															
		Performance Monitoring Well															
		MW-03								PSW-06							
		08/02/2019	08/09/2019	08/16/2019	08/22/2019	09/06/2019	10/09/2019	11/15/2019	02/05/2020	08/02/2019	08/09/2019	08/16/2019	08/22/2019	09/06/2019	10/09/2019	11/15/2019	02/05/2020
Analyte	Unit	Baseline	Day 0	Day 7	Day 13	Day 28	Day 61	Day 98	Day 180	Baseline	Day 0	Day 7	Day 13	Day 28	Day 61	Day 98	Day 180
Plating Metal (Dissolved)																	
Cadmium	ug/L	**0.214**	< 2 U	< 0.500 U	< 0.100 U	< 0.100 U	< 0.100 U	**0.131**	< 0.100 U	< 0.100 U	< 2 U	< 2.00 U	< 0.200 U	< 0.500 U	< 0.200 U	< 0.200 U	< 0.100 U
Copper	ug/L	**11.7**	**120**	**21.0**	**8.46**	**5.18**	**1.61**	**3.13**	**2.25**	**1.25**	**202**	**194**	**137**	**200**	**63.3**	**29.9**	**8.50**
Nickel	ug/L	**11300**	**714**	**404**	**550**	**2960**	**5280**	**8750**	**3140**	**921**	**901**	**1120**	**733**	**159**	**82.0**	**51.0**	**91.7**
Zinc	ug/L	**48.1**	< 80 U	< 20.0 U	**5.20**	**6.22**	**11.7**	**11.7**	**10.1**	**6.53**	< 80 U	< 80.0 U	**9.08**	< 20.0 U	< 8.00 U	< 8.00 U	< 4.00 U
Redox-Sensitive Metals (Dissolved)																	
Arsenic	mg/L	--	**0.0469 J**	--	< 0.100 U	--	--	< 0.250 U	**0.0097 J**	--	**0.267**	--	< 0.250 U	--	--	< 0.250 U	**0.0335 J**
Barium	mg/L	--	**0.0079 J**	--	< 0.0060 U	--	--	**0.0050 J**	**0.0041**	--	**0.0127 J**	--	**0.0206**	--	--	**0.0041 J**	**0.0053 J**
Manganese	mg/L	--	**0.0144**	--	**0.0137**	--	--	**0.606**	**0.176**	--	**0.0777**	--	**0.0489**	--	--	**0.0052**	**0.0466**
General Chemistry Parameters																	
Aluminum	mg/L	**1.48**	**0.336**	**0.262**	**0.0878 J**	**0.0893 J**	**0.0403 J**	< 0.250 U	**0.0790**	**0.0683**	**1.1**	**0.775**	**0.394**	< 2.50 U	**0.762**	**0.534**	**0.264**
Calcium	mg/L	**30.7**	**6.81**	**1.86**	**0.939**	**4.58**	**22.2**	**34.6**	**30.3**	**9.80**	**12.9**	**10.1**	**6.75**	**3.13**	**1.41**	**0.995**	**5.08**
Iron	mg/L	**1.79**	**0.226 J**	**0.122**	**0.145**	**0.314**	**2.16**	**1.10**	**0.0320 J**	**0.951**	**0.244 J**	**0.211 J**	**0.359**	**0.378 U**	**0.233 J**	**0.191 J**	**0.684**
Magnesium	mg/L	**8.14**	**1.26**	**0.252**	**0.165**	**1.23**	**7.75**	**11.1**	**7.59**	**2.73**	**4.02**	**2.09**	**1.39**	< 2.50 U	< 0.500 U	< 0.250 U	**0.773**
Potassium	mg/L	**7.90**	**11**	**3.83**	**2.26**	**2.84**	**7.67**	**9.72**	**6.31**	**3.89**	**22.5**	**14.4**	**8.51**	**3.32 J**	**3.66 U**	**2.55**	**3.27**
Sodium	mg/L	**38.9**	**1780**	**386**	**214**	**158**	**78.9**	**49.6**	**32.2**	**80.4**	**2980**	**2360**	**959**	**393**	**315**	**281**	**189**
Alkalinity, Total	mg/L	< 1.00 U	**3620**	**514**	**240**	**139**	**23.8**	**6.41**	**15.0**	**102**	**6560**	**5400**	**1770**	**815**	**507**	**421**	**250**
Total Organic Carbon	mg/L	--	**83.1**	--	--	--	--	--	--	--	**69.66**	--	--	--	--	--	--
Field Parameters																	
Temperature	deg C	**17.5**	**19.7**	**18.8**	**18.6**	**18.4**	**17.4**	**17.1**	**13.9**	**16.9**	**20.1**	**19.5**	**19**	**20.5**	**17.8**	**17.1**	**14.3**
Specific Conductance	uS/cm	**532.6**	**6016**	**1398**	**968**	**823**	**619**	**594**	**367**	**450.6**	**10305**	**8336**	**3476**	**1913**	**1331**	**1116**	**796**
Dissolved Oxygen	mg/L	**0.16**	**0.48**	**0.18**	**0.17**	**0.14**	**0.2**	**0.2**	**3.55**	**0.16**	**0.55**	**0.07**	**0.1**	**0.07**	**0.14**	**0.11**	**0.19**
pH	pH units	**4.36**	**9.14**	**6.57**	**6.76**	**6.29**	**5.39**	**4.87**	**5.59**	**6.11**	**10.02**	**10.2**	**9.48**	**9.75**	**9.84**	**9.73**	**7.16**
Oxidation Reduction Potential	mV	**287.2**	**-9.2**	**52.8**	**48.7**	**-12**	**1**	**57**	**92.6**	**69.7**	**23.8**	**117.3**	**85.5**	**-0.7**	**61.2**	**27.9**	**116.4**
Turbidity	NTU	**11.4**	**2.84**	**10.4**	**2.64**	**10.8**	**1.56**	**7.09**	**1.16**	**26.4**	**3.99**	--	**7.37**	**10.6**	**7.26**	**6.14**	**8.53**

Notes:

J - Analyte was positively identified. The reported result is an estimate.

U - Analyte was not detected at or above the reported limit.

UJ - Analyte not detected and the reporting limit is an estimate.

Table 6. Metals Pilot Test Performance Monitoring

Project No. 050067, Art Brass Plating, Seattle, Washington

		Water Table Interval															
		Performance Monitoring Well															
		PSW-07								PSW-08							
		08/02/2019	08/09/2019	08/16/2019	08/22/2019	09/06/2019	10/09/2019	11/15/2019	02/05/2020	08/02/2019	08/09/2019	08/16/2019	08/22/2019	09/06/2019	10/09/2019	11/15/2019	02/05/2020
Analyte	**Unit**	**Baseline**	**Day 0**	**Day 7**	**Day 13**	**Day 28**	**Day 61**	**Day 98**	**Day 180**	**Baseline**	**Day 0**	**Day 7**	**Day 13**	**Day 28**	**Day 61**	**Day 98**	**Day 180**
Plating Metal (Dissolved)																	
Cadmium	ug/L	< 0.100 U	< 2 U	< 2.00 U	< 1.00 U	< 0.500 U	0.232	< 0.200 U	< 0.100 U	0.103	< 0.1 U	< 0.100 U	< 0.100 U	< 0.100 U	0.137	< 0.200 U	< 0.100 U
Copper	ug/L	1.75	141	268	398	286	60.2	32.4	29.0	4.29	0.685	0.525	0.835	1.09	25.2	92.3	56.1
Nickel	ug/L	1850	1320	1170	842	1110	177	128	116	4120	217	172	287	1980	669	413	1990
Zinc	ug/L	7.09	< 80 U	< 80.0 U	< 40.0 UJ	24.3	< 8.00 U	< 8.00 U	< 4.00 U	32.8	4.86	< 4.00 U	6.93	19.3	13.7	12.7	11.6
Redox-Sensitive Metals (Dissolved)																	
Arsenic	mg/L	--	0.259	--	< 0.500 U	--	--	< 0.250 U	0.0312 J	--	< 0.05 U	--	< 0.0500 U	--	--	< 0.250 U	< 0.250 U
Barium	mg/L	--	0.0057 J	--	0.0431	--	--	0.0083 J	0.0034 J	--	0.0008 J	--	0.0025 J	--	--	0.0083 J	0.0093 J
Manganese	mg/L	--	0.0402	--	0.0366	--	--	0.0079	0.0120	--	0.0666	--	0.177	--	--	0.0845	0.0690
General Chemistry Parameters																	
Aluminum	mg/L	0.108	1.91	1.47	1.18	2.00 J	1.56	1.12	0.227 J	0.467	0.0941	0.0630	0.0316 J	0.233	0.395 J	0.611	0.359
Calcium	mg/L	5.81	9.11	9.35	5.46	4.71	1.47	1.19	1.09	11.4	2.51	2.60	5.73	13.1	8.04	4.41	4.48
Iron	mg/L	1.50	0.587	0.525	1.15	0.570 U	0.628 J	0.469	0.413	1.41	1.24	1.44	4.90	7.11	1.46	1.76	0.804
Magnesium	mg/L	1.72	1.61	1.58	1.09	0.985 J	< 1.00 U	< 0.250 U	0.192 J	3.20	0.945	0.989	2.26	5.12	2.37	1.26	1.08
Potassium	mg/L	2.98	17.3	15.7	10.5	4.38 J	4.46 U	2.43 J	2.73	5.98	4.83	4.82	5.59	10.0	11.9	6.55	5.41
Sodium	mg/L	88.2	2540	2290	1280	469	392	282	229	58.4	97.1	99.7	114	151	313	200	154
Alkalinity, Total	mg/L	101	5520	4650	2470 J	923	588	449	289	32.4	119	136	188	226	458	261	136
Total Organic Carbon	mg/L	--	114.3	--	--	--	--	--	--	--	2.33	--	--	--	--	--	--
Field Parameters																	
Temperature	deg C	17.6	19.8	19.4	20	20.4	17.8	17.6	14.6	18	17.8	17.6	17.2	19	18.6	18	15
Specific Conductance	uS/cm	469.2	8925	7150	4711	2237	1605	1249	929	423.4	481.3	442.8	568.9	846	1283	872	704
Dissolved Oxygen	mg/L	0.14	0.06	0.05	0.05	0.05	0.1	0.05	0.15	0.15	0.19	0.16	0.15	0.12	0.16	0.09	0.14
pH	pH units	6.15	9.98	9.77	9.48	9.15	9.91	9.8	7.47	5.67	6.19	6.19	6.02	5.83	6.4	6.45	6.09
Oxidation Reduction Potential	mV	54.8	35.3	40.3	-101.3	4.3	47.7	54	109.9	170.6	30.1	38.9	35.1	52.9	-7.1	40.6	125.8
Turbidity	NTU	12.7	3.76	--	6.27	14.2	12.1	11.8	18.4	13.6	14	9.8	9.59	13.2	3.32	15.6	13

Notes:

J - Analyte was positively identified. The reported result is an estimate.

U - Analyte was not detected at or above the reported limit.

UJ - Analyte not detected and the reporting limit is an estimate.

Table 6. Metals Pilot Test Performance Monitoring

Project No. 050067, Art Brass Plating, Seattle, Washington

		Water Table Interval				Shallow Interval						
		Downgradient Well			Upgradient Well	Performance Well						
		MW-08			MW-01	MW-03-30						
		09/06/2019	11/15/2019	02/05/2020	02/05/2020	08/02/2019	08/09/2019	08/16/2019	08/22/2019	09/06/2019	10/09/2019	11/15/2019
Analyte	Unit	Day 28	Day 98	Day 180	Day 180	Baseline	Day 0	Day 7	Day 13	Day 28	Day 61	Day 98
Plating Metal (Dissolved)												
Cadmium	ug/L	--	< 0.100 U	< 0.100 U	**2.58**	< 0.100 U	< 0.1 U	--	--	< 0.500 U	< 0.200 U	< 0.200 U
Copper	ug/L	--	**0.520**	**1.19**	**16.4**	**0.669**	**1.03**	--	--	**90.4**	**32.8**	**41.4**
Nickel	ug/L	--	**6420**	**3480**	**5540**	**9.88**	**16.5**	--	--	**37.2**	**11.7**	**7.19**
Zinc	ug/L	--	**12.2**	**7.22**	**93.8**	< 4.00 U	**4.76**	--	--	**65.7**	< 20.0 U	< 8.00 U
Redox-Sensitive Metals (Dissolved)												
Arsenic	mg/L	--	--	--	**0.0057 J**	--	**0.0103 J**	--	--	--	--	--
Barium	mg/L	--	--	--	**0.0145**	--	**0.0107**	--	--	--	--	--
Manganese	mg/L	--	--	--	**0.422**	--	**0.577**	--	--	--	--	--
General Chemistry Parameters												
Aluminum	mg/L	--	< 0.250 U	**0.0103 J**	**0.841**	< 0.0500 U	< 0.05 U	--	--	**0.840 J**	**0.128 J**	**0.131 J**
Calcium	mg/L	--	**31.9**	**35.8**	**21.6**	**13.4**	**26.7**	--	--	**13.9**	**9.67**	**6.05**
Iron	mg/L	--	**15.7**	**3.28**	**0.161**	**6.49**	**21.5**	--	--	**0.849 U**	**3.16**	**1.05**
Magnesium	mg/L	--	**10.1**	**9.14**	**6.20**	**12.5**	**7.4**	--	--	**9.18**	**7.01**	**6.34**
Potassium	mg/L	--	**8.70**	**8.27**	**8.22**	**8.41**	**4.96**	--	--	**18.9 J**	**14.4**	**9.62**
Sodium	mg/L	--	**33.4**	**26.9**	**47.7**	**476**	**186**	--	--	**1720**	**1400**	**935**
Alkalinity, Total	mg/L	--	**56.7**	**72.6**	< 1.00 U	**1080**	**419**	--	--	**4070**	**2810**	**1870**
Total Organic Carbon	mg/L	--	--	--	--	--	**6.83**	--	--	--	--	--
Field Parameters												
Temperature	deg C	**17.4**	**16.1**	**13.4**	**17.1**	**16.7**	**17.9**	**18.7**	**19.2**	**18.2**	**16.4**	**16.2**
Specific Conductance	uS/cm	**418.8**	**506**	**377.9**	**483.9**	**2011**	**1031**	**4377**	**7377**	**67.5**	**4946**	**3288**
Dissolved Oxygen	mg/L	**0.16**	**0.25**	**0.32**	**1.81**	**0.13**	**0.19**	**0.09**	**0.05**	**0.06**	**0.09**	**0.04**
pH	pH units	**5.77**	**5.67**	**5.73**	**4.15**	**7.12**	**6.55**	**7.68**	**9.6**	**9.58**	**9.25**	**9.4**
Oxidation Reduction Potential	mV	**45.4**	**62.8**	**128.8**	**112.2**	**-120.9**	**-70.9**	**-204.7**	**-97.8**	**-9**	**-346.3**	**61.5**
Turbidity	NTU	**3.39**	**5.96**	**3.08**	**3.05**	**5.01**	**5.58**	**5.68**	**9.86**	**4.46**	**8.46**	**19.7**

Notes:

J - Analyte was positively identified. The reported result is an estimate.

U - Analyte was not detected at or above the reported limit.

UJ - Analyte not detected and the reporting limit is an estimate.

Table 6. Metals Pilot Test Performance Monitoring

Project No. 050067, Art Brass Plating, Seattle, Washington

Analyte	Unit		Intermediate Interval Performance Well MW-03-50					
		02/05/2020 Day 180	08/09/2019 Day 0	08/16/2019 Day 7	08/22/2019 Day 13	09/06/2019 Day 28	10/09/2019 Day 61	02/05/2020 Day 180
Plating Metal (Dissolved)								
Cadmium	ug/L	< 0.100 U	--	--	--	< 0.100 U	< 0.100 U	< 0.100 U
Copper	ug/L	**53.0**	--	--	--	< 0.500 U	< 0.500 U	**4.73**
Nickel	ug/L	**16.4**	--	--	--	**0.551**	**1.13**	**2.94**
Zinc	ug/L	< 4.00 U	--	--	--	**6.06**	**4.46**	**31.4**
Redox-Sensitive Metals (Dissolved)								
Arsenic	mg/L	--	--	--	--	--	--	--
Barium	mg/L	--	--	--	--	--	--	--
Manganese	mg/L	--	--	--	--	--	--	--
General Chemistry Parameters								
Aluminum	mg/L	**0.310**	--	--	--	< 0.0500 U	< 1.00 U	< 0.0500 U
Calcium	mg/L	**4.91**	--	--	--	**11.5**	**11.0**	**11.5**
Iron	mg/L	**1.37**	--	--	--	**0.592**	**0.710 J**	**0.697**
Magnesium	mg/L	**1.07**	--	--	--	**36.4**	**31.6**	**31.3**
Potassium	mg/L	**4.19**	--	--	--	**10.1**	**10.7**	**10.2**
Sodium	mg/L	**253**	--	--	--	**30.3**	**34.2**	**32.8**
Alkalinity, Total	mg/L	**490**	--	--	--	**210**	**211**	**202**
Total Organic Carbon	mg/L	--	--	--	--	--	--	--
Field Parameters								
Temperature	deg C	**14.8**	**20.7**	**20.2**	**19.2**	**19.7**	**17.7**	**14.8**
Specific Conductance	uS/cm	**969**	**198.7**	**185.6**	**196.7**	**466.9**	**469.9**	**414.5**
Dissolved Oxygen	mg/L	**0.02**	**0.13**	**0.16**	**0.17**	**0.12**	**0.18**	**0.14**
pH	pH units	**9.41**	**6.44**	**6.46**	**6.35**	**7.34**	**7.27**	**7.03**
Oxidation Reduction Potential	mV	**65.6**	**-93.8**	**27.9**	**36.6**	**-58.4**	**11.5**	**96**
Turbidity	NTU	**24.8**	**1.7**	**5.5**	**2.5**	**0.34**	**9.66**	**1.46**

Notes:

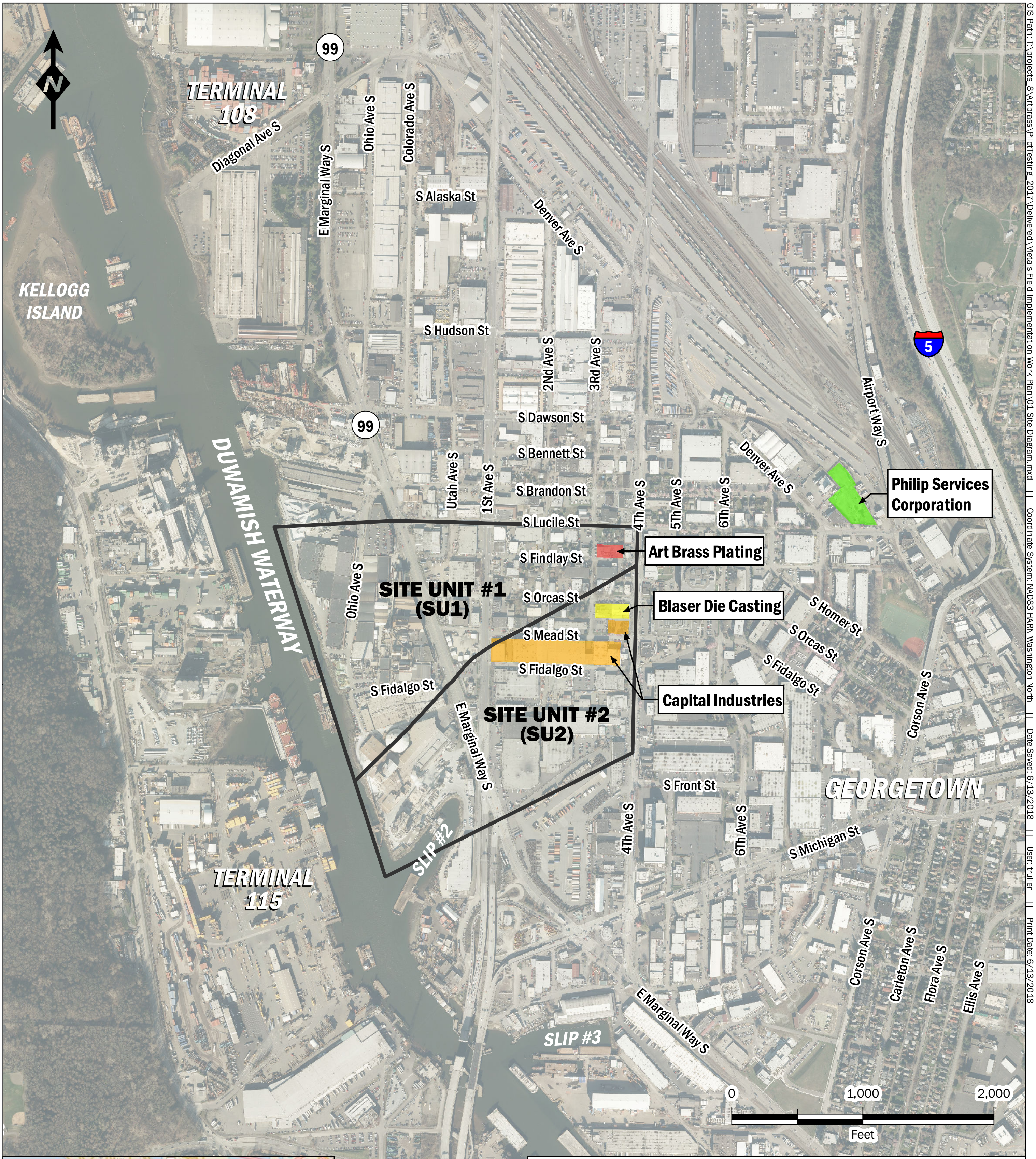
J - Analyte was positively identified. The reported result is an estimate.

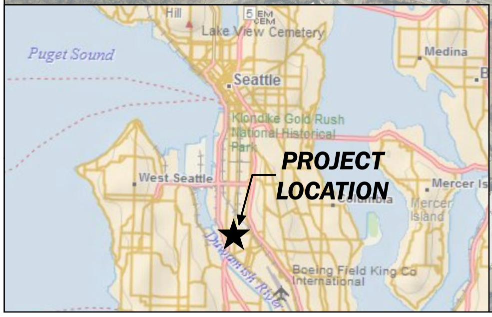
U - Analyte was not detected at or above the reported limit.

UJ - Analyte not detected and the reporting limit is an estimate.

FIGURES

**In-Situ Metals Immobilization –
Pilot Study Completion Report**



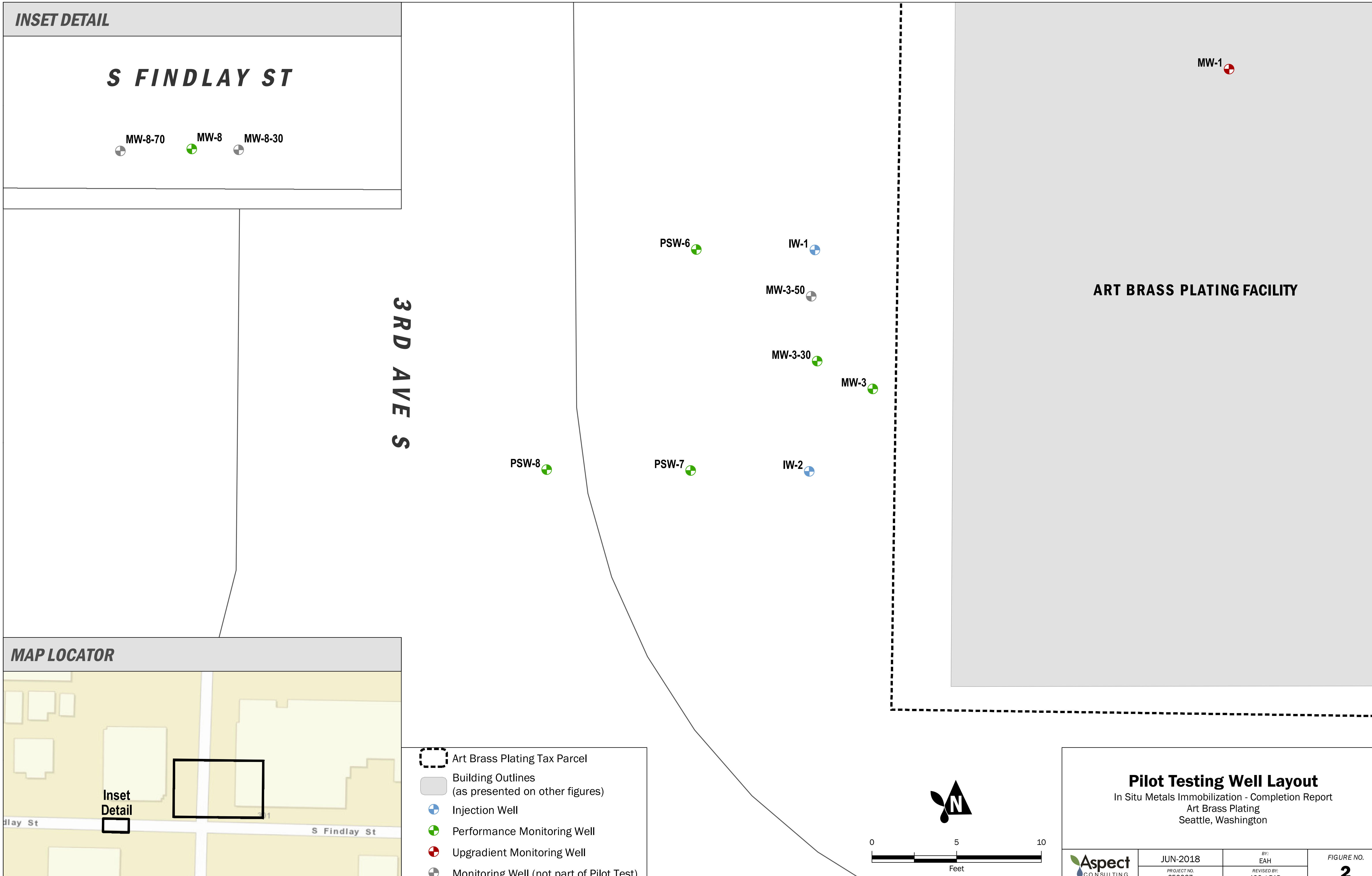


Site Diagram

In Situ Metals Immobilization - Metals Field Implementation Work Plan
Art Brass Plating
Seattle, Washington

Aspect CONSULTING	JUN-2018	BY: PPW	FIGURE: 1
	PROJECT NO. 050067	REVISED BY: DIM / RAP	

GIS Path: T:\projects_8\ArtBrass\PilotTesting_2017\Delivered\Metals Field Implementation Work Plan\01 Site Diagram.mxd || Coordinate System: NAD83 HARN Washington North || Date Saved: 6/13/2018 || User: trullen || Print Date: 6/13/2018



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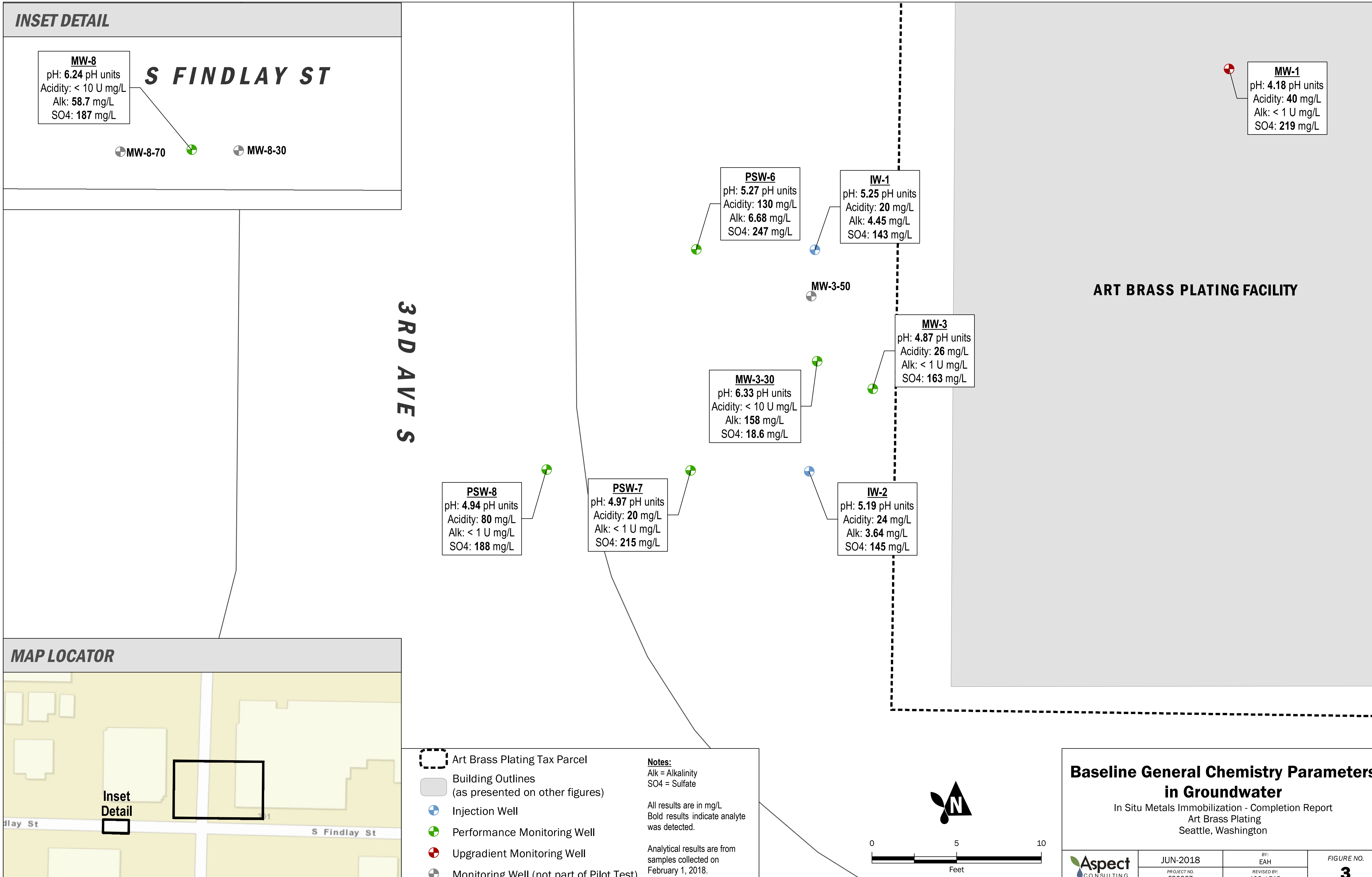

Baseline General Chemistry Parameters in Groundwater

In Situ Metals Immobilization - Completion Report
Art Brass Plating
Seattle, Washington

Aspect CONSULTING | JUN-2018 | PROJECT NO. 050067 | BY: EAH | REVISED BY: ACG / RAP | FIGURE NO. 3

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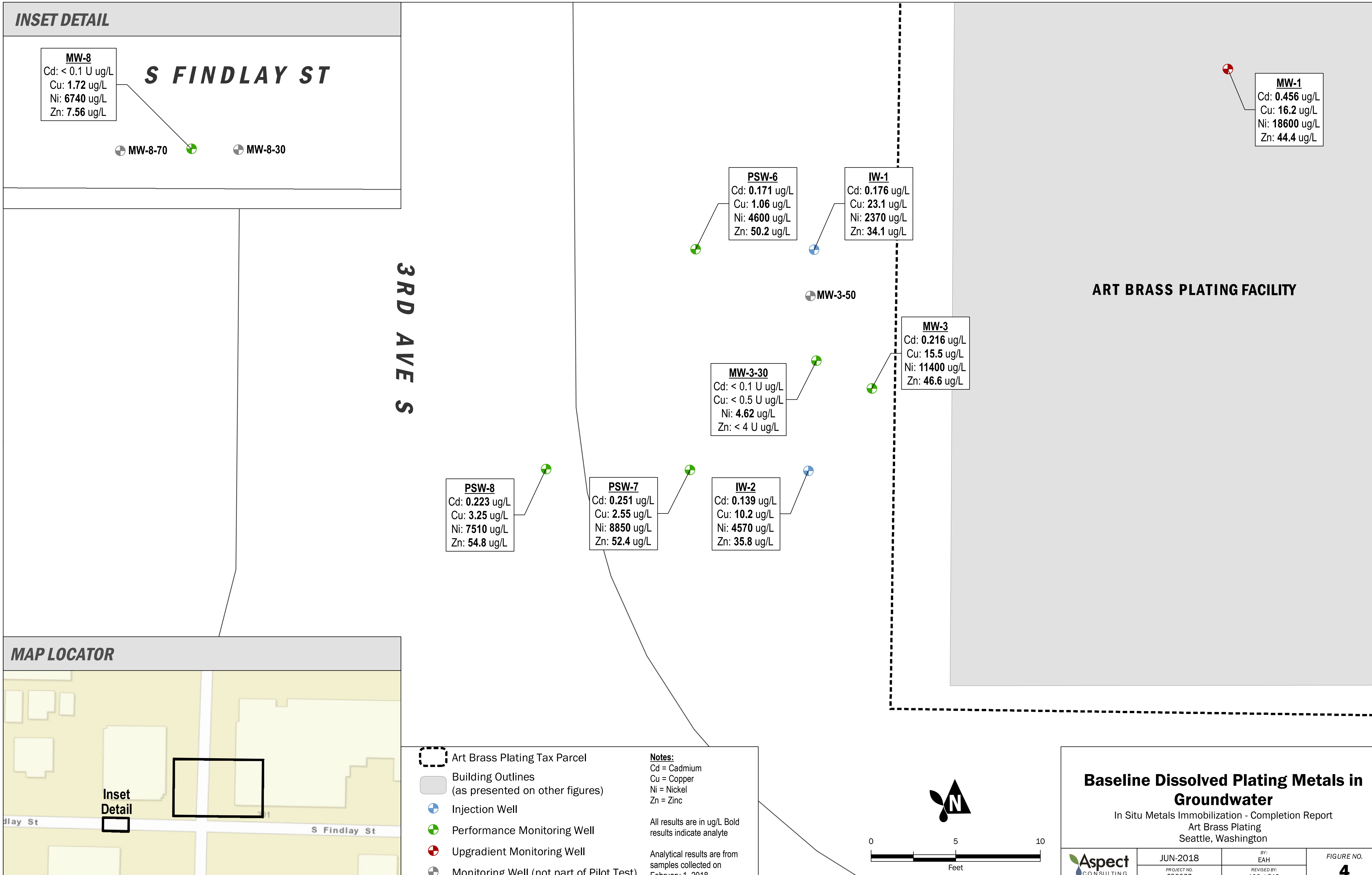

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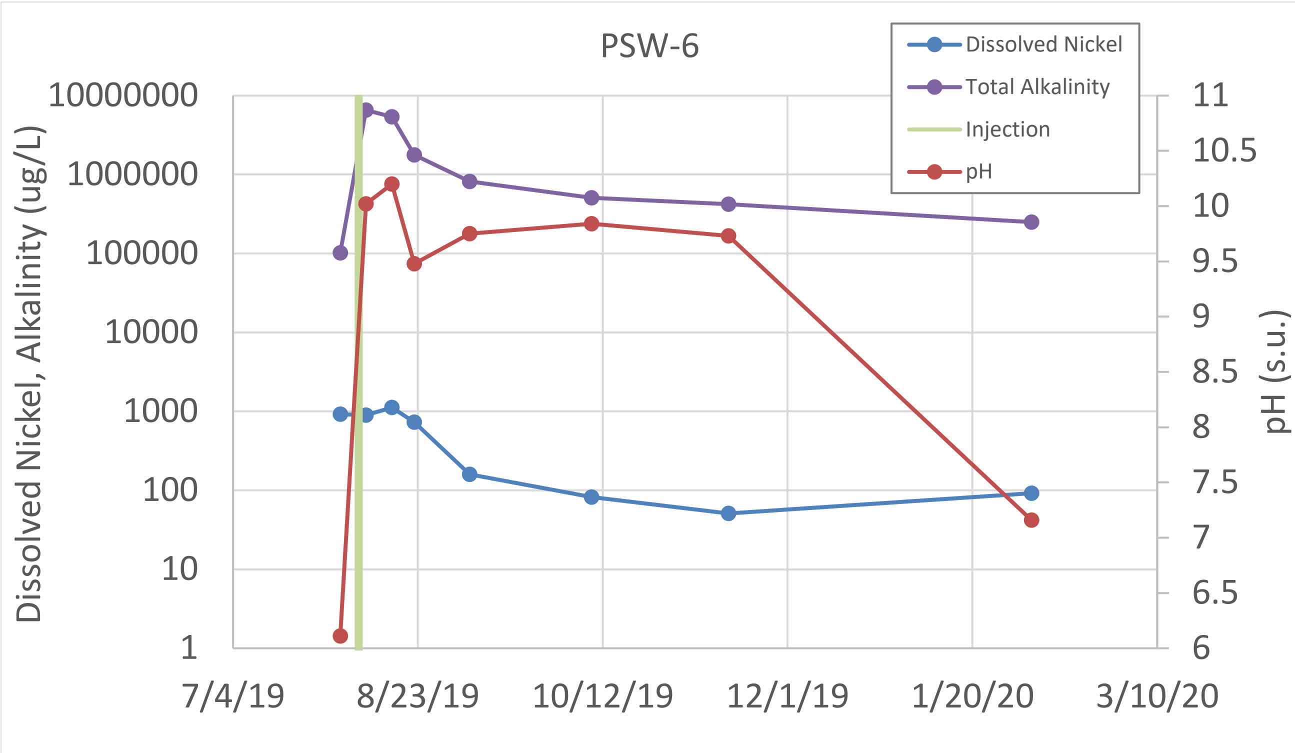


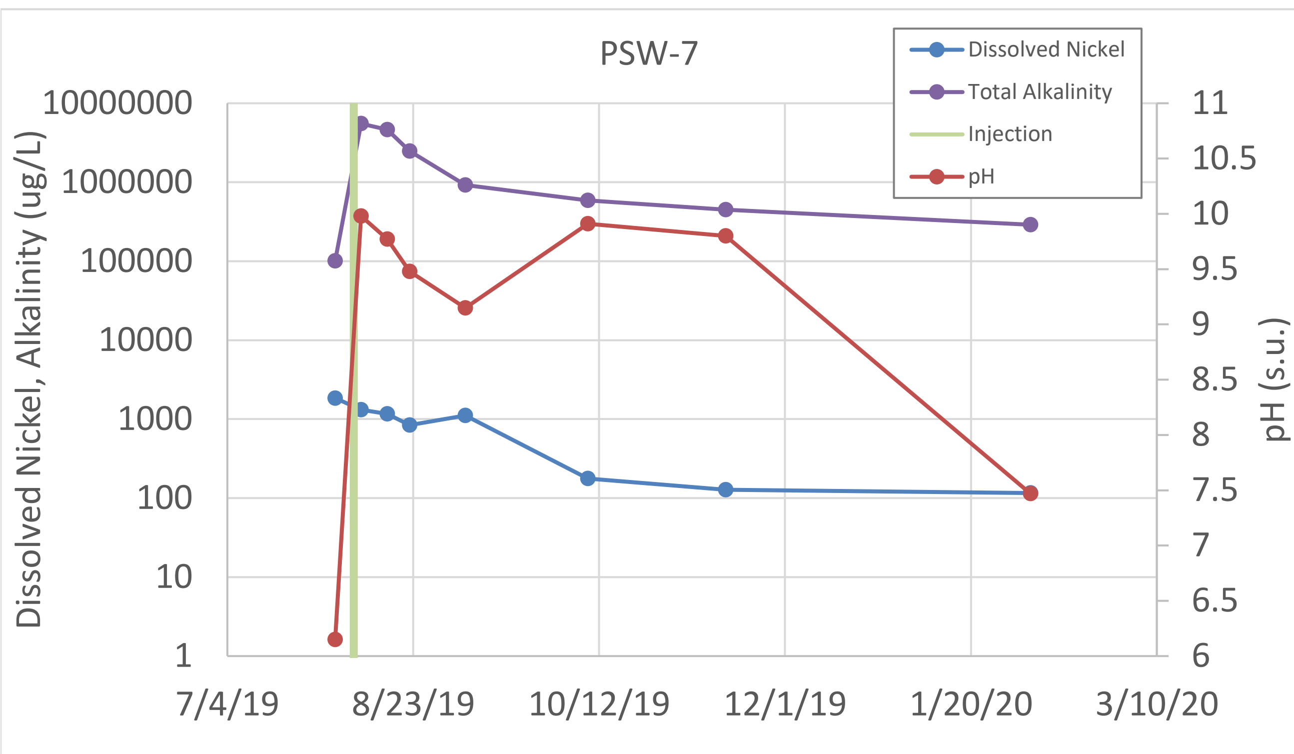


Figure 5

Nickel, pH, and Alkalinity Time Series

In Situ Metals Immobilization - Completion Report

Art Brass Plating, Seattle, WA

Aspect Consulting

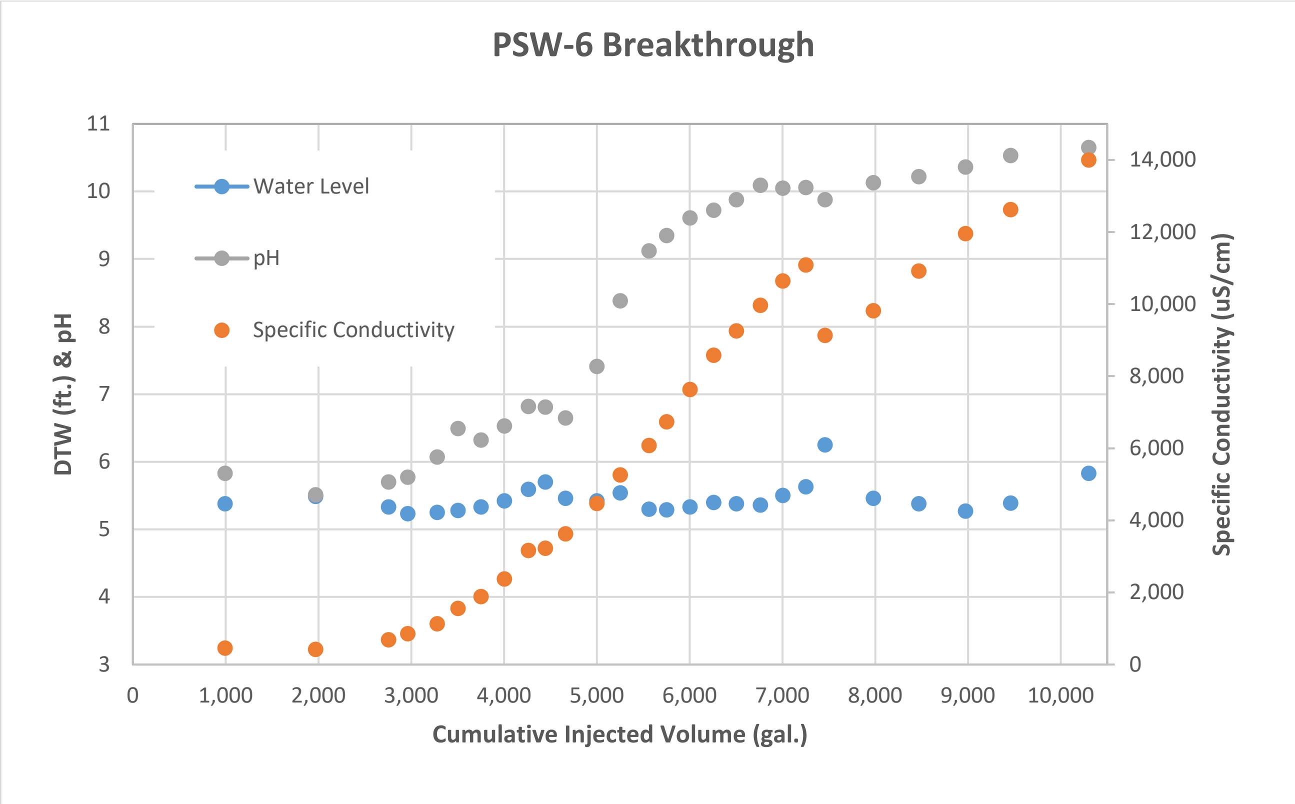
11/19/2020

V:\050067 Art Brass Plating\Pilot Study\Metals\Completion Report\Figures\05 Nickel pH Time Series

APPENDIX A

of In-Situ Metals Immobilization – Pilot Study Completion Report

Dose-Response Breakthrough Plots



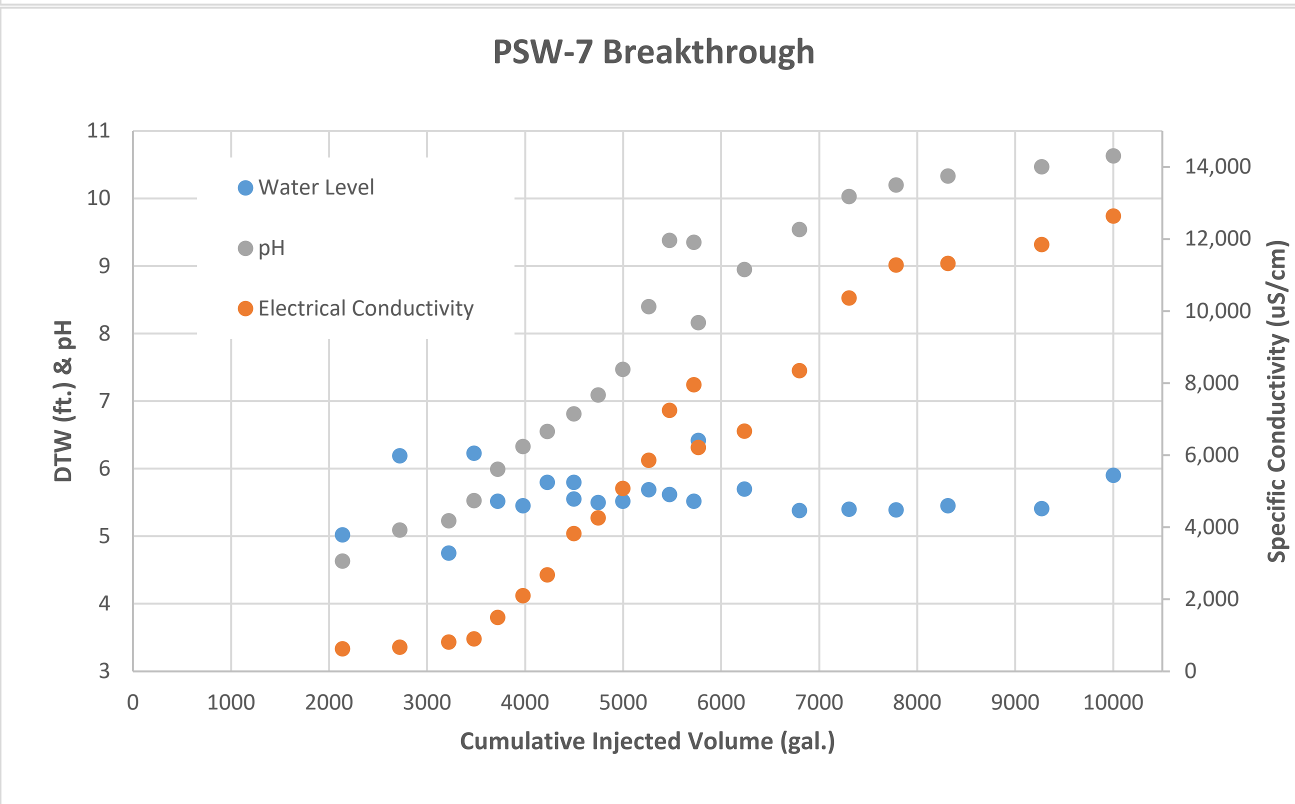


Figure B-1

Dose-Response Breakthrough Plots

In Situ Metals Immobilization - Completion Report

Art Brass Plating, Seattle, WA

Aspect Consulting

10/22/20

V:\050067 Art Brass Plating\Pilot Study\Metals\Completion Report\Appendices\App B_Breakthrough\AppB_Breakthrough Plots

APPENDIX B

of In-Situ Metals Immobilization – Pilot Study Completion Report

Photo Log

Photograph 1. Injection tank and reagent totes in front of Art Brass Plating.

Photograph 2. Mixing a batch of injection-strength reagent from the concentrated reagent in the totes.

Photograph 3. Injection wellhead with pressure gauge and air release valve, with 2-inch flow totalizer to the right.

APPENDIX C

Preliminary Cleanup Level Development

Table C-1
Soil Preliminary Cleanup Levels
West of 4th Site
Seattle, Washington
Farallon PN: 457-009

Constituent of Concern	Puget Sound Background Concentrations for Metals in Soil	Soil Cleanup Level Protective of Surface Water (Vadose Zone) [1]	Soil Cleanup Level Protective of Groundwater as Drinking Water[2]	Soil Cleanup Level Protective of Direct Contact Pathway - Carcinogenic (Method B)[3]	Soil Cleanup Level Protective of Direct Contact Pathway Non-carcinogenic (Method B)[3]	Soil Cleanup Level Protective of Direct Contact Pathway Carcinogenic (Method C)[3]	Soil Cleanup Level Protective of Direct Contact Pathway Non-carcinogenic (Method C)[3]	Soil Cleanup Level Protective of Sediment (Saturated) [4]	Soil Cleanup Level Protective of Sediment (Vadose) [4]
	Soil Preliminary Cleanup Levels (Milligrams/kilogram)								
Tetrachloroethene	Not Applicable	**0.03**	0.08	480	480	63,000	21,000	140	2,500
Trichloroethene	Not Applicable	**0.004**	0.03	12	40	2,900	1,800	2.0	32
cis-1,2-Dichloroethene	Not Applicable	Not Applicable	0.39	Not Applicable	160	Not Applicable	7,000	120	1,800
trans-1,2-Dichloroethene	Not Applicable	**5**	0.59	Not Applicable	1,600	Not Applicable	70,000	1,200	19,000
1,1-Dichloroethene	Not Applicable	**26**	0.055	Not Applicable	4,000	Not Applicable	180,000	2,300	43,000
Vinyl chloride	Not Applicable	**0.001**	0.002	0.67	240	88	11,000	0.6	1.1
1,4-Dioxane	Not Applicable	**0.32**	0.002	10	2,400	1,300	110,000	5.9	82
Arsenic	7.3	**0.082**	Not Applicable	0.67	24	88	1,100	6.5	130
Barium	--	**165**	Not Applicable	Not Applicable	16,000	Not Applicable	700,000	38,000	760,000
Cadmium	0.77	**1.2**	Not Applicable	Not Applicable	80	Not Applicable	3,500	0.0083	0.16
Copper	36	**1.4**	Not Applicable	Not Applicable	3,200	Not Applicable	140,000	0.31	6.1
Iron	36,100	Not Applicable	Not Applicable	Not Applicable	56,000	Not Applicable	2,500,000	--	--
Manganese	1,200	**1.3**	Not Applicable	Not Applicable	3,700	Not Applicable	160,000	--	--
Nickel	48	**11**	Not Applicable	Not Applicable	1,600	Not Applicable	70,000	170	3,300
Zinc	85	**101**	Not Applicable	Not Applicable	24,000	Not Applicable	1,100,000	48	960

NOTES:

-- indicates no value is available. In the case of ARAs, the reference sources do not publish values for the noted chemicals. In the case of calculated values, one or more input parameters are not available.

"Not Applicable" is used where the constituent of concern will not affect the media of potential concern due to an incomplete pathway or no pertinent standard exists.

Bold = selected preliminary cleanup level

[1] Soil cleanup levels for protection of surface water quality are based on vadose conditions. Achievement of soil cleanup levels protective of groundwater would be evaluated via groundwater monitoring for empirical demonstration. Values are calculated using Washington State Model Toxics Control Act Cleanup Regulation (MTCA) Equation 747-1 where the groundwater cleanup level protective of surface water in this table was used as Cw.

[2] Values are calculated using MTCA Equation 747-1 where the potable Method B groundwater cleanup level was used as Cw. Concentrations of hazardous substances in soil that meet the potable groundwater protection standard currently are considered sufficiently protective of the air pathway for unrestricted and industrial land uses.

[3] Cleanup level is based on standard MTCA Method B (unrestricted land use) or Method C (industrial land use) values from the Cleanup and Risk Calculations tables (CLARC).

[4] Cleanup level provided by Ecology 5/25/2022 for inclusion in this table.

Table updated August 14, 2015 based on revisions to AWQC; August 2022 per Ecology comments dated 5/25/2022.

Table C-2
Groundwater and Surface Water Preliminary Cleanup Levels
West of 4th Site
Seattle, Washington
Farallon PN: 457-009

Constituent of Concern	Preliminary Cleanup Levels (Micrograms/liter): Natural Background [1]	Groundwater Screening Level Protective of Indoor Air Quality (Unrestricted Land Use)[2] Carcinogenic	Groundwater Screening Level Protective of Indoor Air Quality (Unrestricted Land Use)[2] Non-carcinogenic	Groundwater Screening Level Protective of Indoor Air Quality (Commercial)[2] Carcinogenic	Groundwater Screening Level Protective of Indoor Air Quality (Commercial)[2] Non-carcinogenic	Groundwater Cleanup Level Protective of Surface Water - Aquatic Receptors	Groundwater Cleanup Level Protection of Surface Water - Human Health [5]	Groundwater Cleanup Level Protection of Sediment [6]
Tetrachloroethene	--	25	48	120	410	--	2.9	250,000
Trichloroethene	--	1.4	3.9	12	34	194 [7]	0.7	5,200
cis-1,2-Dichloroethene	--	--	--	--	--	--	--	360,000
trans-1,2-Dichloroethene	--	77	610	--	650	--	1,000	3,700,000
1,1-Dichloroethene	--	130	3,000	--	1,100	--	4,000	6,600,000
Vinyl chloride	--	0.33	1,500	1.6	460	210 [7]	0.18	1,900
1,4-Dioxane	--	--	130,000	22,000	1,100,000	--	--	20,000
Arsenic	8.0	Not Applicable	Not Applicable	Not Applicable	Not Applicable	36 [8]	0.14	220
Barium	--	Not Applicable	Not Applicable	Not Applicable	Not Applicable	200 [7]	--	930,000
Cadmium	--	Not Applicable	Not Applicable	Not Applicable	Not Applicable	7.9 [8]	--	1.2
Copper	--	Not Applicable	Not Applicable	Not Applicable	Not Applicable	3.1 [8]	--	14
Iron	--	Not Applicable	Not Applicable	Not Applicable	Not Applicable	--	--	--
Manganese	--	Not Applicable	Not Applicable	Not Applicable	Not Applicable	--	100 [11]	--
Nickel	--	Not Applicable	Not Applicable	Not Applicable	Not Applicable	8.2 [8]	100	2,600
Zinc	--	Not Applicable	Not Applicable	Not Applicable	Not Applicable	81 [8]	1,000	770

NOTES:
Bold = selected preliminary cleanup level
-- indicates no value is available. In the case of ARARs, the reference sources do not publish values for the noted chemicals. In the case of calculated values, one or more input parameters are not available.
"Not Applicable" is used where the constituent of concern will not affect the media of potential concern due to an incomplete pathway or no pertinent standard exists.
[1] Natural background value provided by Ecology 5/25/2022 for inclusion in this table.
[2] Cleanup level is based on Guidance for Evaluating Vapor Intrusion in Washington State: Investigation and Remedial Action (Ecology, 2009) and listed in Cleanup and Risk Calculations tables (CLARC; database dated July 2022).
[3]MTCA Cleanup Levels and Risk Calculations Method B Modified based on Asian Pacific Island (API) Exposure scenarios for the consumption of fish for the groundwater-to-surface water pathway
[4] Cleanup levels based on MTCA Equation 730-1 (non-carcinogens) or 730-2 (carcinogens). Default values used with exception of:
[5] Criteria in this column are based on EPA's Partial Approval/Partial Disapproval of Washington's Human Health Water Quality Criteria and Implementation Tools (November 15, 2016), unless otherwise noted below. EPA reversed their 2016 decision on May 10, 2019, which has become the subject of litigation that is expected to be concluded in 2022. If the legal decision affirms the 2016 decision, the 2016 WQC will become the CULs published in the CAP.
[6] Groundwater cleanup levels for protection of sediment were provided by Ecology 5/25/2022 for inclusion in this table.
[7] Aquatic Life, literature value provided by Ecology 5/25/2022 for inclusion in this table
[8] National Recommended Water Quality Criteria published by EPA under 304 of the Federal Clean Water Act - Aquatic Life Criteria Table
[10] 1,4-Dioxane cleanup level is calculated MTCA Method B - Modified based on Ingestion of Fish for Asian Pacific Islander (East of 4th Final Cleanup Action Plan, PSC Georgetown Facility, Seattle, Washington, April 28, 2010).
[11] CWA Section 304, National Recommended Water Quality Criteria, Human Health based on consumption of organisms. Provided by Ecology 5/25/2022 for inclusion in this table.
Table updated August 2022, based on comments from Ecology dated 5/25/2022.

Table C-3
Air Preliminary Cleanup Levels
West of 4th Site
Seattle, Washington
Farallon PN: 457-009

Constituent of Concern	Air Preliminary Cleanup Levels			
	Air Cleanup Level Protective of Inhalation Pathway - Carcinogenic (Residential Sites)[1]	Air Cleanup Level Protective of Inhalation Pathway - Non-carcinogenic (Residential Sites)[1]	Air Cleanup Level Protective of Inhalation Pathway - Carcinogenic (Industrial Sites)[1]	Air Cleanup Level Protective of Inhalation Pathway - Non-carcinogenic (Industrial Sites)[1]
	(Micrograms/cubic meter)			
Tetrachloroethene	**9.6**	18	96	40
Trichloroethene	**0.33**	0.91	6.1	2
cis-1,2-Dichloroethene	Not Applicable	Not Applicable	Not Applicable	Not Applicable
trans-1,2-Dichloroethene	Not Applicable	**18**	Not Applicable	40
1,1-Dichloroethene	Not Applicable	**91**	Not Applicable	200
Vinyl chloride	**0.28**	46	2.8	100
1,4-Dioxane	**0.5**	14	5	30
Arsenic	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Barium	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Cadmium	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Copper	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Iron	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Manganese	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Nickel	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Zinc	Not Applicable	Not Applicable	Not Applicable	Not Applicable

NOTES:

[1] Cleanup level is based on standard Washington State Model Toxics Control Act Cleanup Regulation (MTCA) Method B (unrestricted land use) or Method C (industrial land use) values from the Cleanup and Risk Calculations tables (CLARC, July 2022).

"Not Applicable" is used where the constituent of concern will not affect the media of potential concern due to an incomplete pathway or no pertinent standard exists.

Bold = selected preliminary cleanup level

APPENDIX D

Methodology for Developing Remediation Levels

Contents – Appendix D

Figures

Attachments

Introduction

This appendix describes an approach for the development of remediation levels (RELs) for chlorinated ethenes (chloroethenes) in porewater at the Lower Duwamish Waterway (Waterway) and the approach for using these RELs in developing and evaluating groundwater treatment remedies near the Waterway. These RELs are being developed for the West of 4th Site (the Site) based on Site empirical data and conditions. The purpose of these RELs is to identify Site-specific action levels that are sufficiently protective of human health and the environment under current and potential future Site conditions such that once these RELs are achieved, active remediation can be transitioned to monitored natural attenuation. As detailed in the Section 7.3 of the Sediment Cleanup User Manual (SCUM II; Ecology 2019), point of compliance depends on the receptor (benthic risk versus human health). RELs to achieve cleanup levels for benthic protection are applied on a point-by-point basis, whereas human health protection is applied on a surface weighted average concertation from within exposure areas.

The following sections outline:

- **Exposure Pathway Analysis.** This section provides the basis for focusing on shellfish consumption by humans as the exposure pathway driver for development of RELs.
- **Calculation of Porewater RELs.** This section describes the proposed method for calculating RELs for Site porewater.
- **Comparison of Site Data to Porewater RELs.** This section describes the rationale and application of area-weighted averaging of Site porewater data.
- **Implications for Remedy Design.** This section describes how RELs will be used in developing, evaluating, and designing remedial alternatives.
- **Uncertainty Analysis.** This section discusses uncertainties in developing RELs.

Exposure Pathway Analysis

Previous investigations of Waterway porewater at the Site identified chloroethenes – including trichloroethene (TCE), and vinyl chloride (VC) – above Site[1] preliminary cleanup levels (PCULs) for protection of surface water (SU1 FS Addendum, Table 3-1). The PCULs for TCE and VC are the Washington marine surface water criteria based on protection of human health (WAC 173-201A-240) derived to be protective of cancer risk to subsistence harvesters consuming primarily Pacific salmon, but also other finfish and shellfish, which have bioaccumulated those chemicals. For TCE and VC, human health-based PCULs are below ecological screening levels. Maximum concentrations of chloroethenes in porewater data collected from 48 sediment locations adjacent to the shoreline did not exceed surface water criteria for protection of aquatic life (SU1 FS Addendum, Table 3-1). During the 2020 porewater sampling event, only VC exceeded the Site PCUL (based on protection of human health).

In accordance with Section 7.3 of SCUM II, RELs to achieve cleanup levels must be applied at sediment sites as appropriate for site-specific pathways, receptors, and conceptual site model. At this Site, the contaminants of concern are weakly sorbed to sediment and present in the dissolved phase due to groundwater transport from the upland through the bioactive zone—not from desorption from sediment. The contaminant at this Site accumulates in shellfish that are then collected and consumed by subsistence harvesters. Therefore, to address the mode of exposure, RELs for porewater are appropriate as media of concern. Porewater criterion have been applied at other Ecology sites as triggers for additional testing or remediation when the contaminant is a dissolved-phase issue; for example, hydrogen sulfide at the Port Gamble site (see Operations Maintenance Monitoring Plan; Anchor QEA 2018).

REL development for the Site focuses on a sediment porewater concentration protective of human health at the sediment porewater point of compliance (i.e., to be determined based on receptor species). For seafood at the Site, only shellfish residing in the sediment are exposed to porewater in the biologically active zone (i.e., default depth of 10 cm). Therefore, the proposed REL is based on subsistence level shellfish harvesting using Site-specific information on consumption rates for clams and not crabs (which live on the surface, rather than within, the sediment) or fish.

The focus on shellfish in sediments is further supported by the very short residence time of volatile organic compounds (VOCs) in surface water. VOCs have a high Henry's law constant and volatilize quickly (USEPA, 1979). Furthermore, the mean annual flow rate of the Duwamish River (1,700 cubic feet per second [Penta Environmental, 2001]) is much higher than the rate of groundwater discharge from the Site (approximately 0.03 cubic feet per second[2]). Therefore, concentrations of chloroethenes in surface water from

[1] Chloroethenes are not contaminants of concern for the Lower Duwamish Waterway Superfund Site.

[2] The rate of groundwater discharge from the Site is calculated based on the porewater study area (11,600 square feet), the maximum seepage velocity calculated during the CVOC Pilot Study of 0.98 feet per day (Appendix B of the FS Addendum), and a porosity of 0.25 (porosity from Appendix C of Site Unit 1 FS (Aspect, 2016)).

the Site are assumed to be insignificant, and crab and fish consumption is not included in the Porewater REL calculation. Note that this analysis of the reduction in contaminant concentrations upon discharge to the Waterway is being used to evaluate current exposure risks and appropriate media for monitoring. Porewater sampling will be completed to verify attainment of RELs and ultimately CULs in porewater.

Calculation of Porewater RELs

As discussed above, the proposed Porewater RELs are based on the protection of human health from consumption of potentially contaminated shellfish. The following outlines the calculation of the Porewater REL and input parameter assumptions.

Surface water criteria for protection of human health based on consumption of organisms were used for the calculation of the Porewater REL. As listed in the Ecology's Cleanup Levels and Risk Calculation database (CLARC, January 2020), Washington State's WAC 173-201A-240 criteria is the most stringent applicable criteria for this evaluation. These criteria include bioaccumulation factors accounting for the carcinogenic effects of TCE and VC. The seafood consumption rate used in calculation of this criteria is 0.175 kilograms per day (kg/d).

Potential human consumption of shellfish at the Site is the risk driver for Porewater RELs. To calculate the Porewater REL, the total seafood consumption rate (0.175 kg/d) was adjusted to account for a shellfish portion of that consumption rate. For the Lower Duwamish Waterway (LDW) Superfund Site, EPA applies Tulalip Tribe reasonable maximum exposure (RME) consumption rates to derive surface water criteria for protection of human health (Windward, 2010). These seafood consumption rates provided ingestion scenarios for fish versus shellfish that are applicable to the Site. The Tulalip RME shellfish consumption values (0.0385 kg/day) are applied to sediment porewater calculations.

As shown below, Site-specific Porewater RELs were calculated by adjusting the identified water quality criteria using the ratio of the total seafood consumption rate to the Tulalip RME shellfish consumption rate. The resulting Porewater RELs – which are protective of human health via the shellfish consumption pathway for the Waterway – are 0.82 µg/L for VC and 3.2 µg/L for TCE.

Table D-1. Summary of Porewater REL Calculations

	Risk Factor	LDW Tulalip RME Shellfish Consumption Rate (Windward, 2010)	Total Seafood Consumption Rate (WAC 173-201A)	Ratio of Total Seafood Rate to Tulalip RME Shellfish Rate	Human Health Water Quality Criteria[1] (organism only)	Site-Specific Porewater REL
	unitless	kg/d	kg/d	unitless	µg/L	µg/L
Vinyl Chloride	0.000001	0.0385	0.175	4.55	0.18	0.83
TCE	0.000001	0.0385	0.175	4.55	0.70	3.2

Notes: kg/d = kilograms per day, ug= L – micrograms per liter
1 - PCUL development summarized in Appendix C and Table 3-1 of this FS Addendum.

Comparison of Site Data to RELs

Because the relevant exposure pathway is human consumption of shellfish, achievement of Porewater RELs will be evaluated using area-weighted average concentrations (also known as surface-area weighted average concentrations, or "SWACs") in accordance with Ecology regulations (Sediment Management Standards [SMS]: WAC 173-204) and guidance for bioaccumulative exposures outlined in Ecology's SCUM II. As detailed in the Section 7.3 of the Sediment Cleanup User Manual (SCUM II; Ecology 2019), point of compliance depends on the receptor (benthic risk versus human health). RELs to achieve cleanup levels for benthic protection are applied on a point-by-point basis whereas human health protection is applied on a surface weighted average concertation from within exposure areas.

SCUM II describes the depth of sediment biologically active zone as typically 10 cm below the mudline in Puget Sound and this interval is the SMS default point of compliance for assessing sediment chemistry. The benthic community, including bivalves, is primarily exposed to those chemicals measured in the bulk sediment matrix via their dissolved forms in sediment porewater. Site groundwater moves by advection through the sediment/porewater matrix of the biologically active zone into surface water.

SCUM II notes that area-weighted averages should be used *"when a non-random or biased sampling design was used to collect the data, such as when sampling to target particular areas of concern"* and recommends use of inverse-distance weighting (IDW) for spatial characterization. This is the sampling design used for the 2011 and 2020 porewater studies. The area used for averaging data for each study included the area of discharge of impacted groundwater from the Site (i.e., the area containing detectable chloroethenes)[3]. Area-weighted porewater concentrations were calculated using the 2011 and 2020 porewater data sets as described below.

2011 Porewater Concentrations

Porewater data from 2011 were presented in the Art Brass Plating RI Report (Aspect, 2012). SWACs were calculated based on 2011 porewater data as follows:

- IDW (through algorithms integrated into GIS) was used to interpolate data and calculate SWACs. The IDW tool in ArcGIS includes optimization that considers when minimum mean absolute error is at its lowest. The tool narrows the range of potential parameters, including the power function, through this optimization. Therefore, the power functions used may vary for different data sets. IDW parameters are summarized in Attachment A.

- The data distribution was evaluated for raw and log-transformed data (Attachment A). The data are log-normally distributed and the distribution

[3] Both studies included low but detectable concentrations at one or more boundaries of the study areas, suggesting that the appropriate averaging area for this calculation may be larger. If the study area were expanded, it is likely that the SWACs would be somewhat lower than estimated in this section.

showed lower skewness and kurtosis for log-transformed data, indicating that calculating SWACs using log-transformed data was appropriate.

- The area boundaries were limited to the available dataset because extrapolation beyond the dataset boundaries with IDW introduces additional uncertainty.
- IDW interpolation results and calculated SWACs were compared for different conditions:
    - Raw data versus log-transformed data; and
    - Under a range of power functions (2, 3, and 4).
- A 'best fit' was determined by cross-validation of predicted versus measured data points and comparing root-mean-square errors for the various interpolations (Appendix A).
- The best fit was using log-transformed data and a power function of 4.

The calculated SWACs for each of the chloroethenes under each of the conditions described above are tabulated as follows:

Table D-2. 2011 Calculated SWACs for Chloroethenes

Chemical	IDW Power Function	SWAC (µg/L)	
		Non-transformed	Log Transformed
TCE	2	0.46	0.32
TCE	3	0.47	0.37
TCE	4	0.48	0.4
cis-DCE	2	11.09	1.9
cis-DCE	3	10.57	3.71
cis-DCE	4	10.27	5.06
VC	2	3.85	1.32
VC	3	3.75	2
VC	4	3.7	2.46

Note: µg/L = micrograms per liter

The calculated SWACs for the best fit are as follows:

- TCE: 0.4 µg/L
- Cis-DCE: 5.1 µg/L
- VC: 2.5 µg/L

These SWACs yield a total chloroethenes SWAC concentration[4] of 0.096 µmol/L[5].

The TCE SWAC based on 2011 data was below the Porewater REL. The VC SWAC exceeded the Porewater REL by approximately a factor of 3.

2020 Porewater Concentrations

The 2020 porewater data set was collected using lower detection limits, which improved the accuracy of the SWAC calculation. SWACs were calculated based on 2020 porewater data over the area of detected concentrations (i.e., the porewater study area) as follows:

- Inverse-distance weighting (IDW) was used to interpolate data and calculate SWACs. IDW parameters summarized in Attachment B.
- The data distribution was evaluated for raw and log-transformed data (Attachment B). Similar to the 2011 data, the data are log-normally distributed, and the distribution showed lower skewness and kurtosis for log-transformed data, indicating that calculating SWACs using log-transformed data was appropriate.
- Based on the data distributions, a sensitivity analysis was performed on the log-transformed dataset. IDW interpolation results and calculated SWACs were compared for a range of power functions: 4, 5, and 6 for TCE, 2, 3, and 4 for cis-DCE, and 3, 4, and 5 for VC[6].
- A 'best fit' was determined by conducting cross-validation comparing root-mean-square errors for the various interpolations (Attachment B).
- The best fit, based on the lowest observed RMS errors, were using a power function of 6 for TCE, 4 for cis-DCE, and 5 for VC.

The calculated SWACs for each of the chloroethenes for the range of power functions described above are as follows:

[4] The contribution of other chloroethenes 1,1-DCE and trans-1,2-DCE is insignificant.
[5] Molecular weights of TCE, cis-DCE, and VC are 131.4 grams per mole (g/mol), 97.0 g/mol, and 62.5 g/mol, respectively.
[6] A higher range of power functions was evaluated compared to the analysis of 2011 data because the greater overall range in concentrations resulted in higher skew at lower power functions.

Table D-3. 2020 Calculated SWACs for Chloroethenes

Chemical	IDW Power Function	SWAC (µg/L) Log Transformed
TCE	4	0.0259
TCE	5	0.0262
TCE	6	0.0265
cis-DCE	2	0.79
cis-DCE	3	1.12
cis-DCE	4	1.34
VC	3	3.25
VC	4	4.19
VC	5	4.83

Note: µg/L = micrograms per liter

The predicted distributions for vinyl chloride, with the back-transformed concentrations, for each of the power functions above is shown in Figures D-1 through D-3.

The calculated SWACs for the best fit condition are as follows:

- TCE: 0.027 µg/L
- Cis-DCE: 1.3 µg/L
- VC: 4.8 µg/L

For the 2020 data, these SWACs yield a SWAC concentration for total chloroethenes of 0.090 µmol/L. The TCE SWAC based on 2020 data was below the Porewater REL. The VC SWAC exceeded the Porewater REL by approximately a factor of 6.

Implications for Remedial Alternative Design

VC is the only chemical which has a SWAC greater than the Porewater REL or the surface water PCUL. The SWAC for VC, based on 2020 data, is 4.8 µg/L, 6 times higher than the calculated Porewater REL of 1.2 µg/L. Based on current limited shellfish habitat, limitations on harvesting in this area of the Waterway, and the limited footprint of Site impacts, existing porewater concentrations do not represent an unacceptable exposure risk under current conditions. Additional remedial actions are needed to provide protectiveness under potential future use scenarios.

Source control at upgradient facilities, coupled with the natural attenuation of the groundwater plume, will ultimately achieve cleanup levels at the Waterway, but the projected restoration timeframe is relatively long. Ecology has expressed an expectation for additional active treatment closer to the Waterway to reduce concentrations discharging to the Waterway. In this SU1 FS Addendum, RELs are used to help define remedial alternatives that include treatment near the Waterway, with the objective of achieving Porewater RELs in a faster timeframe than would be achieved by natural attenuation alone. The use of RELs in defining remedial alternatives is described below.

Treatment Objectives

The goal of active groundwater treatment upgradient of the Waterway would be to achieve and sustain porewater concentrations below Porewater RELs faster than what can be achieved through source treatment alone. The SU1 Feasibility Study (SU1 FS; Aspect 2016) considered alternatives with active treatment of groundwater near the Waterway in South Fidalgo Avenue (Fidalgo Avenue) and along the shoreline. Active treatment in these areas would not significantly reduce the overall restoration timeframe for groundwater (i.e., the time to achieve groundwater PCULs across the Site) but would reduce concentrations discharging to the Waterway and meet Ecology's expectations for treatment to the extent practicable to meet RAOs.

A pilot study to evaluate the potential effectiveness of in-situ bioremediation and chemical reduction for treating chloroethenes in groundwater has been on-going since October 2018. Results of the pilot study (Appendix A of this SU1 FS Addendum) indicate a substantial reduction in total chloroethene concentrations in and downgradient of the area of treatment in Fidalgo Avenue. This SU1 FS Addendum further evaluates a subset of remedies while incorporating the results of the pilot study.

Conceptual Design Approach

For the purposes of this SU1 FS Addendum and future remedial design, the porewater analysis is used as follows:

- Treatment would target areas of highest contaminant mass and to reduce overall mass flux such that porewater SWACs are below RELs for all constituents.
- The vinyl chloride SWAC in porewater exceeds the Porewater REL by a factor of 6. To achieve Porewater RELs, active treatment would target a corresponding

overall reduction in contaminant mass flux via groundwater by a factor of 6 (i.e., an 83 percent reduction).

- Remedial design and performance monitoring would be conducted to evaluate pre-treatment and post-treatment mass flux in groundwater. A comparison of the pre- and post-treatment data sets would be based on calculating average concentrations across a vertical plane intersecting the groundwater plume. A consistent approach to collecting and averaging the pre- and post-treatment data sets (i.e., collecting data from the same locations and averaging using the same methods) would be applied to reduce uncertainty.

This approach is based on several simplifying assumptions regarding contaminant fate-and-transport; however, these assumptions are generally conservative, as described in the next section. In addition, after the targeted mass reduction in groundwater is achieved[7], confirmation porewater monitoring would be performed to verify achievement of Porewater RELs.

Remedial alternatives in this SU1 FS Addendum assume an estimated lateral and vertical extent of contaminant concentrations to be treated that would result in the target mass reduction goal. Areas accessible for treatment that are evaluated include along Fidalgo Avenue and along the shoreline, west of the Westrock building. For the purposes of this SU1 FS Addendum, these targeted treatment zones will be estimated based on the available data; however, remedial design is likely to include additional investigation to refine area(s) of treatment and to determine pre- and post-treatment concentrations for evaluating achievement of the targeted concentration reduction.

[7] A target average concentration of total chloroethenes (i.e., a groundwater REL) would be identified based on pre-remediation characterization during design.

Uncertainty Analysis

Contaminant fate-and-transport in the groundwater-to-porewater system includes multiple geochemical environments and variable hydraulics resulting in a variable porewater concentration distribution. Groundwater concentrations approaching the Waterway have changed due to natural attenuation, with an overall decrease in total chloroethenes and shift from TCE to daughter products observed over the past 10 years. Groundwater concentrations are expected to continue to change from continued attenuation and in response to treatment.

Attenuation mechanisms include both physical processes such as mixing, sorption, and volatilization as well as biodegradation. The transformation of TCE to its degradation products between the shoreline and Waterway porewater indicate that biodegradation is a significant component of attenuation. The rate of biodegradation of a particular chloroethene can vary spatially and temporally based on a number of factors, including contaminant concentrations, redox conditions, and availability of organic carbon.

Identification of treatment goals based on the percent reduction in mass flux includes several simplifying assumptions. These simplifying assumptions were chosen to be conservative to provide confidence that the treatment goal is sufficiently protective. Key simplifying assumptions include:

- The relative proportion of TCE, cis-DCE, and VC remain relatively constant. This is a conservative assumption because VC, which is the risk driver in porewater, is already the predominant constituent. Current trends indicate that the distribution of degradation products has shifted toward VC. Were the current trend to continue, then the distribution of degradation products would shift past VC to non-toxic end products ethene and ethane.

- Chloroethene degradation rates will remain relatively constant. This is a conservative assumption as current trends show an increase in chloroethene degradation over time and injection of organic carbon amendments (e.g., from the pilot test) increases the rate of attenuation.

- The mass flux at the shoreline between now and remedy implementation will remain constant. This is also a conservative assumption because the pilot test is expected to reduce concentrations along the shoreline as treated groundwater continues to migrate toward the Waterway and flush out residual contamination.

It is anticipated that performance monitoring of the selected remedy would include empirical confirmation of these assumptions.

References

Aspect Consulting, LLC (Aspect), 2012, Remedial Investigation Report, Art Brass Plating, Agency Review Draft, September 27, 2012.

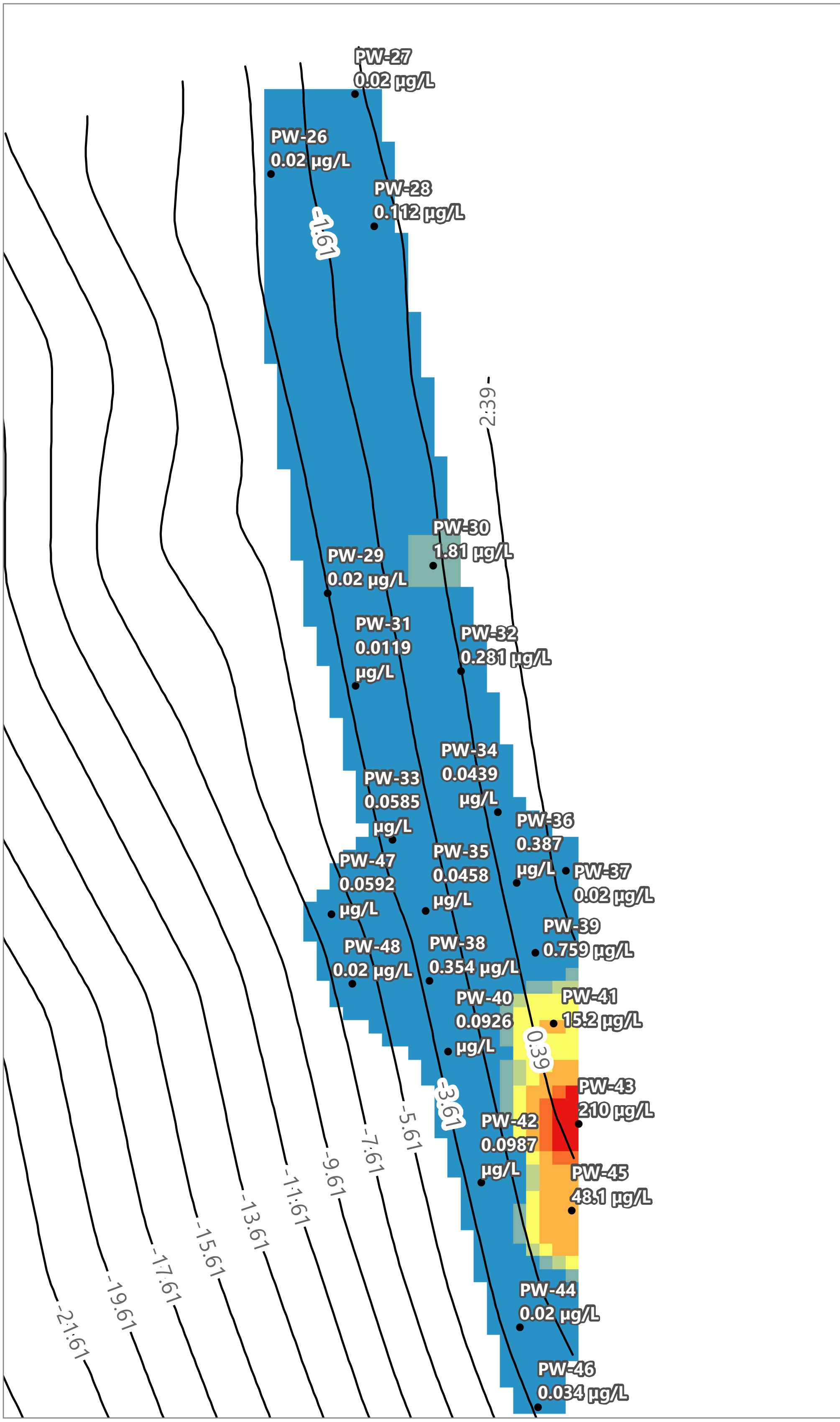
Aspect Consulting, LLC (Aspect), 2016, Feasibility Study, W4 Group – Site Unit 1, Final, August 11, 2016.

U.S. Environmental Protection Agency (EPA), 1979, Water-Related Environmental Fate of 129 Priority Pollutants. Volume II, EPA Publication PB80-204381.

Windward Environmental LLC, 2010, Lower Duwamish Waterway Remedial Investigation Report, Final, July 9, 2010.

APPENDIX D
FIGURES

DRAFT



LEGEND:

— Bathymetric Contour

µg/L

- <1.5
- ≥1.5 - 3.0
- ≥3.0 - 5.0
- ≥5.0 - 15.0
- ≥15.0 - 60.0
- ≥60.0 - 120.0
- ≥120.0 - 208.15

NOTES:
1. Porewater samples (2020) and bathymetric contours (2011) provided by Aspect Consulting.
2. Contour elevations are MLLW, feet.
3. Sample point labels are lab reported results.
4. IDW parameters: Power=variable, search radius=45′, Neighbors (Max)=8, Neighbors (Min)=4, IDW raster cell size=3′x3′.

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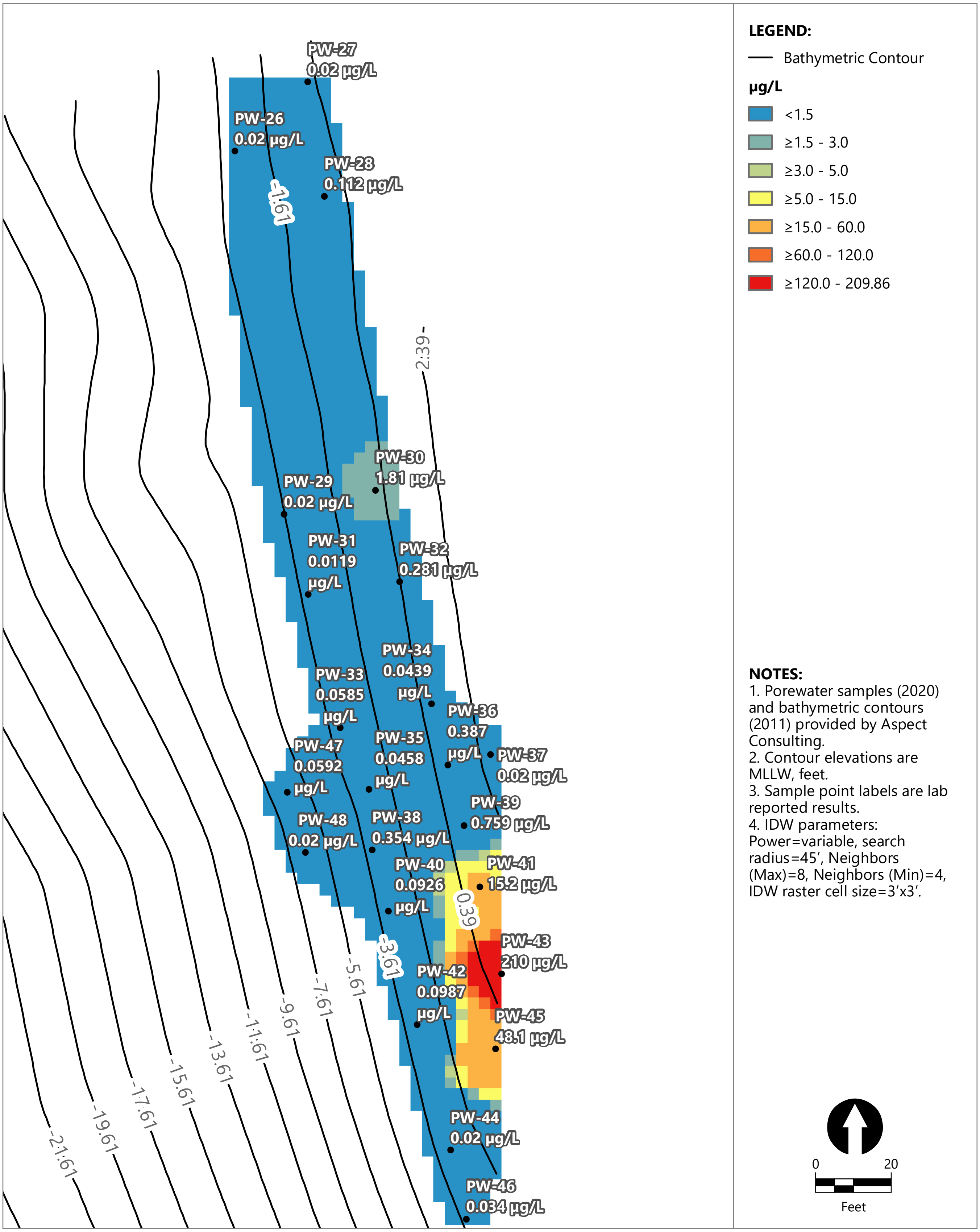
ANCHOR QEA

Figure D-1
IDW: Porewater VC w/Power Function 3 (log-back transformed)

DRAFT



NOTES:
1. Porewater samples (2020) and bathymetric contours (2011) provided by Aspect Consulting.
2. Contour elevations are MLLW, feet.
3. Sample point labels are lab reported results.
4. IDW parameters: Power=variable, search radius=45′, Neighbors (Max)=8, Neighbors (Min)=4, IDW raster cell size=3′x3′.

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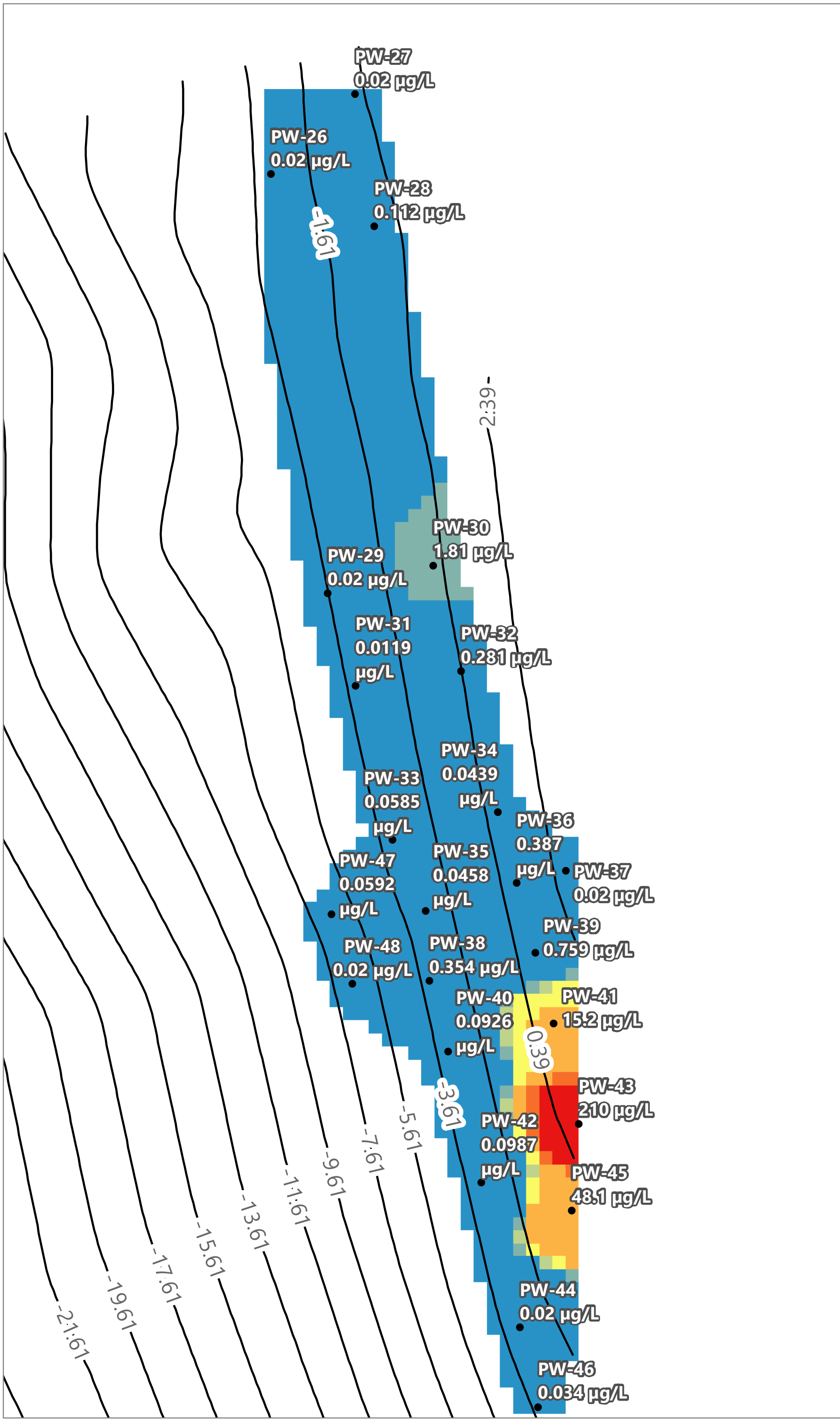
ANCHOR QEA

Figure D-2
IDW: Porewater VC w/Power Function 4 (log-back transformed)

DRAFT



LEGEND:

— Bathymetric Contour

µg/L

- <1.5
- ≥1.5 - 3.0
- ≥3.0 - 5.0
- ≥5.0 - 15.0
- ≥15.0 - 60.0
- ≥60.0 - 120.0
- ≥120.0 - 209.99

NOTES:

1. Porewater samples (2020) and bathymetric contours (2011) provided by Aspect Consulting.
2. Contour elevations are MLLW, feet.
3. Sample point labels are lab reported results.
4. IDW parameters: Power=variable, search radius=45′, Neighbors (Max)=8, Neighbors (Min)=4, IDW raster cell size=3′x3′.

0 20
Feet

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ANCHOR QEA

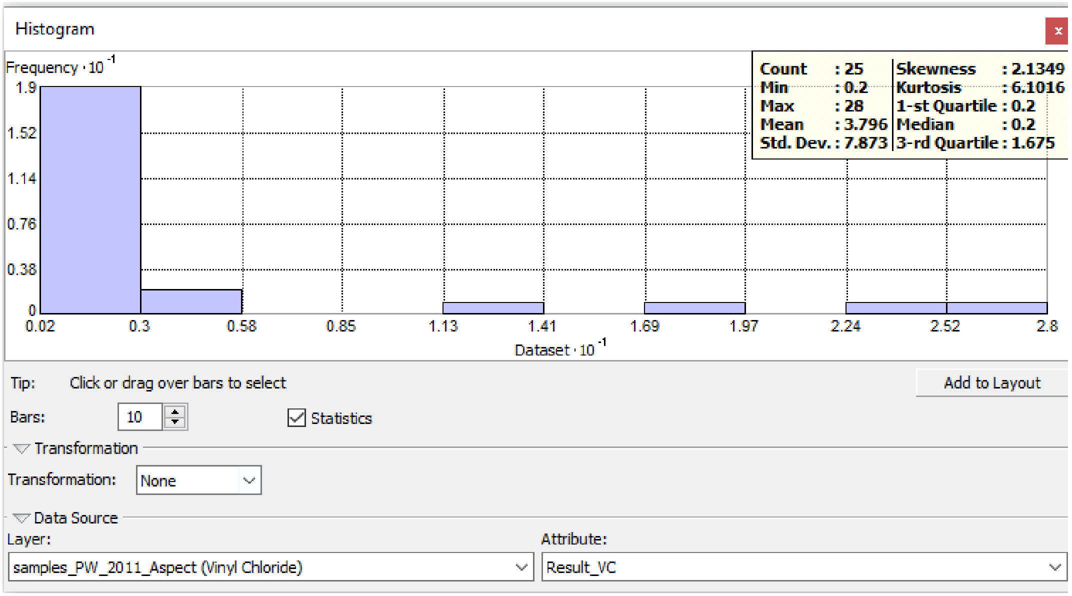
Figure D-3
IDW: Porewater VC w/Power Function 5 (log-back transformed)

ATTACHMENT A

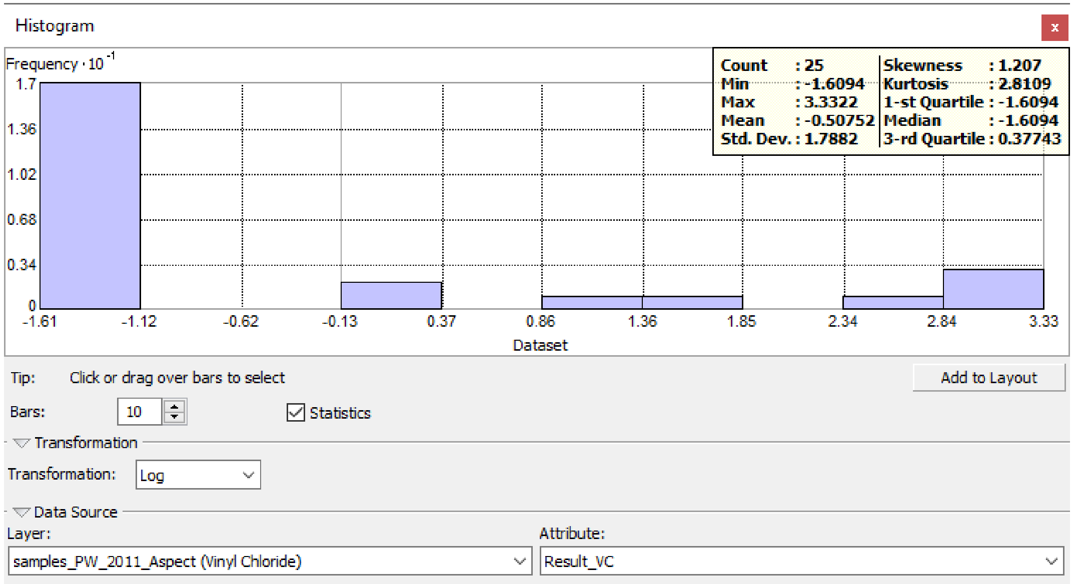
Summary of inverse-distance weighting analysis for 2011 porewater data

Vinyl Chloride

Raw

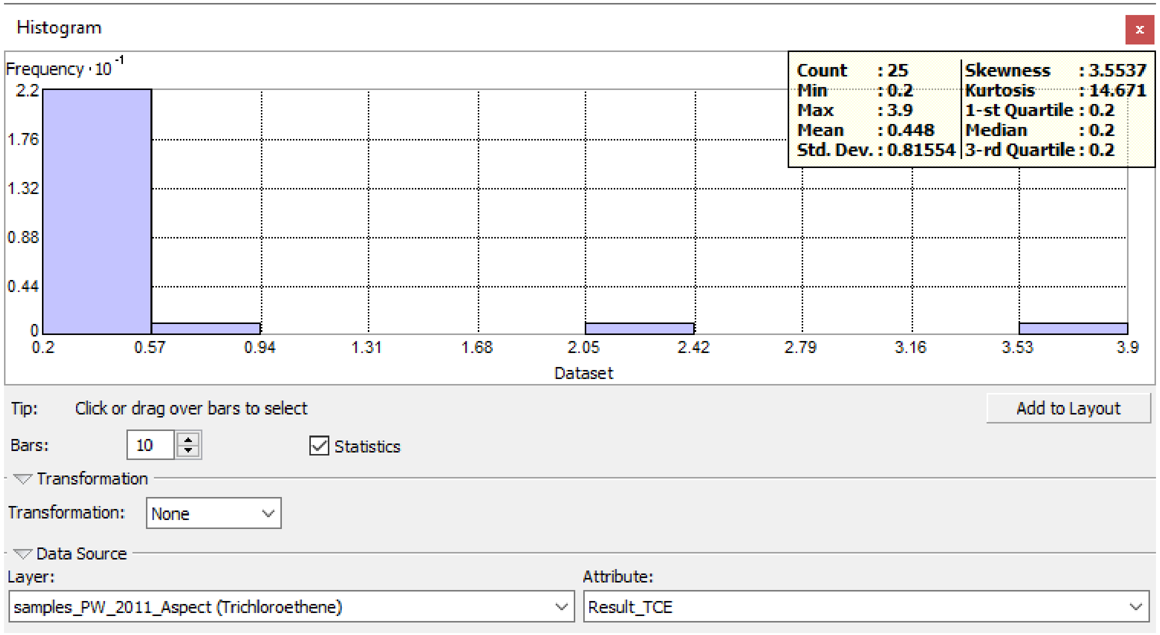


Log Transformed



Trichloroethene

Raw



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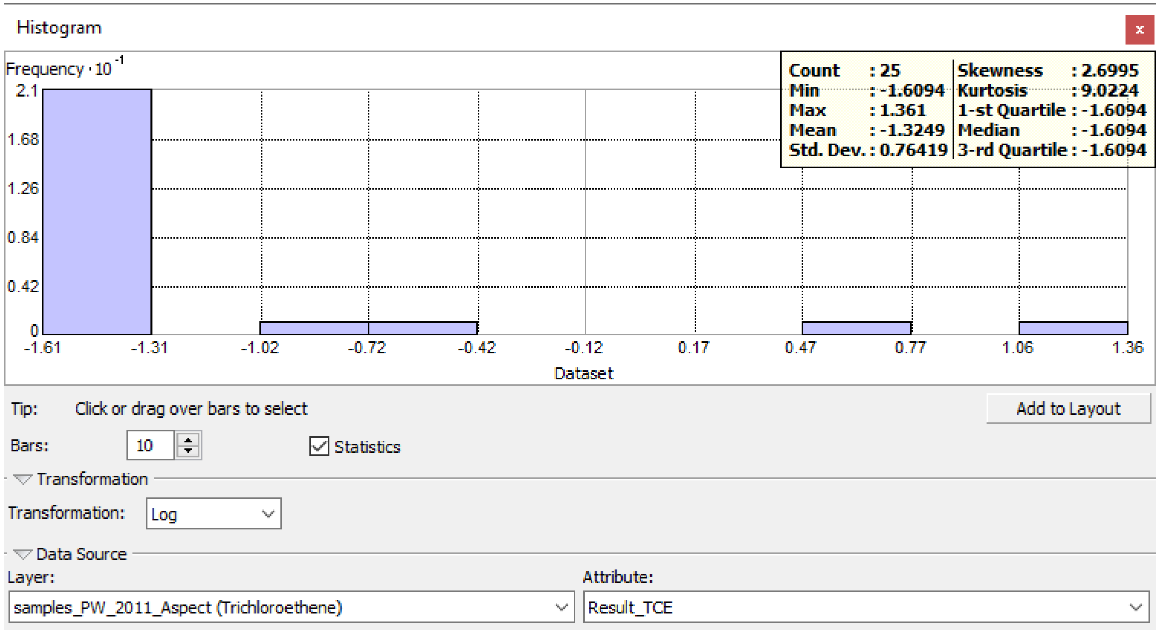
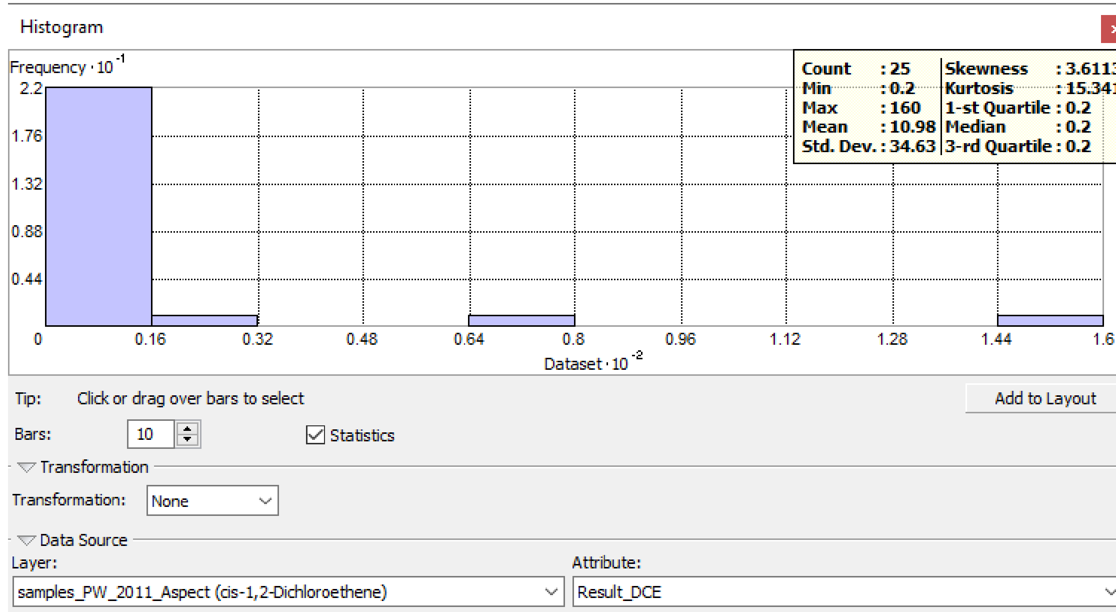
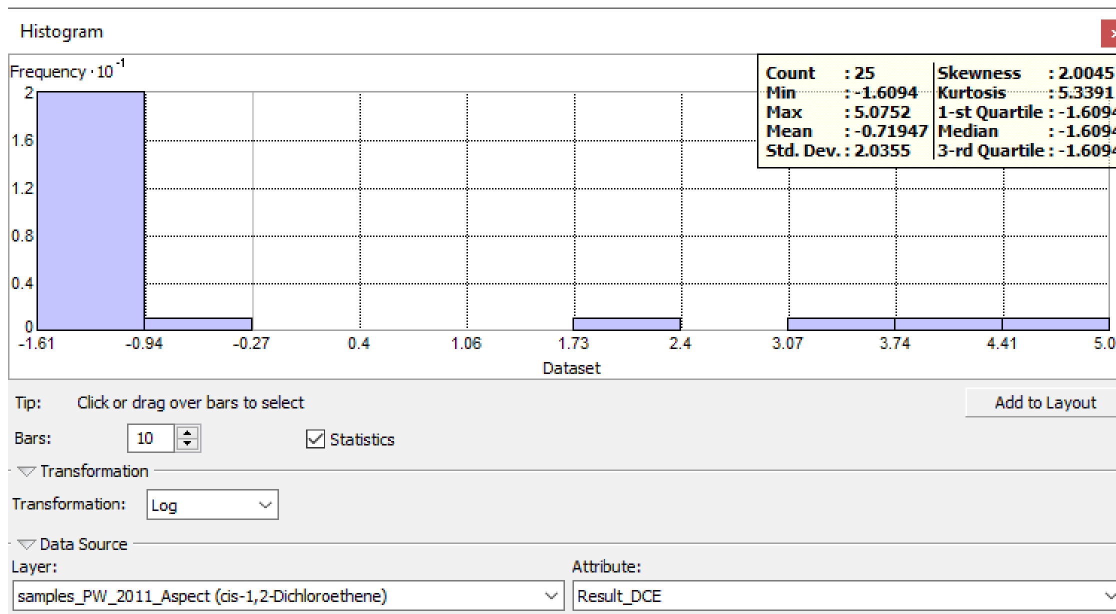


Cis-1,2-Dichloroethene

Raw



Log Transformed

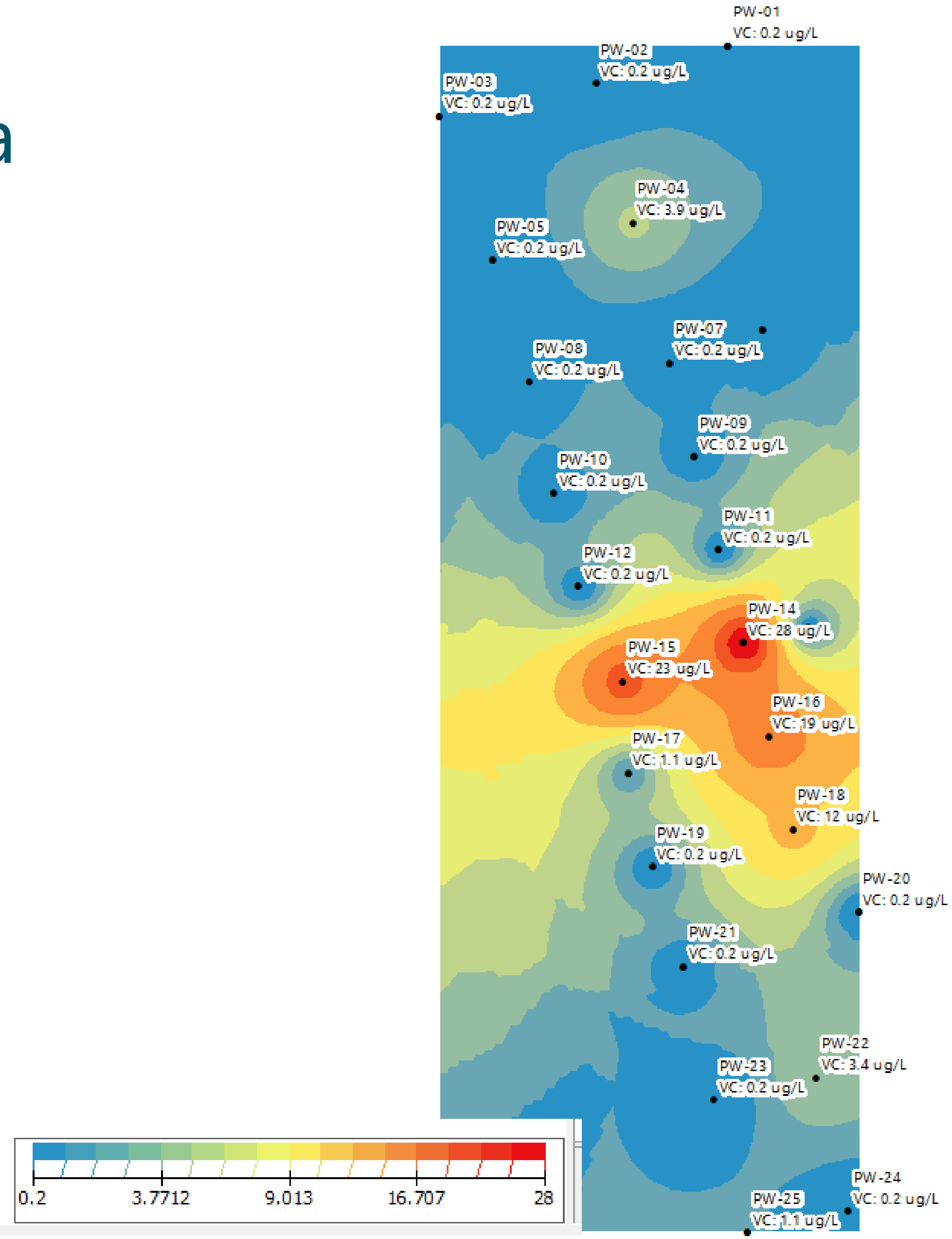


VC Power 2 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.887402122483334	0.687402122483334
2	Yes	0.2	1.0631372945076638	0.8631372945076639
3	Yes	0.2	0.712702502744585	0.512702502744584
4	Yes	3.9	0.2	-3.6999999999999997
5	Yes	0.2	0.9294000786427841	0.7294000786427841
6	Yes	0.2	1.5962547809904213	1.3962547809904213
7	Yes	0.2	1.344068804996428 7	1.1440688049964287
8	Yes	0.2	1.196075607686951	0.996075607686951
9	Yes	0.2	3.1772448175472587	2.9772448175472586
10	Yes	0.2	2.9012046360870656	2.7012046360870654
11	Yes	0.2	8.822947477596466	8.622947477596467
12	Yes	0.2	8.061615154392166	7.861615154392166
13	Yes	0.2	16.36355214131376	16.16355214131376
14	Yes	28	5.783372321381307	-22.216627678618693
15	Yes	23	6.02517702225745	-16.974822977742548
16	Yes	19	10.486263856333938	-8.513736143666062
17	Yes	1.1	11.016753207190298	9.916753207190299
18	Yes	12	7.996118979808124	-4.003881020191876
19	Yes	0.2	6.286669482237483	6.0866694822374825
20	Yes	0.2	7.593154369716711	7.393154369716711
21	Yes	0.2	3.67507449677309	3.47507449677309
22	Yes	3.4	1.533567835997844	-1.866432164002156
23	Yes	0.2	1.924384426002489	1.724384426002489
24	Yes	0.2	2.0812074865697485	1.8812074865697486
25	Yes	1.1	1.0406170691151626	-0.0593829308848374 8

Predicted / Error

Regression function	0.181543216841165 * x + 2.97066154467545
Prediction Errors	
Samples	25 of 25
Mean	0.7119186
Root-Mean-Square	7.786902
Export Result Table	



VC Power 3 – Raw Data

Source ID	Included	Measured	Predicted	Error
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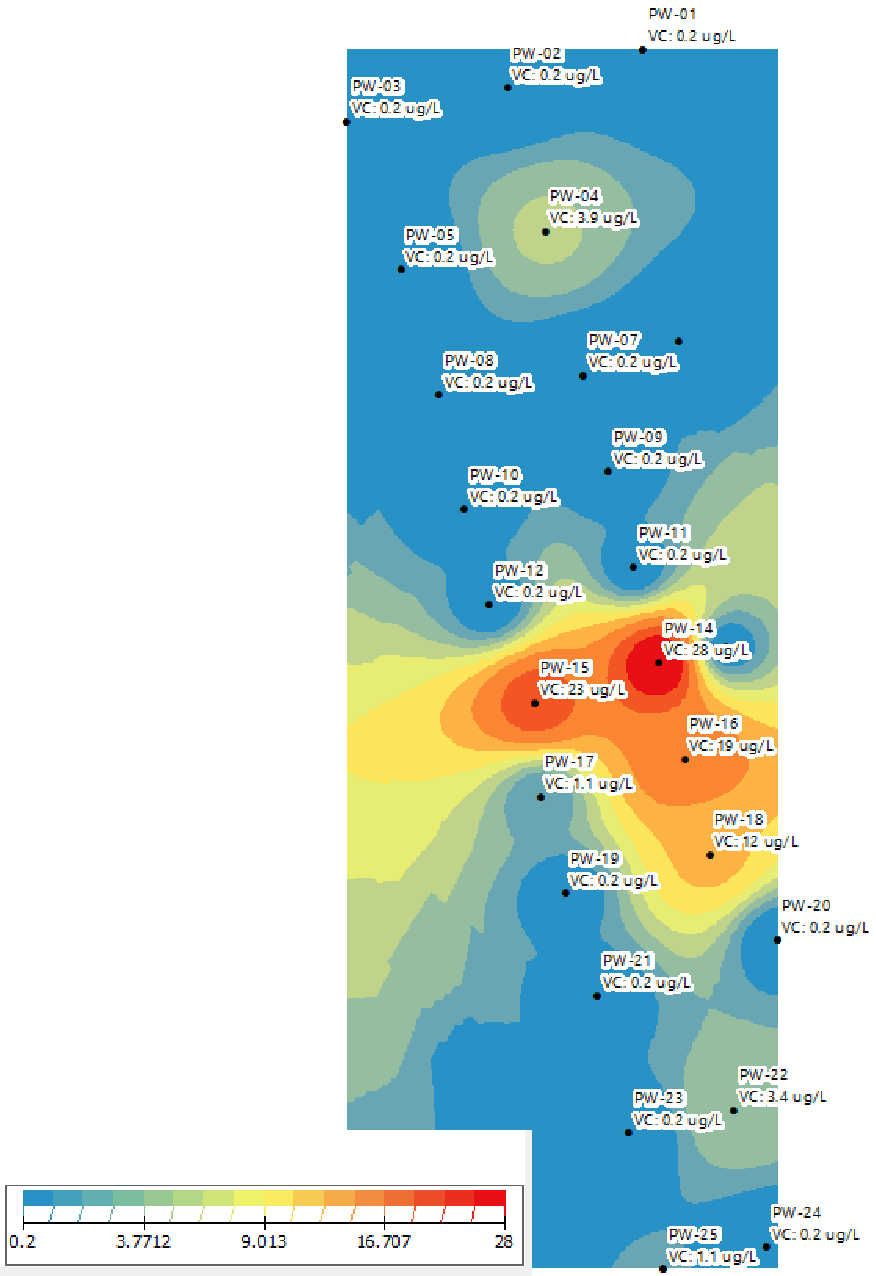
2	Yes	0.2	1.2072826750832635	1.0072826750832635
3	Yes	0.2	0.653414058058319	0.453414058058319
4	Yes	3.9	0.2	-3.6999999999999997
5	Yes	0.2	1.0222645297532484	0.8222645297532485
6	Yes	0.2	1.0366897340924695	0.8366897340924695
7	Yes	0.2	0.8798096488791365	0.6798096488791365
8	Yes	0.2	0.7872915417812767	0.5872915417812767
9	Yes	0.2	1.9754635415530757	1.7754635415530757
10	Yes	0.2	1.9029174840158327	1.7029174840158328
11	Yes	0.2	9.768325285307908	9.568325285307909
12	Yes	0.2	8.542935164204238	8.342935164204238
13	Yes	0.2	20.99418141368581	20.79418141368581
14	Yes	28	5.088324922323735	-22.911675077676264
15	Yes	23	5.723721438167892	-17.276278561832108
16	Yes	19	12.499038795771103	-6.500961204228897
17	Yes	1.1	12.080267918084726	10.980267918084726
18	Yes	12	8.755757676712019	-3.244242323287981
19	Yes	0.2	4.829670369911251	4.629670369911251
20	Yes	0.2	8.602359592758027	8.402359592758028
21	Yes	0.2	2.6370445512884153	2.437044551288415
22	Yes	3.4	0.9071427741477698	-2.49285722585223
23	Yes	0.2	1.9860540921593233	1.7860540921593233
24	Yes	0.2	1.709058873268876	1.509058873268876
25	Yes	1.1	0.7150162981082957	-0.3849837018917044

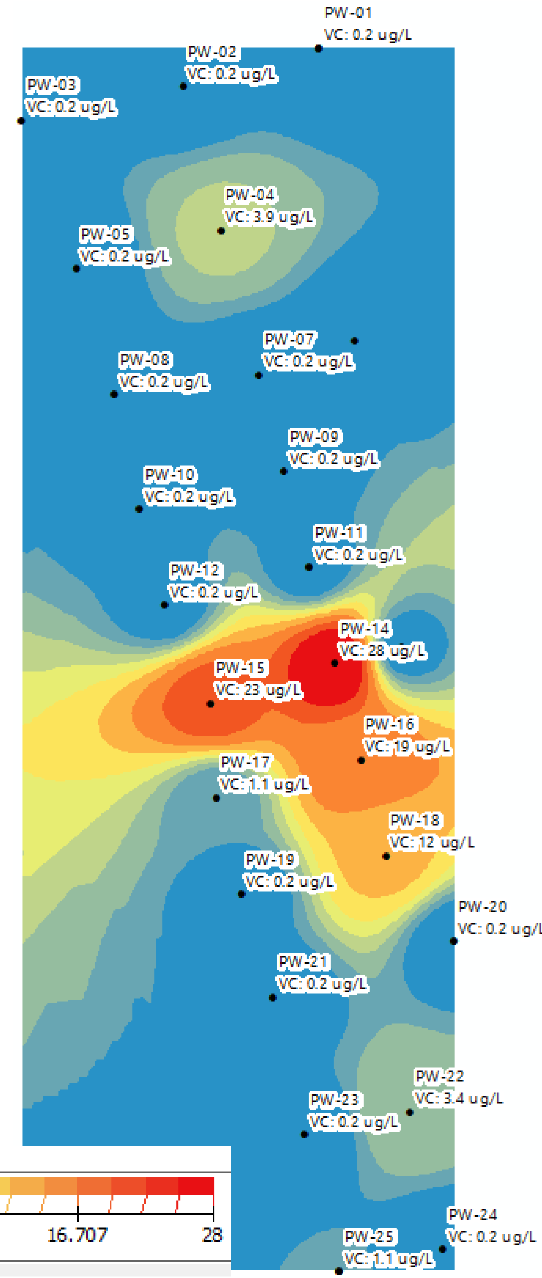
Regression function	0.20200751955005 * x + 2.75610087793889
Prediction Errors	
Samples	25 of 25
Mean	0.8189069
Root-Mean-Square	8.303539
Export Result Table	

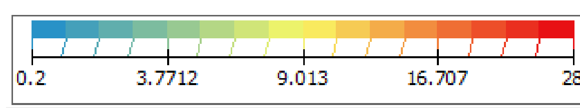


VC Power 4 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.7720377429915322	0.5720377429915322
2	Yes	0.2	1.302897987480908	1.102897987480908
3	Yes	0.2	0.5691814907762659	0.3691814907762659
4	Yes	3.9	0.2	-3.6999999999999997
5	Yes	0.2	1.0767492991002499	0.8767492991002499
6	Yes	0.2	0.6739977598740508	0.47399775987405074
7	Yes	0.2	0.6125371004698179	0.4125371004698179
8	Yes	0.2	0.5393275913706761	0.3393275913706761
9	Yes	0.2	1.176134705305592	0.976134705305592
10	Yes	0.2	1.1703927327043258	0.9703927327043258
11	Yes	0.2	10.606922277416666	10.406922277416667
12	Yes	0.2	8.754534551793657	8.554534551793658
13	Yes	0.2	24.05193854595065	23.851938545950652
14	Yes	28	4.059313339222264	-23.940686660777736
15	Yes	23	5.090080138610961	-17.90991986138904
16	Yes	19	14.119283420970786	-4.8807165790292135
17	Yes	1.1	12.69946215366675	11.59946215366675
18	Yes	12	9.583278585016153	-2.416721414983847
19	Yes	0.2	3.525628242253574	3.3256282422535737
20	Yes	0.2	9.625542873165886	9.425542873165886
21	Yes	0.2	1.8242046121760431	1.6242046121760432
22	Yes	3.4	0.5642935383972891	-2.835706461602711
23	Yes	0.2	2.140459575792527	1.940459575792527
24	Yes	0.2	1.556370251485692	1.3563702514856921
25	Yes	1.1	0.5231544299602315	-0.5768455700397686

Regression function	0.205103972679483 * x + 2.64646045232763
Prediction Errors	
Samples	25 of 25
Mean	0.8767089
Root-Mean-Square	8.817236
Export Result Table	

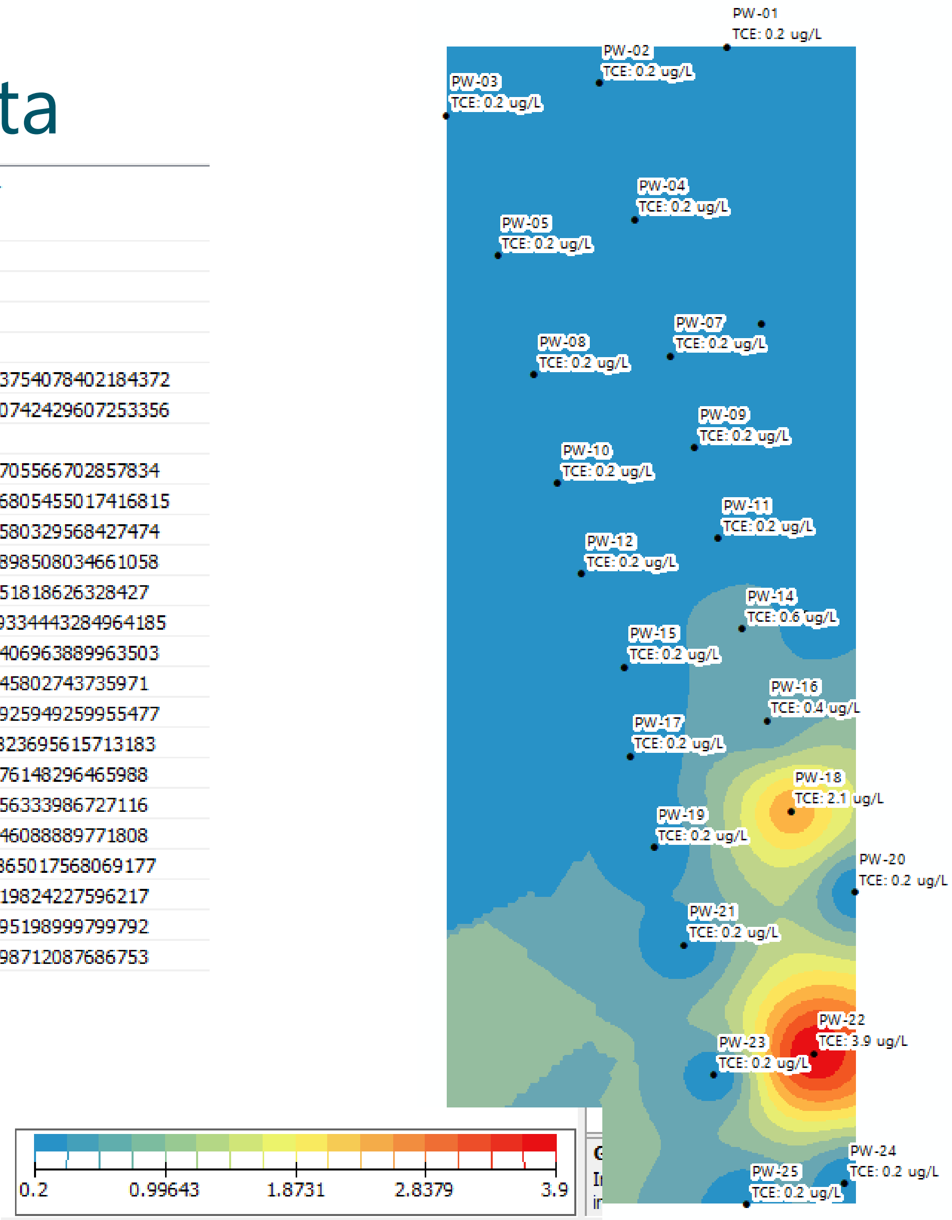




TCE Power 2 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.2	0
2	Yes	0.2	0.2	0
3	Yes	0.2	0.2	0
4	Yes	0.2	0.2	0
5	Yes	0.2	0.2	0
6	Yes	0.2	0.21375407840218438	0.013754078402184372
7	Yes	0.2	0.21074242960725337	0.010742429607253356
8	Yes	0.2	0.2	0
9	Yes	0.2	0.22705566702857835	0.02705566702857834
10	Yes	0.2	0.21680545501741683	0.016805455017416815
11	Yes	0.2	0.33580329568427475	0.13580329568427474
12	Yes	0.2	0.2389850803466106	0.0389850803466 1058
13	Yes	0.2	0.485181862632 8427	0.285181862632 8427
14	Yes	0.6	0.30665556715035813	-0.29334443284964185
15	Yes	0.2	0.34406963889963504	0.14406963889963503
16	Yes	0.4	0.6845802743735971	0.2845802743735971
17	Yes	0.2	0.3892594925995548	0.18925949259955477
18	Yes	2.1	0.41763043842868175	-1.6823695615713183
19	Yes	0.2	0.5876148296465988	0.3876148296465988
20	Yes	0.2	1.345633398672 7116	1.145633398672 7116
21	Yes	0.2	0.7946088889771807	0.5946088889771808
22	Yes	3.9	0.31349824319308206	-3.5865017568069177
23	Yes	0.2	1.4519824227596216	1.2519824227596217
24	Yes	0.2	1.1495198999799792	0.9495198999799792
25	Yes	0.2	0.8298712087686754	0.6298712087686753

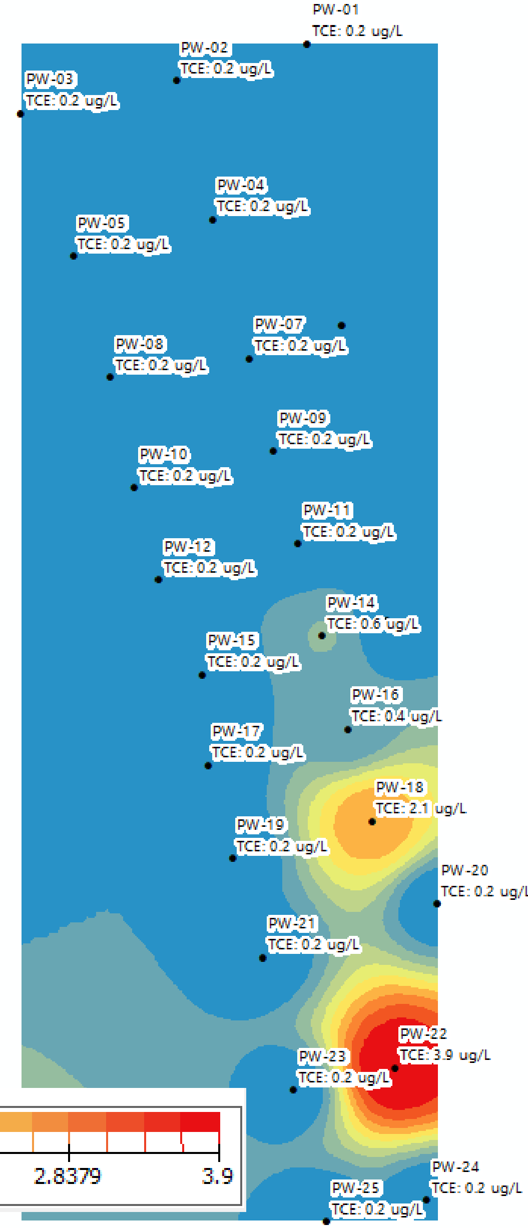
Regression function	-0.0125350058770527 * x + 0.394826713661247
Prediction Errors	
Samples	25 of 25
Mean	0.02173009
Root-Mean-Square	0.9099813
Export Result Table	

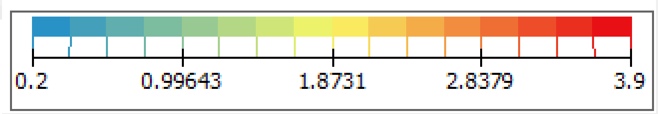


TCE Power 3 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.2	0
2	Yes	0.2	0.2	0
3	Yes	0.2	0.2	0
4	Yes	0.2	0.2	0
5	Yes	0.2	0.2	0
6	Yes	0.2	0.206482822259033308	0.006482822259033072
7	Yes	0.2	0.20473734899175583	0.004737348991755819
8	Yes	0.2	0.2	0
9	Yes	0.2	0.21707037304522458	0.017070373045224574
10	Yes	0.2	0.20964523010287164	0.009645230102871633
11	Yes	0.2	0.33388079142848237	0.13388079142848236
12	Yes	0.2	0.2280952702804628	0.028095270280462797
13	Yes	0.2	0.5210936266412575	0.32109362664125746
14	Yes	0.6	0.2698971169078975	-0.33010288309210245
15	Yes	0.2	0.30988921449417195	0.10988921449417194
16	Yes	0.4	0.8237011339877187	0.4237011339877187
17	Yes	0.2	0.33946818082380914	0.13946818082380913
18	Yes	2.1	0.3633386493724836	-1.7366613506275166
19	Yes	0.2	0.4922145932887165	0.29221459328871646
20	Yes	0.2	1.6170013182605678	1.4170013182605679
21	Yes	0.2	0.7121145060963735	0.5121145060963734
22	Yes	3.9	0.26426983477379473	-3.6357301652262053
23	Yes	0.2	1.7969539798732574	1.5969539798732575
24	Yes	0.2	1.104713943868353	0.9047139438683531
25	Yes	0.2	0.6815271277919164	0.48152712779191637

Regression function	-0.0218368563671735 * x + 0.379042513605209
Prediction Errors	
Samples	25 of 25
Mean	0.0278438
Root-Mean-Square	0.9514828
Export Result Table	

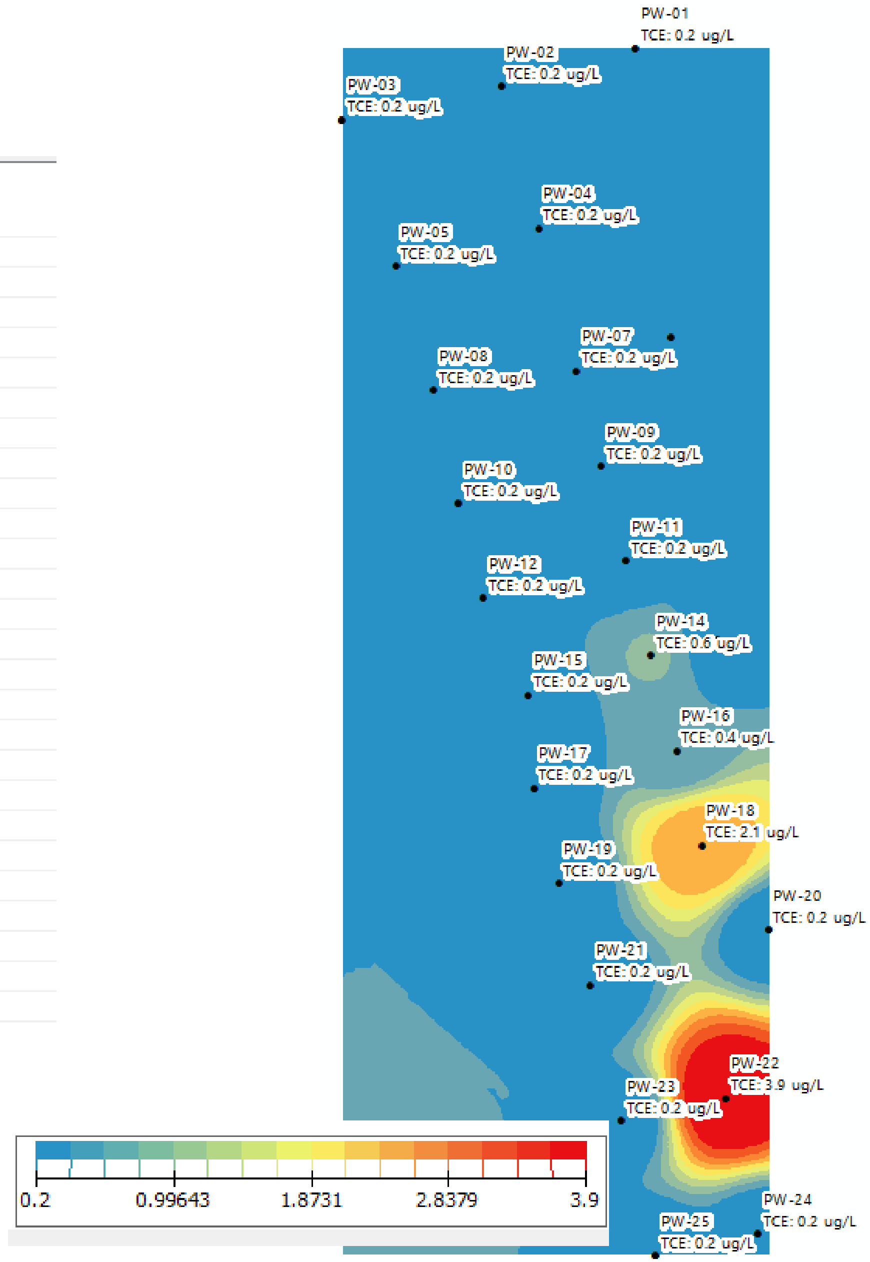




TCE Power 4 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.2	0
2	Yes	0.2	0.2	0
3	Yes	0.2	0.2	0
4	Yes	0.2	0.2	0
5	Yes	0.2	0.2	0
6	Yes	0.2	0.202628774596829	0.0026287745968289755
7	Yes	0.2	0.20189672196445074	0.0018967219644507316
8	Yes	0.2	0.2	0
9	Yes	0.2	0.20991672373988887	0.00991672373988886
10	Yes	0.2	0.2049492914394757	0.0049492914394757
11	Yes	0.2	0.34192797010916315	0.14192797010916314
12	Yes	0.2	0.21855271048980904	0.018552710489809027
13	Yes	0.2	0.5493614763039122	0.3493614763039122
14	Yes	0.6	0.24491000876131358	-0.3550899912386864
15	Yes	0.2	0.28173785432857573	0.08173785432857572
16	Yes	0.4	0.9412163499406541	0.541216349940654
17	Yes	0.2	0.2922793907398257	0.09227939073982566
18	Yes	2.1	0.33499023663638394	-1.7650097633636161
19	Yes	0.2	0.41101715171022457	0.21101715171022456
20	Yes	0.2	1.8279235088848818	1.6279235088848818
21	Yes	0.2	0.6015624786351819	0.40156247863518185
22	Yes	3.9	0.2337449603038381	-3.666255039696162
23	Yes	0.2	2.132810083041032	1.932810083041032
24	Yes	0.2	0.9921020709432746	0.7921020709432747
25	Yes	0.2	0.5395501113542667	0.33955011135426666

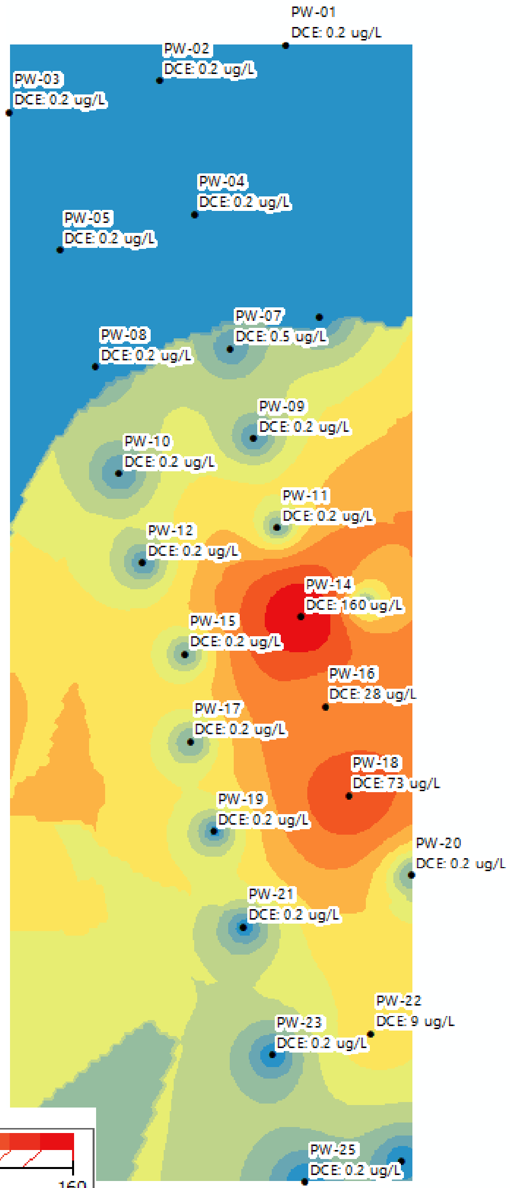
Regression function	-0.0233505405570074 * x + 0.358892613913598
Prediction Errors	
Samples	25 of 25
Mean	0.03052311
Root-Mean-Square	0.9893018
Export Result Table	

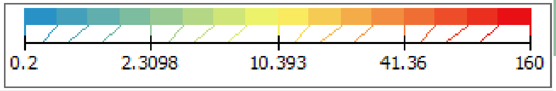


DCE Power 2 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.22167355012771273	0.021673550127712715
2	Yes	0.2	0.2174960244752333	0.017496024475233296
3	Yes	0.2	0.21775892715765185	0.017758927157651844
4	Yes	0.2	0.2508657980535228	0.050865798053522815
5	Yes	0.2	0.22957026284969817	0.029570262849698 16
6	Yes	0.2	5.799028763803177	5.599028763803177
7	Yes	0.5	4.491600628097714	3.991600628097743
8	Yes	0.2	0.24467330299303172	0.04467330299303171
9	Yes	0.2	9.793693306825151	9.593693306825152
10	Yes	0.2	6.938017912674073	6.7380179126740725
11	Yes	0.2	36.130239307986386	35.930239307986386
12	Yes	0.2	13.691003158577356	13.491003158577357
13	Yes	0.2	75.23047814074111	75.03047814074111
14	Yes	160	7.473646543776972	-152.52635345622303
15	Yes	0.2	25.855777581212 56	25.655777581212 56
16	Yes	28	49.20581864929 4926	21.20581864929 4926
17	Yes	0.2	20.139663758793674	19.939663758793674
18	Yes	73	17.748072851135046	-55.25192714886495
19	Yes	0.2	18.237041550009053	18.037041550009054
20	Yes	0.2	35.23947031897144	35.03947031897144
21	Yes	0.2	10.046988885272027	9.846988885272028
22	Yes	9	5.143853610120 36	-3.8561463898796404
23	Yes	0.2	6.176013407107251	5.976013407107251
24	Yes	0.2	5.075795060060939	4.875795060060 9385
25	Yes	0.2	3.5663334007192082	3.366333400719208

Regression function	0.00300243386205739 * x + 10.0951642804598
Prediction Errors	
Samples	25 of 25
Mean	3.314583
Root-Mean-Square	38.39042
Export Result Table	

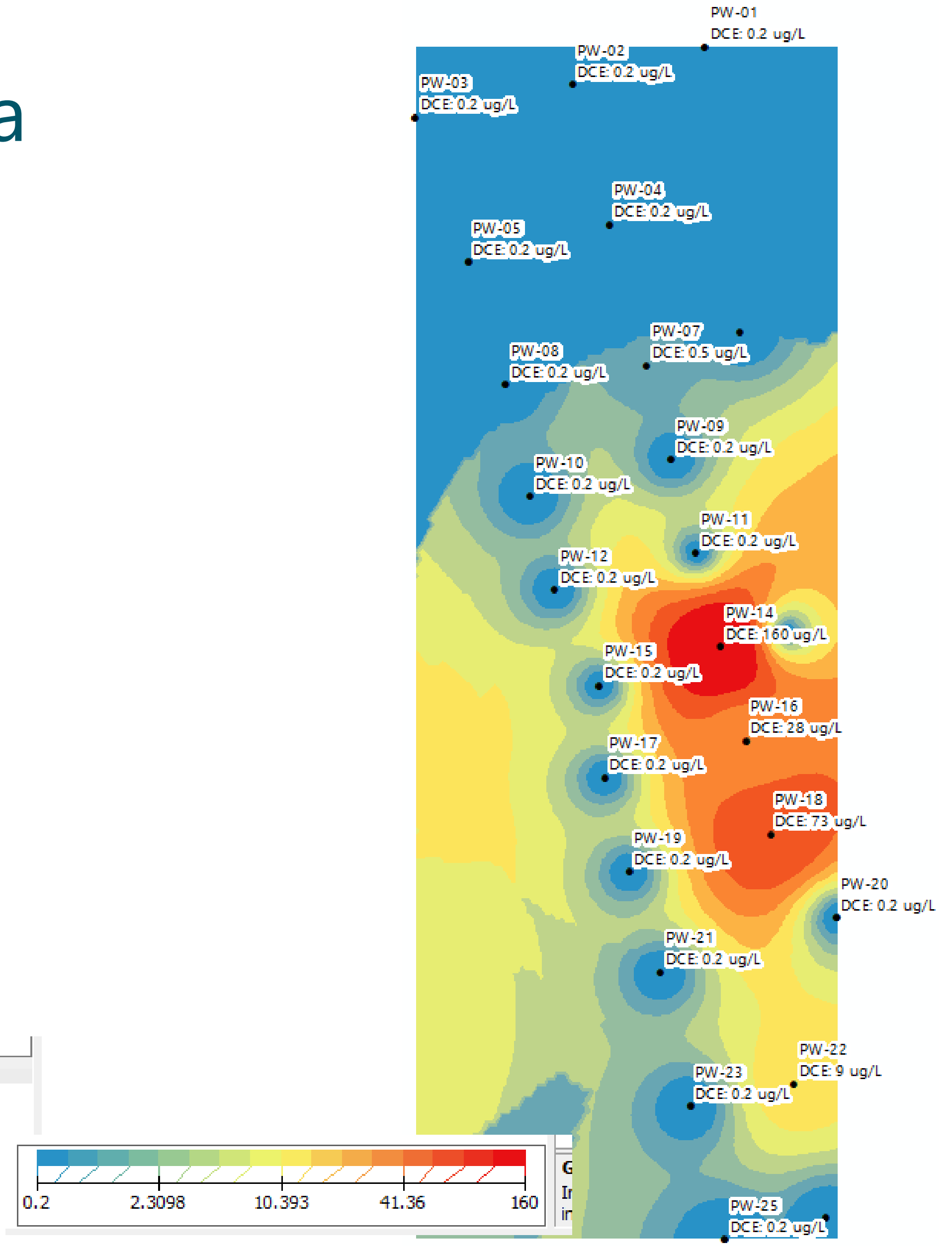




DCE Power 3 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.21314655614706...	0.013146556147069638
2	Yes	0.2	0.210208944486174	0.010208944486617383
3	Yes	0.2	0.21026507551457...	0.010265075514578226
4	Yes	0.2	0.2589319117662278	0.05893191176622781
5	Yes	0.2	0.22357142616308...	0.023571426163088022
6	Yes	0.2	2.946149375011432	2.7461493750114316
7	Yes	0.5	2.0925709222064395	1.5925709222064395
8	Yes	0.2	0.24868253325597...	0.048682533255972715
9	Yes	0.2	6.535035552411511	6.335035552411511
10	Yes	0.2	4.072561047839411	3.872561047839411
11	Yes	0.2	45.06620286726855	44.86620286726855
12	Yes	0.2	10.27516985670685	10.07516985670685
13	Yes	0.2	106.60547678499685	106.40547678499685
14	Yes	160	6.097097960103978	-153.90290203989602
15	Yes	0.2	24.677379925229328	24.47737992522933
16	Yes	28	63.275176150279435	35.275176150279435
17	Yes	0.2	14.997199322312042	14.797199322312043
18	Yes	73	17.12894631861299	-55.87105368138701
19	Yes	0.2	13.743904109879153	13.543904109879154
20	Yes	0.2	43.60085003013769	43.40085003013769
21	Yes	0.2	8.307130983924518	8.107130983924518
22	Yes	9	2.90955276619329	-6.09044723380671
23	Yes	0.2	5.486421974107799	5.286421974107799
24	Yes	0.2	3.2425325556624376	3.0425325556624374
25	Yes	0.2	1.9731876938916315	1.7731876938916316

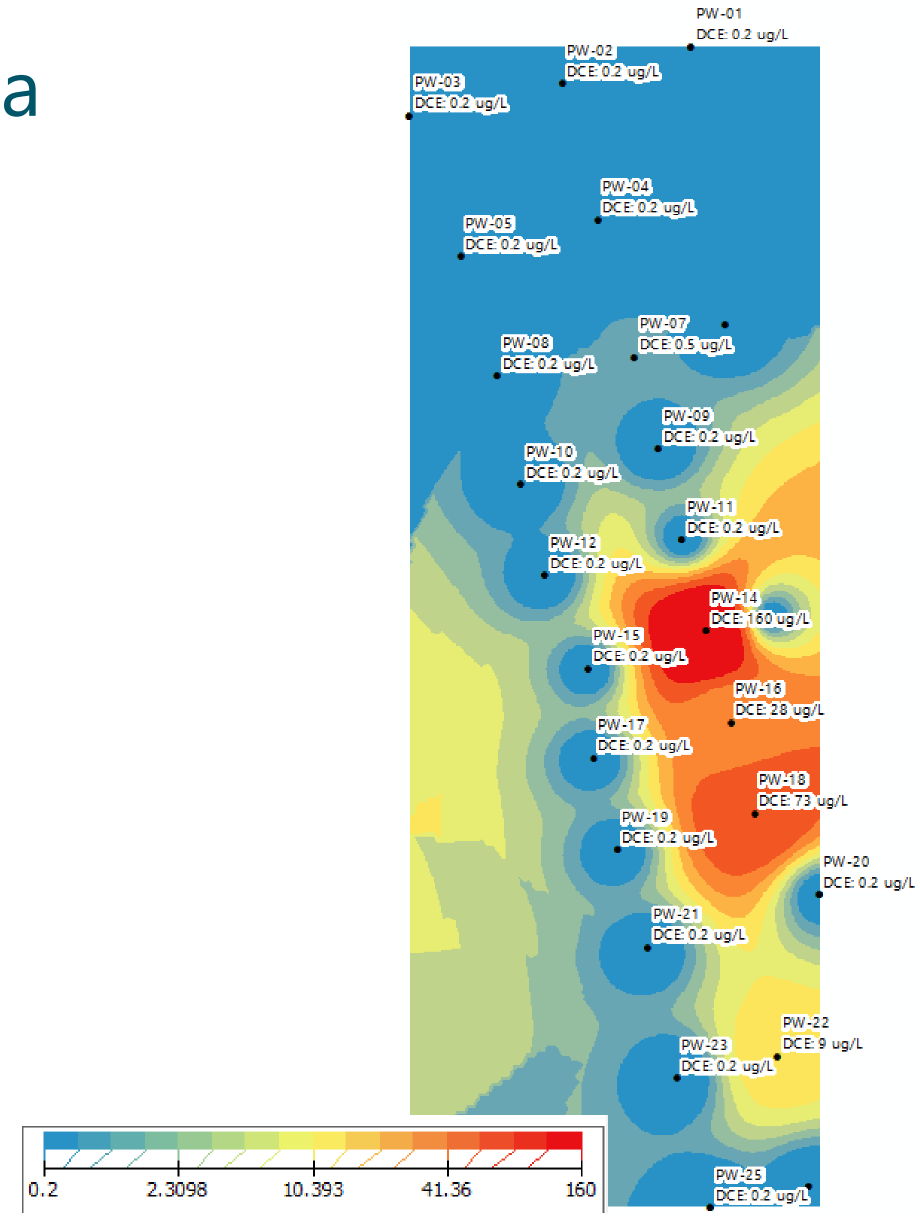
Regression function	0.0309565362321196 * x + 11.2208540821101
Prediction Errors	
Samples	25 of 25
Mean	4.395894
Root-Mean-Square	42.22898
Export Result Table	



DCE Power 4 – Raw Data

Source ID	Included	Measured	Predicted	Error
1	Yes	0.2	0.207013640888...	0.00701364088848927
2	Yes	0.2	0.205589008944...	0.00558900894419076
3	Yes	0.2	0.205462896411...	0.005462896411328161
4	Yes	0.2	0.266052975001...	0.06605297500131924
5	Yes	0.2	0.217771932500...	0.017771932500113746
6	Yes	0.2	1.451653602956...	1.2516536029560694
7	Yes	0.5	0.957740424798...	0.45774042479806987
8	Yes	0.2	0.248924480981...	0.04892448098163843
9	Yes	0.2	4.03782778103119	3.83782778103119
10	Yes	0.2	2.190969620185...	1.9909696201854026
11	Yes	0.2	53.08806188505...	52.88806188505057
12	Yes	0.2	7.039523763951...	6.839523763951546
13	Yes	0.2	128.9161842130...	128.71618421301312
14	Yes	160	4.758447626969...	-155.2415523730307
15	Yes	0.2	21.89157101413...	21.691571014139104
16	Yes	28	75.15954646701...	47.15954646701337
17	Yes	0.2	10.06890417954...	9.86890417954644
18	Yes	73	16.80855852460...	-56.191441475391436
19	Yes	0.2	9.790751703405...	9.590751703405623
20	Yes	0.2	52.376085548202	52.176085548201996
21	Yes	0.2	6.336601831284...	6.136601831284553
22	Yes	9	1.587657687212...	-7.412342312787828
23	Yes	0.2	5.479705877551...	5.279705877551072
24	Yes	0.2	2.35682238155513	2.1568223815551297
25	Yes	0.2	1.196903281414...	0.9969032814148868

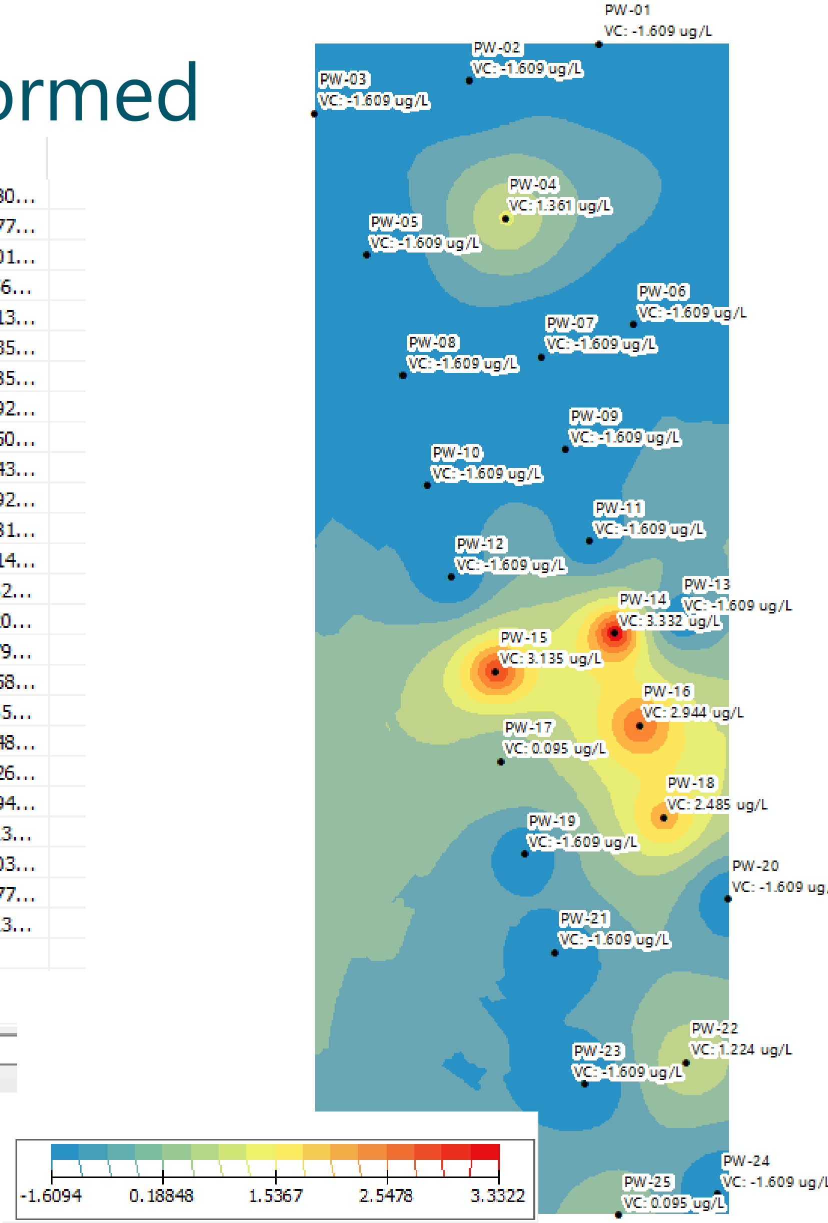
Regression function	0.0337353784918553 * x + 11.1947722423036
Prediction Errors	
Samples	25 of 25
Mean	5.293773
Root-Mean-Square	45.79173
Export Result Table	



VC Power 2 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.6094379124341003	-1.057581369653611	0.551856542780...
2	Yes	-1.6094379124341003	-0.9164985866561923	0.692939325777...
3	Yes	-1.6094379124341003	-1.1978327960324178	0.411605116401...
4	Yes	1.3609765531356006	-1.6094379124341003	-2.97041446556...
5	Yes	-1.6094379124341003	-1.0238647922210724	0.585573120213...
6	Yes	-1.6094379124341003	-1.0860020516983633	0.523435860735...
7	Yes	-1.6094379124341003	-1.1576300731488336	0.451807839285...
8	Yes	-1.6094379124341003	-1.2204721901414177	0.388965722292...
9	Yes	-1.6094379124341003	-0.9428293969832433	0.666608515450...
10	Yes	-1.6094379124341003	-0.970491368590672	0.638946543843...
11	Yes	-1.6094379124341003	0.13196476335799578	1.741402675792...
12	Yes	-1.6094379124341003	0.08254553074721008	1.691983443181...
13	Yes	-1.6094379124341003	1.6154673442802165	3.224905256714...
14	Yes	3.332204510175204	-0.20762706544890228	-3.53983157562...
15	Yes	3.1354942159291497	-0.021444230273636344	-3.15693844620...
16	Yes	2.9444389791664403	0.8407909643703869	-2.10364801479...
17	Yes	0.09531017980432493	0.7674784907624099	0.672168310958...
18	Yes	2.4849066497880004	0.3238203341320775	-2.16108631565...
19	Yes	-1.6094379124341003	0.348365254114474	1.957803166548...
20	Yes	-1.6094379124341003	0.8571040647928796	2.466541977226...
21	Yes	-1.6094379124341003	-0.27538710523957216	1.334050807194...
22	Yes	1.2237754316221157	-1.0350072165115503	-2.25878264813...
23	Yes	-1.6094379124341003	-0.1643707770308739	1.445067135403...
24	Yes	-1.6094379124341003	0.015170516643547856	1.624608429077...
25	Yes	0.09531017980432493	-1.0208841673258948	-1.11619434713...

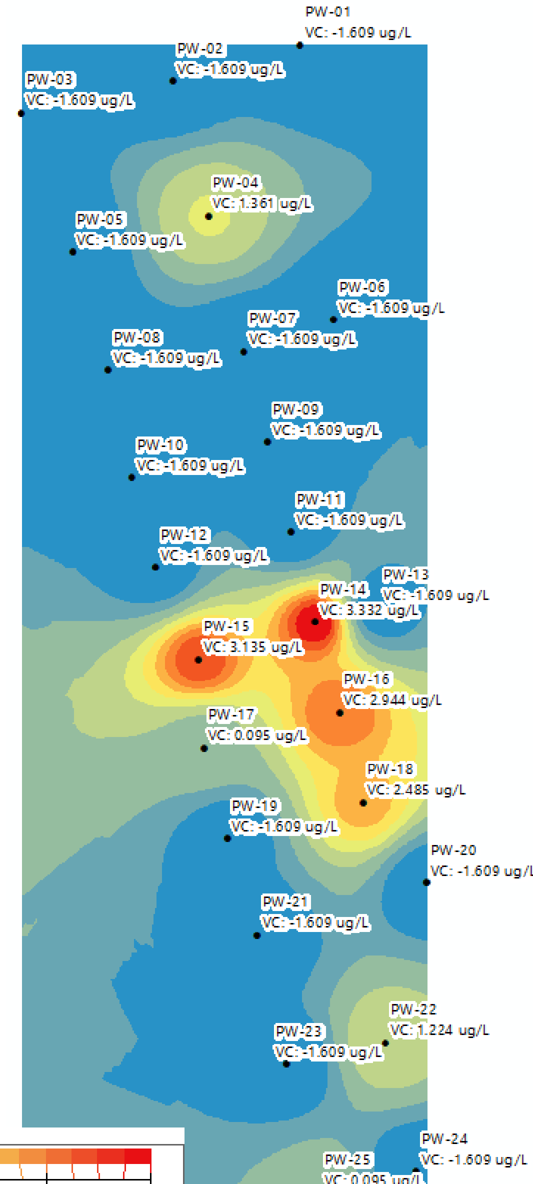
Regression function	0.105727333240768 * x + -0.39036714226354
Prediction Errors	
Samples	25 of 25
Mean	0.150535
Root-Mean-Square	1.818944
Export Result Table	

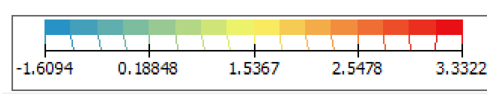


VC Power 3 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.6094379124341003	-1.0726430949184524	0.5367948175156478
2	Yes	-1.6094379124341003	-0.8007765532489459	0.8086613591851544
3	Yes	-1.6094379124341003	-1.2454304321771774	0.36400748025692287
4	Yes	1.3609765531356006	-1.6094379124341003	-2.97041446556970 1
5	Yes	-1.6094379124341003	-0.9493118438654742	0.6601260685686261
6	Yes	-1.6094379124341003	-1.2193547109346123	0.39008320149948794
7	Yes	-1.6094379124341003	-1.2694743460491893	0.339963566384911
8	Yes	-1.6094379124341003	-1.3398015217657144	0.26963639066838585
9	Yes	-1.6094379124341003	-1.2223705129693896	0.3870673994647107
10	Yes	-1.6094379124341003	-1.2207607930626228	0.38867711937147753
11	Yes	-1.6094379124341003	0.21809303332391367	1.82753094575801 4
12	Yes	-1.6094379124341003	0.15686697646498224	1.7663048888990824
13	Yes	-1.6094379124341003	2.3204887903442253	3.9299267027783253
14	Yes	3.332204510175204	-0.415549488847695	-3.747753999022899
15	Yes	3.1354942159291497	0.022082854890860 26	-3.113411361038289
16	Yes	2.9444389791664403	1.2875783292500744	-1.6568606499163658
17	Yes	0.09531017980432493	0.9635133742987274	0.8682031944944024
18	Yes	2.4849066497880004	0.4941231620112024	-1.990783487776798
19	Yes	-1.6094379124341003	0.14589646236818188	1.755334374802282
20	Yes	-1.6094379124341003	1.2932492113080154	2.9026871237421155
21	Yes	-1.6094379124341003	-0.6166036330176892	0.9928342794164111
22	Yes	1.2237754316221157	-1.2449242823438933	-2.468699713966009
23	Yes	-1.6094379124341003	0.018563128270520146	1.6280010407046204
24	Yes	-1.6094379124341003	0.10847245304107063	1.7179103654751708
25	Yes	0.09531017980432493	-1.206677543506617	-1.301987723310942

Regression function	0.15667043044048 * x + -0.458016990326039
Prediction Errors	
Samples	25 of 25
Mean	0.1713536
Root-Mean-Square	1.896987
Export Result Table	

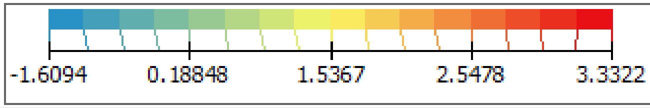


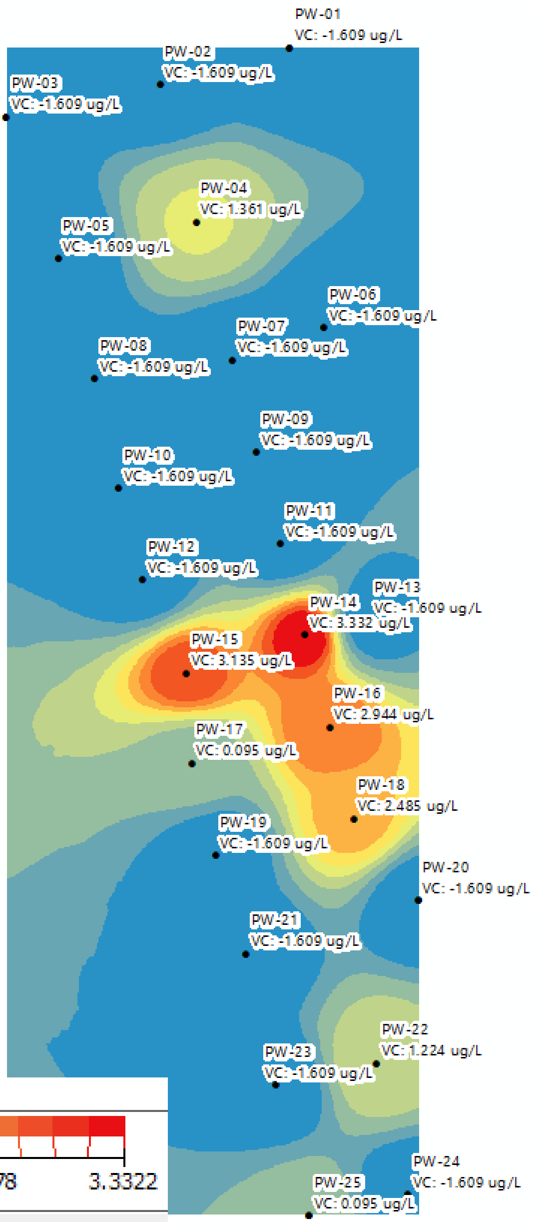


VC Power 4 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.6094379124341003	-1.1501975917222382	0.45924032071186205
2	Yes	-1.6094379124341003	-0.7240151729581543	0.885422739475946
3	Yes	-1.6094379124341003	-1.313053577130747	0.2963843353033533
4	Yes	1.3609765531356006	-1.6094379124341003	-2.970414465569701
5	Yes	-1.6094379124341003	-0.9055706689947818	0.7038672434393185
6	Yes	-1.6094379124341003	-1.3431034897304845	0.26633442270361574
7	Yes	-1.6094379124341003	-1.3606435349433403	0.24879437749075994
8	Yes	-1.6094379124341003	-1.4285082768819977	0.18092963555210262
9	Yes	-1.6094379124341003	-1.4021387835947092	0.20729912883939106
10	Yes	-1.6094379124341003	-1.3941548914103976	0.21528302102370267
11	Yes	-1.6094379124341003	0.31392285096389205	1.9233607633979923
12	Yes	-1.6094379124341003	0.18439313369094898	1.7938310461250493
13	Yes	-1.6094379124341003	2.769725906867306	4.379163819301406
14	Yes	3.332204510175204	-0.6812331892117791	-4.013437699386983
15	Yes	3.1354942159291497	0.007226388713153731	-3.128267827215996
16	Yes	2.9444389791664403	1.6400513602276603	-1.30438761893878
17	Yes	0.09531017980432...	1.0642752819705614	0.9689651021662364
18	Yes	2.4849066497880004	0.68495557228581	-1.7999510775021903
19	Yes	-1.6094379124341003	-0.052166775667915055	1.5572711367661851
20	Yes	-1.6094379124341003	1.6924567012057692	3.3018946136398695
21	Yes	-1.6094379124341003	-0.9138889946215403	0.69554891781256
22	Yes	1.2237754316221157	-1.380660756458277	-2.604436188080393
23	Yes	-1.6094379124341003	0.2138295649094028	1.8232674773435031
24	Yes	-1.6094379124341003	0.16814907548619593	1.7775869879202961
25	Yes	0.09531017980432...	-1.3395999487471129	-1.4349101285514378

Regression function	0.175649720323693 * x + -0.480796366870682
Prediction Errors	
Samples	25 of 25
Mean	0.1771456
Root-Mean-Square	1.976482
Export Result Table	

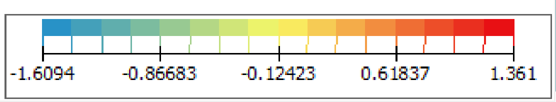


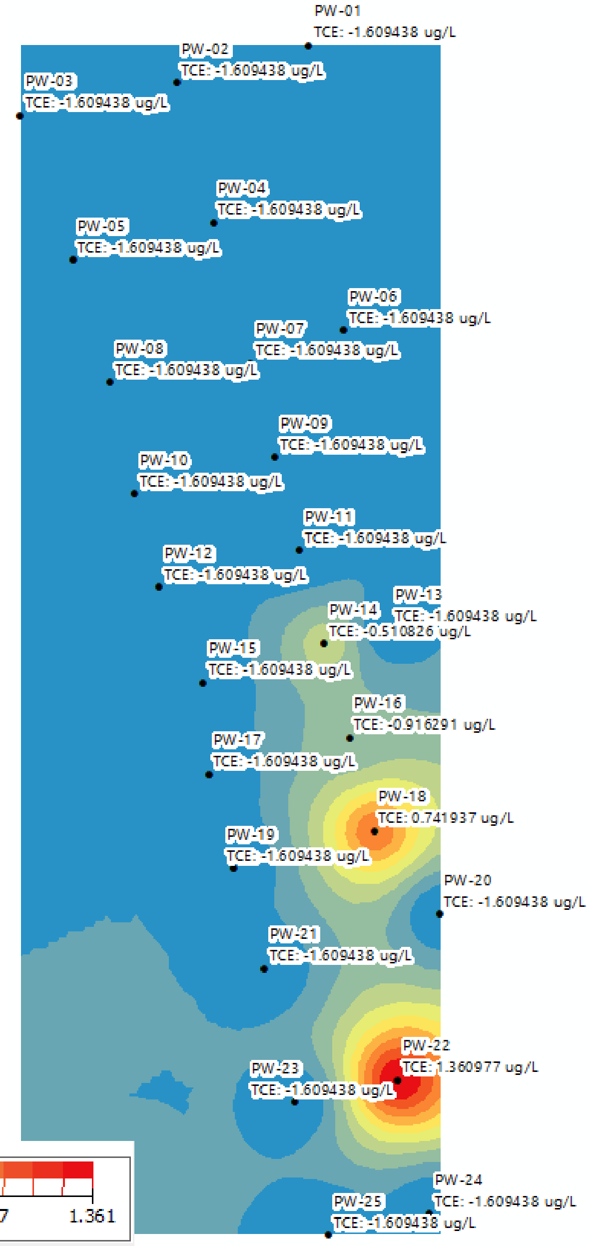


TCE Power 2 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.609437912434...	-1.6094379124341003	0
2	Yes	-1.609437912434...	-1.6094379124341003	0
3	Yes	-1.609437912434...	-1.6094379124341003	0
4	Yes	-1.609437912434...	-1.6094379124341003	0
5	Yes	-1.609437912434...	-1.6094379124341003	0
6	Yes	-1.609437912434...	-1.5716619135542393	0.03777599887986094
7	Yes	-1.609437912434...	-1.5799334994923986	0.029504412941701696
8	Yes	-1.609437912434...	-1.6094379124341003	0
9	Yes	-1.609437912434...	-1.531590768053885	0.07784714438021534
10	Yes	-1.609437912434...	-1.563281213937117	0.04615669849698323
11	Yes	-1.609437912434...	-1.2945005624810806	0.3149373499530197
12	Yes	-1.609437912434...	-1.4965785151346307	0.11285939729946959
13	Yes	-1.609437912434...	-0.9379123245499225	0.6715255878841778
14	Yes	-0.510825623765...	-1.407030765363705	-0.8962051415977144
15	Yes	-1.609437912434...	-1.3164447950197145	0.29299311741438583
16	Yes	-0.916290731874...	-0.8825701046905605	0.033720627183594476
17	Yes	-1.609437912434...	-1.28403504037223	0.32540287206187024
18	Yes	0.7419373447293...	-1.2500395390728511	-1.9919768838022285
19	Yes	-1.609437912434...	-1.1234525166136322	0.48598539582046807
20	Yes	-1.609437912434...	-0.3291516335651835	1.2802862788689167
21	Yes	-1.609437912434...	-1.0195199648011268	0.5899179476329734
22	Yes	1.3609765531356...	-1.4558070920339012	-2.816783645169502
23	Yes	-1.609437912434...	-0.5680558868907235	1.0413820255433768
24	Yes	-1.609437912434...	-0.8115340445595659	0.7979038678745344
25	Yes	-1.609437912434...	-1.0811668270905164	0.5282710853435839

Regression function	0.0179330658339494 * x + -1.33597500515189
Prediction Errors	
Samples	25 of 25
Mean	0.03846017
Root-Mean-Square	0.8413125
Export Result Table	

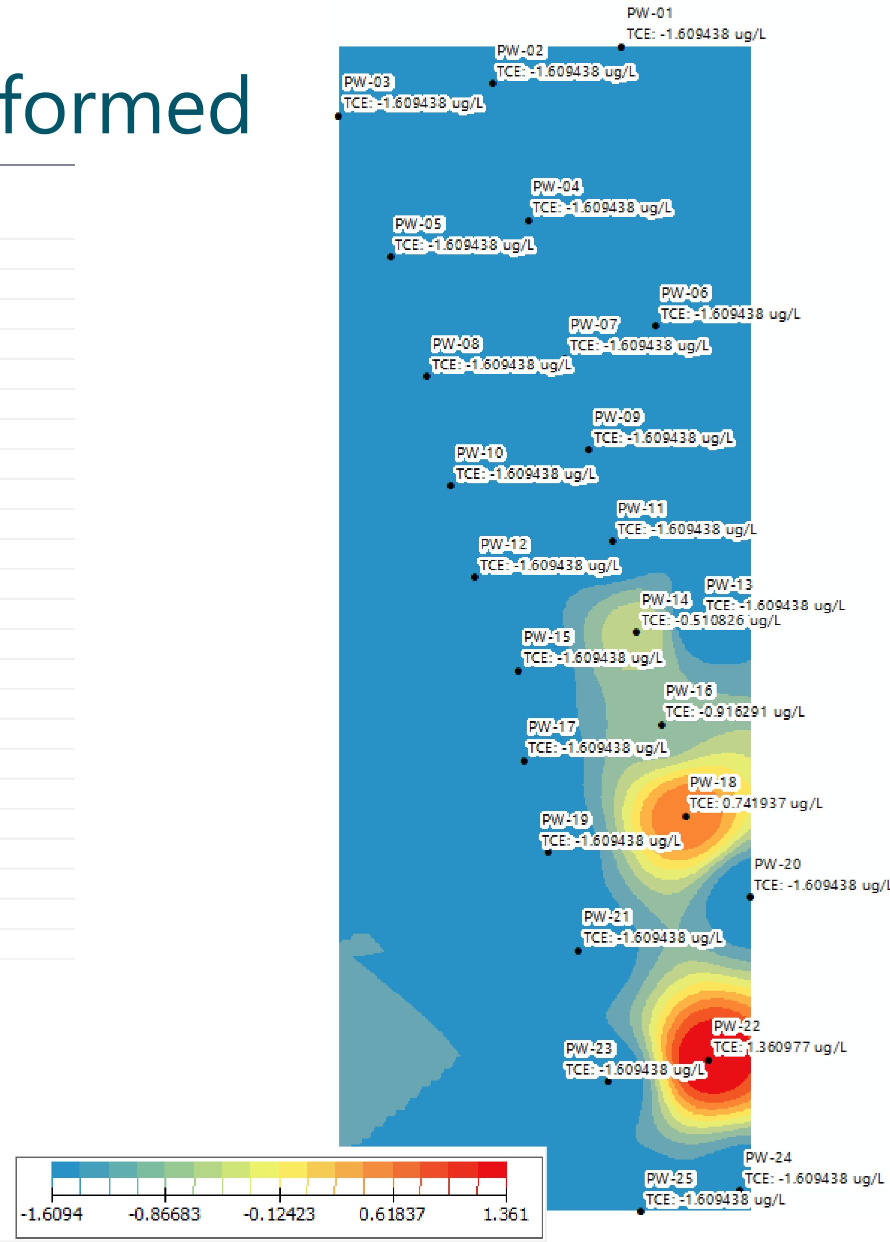




TCE Power 3 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.6094379124341003	-1.6094379124341003	0
2	Yes	-1.6094379124341003	-1.6094379124341003	0
3	Yes	-1.6094379124341003	-1.6094379124341003	0
4	Yes	-1.6094379124341003	-1.6094379124341003	0
5	Yes	-1.6094379124341003	-1.6094379124341003	0
6	Yes	-1.6094379124341003	-1.591632641936538	0.017805270497562198
7	Yes	-1.6094379124341003	-1.5964266378889693	0.013011274545130957
8	Yes	-1.6094379124341003	-1.6094379124341003	0
9	Yes	-1.6094379124341003	-1.5609694658330773	0.04846844660102301
10	Yes	-1.6094379124341003	-1.5829469916389844	0.026490920795115835
11	Yes	-1.6094379124341003	-1.2655691995248355	0.3438687129092648
12	Yes	-1.6094379124341003	-1.529083087996498	0.08035482443760222
13	Yes	-1.6094379124341003	-0.7751679362805202	0.8342699761535801
14	Yes	-0.5108256237659907	-1.4517389733532655	-0.9409133495872748
15	Yes	-1.6094379124341003	-1.363315874412834	0.2461220380212663
16	Yes	-0.916290731874155	-0.6738895498684466	0.24240118200570837
17	Yes	-1.6094379124341003	-1.364278372081536	0.24515954035256438
18	Yes	0.7419373447293773	-1.257523020895844	-1.9994603656252212
19	Yes	-1.6094379124341003	-1.2336037307496497	0.3758341816844506
20	Yes	-1.6094379124341003	0.0010137220975611...	1.6104516345316613
21	Yes	-1.6094379124341003	-1.1085096288755263	0.500928283558574
22	Yes	1.3609765531356006	-1.5244335020594013	-2.8854100551950017
23	Yes	-1.6094379124341003	-0.30937557755400724	1.300062334880093
24	Yes	-1.6094379124341003	-0.8712220601559177	0.7382158522781825
25	Yes	-1.6094379124341003	-1.2152644429978567	0.39417346943624354

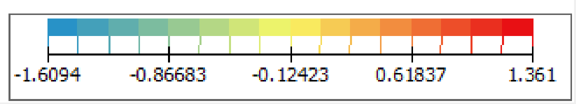
Regression function	0.0168468661872145 * x + -1.35297486713553
Prediction Errors	
Samples	25 of 25
Mean	0.04767337
Root-Mean-Square	0.8851817
Export Result Table	

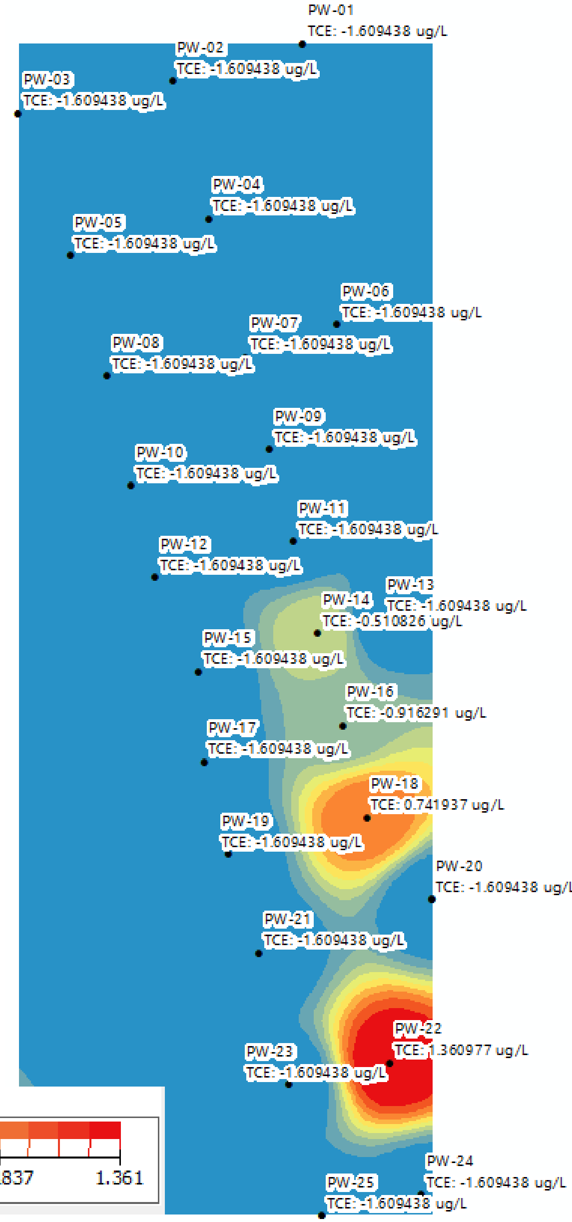


TCE Power 4 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.60943791243...	-1.6094379124341003	0
2	Yes	-1.60943791243...	-1.6094379124341003	0
3	Yes	-1.60943791243...	-1.6094379124341003	0
4	Yes	-1.60943791243...	-1.6094379124341003	0
5	Yes	-1.60943791243...	-1.6094379124341003	0
6	Yes	-1.60943791243...	-1.602217902243563	0.007220010190537307
7	Yes	-1.60943791243...	-1.6042285072882696	0.005209405145830681
8	Yes	-1.60943791243...	-1.6094379124341003	0
9	Yes	-1.60943791243...	-1.5815602327498588	0.027877679684241485
10	Yes	-1.60943791243...	-1.5958445314450806	0.013593380989019632
11	Yes	-1.60943791243...	-1.2282248024211548	0.3812131100129454
12	Yes	-1.60943791243...	-1.5568931737962897	0.05254473863781062
13	Yes	-1.60943791243...	-0.6640344697697664	0.9454034426643338
14	Yes	-0.51082562376...	-1.4910715905767453	-0.980245966810754 6
15	Yes	-1.60943791243...	-1.411513127375 3099	0.1979247850587904
16	Yes	-0.91629073187...	-0.49761733956535...	0.41867339230880296
17	Yes	-1.60943791243...	-1.4431627469798283	0.166275165454272
18	Yes	0.741937344729...	-1.246963166107945	-1.9889005108373223
19	Yes	-1.60943791243...	-1.3346645816477851	0.27477333078631516
20	Yes	-1.60943791243...	0.27993218137992004	1.8893700938140203
21	Yes	-1.60943791243...	-1.220782037416	0.38865587508100017
22	Yes	1.360976553135...	-1.5655807190093654	-2.926557272144966
23	Yes	-1.60943791243...	-0.04948996254725...	1.559947949886841
24	Yes	-1.60943791243...	-0.9699403947169697	0.6394975177171306
25	Yes	-1.60943791243...	-1.3345517384744303	0.27488617395966997

Regression function	0.024081068023136 4 * x + -1.36023346824583
Prediction Errors	
Samples	25 of 25
Mean	0.05389449
Root-Mean-Square	0.9269433
Export Result Table	

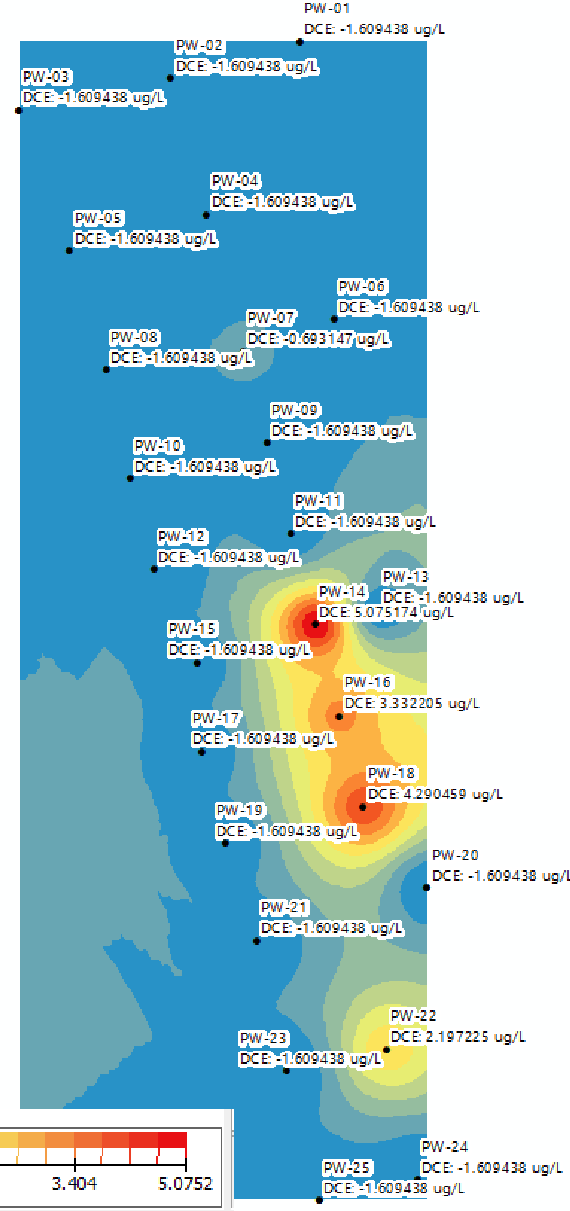


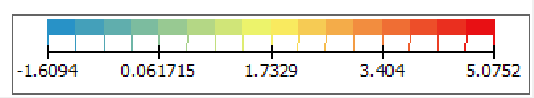


DCE Power 2 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.6094379124341003	-1.5432403354046567	0.06619757702944362
2	Yes	-1.6094379124341003	-1.5559997621964348	0.053438150237665516
3	Yes	-1.6094379124341003	-1.5551967778921516	0.05424113454194868
4	Yes	-1.6094379124341003	-1.4540783813480156	0.1553595310860847
5	Yes	-1.6094379124341003	-1.51912138647323	0.09031652596087025
6	Yes	-1.6094379124341003	-1.0611005449727005	0.5483373674613998
7	Yes	-0.6931471805599453	-1.429915485093368	-0.7367683045334227
8	Yes	-1.6094379124341003	-1.472992134118364	0.13644577831573623
9	Yes	-1.6094379124341003	-0.9151245801983694	0.6943133322357309
10	Yes	-1.6094379124341003	-1.2545609416246428	0.35487697080945746
11	Yes	-1.6094379124341003	0.19918233993106493	1.808620252365165
12	Yes	-1.6094379124341003	-0.8567522686277377	0.7526856438063626
13	Yes	-1.6094379124341003	2.2107664775398224	3.820204389973923
14	Yes	5.075173815233827	-0.5794726734451429	-5.65464648867897
15	Yes	-1.6094379124341003	-0.10227696849665743	1.507160943937443
16	Yes	3.332204510175204	1.0419556878378988	-2.290248822337305
17	Yes	-1.6094379124341003	-0.16763851580987696	1.4417993966242233
18	Yes	4.290459441148391	0.21602032612308453	-4.0744391150253065
19	Yes	-1.6094379124341003	-0.08664309454214297	1.5227948178919573
20	Yes	-1.6094379124341003	1.610415128862106	3.219853041296206
21	Yes	-1.6094379124341003	-0.3457203587884133	1.263717553645687
22	Yes	2.1972245773362196	-1.1293208449895809	-3.3265454223258004
23	Yes	-1.6094379124341003	-0.14812732606740708	1.461310586366693
24	Yes	-1.6094379124341003	-0.4195787170447097	1.1898591953893907
25	Yes	-1.6094379124341003	-0.8534650976598146	0.7559728147742857

Regression function	0.136912742823502 * x + -0.650923692927885
Prediction Errors	
Samples	25 of 25
Mean	0.1925943
Root-Mean-Square	2.074491
Export Result Table	

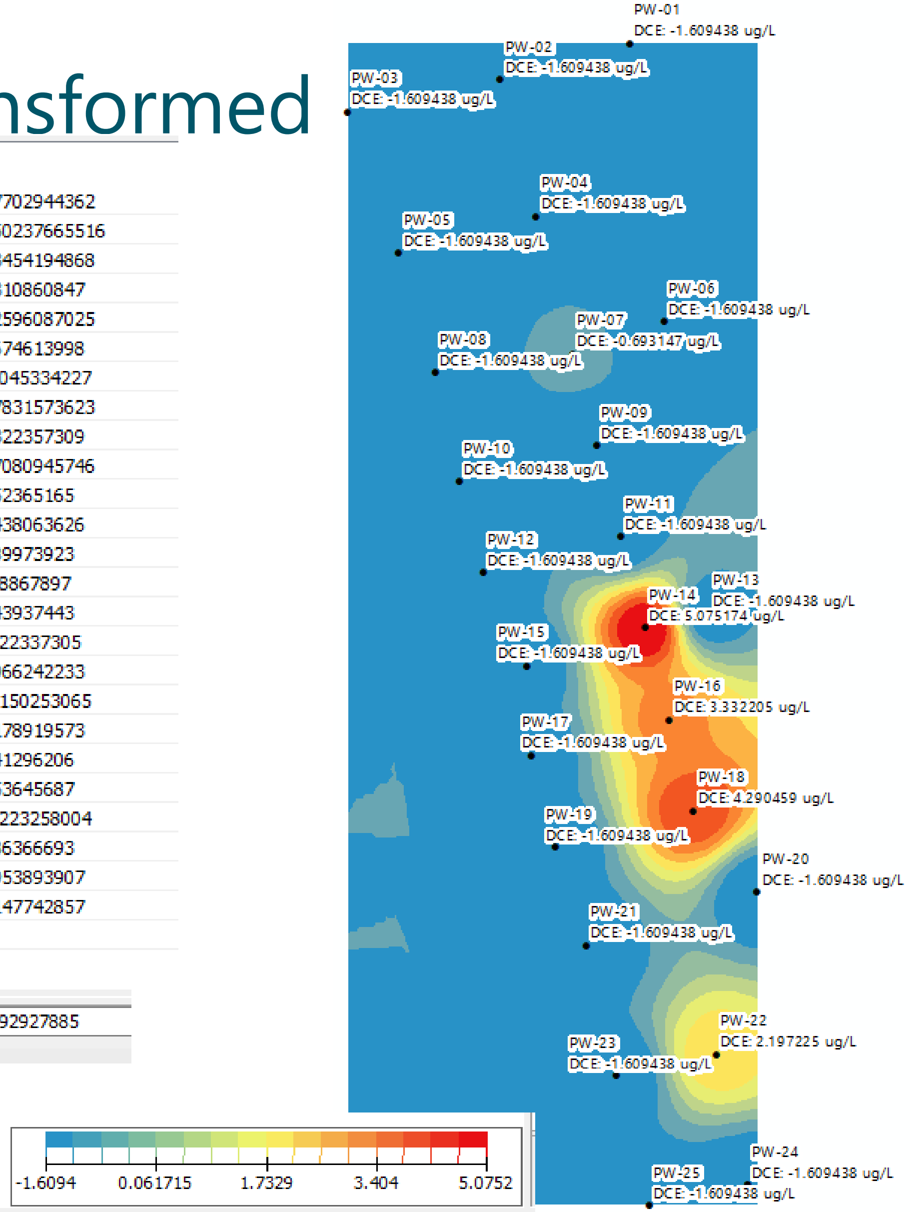




DCE Power 3 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.6094379124341003	-1.5432403354046567	0.06619757702944362
2	Yes	-1.6094379124341003	-1.5559997621964348	0.053438150237665516
3	Yes	-1.6094379124341003	-1.5551967778921516	0.05424113454194868
4	Yes	-1.6094379124341003	-1.4540783813480156	0.1553595310860847
5	Yes	-1.6094379124341003	-1.51912138647323	0.09031652596087025
6	Yes	-1.6094379124341003	-1.0611005449727005	0.5483373674613998
7	Yes	-0.6931471805599453	-1.429915485093368	-0.7367683045334227
8	Yes	-1.6094379124341003	-1.472992134118364	0.13644577831573623
9	Yes	-1.6094379124341003	-0.9151245801983694	0.6943133322357309
10	Yes	-1.6094379124341003	-1.2545609416246428	0.3548769708094574
11	Yes	-1.6094379124341003	0.1991823399310649	1.80862025236516
12	Yes	-1.6094379124341003	-0.8567522686277377	0.7526856438063626
13	Yes	-1.6094379124341003	2.2107664775398224	3.820204389973923
14	Yes	5.075173815233827	-0.5794726734451429	-5.65464648867897
15	Yes	-1.6094379124341003	-0.10227696849665743	1.507160943937443
16	Yes	3.332204510175204	1.0419556878378988	-2.290248822337305
17	Yes	-1.6094379124341003	-0.16763851580987696	1.4417993966242233
18	Yes	4.290459441148391	0.21602032612308453	-4.074439115025306
19	Yes	-1.6094379124341003	-0.08664309454214297	1.5227948178919573
20	Yes	-1.6094379124341003	1.610415128862106	3.219853041296206
21	Yes	-1.6094379124341003	-0.3457203587884133	1.263717553645687
22	Yes	2.1972245773362196	-1.1293208449895809	-3.3265454223258004
23	Yes	-1.6094379124341003	-0.14812732606740708	1.461310586366693
24	Yes	-1.6094379124341003	-0.4195787170447097	1.1898591953893907
25	Yes	-1.6094379124341003	-0.8534650976598146	0.7559728147742857

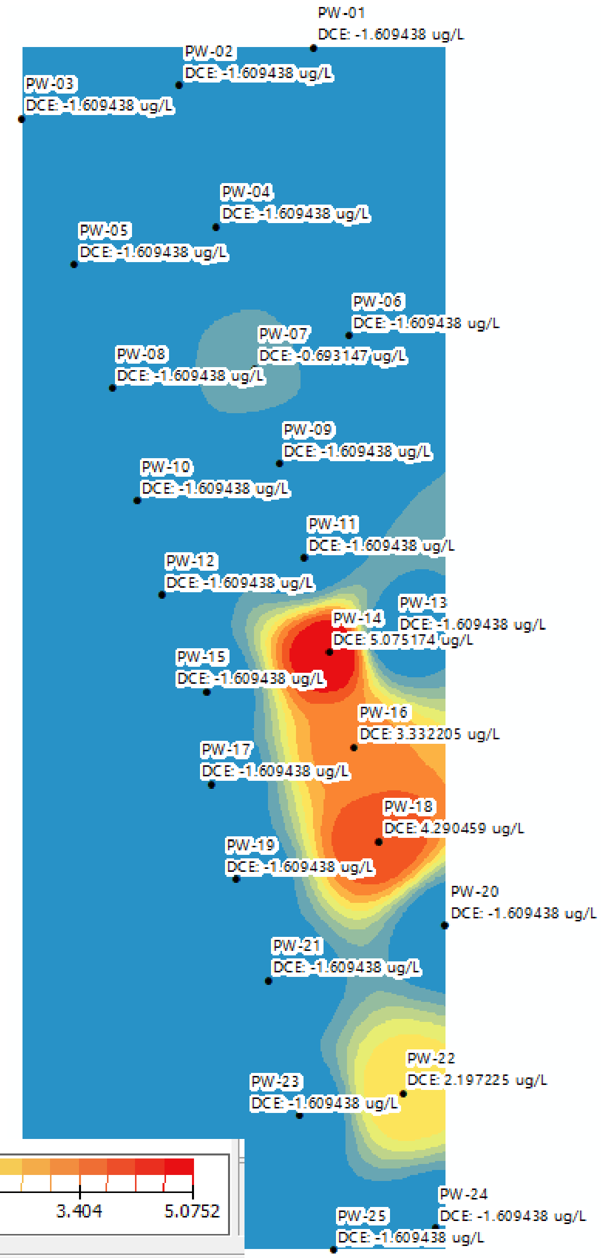
Regression function	0.136912742823502 * x + -0.650923692927885
Prediction Errors	
Samples	25 of 25
Mean	0.1925943
Root-Mean-Square	2.074491
Export Result Table	

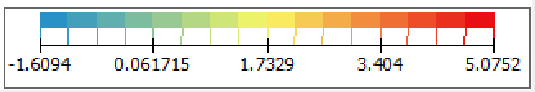


DCE Power 4 – Log transformed

Source ID	Included	Measured	Predicted	Error
1	Yes	-1.60943791243...	-1.5880161319580...	0.021421780476054586
2	Yes	-1.60943791243...	-1.59236738878 1021	0.017070523653079 26
3	Yes	-1.60943791243...	-1.592752574597805	0.016685337836295222
4	Yes	-1.60943791243...	-1.40769214974602	0.20174576268808 03
5	Yes	-1.60943791243...	-1.5551570556429...	0.054280856791157 68
6	Yes	-1.60943791243...	-0.950192945015955	0.6592449674181453
7	Yes	-0.69314718055...	-1.5777407877148...	-0.8845936071549231
8	Yes	-1.60943791243...	-1.4600077508166...	0.1494301616174 2895
9	Yes	-1.60943791243...	-1.1057926650397...	0.50364524739432 8
10	Yes	-1.60943791243...	-1.4847991660265...	0.12463874640752892
11	Yes	-1.60943791243...	0.7096770634604597	2.3191149758945597
12	Yes	-1.60943791243...	-1.2716012203126...	0.33783669212142065
13	Yes	-1.60943791243...	4.129433892364221	5.738871804798322
14	Yes	5.075173815233...	-0.8596417470576...	-5.9348155622915115
15	Yes	-1.60943791243...	-0.4669800421220...	1.142457870312093
16	Yes	3.332204510175...	2.4461469411438004	-0.8860575690314034
17	Yes	-1.60943791243...	-0.8319251915759...	0.7775127208581156
18	Yes	4.290459441148...	0.7714865481766329	-3.518972892971758
19	Yes	-1.60943791243...	-0.765878473379682	0.843559439054418 3
20	Yes	-1.60943791243...	2.99237861744374	4.601816529877841
21	Yes	-1.60943791243...	-0.840785888706608	0.7686520237274923
22	Yes	2.197224577336...	-1.4843352595531...	-3.6815598368893268
23	Yes	-1.60943791243...	0.41853849862266...	2.027976411056761
24	Yes	-1.60943791243...	-0.7742818643183...	0.8351560481157184
25	Yes	-1.60943791243...	-1.249160607697438	0.3602773047366623

Regression function	0.222125188462135 * x + -0.66230097164(
Prediction Errors	
Samples	25 of 25
Mean	0.2638158
Root-Mean-Square	2.291318
Export Result Table	





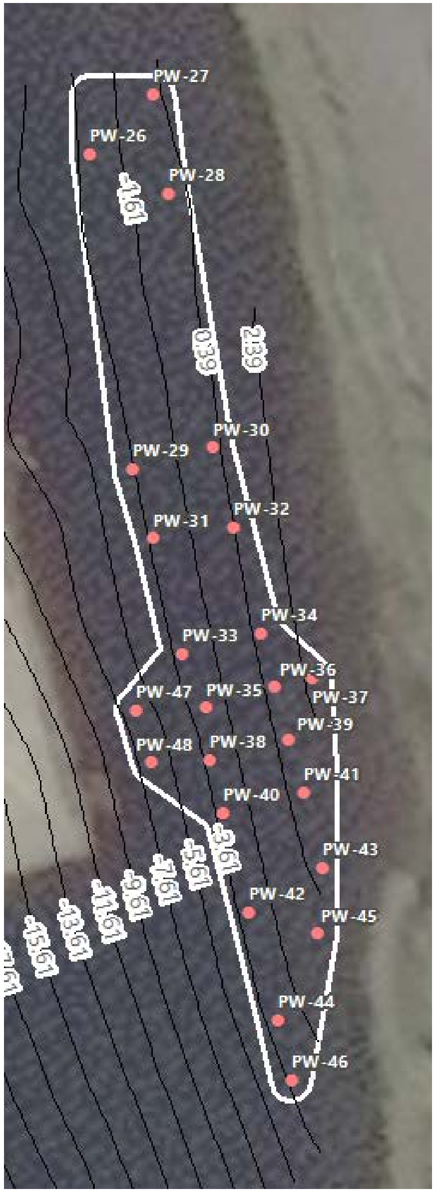
ATTACHMENT B

Summary of inverse-distance weighting analysis for 2020 porewater data

2020 Porewater Samples SWAC's

Chemical	IDW Power	SWAC (µg/L)
VC	3	3.25
VC	4	4.19
VC	5	4.83
DCE	2	0.79
DCE	3	1.12
DCE	4	1.34
TCE	4	0.0259
TCE	5	0.0262
TCE	6	0.0265

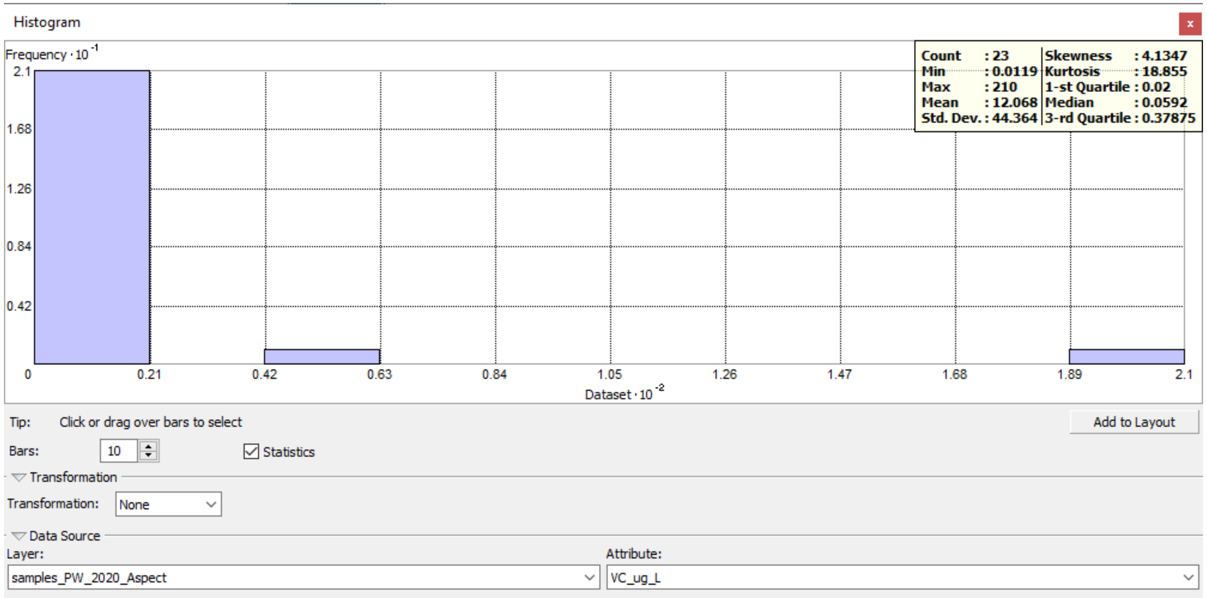
Notes:
1. Full SWAC area encompasses all sample points.
2. Bathymetric contours are 2011, MLLW feet.
3. IDW parameters: Power=variable, search radius=45′, Neighbors (Max)=8, Neighbors (Min)=4, IDW raster cell size=3′x3′.



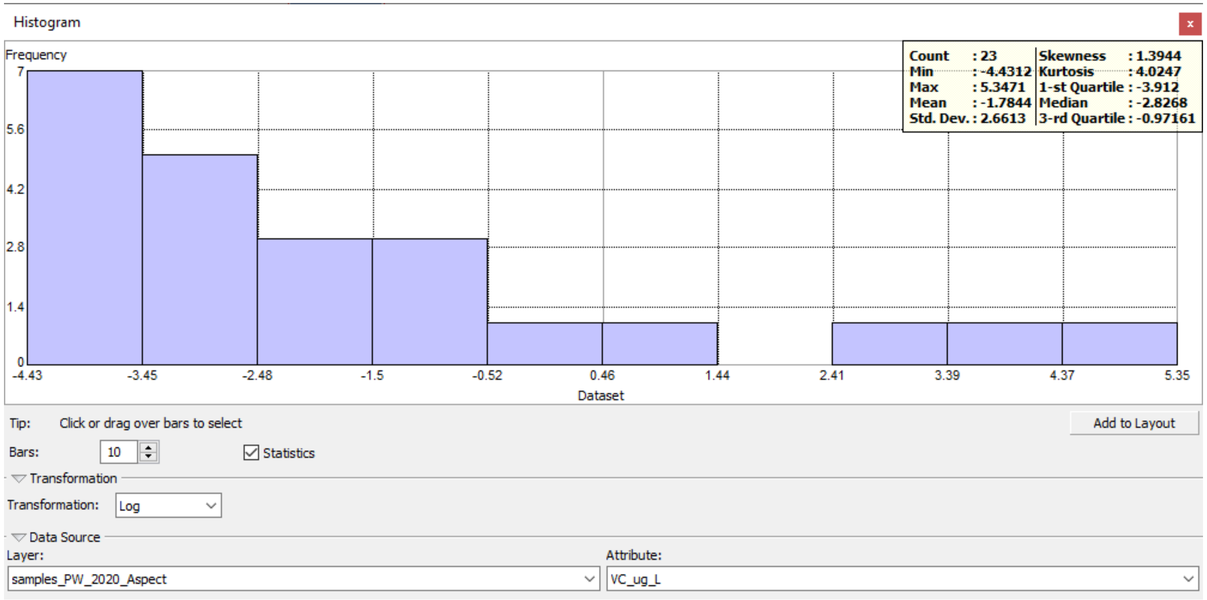
Full SWAC Area

Results Distribution Histogram: Vinyl Chloride

Raw

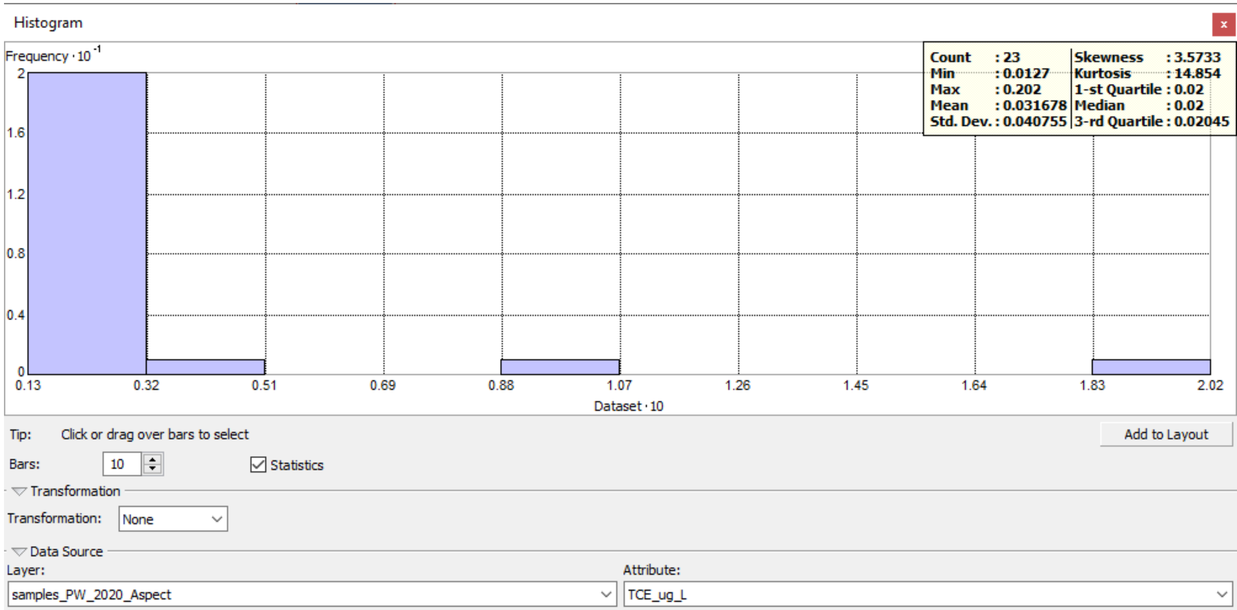


Log Transformed

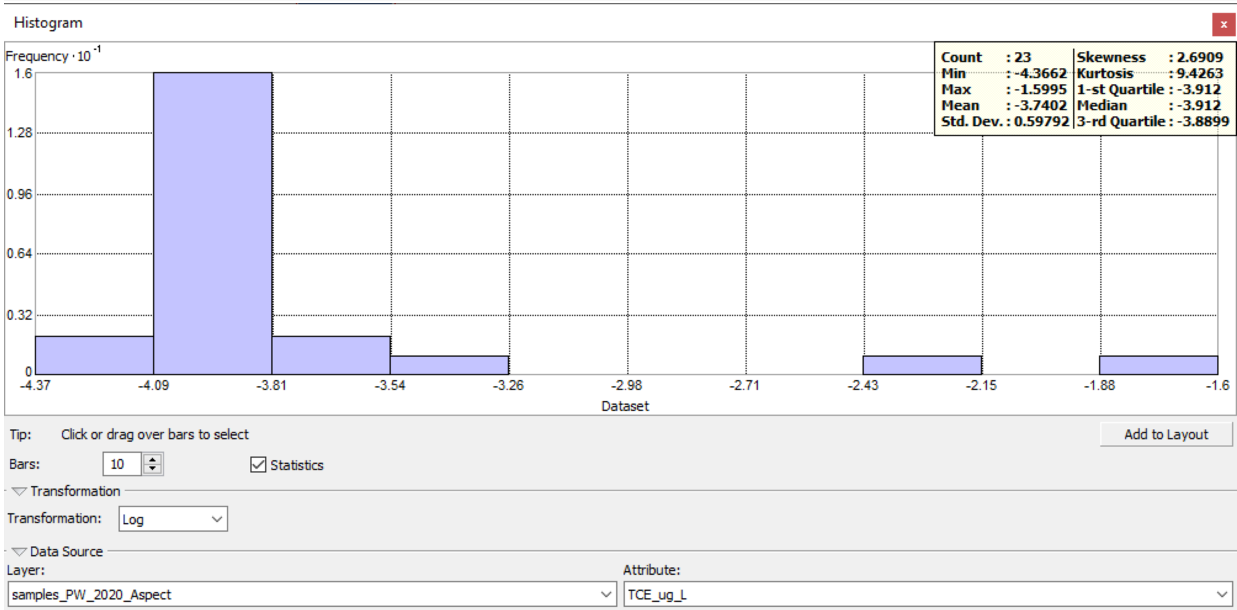


Results Distribution Histogram:
Trichloroethene

Raw

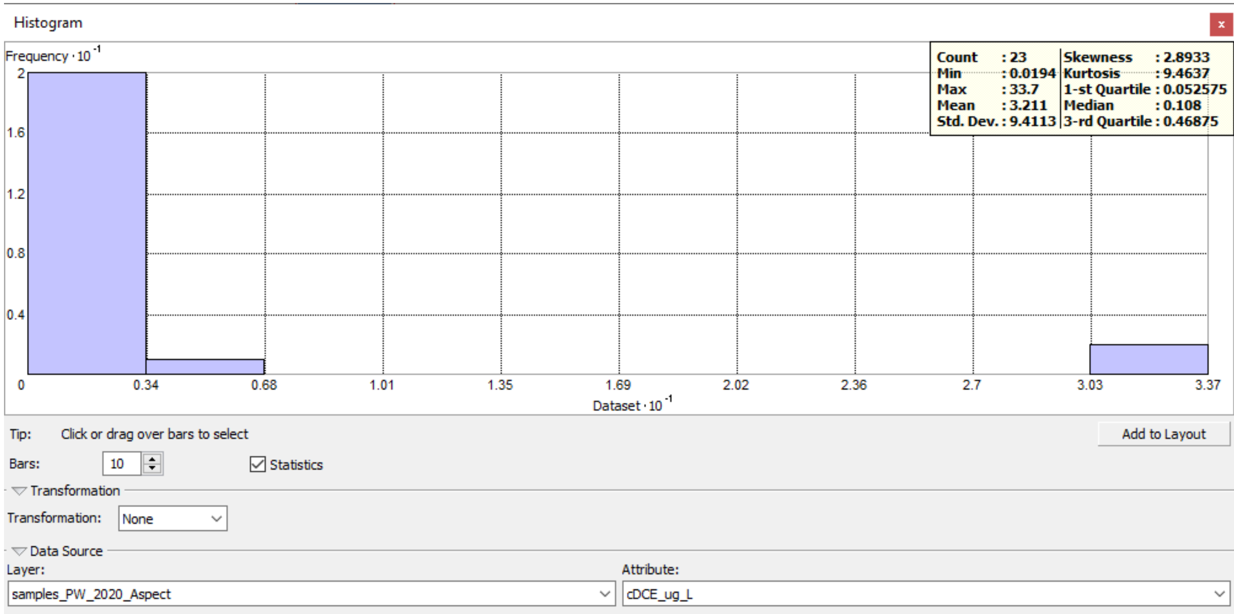


Log Transformed

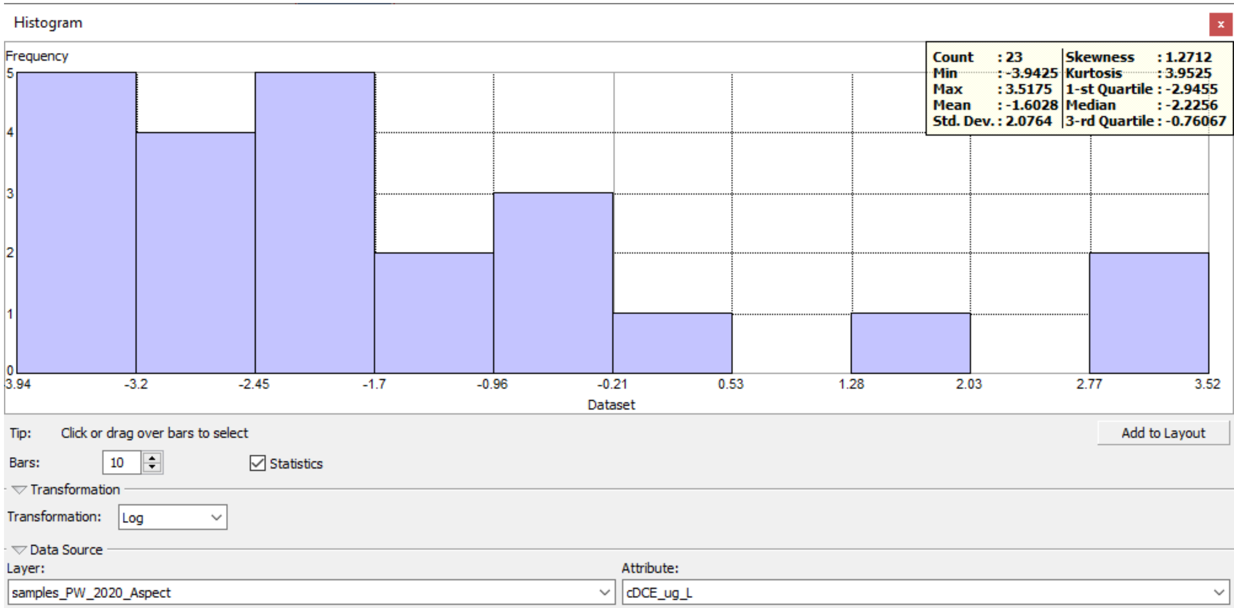


Results Distribution Histogram: Cis-1.2-Dichloroethene

Raw



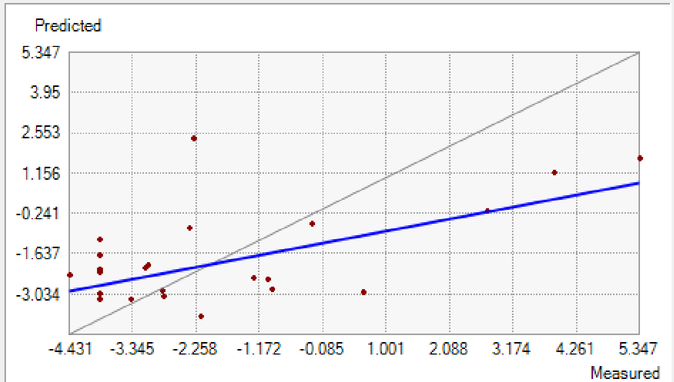
Log Transformed



VC Power 3 – Log transformed

Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

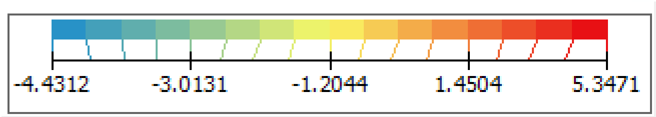
Source ID	Included	Measured	Predicted	Error
1	Yes	-3.912...	-3.019...	0.8923353669563467
2	Yes	-3.912...	-3.200...	0.7111568373614285
3	Yes	-2.189...	-3.812...	-1.622909293032369
4	Yes	-3.912...	-2.258...	1.653055958385266
5	Yes	0.5933...	-2.931...	-3.525159984906668
6	Yes	-4.431...	-2.379...	2.051940012935 8507
7	Yes	-1.269...	-2.442...	-1.1732400347502778
8	Yes	-2.838...	-2.877...	-0.03836344342673792
9	Yes	-3.125...	-2.090...	1.0352415694428299
10	Yes	-3.083...	-2.003...	1.080155158082904
11	Yes	-0.949...	-2.846...	-1.896715509490662
12	Yes	-3.912...	-1.124...	2.7871112718192412
13	Yes	-1.038...	-2.510...	-1.472207360382293
14	Yes	-0.275...	-0.561...	-0.28564337025535225
15	Yes	-2.379...	-0.721...	1.658201620924 0034
16	Yes	2.7212...	-0.113...	-2.834353857160423
17	Yes	-2.315...	2.386...	4.702497896592135
18	Yes	5.3471...	1.690...	-3.656444263818019
19	Yes	-3.912...	-1.649...	2.262506543061405
20	Yes	3.8732...	1.209...	-2.6639058686031856
21	Yes	-3.381...	-3.188...	0.19287910557050614
22	Yes	-2.826...	-3.117...	-0.29107820034520504
23	Yes	-3.912...	-2.157...	1.7542920006744374

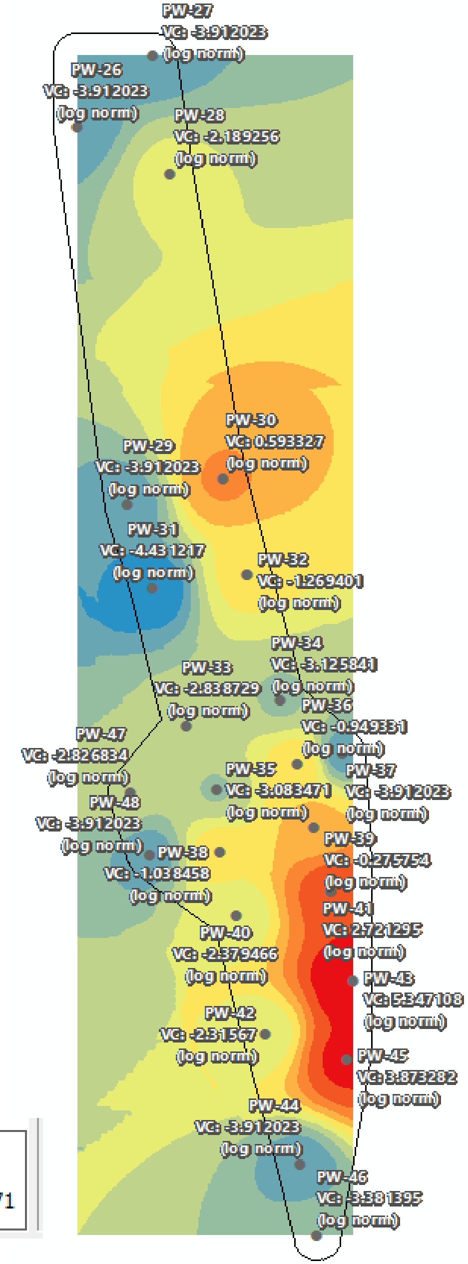


Predicted | Error

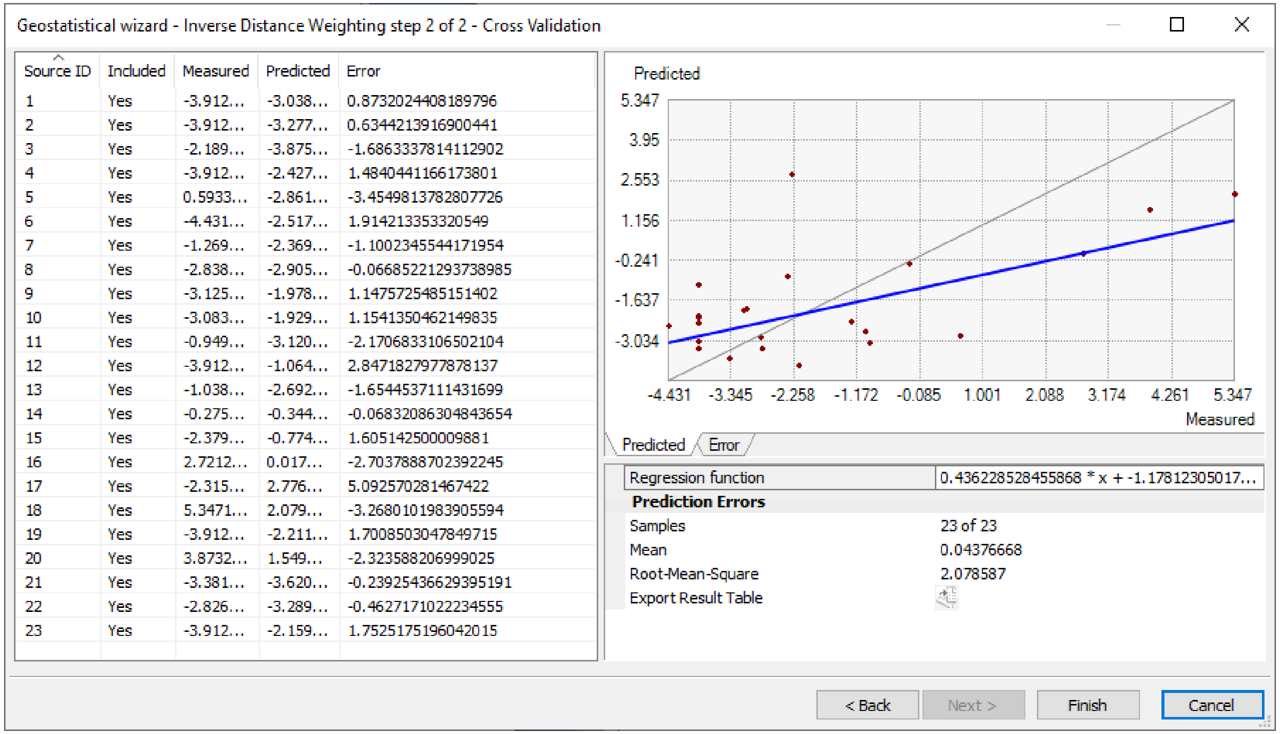
Regression function	0.383651702170748 * x + -1.23863732197...
Prediction Errors	
Samples	23 of 23
Mean	0.05745009
Root-Mean-Square	2.108138
Export Result Table	

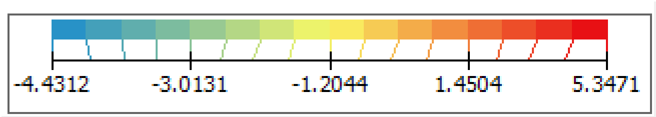
< Back | Next > | Finish | Cancel

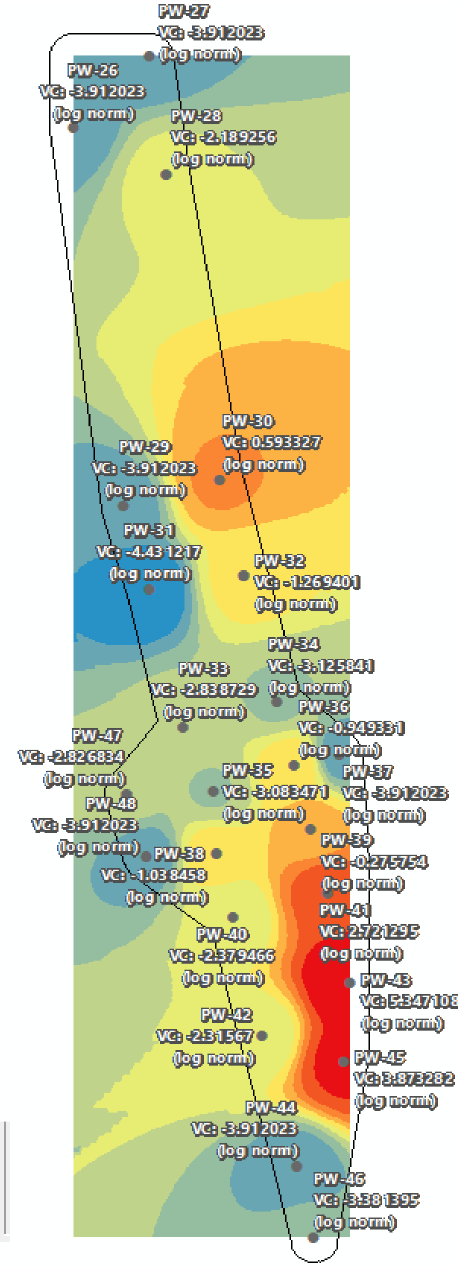




VC Power 4 – Log transformed



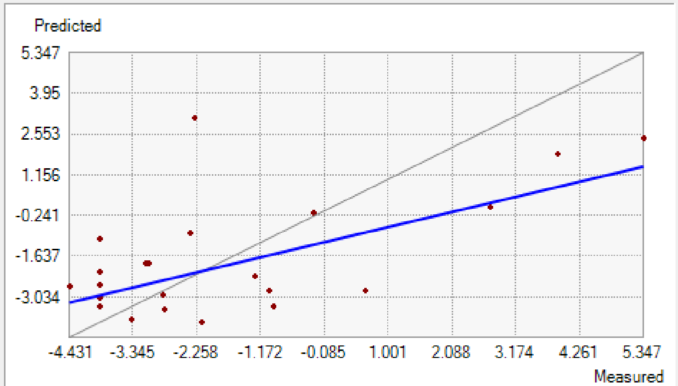




VC Power 5 – Log transformed

Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

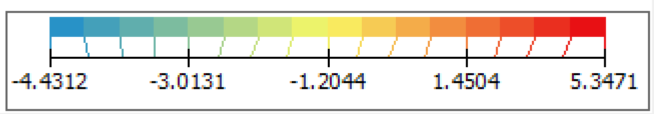
Source ID	Included	Measured	Predicted	Error
1	Yes	-3.912...	-3.043...	0.8686047900977729
2	Yes	-3.912...	-3.337...	0.5744243983858
3	Yes	-2.189...	-3.899...	-1.7097621236254965
4	Yes	-3.912...	-2.596...	1.3157189948095822
5	Yes	0.5933...	-2.803...	-3.3972721764887286
6	Yes	-4.431...	-2.652...	1.779116877246853
7	Yes	-1.269...	-2.316...	-1.0469985558019188
8	Yes	-2.838...	-2.938...	-0.09991052128795852
9	Yes	-3.125...	-1.848...	1.2772694475370217
10	Yes	-3.083...	-1.851...	1.231908424708596
11	Yes	-0.949...	-3.330...	-2.381426266174221
12	Yes	-3.912...	-1.019...	2.8920694792926636
13	Yes	-1.038...	-2.816...	-1.7785172889024619
14	Yes	-0.275...	-0.136...	0.138859160880356
15	Yes	-2.379...	-0.830...	1.5486176482043816
16	Yes	2.7212...	0.053...	-2.667609588328636
17	Yes	-2.315...	3.104...	5.420510501960093
18	Yes	5.3471...	2.409...	-2.9371356579533647
19	Yes	-3.912...	-2.610...	1.3016343081808568
20	Yes	3.8732...	1.868...	-2.0046601564793045
21	Yes	-3.381...	-3.797...	-0.4164452112402883
22	Yes	-2.826...	-3.427...	-0.6002645218682741
23	Yes	-3.912...	-2.155...	1.7570050036794123

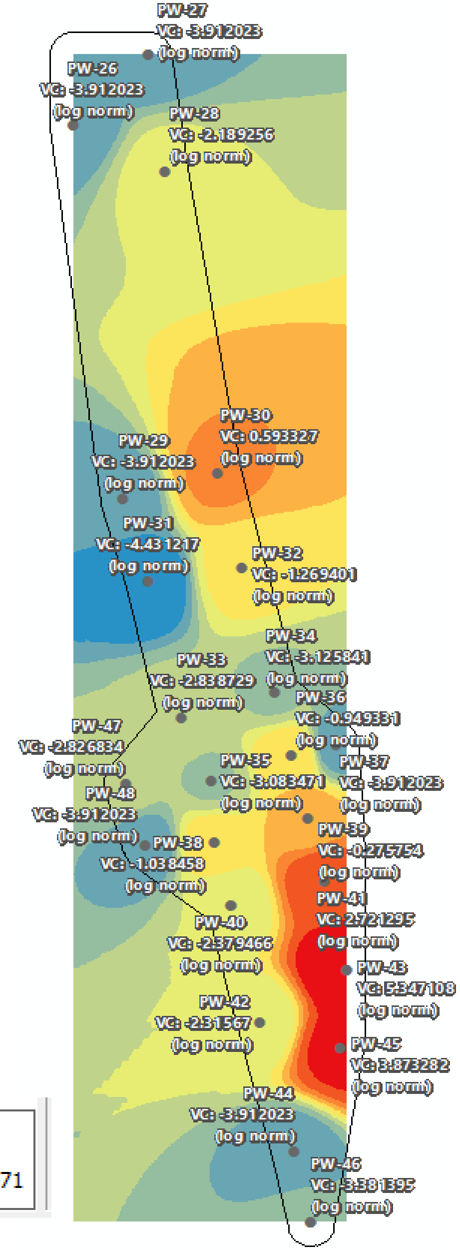


Predicted | Error

Regression function	0.477180040531556 * x + -1.11825656697...
Prediction Errors	
Samples	23 of 23
Mean	0.04633639
Root-Mean-Square	2.072335
Export Result Table	

< Back | Next > | Finish | Cancel

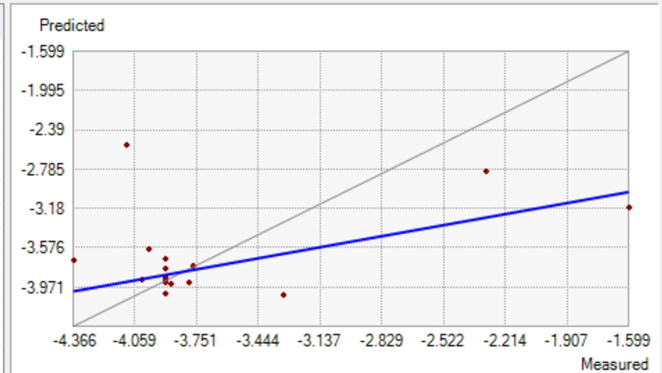




TCE Power 4 – Log transformed

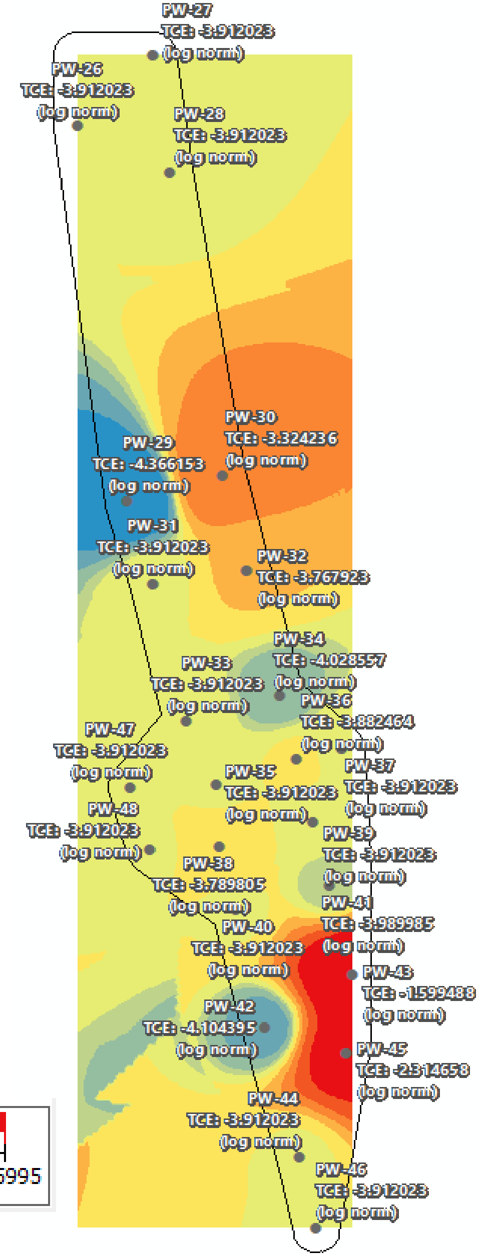
Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

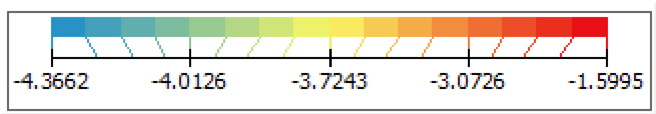
Source ID	Included	Measured	Predicted	Error
1	Yes	-3.912...	-3.911...	0.00036522815926165464
2	Yes	-3.912...	-3.911...	0.00046280876246873603
3	Yes	-3.912...	-3.910...	0.00200044498661045
4	Yes	-4.366...	-3.699...	0.667062937381194
5	Yes	-3.324...	-4.044...	-0.720076244540667
6	Yes	-3.912...	-4.029...	-0.11721052373158924
7	Yes	-3.767...	-3.755...	0.012070745281717699
8	Yes	-3.912...	-3.920...	-0.00815311755292969
9	Yes	-4.028...	-3.890...	0.13813658276710417
10	Yes	-3.912...	-3.867...	0.04430772930968052
11	Yes	-3.882...	-3.927...	-0.0452818753356925
12	Yes	-3.912...	-3.897...	0.01426718302816532
13	Yes	-3.789...	-3.913...	-0.12349470101099858
14	Yes	-3.912...	-3.900...	0.011837209328199982
15	Yes	-3.912...	-3.780...	0.13146932530699607
16	Yes	-3.989...	-3.577...	0.4123381452588375
17	Yes	-4.104...	-2.540...	1.5636794942963501
18	Yes	-1.599...	-3.163...	-1.5638823665783006
19	Yes	-3.912...	-3.677...	0.2347041712886866
20	Yes	-2.314...	-2.799...	-0.4846823094272259
21	Yes	-3.912...	-3.857...	0.05469412986942279
22	Yes	-3.912...	-3.903...	0.008330728063315362
23	Yes	-3.912...	-3.869...	0.04282293238429258



Regression function	0.360995711033024 * x + -2.43794844805...
Prediction Errors	
Samples	23 of 23
Mean	0.01198994
Root-Mean-Square	0.5270572
Export Result Table	

< Back Next > Finish Cancel

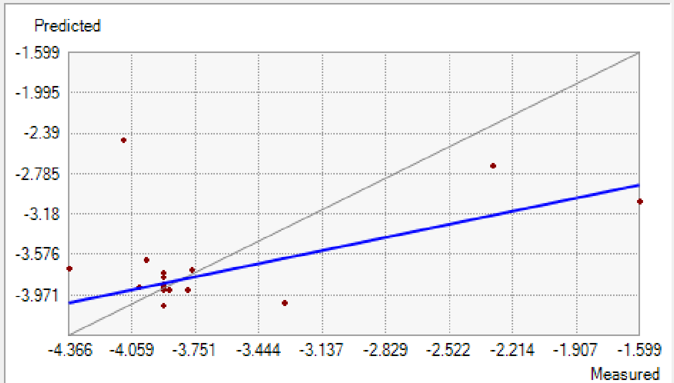




TCE Power 5 – Log transformed

Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

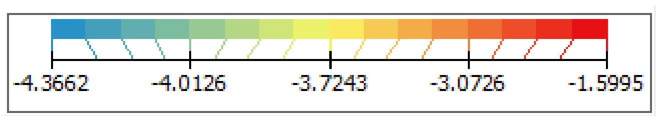
Source ID	Included	Measured	Predicted	Error
1	Yes	-3.912...	-3.911...	9.983897146881304e-05
2	Yes	-3.912...	-3.911...	0.00012802084246743561
3	Yes	-3.912...	-3.911...	0.0007823598357061812
4	Yes	-4.366...	-3.711...	0.6548397489848123
5	Yes	-3.324...	-4.049...	-0.7248852482074226
6	Yes	-3.912...	-4.067...	-0.15498364142034182
7	Yes	-3.767...	-3.729...	0.038748319150824884
8	Yes	-3.912...	-3.920...	-0.008320247143743131
9	Yes	-4.028...	-3.890...	0.13805226541953441
10	Yes	-3.912...	-3.858...	0.053794289743995805
11	Yes	-3.882...	-3.924...	-0.04246544047837775
12	Yes	-3.912...	-3.891...	0.020265525624138192
13	Yes	-3.789...	-3.912...	-0.12297311287956392
14	Yes	-3.912...	-3.915...	-0.0030129104558098696
15	Yes	-3.912...	-3.792...	0.11926414622094583
16	Yes	-3.989...	-3.632...	0.35782956560576595
17	Yes	-4.104...	-2.446...	1.6577896156587397
18	Yes	-1.599...	-3.050...	-1.4506398846755437
19	Yes	-3.912...	-3.757...	0.15479968705216995
20	Yes	-2.314...	-2.697...	-0.3830656839944937
21	Yes	-3.912...	-3.890...	0.021391841838706238
22	Yes	-3.912...	-3.905...	0.006160228272828139
23	Yes	-3.912...	-3.867...	0.0448615141460027

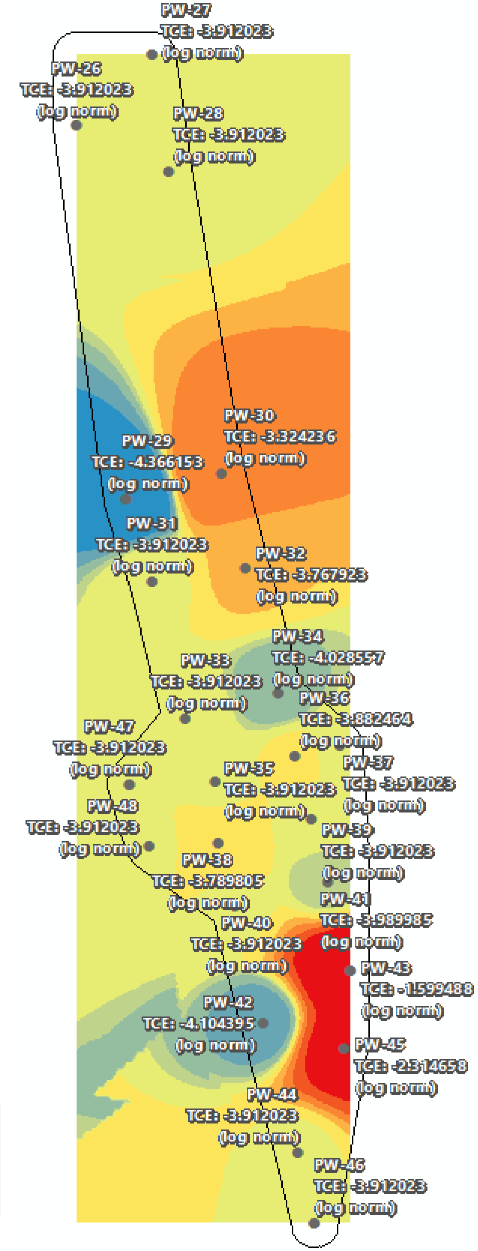


Predicted | Error

Regression function	0.417108870441445 * x + -2.22861445838...
Prediction Errors	
Samples	23 of 23
Mean	0.01645482
Root-Mean-Square	0.5186631
Export Result Table	

< Back | Next > | Finish | Cancel

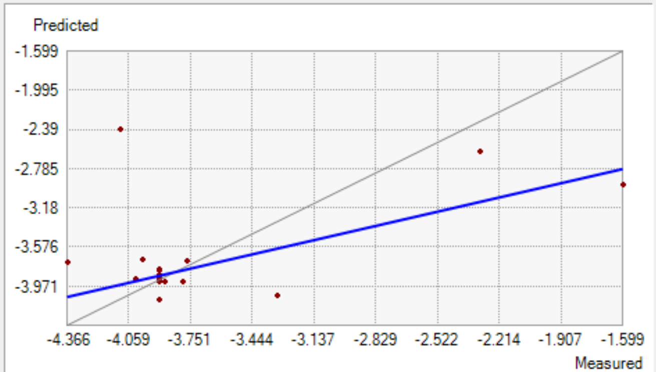




TCE Power 6 – Log transformed

Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

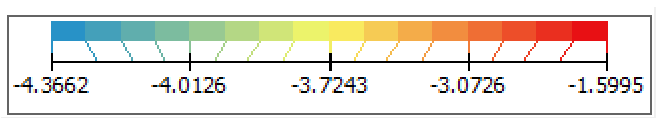
Source ID	Included	Measured	Predicted	Error
1	Yes	-3.912...	-3.911...	2.7210086337881023e-05
2	Yes	-3.912...	-3.911...	3.4877732826732455e-05
3	Yes	-3.912...	-3.911...	0.0002987761101747033
4	Yes	-4.366...	-3.725...	0.6409477592493662
5	Yes	-3.324...	-4.053...	-0.7287779455677819
6	Yes	-3.912...	-4.100...	-0.18806294081122177
7	Yes	-3.767...	-3.708...	0.059146947959996865
8	Yes	-3.912...	-3.919...	-0.007672752785470305
9	Yes	-4.028...	-3.889...	0.13868799695246192
10	Yes	-3.912...	-3.849...	0.062404459667272594
11	Yes	-3.882...	-3.922...	-0.03957221138767819
12	Yes	-3.912...	-3.887...	0.02410452578561717
13	Yes	-3.789...	-3.912...	-0.1226525105011742
14	Yes	-3.912...	-3.923...	-0.01108882548178558
15	Yes	-3.912...	-3.797...	0.11455429821786911
16	Yes	-3.989...	-3.690...	0.2994441593732069
17	Yes	-4.104...	-2.378...	1.7261804914910872
18	Yes	-1.599...	-2.947...	-1.3478232258155587
19	Yes	-3.912...	-3.811...	0.10100025652201383
20	Yes	-2.314...	-2.610...	-0.29564175306469975
21	Yes	-3.912...	-3.903...	0.00838391371813385
22	Yes	-3.912...	-3.907...	0.0043281114735980175
23	Yes	-3.912...	-3.866...	0.04578128561795003

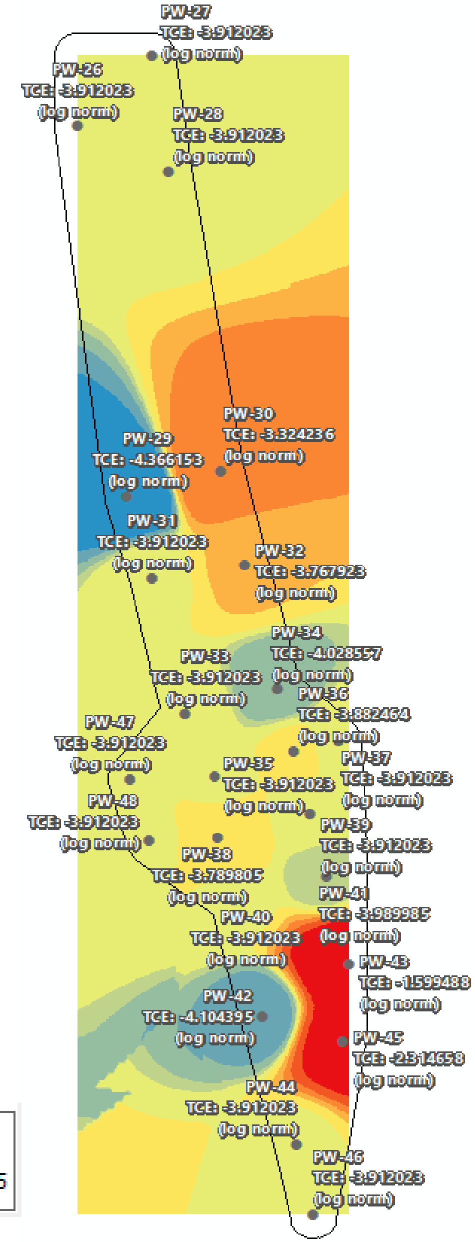


Predicted | Error

Regression function	0.46654603310491 * x + -2.04283935760356
Prediction Errors	
Samples	23 of 23
Mean	0.02104491
Root-Mean-Square	0.5116132
Export Result Table	

< Back | Next > | Finish | Cancel

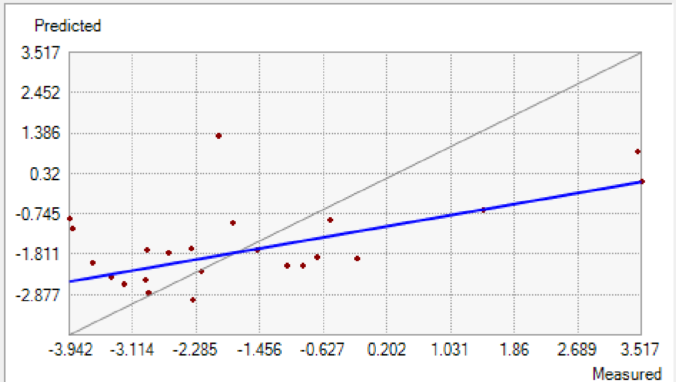




DCE Power 2 – Log transformed

Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

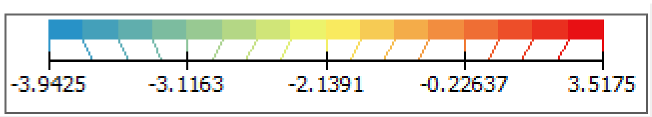
Source ID	Included	Measured	Predicted	Error
1	Yes	-3.228...	-2.594...	0.6339401700954164
2	Yes	-2.907...	-2.806...	0.10159580544754387
3	Yes	-2.340...	-2.991...	-0.6509017382530322
4	Yes	-2.941...	-1.693...	1.2480727691009068
5	Yes	-1.491...	-1.678...	-0.18683876345983386
6	Yes	-2.357...	-1.650...	0.7060863985807657
7	Yes	-0.197...	-1.912...	-1.7152965798369868
8	Yes	-2.225...	-2.250...	-0.0251184769923376
9	Yes	-0.715...	-1.879...	-1.1637969289921086
10	Yes	-2.649...	-1.761...	0.8874667694748548
11	Yes	-0.896...	-2.107...	-1.2105180165830238
12	Yes	-3.942...	-0.852...	3.089885663288194
13	Yes	-1.111...	-2.079...	-0.9679758276282706
14	Yes	-0.549...	-0.905...	-0.35533715117812126
15	Yes	-1.820...	-0.967...	0.85267090755532
16	Yes	1.4445...	-0.628...	-2.0731994682079273
17	Yes	-2.002...	1.346...	3.3490896160502746
18	Yes	3.4688...	0.919...	-2.5489442052796036
19	Yes	-3.912...	-1.107...	2.8045181641808266
20	Yes	3.5174...	0.122...	-3.395244387683246
21	Yes	-3.408...	-2.392...	1.0157943465274957
22	Yes	-2.946...	-2.485...	0.4615744817375571
23	Yes	-3.649...	-2.023...	1.6266574925787811

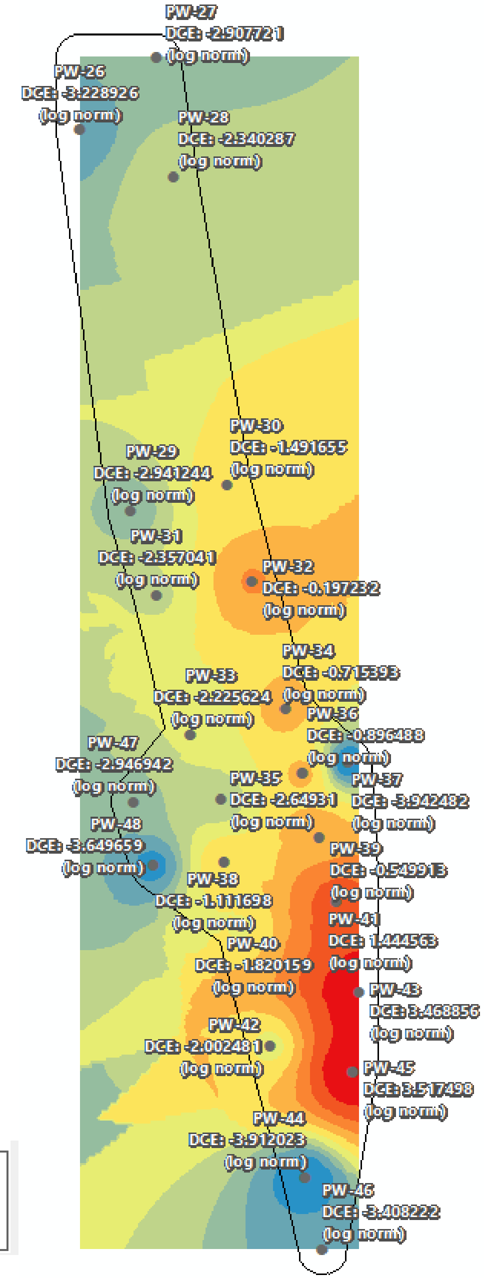


Predicted | Error

Regression function	0.352617391468907 * x + -1.14147480789...
Prediction Errors	
Samples	23 of 23
Mean	0.1080079
Root-Mean-Square	1.695397
Export Result Table	

< Back | Next > | Finish | Cancel

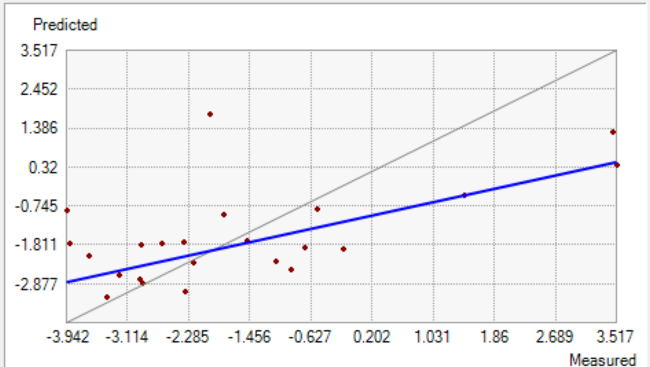




DCE Power 3 – Log transformed

Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

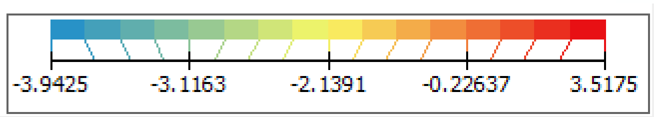
Source ID	Included	Measured	Predicted	Error
1	Yes	-3.228...	-2.614...	0.6140946991711305
2	Yes	-2.907...	-2.864...	0.04276110079167417
3	Yes	-2.340...	-3.063...	-0.7231600258224855
4	Yes	-2.941...	-1.788...	1.1523570853057552
5	Yes	-1.491...	-1.681...	-0.18981770615193105
6	Yes	-2.357...	-1.722...	0.6346333603467178
7	Yes	-0.197...	-1.907...	-1.7102063146606992
8	Yes	-2.225...	-2.289...	-0.06338566229384623
9	Yes	-0.715...	-1.875...	-1.1597909942437075
10	Yes	-2.649...	-1.745...	0.9041489327036465
11	Yes	-0.896...	-2.478...	-1.5817006091805332
12	Yes	-3.942...	-0.847...	3.0949497997363156
13	Yes	-1.111...	-2.250...	-1.138485436993501
14	Yes	-0.549...	-0.818...	-0.26843014086352246
15	Yes	-1.820...	-0.974...	0.8458785110423173
16	Yes	1.4445...	-0.437...	-1.8824988312768214
17	Yes	-2.002...	1.766...	3.768672831818795
18	Yes	3.4688...	1.309...	-2.1589058403003625
19	Yes	-3.912...	-1.768...	2.143370824251965
20	Yes	3.5174...	0.397...	-3.120092620217707
21	Yes	-3.408...	-3.236...	0.1717333680923021
22	Yes	-2.946...	-2.736...	0.20994795841148317
23	Yes	-3.649...	-2.095...	1.5536809588912646

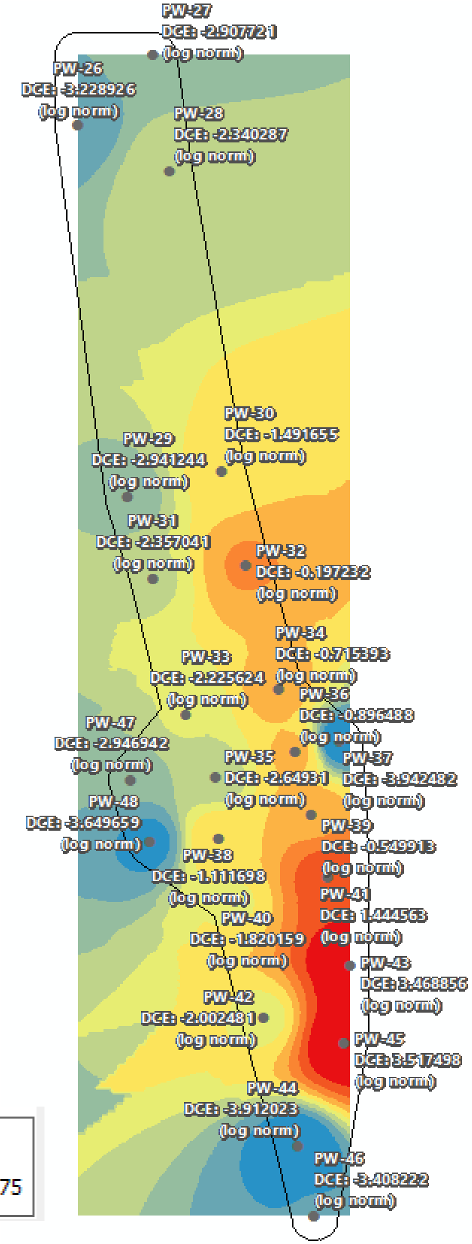


Predicted | Error

Regression function	0.440904145763519 * x + -1.09573045343...
Prediction Errors	
Samples	23 of 23
Mean	0.04955458
Root-Mean-Square	1.630528
Export Result Table	

< Back | Next > | Finish | Cancel

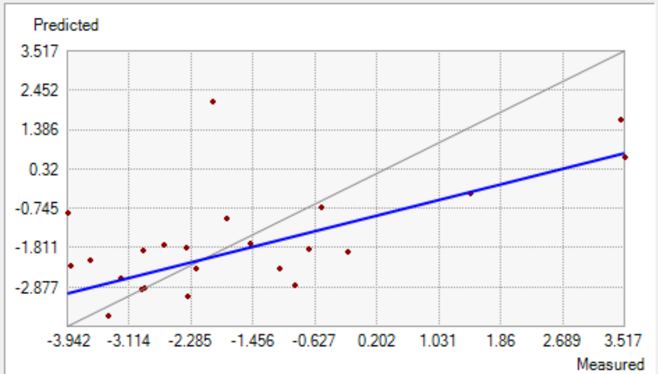




DCE Power 4 – Log transformed

Geostatistical wizard - Inverse Distance Weighting step 2 of 2 - Cross Validation

Source ID	Included	Measured	Predicted	Error
1	Yes	-3.228...	-2.620...	0.6085306688539154
2	Yes	-2.907...	-2.902...	0.0052752492632910375
3	Yes	-2.340...	-3.098...	-0.7582931184545663
4	Yes	-2.941...	-1.875...	1.0654175373243624
5	Yes	-1.491...	-1.669...	-0.17816506469796733
6	Yes	-2.357...	-1.794...	0.5623035410979709
7	Yes	-0.197...	-1.908...	-1.711413706258515
8	Yes	-2.225...	-2.347...	-0.12230613566784587
9	Yes	-0.715...	-1.819...	-1.1039910419519834
10	Yes	-2.649...	-1.712...	0.9369702743048194
11	Yes	-0.896...	-2.814...	-1.9176386166297794
12	Yes	-3.942...	-0.857...	3.084585925903287
13	Yes	-1.111...	-2.374...	-1.263173834328425
14	Yes	-0.549...	-0.688...	-0.1389392488837855
15	Yes	-1.820...	-0.991...	0.8289795788633927
16	Yes	1.4445...	-0.334...	-1.7795323605858895
17	Yes	-2.002...	2.151...	4.153771394101419
18	Yes	3.4688...	1.662...	-1.8059770379382367
19	Yes	-3.912...	-2.289...	1.6227325009303617
20	Yes	3.5174...	0.670...	-2.846650717748198
21	Yes	-3.408...	-3.637...	-0.2292576001087232
22	Yes	-2.946...	-2.935...	0.011467316936963456
23	Yes	-3.649...	-2.140...	1.5094002598095138



Predicted | Error

Regression function	0.509135074241383 * x + -1.04195845523...
Prediction Errors	
Samples	23 of 23
Mean	0.02322155
Root-Mean-Square	1.611277
Export Result Table	

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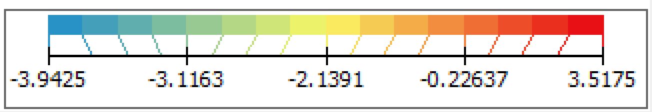

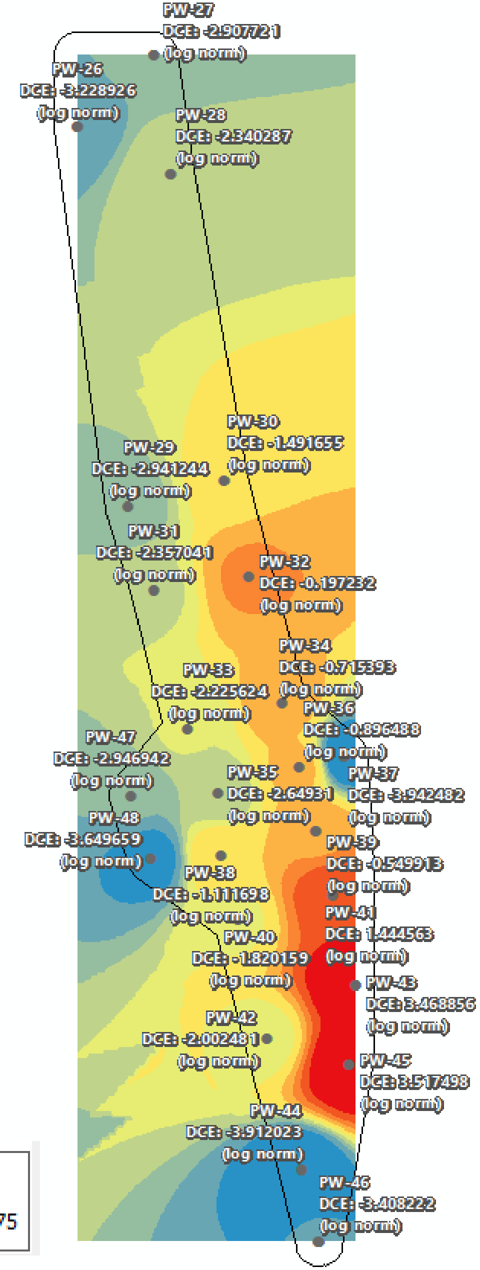

APPENDIX E

Restoration Time Frame Calculations for Porewater

E. Restoration Time Frame Calculations for Porewater

This appendix documents calculations for the estimated time to achieve remediation levels (RELs) in porewater in the Lower Duwamish Waterway (Waterway) at the South Fidalgo Street end. REL development for chlorinated volatile organic compounds (CVOCs) is detailed in Appendix C of this Site Unit 1 Feasibility Study Addendum (SU1 FS Addendum). Both remedial alternatives evaluated in this SU1 FS Addendum include ISCR/EAnB technology for groundwater treatment of the Downgradient TCE Plume. Treated groundwater will be generated in the ISCR/EAnB treatment transects in South Fidalgo Street in Alternatives 2A and 2B and an additional transect at the Waterway shoreline in Alternative 2B. Porewater RELs in the Waterway will be achieved through the arrival of treated groundwater, and the timing of arrival can be estimated based on groundwater travel time.

For this SU1 FS Addendum, restoration time frame of Waterway porewater was estimated based on the physical flushing of the aquifer matrix with treated groundwater from the treatment transects. This calculation was based on the required number of pore volumes to achieve RELs using a mixed linear reservoir model (Zheng et al, 1991). In the mixed linear reservoir model, the solute distribution is considered thoroughly mixed, thus the solute distribution in the contaminated zone is characterized by a single concentration, which changes instantaneously in response to inflow an outflow. This simplifying assumption is limitation of the mixed linear reservoir model. However, decades of applied groundwater remediation have demonstrated the applicability of the mixed linear reservoir model for estimating cleanup time frames downgradient of in-situ groundwater treatment transects (Suthersan et al, 2017). The use as a predictive tool for estimating time frames is most applicable for advection-dominated transport environments in large dissolved-phase solvent plumes. The applicability increases with flushing zone scale, where bulk hydrogeologic properties can envelop heterogeneities that dominate smaller scales.

The use of the mixed linear reservoir model to estimate time required to reach the Porewater RELs in each of the SU1 FS Addendum alternatives is described below.

Alternative 2A

The CVOC Pilot Study (Appendix A of this SU1 FS Addendum) demonstrated the ISCR/EAnB technology ability to treat groundwater and generate a clean water front for downgradient flushing. Alternative 2A includes two treatment transects in South Fidalgo Street. The restoration time frame calculation was completed based on the eastern-most transect located to represent the maximum time for porewater to achieve RELs. The distance from this transect to Waterway porewater is approximately 510 feet and is the assumed groundwater travel distance used in the calculations. The model was simulated for two scenarios:

- Time for TCE to reach Porewater REL of 3.2 µg/L. A starting concentration of 344 ug/L TCE was assumed (Table E-1).
- Time for VC to reach Porewater REL of 0.82 µg/L. A starting concentration of 184 ug/L VC was assumed (Table E-2).

Estimated time frames of 13 and 9 years were estimated for TCE and VC, respectively. Therefore, it is estimated that within 13 years, Porewater RELs would be achieved by Alternative 2A. This estimate is considered conservative because TCE is predicted to have the longer restoration time frame; however, TCE concentrations already achieve Porewater RELs.

Alternative 2B

Alternative 2B includes an additional treatment transect near the Waterway shoreline that would be located an estimated distance of 130 feet from porewater. This distance is the assumed groundwater travel distance used in the calculations. The model simulated time for VC to reach Porewater REL of 0.82 µg/L (TCE has not exceeded Porewater RELs at shoreline monitoring wells during recent sampling events). Based on an assumed starting concentration of 184 µg/L VC, an estimated time frame of 3 years to achieve Porewater RELs was estimated (Table E-3). An additional 2 years is required to design and implement Alternative 2B; therefore, it is estimated that within 5 years, Porewater RELs would be achieved in Alternative 2B. However, although Alternative 2B is predicted to achieve Porewater RELs 8 years faster, it is only estimated to reduce the restoration time frame for attaining CULs by approximately 30 percent.

The estimate of Alternative 2A is considered more accurate than Alternative 2B given the larger flushing distance, the pilot study effectiveness in South Fidalgo Street, and the hydrogeologic and geochemical uncertainties associated with treatment at the Waterway shoreline.

References

Suthersan S., J. Horst, M. Schnobrich, N. Welty, and J. McDonough (2017), Remediation Engineering – Design Concepts (Second Edition), CRC Press, 2017.

Zheng C., G.D Bennett, and C.B. Andrews, 1991, Analysis of Ground-Water Remedial Alternatives at a Superfund Site, Groundwater, 29(6), pages 818-925, November 1991.

Table E-1. Alternatives 2A - Estimate of Time to Reach Trichloroethene Porewater REL

Project No. 050067, West of 4th - SU1, Seattle, Washington

Calculations based on mixed linear reservoir model (Zheng et al, 1991)

$t = -\ln(Ct/Co) * PV_t * R$

where:

Ct = concentration at time t = cleanup level to be achieved
Co = Initial concentration
PV_t = time to flush 1 pore volume
R = retardation factor = $1 + (Kd * p_b/n)$
Kd = partition coefficient = $Koc*foc$
Koc = soil sorption coefficient
foc = organic carbon content
p_b = aquifer bulk density (g/cc = kg/L)
n = effective porosity

V	1	ft/d	Average groundwater seepage velocity, see footnote a.
Ct =	3.2	ug/L	Porewater REL for TCE
Co =	344	ug/L	December 2019 TCE concentration at PSW-5, immediately upgradient of CVOC pilot treatment transect
Pore volume (PV) length =	510	ft	Distance from upgradient treatment transect in South Fidalgo Street to Waterway porewater
PV_t =	1.4	year	Calculated based on groundwater seepage velocity and PV length
Koc =	94.3		Default value from WAC 173-340-747
foc =	0.001		Default value from WAC 173-340-747
Kd =	0.0943		Calculated
p_b =	1.5	kg/L	MTCA Default value
n =	0.15	dimensionless	Best professional judgement, see footnote b.
R =	1.9	dimensionless	Calculated
t =	**13**	**years**	

Notes:

a) The CVOC Pilot Study Completion Reports estimates 0.52 - 0.98 ft/day based on total organic carbon (TOC) breakthrough observed downgradient of treatment transect. The Darcy's law estimated seepage velocity of 0.9 - 1.9 ft/day was also reported in Completion Report. Since TOC is reactive in an aquifer, TOC transport velocity must be less than the average groundwater seepage velocity. Therefore, a 1 ft/d average groundwater seepage velocity is used for purposes of this estimate.

b) The batch flushing model is premised on advection-driven clean-water flushing that occurs in a small portion of the soil porosity that controls solute transport. Based on this premise, and the uniform, high permeability soils in the alluvial unit, a mobile porosity of 15% is assumed.

REL = Remediation Level

TCE = trichloroethene

Table E-2. Alternatives 2A - Estimate of Time to Reach Vinyl Chloride Porewater REL

Project No. 050067, West of 4th - SU1, Seattle, Washington

Calculations based on mixed linear reservoir model (Zheng et al, 1991)

$t = -\ln(Ct/Co) * PV_t * R$

where:

Ct = concentration at time t = cleanup level to be achieved
Co = Initial concentration
PV_t = time to flush 1 pore volume
R = retardation factor = 1 + (Kd* p_b/n)
Kd = partition coefficient = Koc*foc
Koc = soil sorption coefficient
foc = organic carbon content
p_b = aquifer bulk density (g/cc = kg/L)
n = effective porosity

V	1	ft/d	Average groundwater seepage velocity, see footnote a.
Ct =	0.82	ug/L	Porewater REL for VC
Co =	184	ug/L	Maximum VC concentration observed during CVOC pilot study.
Pore volume (PV) length =	510	ft	Distance from upgradient treatment transect in South Fidalgo Street to Waterway porewater
PV_t =	1.4	year	Calculated based on groundwater seepage velocity and PV length
Koc =	18.6		Default value from WAC 173-340-747
foc =	0.001		Default value from WAC 173-340-747
Kd =	0.0186		Calculated
p_b =	1.5	kg/L	MTCA Default value
n =	0.15	dimensionless	Best professional judgement, see footnote b.
R =	1.2	dimensionless	Calculated
t =	**9**	**years**	

Notes:

a) The CVOC Pilot Study Completion Reports estimates 0.52 - 0.98 ft/day based on total organic carbon (TOC) breakthrough observed downgradient of treatment transect. The Darcy's law estimated seepage velocity of 0.9 - 1.9 ft/day was also reported in Completion Report. Since TOC is reactive in an aquifer, TOC transport velocity must be less than the average groundwater seepage velocity. Therefore, a 1 ft/d average groundwater seepage velocity is used for purposes of this estimate.

b) The batch flushing model is premised on advection-driven clean-water flushing that occurs in a small portion of the soil porosity that controls solute transport. Based on this premise, and the uniform, high permeability soils in the alluvial unit, a mobile porosity of 15% is assumed.

REL = Remediation Level
VC = vinyl chloride

Table E-3. Alternatives 2B - Estimate of Time to Reach Vinyl Chloride Porewater REL

Project No. 050067, West of 4th - SU1, Seattle, Washington

Calculations based on mixed linear reservoir model (Zheng et al, 1991)

$t = -\ln(Ct/Co) * PV_t * R$

where:

- Ct = concentration at time t = cleanup level to be achieved
- Co = Initial concentration
- PV_t = time to flush 1 pore volume
- R = retardation factor = 1 + (Kd* p_b/n)
- Kd = partition coefficient = Koc*foc
- Koc = soil sorption coefficient
- foc = organic carbon content
- p_b = aquifer bulk density (g/cc = kg/L)
- n = effective porosity

V	1	ft/d	Average groundwater seepage velocity, see footnote a.
Ct =	0.82	ug/L	Porewater REL for VC
Co =	184	ug/L	Maximum VC concentration observed during CVOC pilot study
Pore volume (PV) length =	130	ft	Distance from shoreline treatment transect to Porewater (Alternative 2B)
PV_t =	0.4	year	Calculated based on groundwater seepage velocity and PV length
Koc =	18.6		Default value from WAC 173-340-747
foc =	0.001		Default value from WAC 173-340-747
Kd =	0.0186		Calculated
p_b =	1.5	kg/L	MTCA Default value
n =	0.15	dimensionless	Best professional judgement, see footnote b.
R =	1.2	dimensionless	Calculated
t =	**3**	**years**	

Notes:

a) The CVOC Pilot Study Completion Reports estimates 0.52 - 0.98 ft/day based on total organic carbon (TOC) breakthrough observed downgradient of treatment transect. The Darcy's law estimated seepage velocity of 0.9 - 1.9 ft/day was also reported in Completion Report. Since TOC is reactive in an aquifer, TOC transport velocity must be less than the average groundwater seepage velocity. Therefore, a 1 ft/d average groundwater seepage velocity is used for purposes of this estimate.

b) The batch flushing model is premised on advection-driven clean-water flushing that occurs in a small portion of the soil porosity that controls solute transport. Based on this premise, and the uniform, high permeability soils in the alluvial unit, a mobile porosity of 15% is assumed.

REL = Remediation Level
VC = vinyl chloride