

TREATABILITY TESTING WORK PLAN

Glacier Northwest Inc. Site

Prepared for: Glacier Northwest, Inc.

Project No. AS230067A • August 5, 2024 FINAL



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Aspect Consulting

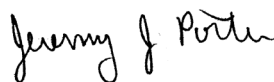


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Acronyms

Aspect	Aspect Consulting
ASTM	ASTM International
BFS	ground granulated blast furnace slag
bgs	below ground surface
COPCs	contaminants of potential concern
D/Fs	dioxins/furans
DGI	Data Gaps Investigation
DIW	deionized water
Ecology	Washington Department of Ecology
EPA	United States Environmental Protection Agency
ERM	Environmental Resource Management
FS	Feasibility Study
gpm	gallons per minute
mg/kg	milligrams/kilograms
mg/L	milligrams per liter
µg/L	micrograms per liter
LDW	Lower Duwamish Waterway
LEAF	leaching environmental assessment framework
MTCA	Model Toxics Control Act
PCE	tetrachloroethylene
PC	Portland cement
PCP	pentachlorophenol
PRB	permeable reactive barrier
psi	pounds per square inch
PVC	polyvinyl chloride
SB	soil-bentonite
SPLP	Synthetic Precipitation Leaching Procedure
S/S	solidification/stabilization
SVE	soil vapor extraction
TTWP	Treatability Testing Work Plan
UCS	unconfined compressive strength
ZVI	zero-valent iron

1 Introduction

Aspect Consulting (Aspect) has prepared this Treatability Testing Work Plan (TTWP) on behalf of Glacier Northwest, Inc. (Glacier) to support cleanup alternative development for the Glacier Northwest, Inc. Site (Site). The Site, as defined by the Model Toxics Control Act (MTCA) is “any area where a hazardous substance has been deposited, stored, disposed of, placed, or otherwise come to be located” and is associated with King County Tax Parcel No. 1924049292, located at 5900 West Marginal Way SW in Seattle, Washington (the Property). This TTWP was prepared to support the Feasibility Study (FS) for the Site, consistent with the Agreed Order No. DE 6000 (Agreed Order) entered with the Washington State Department of Ecology (Ecology). A Draft FS for the Site was previously submitted by Environmental Resource Management (ERM) in April 2020 (ERM, 2020b), followed by multiple rounds of Ecology comments and ERM responses. Those Ecology comments provide the basis for this TTWP.

This TTWP describes the approach and methods planned to evaluate solidification/stabilization (S/S) and permeable reactive barrier (PRB) technologies for evaluation in the FS. The goal of the treatability testing is to evaluate potential effectiveness of the technologies and determine design parameters that can be used in the FS to evaluate practicable application of the technologies for treating Site contaminants of potential concern (COPCs).

The following subsections provide background information relating to the Site and TTWP implementation. Sections 2 and 3 describe the test methodologies for S/S and PRBs, respectively. Section 4 provides references for the information cited in this document.

1.1 Project Description

The Site as defined in the Agreed Order consists of Tax Parcel No. 1924049029 (Property), which encompasses approximately 13.7 acres of uplands and 4.2 acres of aquatic property (Embayment) on the western shoreline of the Lower Duwamish Waterway (LDW).

Across the majority of the upland Property, the stratigraphy consists of 6.5 to 18.7 feet of shallow fill with anthropogenic debris and dredge fill material on top of a silt aquitard that ranges from 3.5 to 12 feet thick. The dredged fill material consists of well to poorly graded, fine to medium-grained sand, silty sand, and sandy silt. The silt aquitard is comprised of native floodplain/tidal deposits formed as the ground surface prior to dredging of the LDW, and it is underlain by the alluvial lower sand unit, which extends from between 15 and 20 feet below ground surface (bgs) to between 50 and 130 feet bgs. The lower sand unit consists of fine- to coarse-grained sand, with smaller quantities of silt and clay, which were deposited as high-energy alluvial deposits. The shoreline where the upland meets the Embayment at the eastern edge of the Property has been redeveloped numerous times during the history of both the Property and the LDW. A wooden bulkhead was constructed in 1922 within approximately 40 to 50 feet of the

current shoreline. The current shoreline was formed in approximately 1967 to 1968 as soil from the northern portion of the Property (which had been previously dredged and placed there) was used to expand the shoreline eastward. This bank fill material to the east of the bulkhead consists of a heterogeneous mix of silt, sand, gravel, and construction debris such as bricks, wood, and concrete. Historical Site operations have resulted in contamination primarily in the fill soils and silt aquitard, and in the groundwater present in both the fill and underlying sand aquifer units.

Two distinct aquifers are present at the Site: shallow, unconfined groundwater is present within the shallow and dredged fill material at depths between 4 and 13 feet bgs, and deep, confined groundwater is present within the lower alluvial sand unit. These two systems are hydraulically separated by the native silt floodplain/tidal deposits, which act as an aquitard.

Field parameter data provided in Appendix Z of the Remedial Investigation report (ERM, 2020a) was evaluated for prevalence of salinity in Site groundwater. The salinity observed in shallow wells between Spring 2010 and Fall 2015 varied between approximately 0.1 to 0.5 percent, which is within the range of typical groundwater salinity. The sole exception was MW-27. MW-27 is located on the south-adjacent Terminal 115 property, on the edge of the Embayment in a portion of that property that was created by anthropogenic filling between approximately 1967 and 1974. The well is also adjacent to a 48-inch-diameter stormwater main and outfall that likely serves as a preferential flowpath for more saline surface water from the LDW to infiltrate the shallow aquifer during high tide cycles. Salinity in the deep groundwater unit monitoring wells varied between approximately 0.3 to 1.2 percent, coinciding with distance from the LDW.

This TTWP evaluates S/S for decreasing the leachability of arsenic, copper, pentachlorophenol (PCP), and dioxins/furans (D/Fs) in Site soils. S/S treatability testing will involve field soil and groundwater sample collection; mixing soil, water and reagents in an array of S/S designs; and conducting lab-based physical and chemical tests to evaluate treatment performance.

The treatability testing will also evaluate using a zero-valent iron (ZVI)-based PRB to decrease concentrations of arsenic, copper, and PCP in Site groundwater. PRB treatability will be tested by constructing columns filled with sand and ZVI, pumping Site groundwater through the columns, and sampling the water to evaluate treatment performance.

A Data Gaps Investigation (DGI) consisting of collection and analysis of soil and groundwater samples from the Site will be conducted to close data gaps identified during the FS. The DGI field work will provide an opportunity to identify sample locations and to collect soil and groundwater to be used in treatability testing. As a result, specific sample locations are not identified in this TTWP and will be selected based on DGI results.

1.2 Roles and Responsibilities

The following parties will be responsible for TTWP implementation:

- **Engineer** – Responsible for writing, revising, and facilitating this TTWP, including design and oversight of sample collection, treatability testing, and analysis of test results. The Engineer will also implement PRB column testing. Aspect Consulting is the Engineer.
- **Driller** – Subcontracted by Engineer to conduct drilling field services required to collect soil samples. The Driller is anticipated to be the same contractor to perform DGI drilling.
- **Geotechnical Lab** – Subcontracted by Treatability Testing Lab to perform geotechnical analysis of soil samples and treated soil mixes.
- **Treatability Testing Lab** – Subcontracted by Engineer to perform treatability testing and coordinate baseline chemical analyses.
- **Analytical Labs** – Subcontracted by Engineer and Treatability Testing Lab to perform chemical analysis of soil and water samples. Different analytical labs may be used for S/S and PRB testing.

1.3 Reporting and Schedule

Treatability testing results will be compiled and discussed in a comprehensive report following completion of both treatability tests. All field data, sample collection logs, lab analytical reports, calculations and analysis will be provided as attachments to the report. Results, conclusions, and recommendations for remedial technology selection, application, and design will be included in the report.

Treatability testing will be conducted after the DGI field work is completed and results are available. The FS Data Gaps Work Plan will describe how TTWP media collection will be integrated with DGI field work. A typical schedule for a S/S treatability study requires up to 150 days to complete and at a minimum includes 2 to 3 days for sample collection, 15 days for initial contaminant characterization and physical testing, 2 to 3 days for sample homogenization and sample molding, 28-day curing time, 63-day LEAF testing, 15-day turnaround for analytical results, and 10 days to process data. The results report will be submitted to Ecology no later than 90 days after treatability testing analytical results are available.

2 S/S Treatability Test Work Plan

2.1 Background

The S/S technology was evaluated in the Draft FS (ERM, 2020b) to reduce leachability of Site COPCs including arsenic, copper, PCP, and D/Fs from soil to groundwater. S/S was included in several remedial alternatives for treatment of upland and bank soils. Evaluation of S/S in the draft FS included bench-scale treatability testing, which is summarized in Section 2.2.

S/S treatability review and testing will focus on arsenic because arsenic contamination represents the most significant source of risk among COPCs, and because the arsenic treatment area is likely the largest and will include treatment of other COPC sources.

2.1.1 Completed Treatability Testing

Preliminary, bench-scale S/S treatability testing was performed in 2020. Methods were detailed in Ecology's approved October 2018 5900 West Marginal Way Site Proof-of-Concept Treatability Testing Work Plan (Work Plan; Anchor QEA and ERM, 2018) and deviation notifications summarized in May 28, 2019, and November 7, 2019, emails to Ecology. Results were summarized in a report provided in the Draft FS Appendix II entitled "Treatability Testing."

The S/S treatability testing component evaluated two approaches for reducing arsenic mobility: (1) S/S using a mixture of ferrous sulfate and Portland cement (PC), and (2) arsenic sequestration by inducing sulfate-reducing conditions to promote formation of biogenic sulfides. Treatment effectiveness was evaluated by performing a modified synthetic precipitation leaching procedure (SPLP) test on treated soils and controls using groundwater from upgradient monitoring well MW-23S as leaching fluid.

The first test consisted of mixing two reagent combinations with Dredge fill and Aquitard soils: 5 percent PC with 1 percent ferrous sulfate by dry weight, and 5 percent PC with 2 percent ferrous sulfate by dry weight. The 1 percent and 2 percent ferrous sulfate mixes reduced SPLP arsenic concentrations from Dredge Fill soil by 85 percent and 94 percent, respectively. The mixes applied to Aquitard soil each reduced SPLP arsenic concentrations by 43 percent. The difference in performance between the soils was attributed to arsenic being bound more strongly to Aquitard soil than to Dredge Fill soil.

Biogenic sulfate reduction-sulfate sequestration testing consisted of amending soils with ferrous sulfate at doses of 1 percent and 2 percent by dry weight. Small amounts of lactate and ammonium phosphate were also added to promote microbial activity. The treated soils were incubated under anaerobic conditions, sampled, and tested by SPLP at 14, 28, and 42 days. For Dredge Fill, arsenic leachability was initially reduced by more than 90 percent, but with 1 percent dose, leachability increased over time. For aquitard soils, treatment was not effective and increased arsenic leachability from the aquitard soil. In situ S/S was therefore determined to be a more feasible option for soil remediation at the Site.

2.1.2 Case Studies

Existing S/S implementation case studies were reviewed to understand the effect of S/S on downgradient arsenic concentrations and the effect of S/S on downgradient pH.

Solidification/stabilization was used to treat arsenic in soil at the Boeing Isaacson-Thompson site in 1991 (Landau, 2023). Arsenic concentrations in unsaturated soil greater than 200 milligrams per kilogram (mg/kg) were targeted for treatment. Saturated soil was not treated. Treatment reagents included cementitious materials and soluble silicate solutions, which may have transported to saturated soil and increased soil and groundwater pH. North of, and below, the stabilized mass, arsenic concentrations greater than 200 mg/kg were left in place, untreated (Figures 3-9 and 5-7 of the Boeing Isaacson-Thompson FS; Landau, 2023). Currently, arsenic concentrations as high as 285,000

micrograms per liter ($\mu\text{g/L}$) remain in groundwater (Figure 3-6; Landau, 2023), and the highest concentrations are co-located with untreated soil below and cross-gradient (Figure 3-1c; Landau, 2023) of the solidified mass. Figure 3-24 of the FS indicates that while groundwater pH below the stabilized mass is elevated, groundwater downgradient (west) of the stabilized mass fluctuates throughout the year, ranging from 5.3 to 9.43, but primarily remaining circumneutral (6 to 8). Most notable are IT-MW-18 and IT-MW-21, located immediately downgradient of the stabilized mass and ranging from 5.3 to 7.73. Figure 5-7 of the FS (Landau, 2023) indicates monitoring well screens span from below the water table to above the water table and into the solidified mass. Results from this site indicate that the extent of treatment, selection of treatment reagents, and approach for implementation have a significant impact on treatment performance, and that S/S using cementitious materials may not result in pH leaching or elevated downgradient pH.

A Portland cement stabilization treatment was applied to soil at the Diversified Industries Everett site to reduce leaching of metals in 2014 (ZGA, 2023). The treatment appears to have effectively reduced dissolved arsenic concentrations in downgradient groundwater: arsenic concentrations in groundwater at the primary downgradient monitoring well decreased steadily from 540 and 510 $\mu\text{g/L}$ of total and dissolved arsenic, respectively, to 280 and 270 $\mu\text{g/L}$, respectively, in 2017 and to 60 $\mu\text{g/L}$ dissolved arsenic in 2022. MTCA-compliant results ($<5 \mu\text{g/L}$) for downgradient wells MW-9, MW-10, MW-12, MW-106, and MW-107 indicate that arsenic in groundwater is not migrating off-property. Limited pH data is available for the site, and the only pre-treatment data available indicate soil pH readings of 7.6 and 10.5 in areas upgradient of stabilization (Shannon & Wilson, 2004; Table 6). Sample collection logs from 2022 indicate a pH of 5.76 at MW-7, indicating the connection between soil, stabilization, and groundwater pH is not well understood at the site. Results from this site indicate that S/S can effectively reduce arsenic groundwater concentrations.

At the Pacific Car and Foundry site in Renton, excavation and immobilization (stabilization) of soils containing lead, chromium, arsenic, and carcinogenic polycyclic aromatic hydrocarbons concentrations greater than their respective action levels was conducted between 1995 and 1997 to prevent direct contact and protect groundwater quality. Only six of 280 soil samples analyzed for arsenic during the remedial investigation exceeded 100 mg/kg (Haley & Aldrich, 2023). It has previously been postulated that the presence of arsenic in groundwater may be caused, in whole, or in part, by natural conditions, but this has not been confirmed. There were only two instances of arsenic exceeding 20 $\mu\text{g/L}$ since 1998, at concentrations of 21 and 37 $\mu\text{g/L}$ in 1998 and 2003, respectively. Statistical analysis of groundwater arsenic concentration trends at key compliance monitoring wells since 1998 indicates that arsenic concentrations are decreasing at one well, probable decreasing at one well, stable at two wells, increasing at one well, and there is no trend at one well. pH readings were rarely outside the circumneutral range of 6 to 8 between 1998 and 2021, indicating stabilization did not elevate pH to the extent that could notably affect arsenic mobility (pH greater than 9). Results from this site indicate that S/S may not be effective for reducing groundwater arsenic concentrations close to area background, and that S/S did not notably affect groundwater pH.

Soil stabilization was used to treat volatile organic compounds and metals at the Park Redevelopment Area site in Newark, California. (ERM, 2023). pH in groundwater monitoring wells within 20 feet of stabilization footprint (W-75, W-83, W-84, W-85) ranged from 6.75 to 7.34 prior to ISS. The maximum pH measured during the eleven quarterly sampling events at these four wells following the start of construction in February 2020 was 8.14.

2.1.3 Riverbank Soils

The Draft FS assembled multiple alternatives that included riverbank stabilization. In response to Ecology comments, further description of methods and constructability for riverbank stabilization will be evaluated in the next FS draft. As described in Section 1.1, the riverbank soil is primarily made up of the bank fill material described in Section 2.8.2.5 of the Remedial Investigation report (ERM, 2020a), which consists of a heterogenous mixture of silt, sand, gravel, and debris. Based on its composition, we anticipate the upland soil testing should be directly applicable to riverbank soils.

2.1.4 Salinity

The primary S/S concern relating to salinity is the abundant sulfate present in seawater decreasing the durability of the monolith through sulfate attack. Sulfates can cause structural problems for concrete and cement products after reacting with tricalcium aluminate (C3A) and causing delayed ettringite formation through the following process:

1. Gypsum forms when sulfates react with $\text{Ca}(\text{OH})_2$ in hardened cement.
2. Gypsum reacts with hydration products of C3A (calcium-alumino-monsulfohydrate $\text{C}_4\text{ASH}_{12}$) to form ettringite.

Ettringite is an expansive crystalline mineral. When ettringite is formed in hardened cement, concrete or a soil/cement matrix (e.g., S/S), volume expansion occurs which creates large internal forces and cracking of the cementitious matrix. These cracks allow for further infiltration of sulfate which accelerates deterioration of the cement.

While the extent of S/S is not currently anticipated to occur within saline groundwater, shoreline stabilization will be exposed to brackish water from the LDW. Cements with low C3A content, such as marine cement, Type V cement, or ground granulated blast furnace slag (BFS) are frequently used to effectively mitigate sulfate attack and will be included in treatability testing.

2.2 S/S Treatability Testing

Trial mixes of treated soil will be evaluated through lab-based testing using soil and water samples collected from the Site mixed with treatment reagents. Treatability testing will evaluate the performance of mix designs and design parameters for use in ferrous sulfate evaluation and full-scale treatment design and technical specifications. Further information about the roles and responsibilities of parties involved in treatability testing is provided in Section 1.2.

2.2.1 Objectives and Performance Criteria

S/S as a remediation technology targets reduction of contaminant flux from soil to groundwater by solidifying a soil mass and reducing its hydraulic conductivity. S/S is

constructed by mixing cementitious reagent(s) with impacted Site soils, resulting in a solidified monolith of increased strength and reduced hydraulic conductivity in comparison to the existing Site soil conditions. After S/S, groundwater, which may be mounded behind the solidified mass, is ultimately diverted around the solidified treatment zone, limiting contact of groundwater with treated soils (i.e., practically excluding continued advection and dispersion). Thereby, release is controlled by diffusion to the boundary of the solidified treatment zone reducing leaching of contaminants to groundwater.

The treatability testing will evaluate the efficacy of different S/S mix designs and results will be evaluated based on the following strength, hydraulic conductivity, and leachability performance criteria:

1. Achieve an unconfined compressive strength of at least 50 pounds per square inch (psi) according to ASTM International (ASTM) D1633.
2. Achieve an average hydraulic conductivity of the treated soils equal to or less than 1×10^{-6} centimeters per second (cm/s) according to ASTM D5084D (flexible wall permeameter).
3. Reduce leachability of arsenic as determined by EPA's leaching environmental assessment framework (LEAF; SW-846 Method 1315). The reduction in arsenic leaching from the treated monolith will be evaluated in the FS with respect to proposed remediation levels, cleanup levels, points of compliance, and components of the assembled remedial alternatives yet to be determined.

A fourth objective considered during development of this work plan, but ultimately omitted from the objectives of this work plan, was to evaluate the potential for S/S to enhance leaching of contaminants into downgradient groundwater due to elevated pH or other secondary S/S effects on groundwater. After evaluating several options for leach testing, we concluded that while results may capture a worst-case scenario, they would not incorporate the primary factors mitigating downgradient leaching: aquifer buffering capacity and groundwater flow volume relative to monolith surface area. We believe the case studies provided in Section 2.1.2 provided promising data, and that a field pilot test would be more appropriate for evaluating this effect. If the pilot test is conducted, it would likely be implemented pre-remedial design. If the pilot test indicates potential for downgradient leaching, pH increase could be addressed during engineering design. For example, a soil-bentonite (SB) slurry wall could be installed along the perimeter of the S/S monolith during full-scale implementation, minimizing contact between ambient groundwater and the monolith, thereby reducing geochemical influence of the monolith on groundwater. Other approaches during engineering design could also be employed to mitigate downgradient leaching, if necessary.

2.2.2 Treatability Test Media

Soil and water will be collected from the Site and reagents will be ordered from suppliers and used in treatability testing.

2.2.2.1 Soil

Soil will be collected from the Site and shipped to the Treatability Lab for testing. Soil will be collected from three areas representing different soil conditions at the Site:

- Soil #1 will be collected from an area known to contain high arsenic concentrations in soil and groundwater, and will represent the center of the S/S treatment area.
- Soil #2 will be collected from an area known to contain lower arsenic concentrations. Soil #2 would be considered representative of soils on the perimeter of the S/S treatment area, and where groundwater contact and thus leaching would predominantly occur.
- Soil #3 will be collected from the same area as Soil #1, but will include a vertical interval that extends through the silt aquitard and into the alluvial sands if elevated concentrations of COPCs are detected in the alluvial sands.

Specific soil collection locations will be selected based on the results of the DGI and after this TTWP is approved by Ecology. Riverbank soils are made up of a dredge fill that is similar to the upland shallow soils but has been previously redistributed during shoreline improvements in the late 1960s; therefore, upland soil S/S is expected to perform similar to riverbank soils, and riverbank soils will not be tested separately.

Soil samples will be collected using sonic drilling. Continuous soil cores will be collected using a core barrel, logged, and classified using the Unified Soil Classification System. Only one core is anticipated to be required to achieve the target volume at each location, however multiple cores may be collected from adjacent boreholes, if needed, to provide enough material for a single sample. Soil from the anticipated depth of shallow saturated soil treatment will be removed from the core for testing: 5 to 12 feet bgs (1 foot into the silt aquitard). This interval consists primarily of dredge fill, with limited shallow fill and silt aquitard. The organic carbon content and anthropogenic debris make this material an appropriate and conservative choice for performance evaluation. Three 5-gallon buckets of Soil #1, two 5-gallon buckets of Soil #2, and one 5-gallon bucket of Soil #3 will be collected and shipped to either the Treatability Lab or the Geotechnical Lab, depending on the contracted Treatability Lab's proposed methods. At the lab, soil from the target interval at each location will be homogenized for testing, and sieved to remove debris and particles larger than ½ inch diameter. Required sample volumes will be verified with the selected Treatability Testing Lab prior to implementation.

Undisturbed sample for bulk density testing will be collected using a Shelby tube sampler advanced through the sonic drill casing, in front of the cutting head. Bulk density samples will be stored and transported separately from the bulk, homogenized samples collected for mix testing.

2.2.2.2 Water

Water from three on-Site sources will be collected and shipped to the Treatability Lab to be used in testing:

- Water #1 will consist of shallow groundwater containing moderate concentrations of arsenic exceeding the screening level, collected from the anticipated treatment area.
- Water #2 will be tap water from an on-site source, representing makeup water used during mixing.
- Water #3 will be deionized water made anaerobic by nitrogen sparging and will be used as an eluent for leach testing

Specific water collection locations will be selected based on the results of the DGI and after this TTWP is approved by Ecology. Approximately 5 gallons of tap water will be collected from the Site to be used as makeup water for the reagent mixture. The volume of groundwater required for treatment mixes and leachability testing will be determined by the Treatability Lab prior to sampling.

2.2.2.3 Treatment Reagents

Test Reagents will include PC and BFS. A regionally-available Type I/II or Type IL PC (ASTM 150/150M), Type V PC (ASTM 150/150M) and grade 100 or 120 BFS (ASTM C989/989M) will be provided by CalPortland. Type V PC was included for its potential use in riverbank stabilization, where its added resistance to sulfate attack will improve S/S durability and performance (see Section 2.1.4). The specific sources of the PC and BFS will be noted in the treatability testing results report.

BFS was selected because its reactivity is driven by PC hydration byproducts, which creates a synergy with PC. Past treatability testing has shown hydraulic conductivity reduction and unconfined compressive strength can be improved when a mix of PC and BFS is used compared to an equivalent dosing of PC alone.

Ferrous sulfate, which was included in preliminary testing, will not be used, as the chemical stabilization it provides is not necessary to achieve performance objectives. Additionally, preliminary treatability testing showed that ferrous sulfate was not effective in aquitard soil and contrarily enhanced leachability of arsenic. See Section 2.1.1 for a summary of preliminary treatability testing. Furthermore, chemical stabilization can be reversed by changes in groundwater geochemistry, making the approach less permanent.

2.2.3 Treatability Test Design

Treatability testing will include baseline media characterization, mixing treated soil cylinders, and physical and chemical testing of the mix cylinders.

2.2.3.1 Media Characterization and Baseline Testing

Each soil collected for treatability testing will undergo physical and chemical testing to characterize baseline properties. Each soil will be analyzed for COPCs targeted for S/S treatment including arsenic, copper, PCP, and D/Fs. Soil will also be analyzed for pH, moisture content, grain size distribution, Atterberg limits, organic content, and compaction. Table 1 summarizes baseline analytes and methods for each soil sample.

Site groundwater and tap water will be tested for pH, redox potential, dissolved oxygen, specific conductivity, and turbidity at the time of collection, and again once the sample

has arrived at the treatability laboratory. At the lab, each water source will be analyzed for arsenic, copper, PCP, and D/Fs.

Each untreated soil will be leach tested using site groundwater to establish a baseline for leach test performance using LEAF SW-846 Method 1316: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio. The leachate will be analyzed for total and dissolved arsenic. The results will be used to estimate reduction in leachability to evaluate treatment performance.

2.2.3.2 Test Mixes

PC and BFS will be mixed with soil and water to create a total of 22 test mixtures as summarized in Table 2. Soil #1 and Soil #2 will be mixed with total cement contents of 4 percent, 6 percent, 8 percent, and 10 percent, with varying percentages of PC and BFS. A limited number of mixes will be tested with Soil #3 and with Type V cement. Mix water will consist of 50 percent Water #1 and 50 percent Water #2. Ratio of mix water is based on ideal water-to-cement ratios as well as practical limitations and past experience as shown in Table 2. The optimum total water (i.e., water available from soil moisture measured by ASTM D2216 plus water used to develop mix design grout) to reagent ratio is between 2.0 to 5.0. If mix design grout calculations fall outside of this range (i.e., < 2.0 or > 5.0) the grout water to cement ratio may be adjusted from Table 2 to add or reduce moisture as necessary within a range of 0.8 to 2.0.

Each selected treatment condition will be prepared and cured in general accordance with ASTM D1632, Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory for up to a 56-day period. If 28-day test results are sufficient to select a mix that achieves performance targets, curing may end after 28 days.

2.2.3.3 Treatability Testing

Treatability testing will be conducted in two sequential phases. Phase 1 will consist of unconfined compressive strength testing and hydraulic conductivity testing, together referred to as physical testing. Phase 2 will consist of leach testing a subset of mixes based on the results of physical testing.

2.2.3.3.1 Phase 1 - Physical Testing

Physical properties of the cured and uncured mixtures will be tested to evaluate treatment performance and field constructability factors.

Properties of the uncured grout will be tested prior to casting cylinders to evaluate workability of the slurry mixture. Test methods will include Grout Density (ASTM D4380), Grout pH (API RP 13B-1), and Grout Viscosity (ASTM D6910). Only the Soil #1 grout will be tested, as the Soil #2 mixes are expected to perform similarly.

Cured mix strength will be tested using unconfined compressive strength (UCS) by ASTM D1633 and hydraulic conductivity will be tested using ASTM D5084. The eight Soil #1 mixes will be tested at 7 days, and six of eight mixes will be selected based on results and carried forward. The selected mixes will be tested for UCS and hydraulic conductivity at 28 days for both Soil #1 and Soil #2. Soil #1 mixes will also be tested for volumetric expansion at 28 days using simple volume measurements. Two mixes of each soil will be tested in duplicate for hydraulic conductivity at 28 days. If needed, up to two

additional samples of each soil will be analyzed for UCS and hydraulic conductivity after 56 days. The three Soil #3 mixes and three Type V cement mixes will be tested for UCS at 7 days and 28 days, and for volumetric expansion at 28 days. Up to two mixes of each may be tested for UCS at 56 days, contingent on 28-day results.

2.2.3.3.2 Phase 2 – Mix Leach Testing

The leachability performance will be evaluated using EPA's LEAF SW-846 Method 1315 for mass transfer rates of constituents in monolithic or compacted granular materials using a semi-dynamic tank leaching procedure. This leaching test was developed specifically for larger monoliths and thereby better represents in situ leachability than do leaching test methods like the Toxicity Characteristic Leachate Procedure or Synthetic Precipitation Leaching Procedure (SPLP) that require particle size reduction.

Water #3 (anaerobic deionized water) will be used as an eluent. The water will be made anaerobic by sparging with nitrogen, and parameters including redox potential will be measured prior to leach testing. Two mixes of Soil #1 and #2 will be selected for leach testing based on the results of Phase 1. Samples will be analyzed after curing 28 days. If deemed necessary based on 28-day physical testing results, samples will instead be leach tested after contingent 56-day UCS analysis is performed. Leachate from all samples will be analyzed for pH, redox potential, arsenic, PCP, copper, and D/F. Arsenic and PCP will be analyzed in duplicate.

3 PRB Treatability Test Work Plan

The Draft FS (ERM, 2020b) identified hydraulic control through groundwater extraction as a primary component of several remedial alternatives. PRBs present an alternative means of controlling COPC mass discharge into the LDW while reducing the ongoing operations and maintenance cost of a mechanical system and reducing reliance on the integrity of the historical bulkhead.

This TTWP describes the means and methods for evaluating potential performance and determining design parameters of a ZVI PRB for treating arsenic in groundwater. Treatment of PCP and copper will also be evaluated, although they are not the primary COPCs targeted for treatment. Treatment of other chlorophenols will not be evaluated because the maximum screening level exceedance factors observed at the Site are six orders of magnitude lower than that of PCP (ERM, 2020a; Appendix V, Table V-3). The PCP treatment performance evaluation will therefore address broader chlorophenol treatment given that PCP is the chlorophenol most resistant to reductive dechlorination by ZVI. ZVI is not expected to notably treat other COPCs including polycyclic aromatic hydrocarbons, petroleum hydrocarbons, D/Fs, and polychlorinated biphenyls.

3.1 Salinity

The effect of salinity or total dissolved solids on ZVI PRB performance can range from improved treatment efficiency (Tao et al., 2023) and depassivation (Liu, Li, and Waite, 2013) to decreased treatment efficiency (Su and Puls, 2001), and permeability reduction

(Xin et al., 2018), depending on the concentrations and species of dissolved solids and geochemical composition of the water (Mak, Rao, and Lo, 2009). For this reason, we will incorporate saline Site water into column testing to evaluate Site-specific performance effects.

3.2 Treatment Media

ZVI will be the PRB treatment media. The effective removal of arsenic from groundwater by ZVI in a PRB has been demonstrated in previous studies (Su, 2007; Beak and Wilkin, 2009). The primary removal mechanisms include adsorption to and co-precipitation with fresh forms of iron that are produced as the ZVI corrodes, such as oxides, sulfides, carbonates, and carbonate/green rusts (Beak and Wilkin, 2009). Treatability testing, which includes column testing and geochemical evaluation, is necessary to evaluate the demonstrated technology under Site-specific conditions.

3.3 Column Testing

Flow-through column testing will be conducted to achieve the following objectives:

1. Verify ZVI reactivity in the presence of Site groundwater.
2. Collect basis of design parameters reaction rate and arsenic uptake capacity for determining PRB width and iron content.
3. Evaluate secondary water quality factors that may impact PRB performance (i.e., mineral precipitation).

Column testing will be conducted at the Site using groundwater pumped at a low flowrate from a Site groundwater monitoring well as the column influent. The testing will be conducted on-Site because groundwater at the Site is anaerobic and reducing, and it is considered impractical to maintain reducing conditions during transport of the volume of groundwater required for off-Site column testing. Flow-through columns will be operated by in-line groundwater routing to minimize exposure to air and maintain the in situ groundwater redox potential to the greatest extent practicable.

Three columns will be operated with a test variable of ZVI percentage: 20 percent ZVI, 50 percent ZVI, and a control column. ZVI will be mixed with sand for packing columns. The control column will be packed with sand only. The ZVI and sand will be procured from sources selected by the Engineer and approved for construction use. We anticipate using a Connelly -8+50 ZVI (CC-1004), and a quartz sand selected from local sources to match ZVI gradation.

A fourth column filled with 20 percent ZVI and tested using saline water will be contingent on results of the DGI. If DGI sampling results indicate that a new monitoring well contains arsenic exceeding the groundwater screening level, contains substantial salinity, and is located in an area where a PRB may be considered, water from that well may be used in the fourth column test to evaluate the effect of salinity on PRB performance.

The columns will be 3 inches in diameter and 36 inches long and be constructed of PVC. Each column will be constructed with three sample ports located approximately 6 inches (Port 1), 12 inches (Port 2), and 24 inches (Port 3) from the bottom of the column.

Aliquots of dry ZVI reactive material and sand mix should be packed vertically in lift sections to achieve a homogeneous mixture. Estimated values of bulk density, porosity, and pore volume should be determined gravimetrically using field methods. Before beginning the test with Site groundwater, the columns will be prepped by flushing with carbon dioxide (CO₂) gas at the bottom of the columns for approximately 90 minutes to 2 hours to replace air contained in the pore spaces of the ZVI material. After the CO₂ flush, the column will be saturated with deionized water (DIW) until 1-2 liters of effluent has been collected. The flow will then be reduced to the desired flow rate (less than 100 milliliters per minute [mL/min]), and DIW will flow through the column for at least 4 hours prior to the introduction of Site groundwater. Site groundwater will then be pumped through the column at a high flow rate (up to 1,000 mL/min) to accelerate ion flux and initiate iron corrosion more rapidly. Iron corrosion occurs naturally as groundwater equilibrates with ZVI and is required for COPC treatment. Initiation of iron corrosion will be indicated by an increase in effluent pH. Influent flow rate will then be decreased to the target flow rate. The target flow rate will depend on groundwater flow velocity estimated and COPC concentrations measured during the DGI, and is anticipated to be less than 100 mL/min.

Column testing will be conducted at the location of the selected source groundwater monitoring well to minimize disturbance of column influent. The Site groundwater will be routed directly to the bottom end of the column and out of the top end by dedicated high-precision peristaltic pumps. The column study will be maintained until steady state is achieved. Steady state is achieved when arsenic concentrations at each distance along the column do not change significantly (less than the 20 percent relative percent difference [RPD]) between sampling events. If possible, the 20 percent column will be operated long enough to exhaust ZVI treatment and observe arsenic breakthrough. The duration of testing is intended to be flexible, and may be shortened if breakthrough is observed early, or lengthened if results are unexpected or if data indicates breakthrough is in progress but has not occurred.

Each column will be sampled approximately daily up to 10 times according to the monitoring plan in Table 3. The selected sampling frequency is intended to be flexible and may be adjusted based on DGI results or column test data. Influent and effluent groundwater of each column will be analyzed for total metals, dissolved metals, PCP, anions, alkalinity, total organic carbon, and ferrous iron. Total and dissolved metals to be analyzed are listed in Table 4. The sample ports will only be analyzed for total and dissolved arsenic. The sample ports of the 20-percent column and effluent of the control and 50-percent column will also be analyzed for total and dissolved copper. Only influent and effluent of the 50-percent column will be analyzed for PCP. All PCP analysis will be conducted at one-third of the frequency of the other analytes (approximately once every three days). Measurements of field parameters (pH, Eh, dissolved oxygen, and electrical conductivity) will be collected at influent, effluent, and the sample ports using a YSI meter with a flow-through cell. The Engineer will coordinate with the Analytical Lab to

determine the minimum sample volume required to achieve data quality objectives in order to minimize impact on column hydraulics and sample collection time.

Each column test sample will be assigned a unique sample identification number that includes the column name, the column sample location, and the 8-digit date on which the sample was collected. For example, a groundwater sample collected from the control column Port 1 on December 31, 2024, would be identified as Control-Port1-123124.

Upon completion of the column testing, the columns will be frozen and retained for contingent geochemical evaluations discussed in Section 3.3.2.

3.3.1 Data Evaluation

Geochemical evaluations will be performed to evaluate PRB treatment. Data evaluation may include evaluation of treatment kinetics, evaluation of arsenic treatment capacity, evaluation of potential precipitation through losses of pH/Eh sensitive species, and evaluation of potential downgradient effects based on effluent pH.

3.3.2 Contingent Geochemical Evaluations

Additional geochemical evaluations may be necessary if the results of column testing and geochemical modeling indicate excessive secondary mineral precipitation inside the PRB or potential mobilization of arsenic from soil downgradient of the PRB. The additional geochemical evaluations would include scanning electron microscopy and/or x-ray diffraction to pinpoint and identify mineralization occurring on the ZVI in the presence of Site groundwater or on-Site soils, or sequential extraction analysis to evaluate the forms of solid arsenic bound to the media. Either test could use spent column testing media (ZVI/sand) or Site soils.

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5 Limitations

Work for this project was performed for Glacier Northwest, Inc. (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 1. S/S Soil and Water Sample Testing

Project No. AS230067A Seattle, Washington

Media to be Tested		Soil #1	Soil #2	Soil #3	Water #1	Water #2	Water #3
Sample Description		Center of S/S	Edge of S/S	Edge of S/S, Includes Aquitard	Moderate COC concentrations	Tap Water	Anaerobic Eluent ¹
Analyte	Test						
Soil pH	ASTM D4972	X	X	X	--	--	--
Moisture Content	ASTM D2216	X	X	X	--	--	--
Grain-size Distribution	ASTM D422	X	X	X	--	--	--
Atterberg Limits	ASTM D4318	X	X	X	--	--	--
USCS Soil Classification	ASTM D2488	X	X	X	--	--	--
Organic Content	ASTM D2974	X	X	X	--	--	--
3-Point Proctor Test	ASTM D698	X	X	X	--	--	--
Bulk Density	ASTM D7263	X	X	X	--	--	--
Leach testing	LEAF EPA 1316	X	X	X	--	--	--
Arsenic and Copper	EPA 6020B	X	X	X	X	X	--
Pentachlorophenol	EPA 8270E LL	X	X	X	X	X	--
Dioxins/Furans - 17 Isomers	8290A	X	X	X	X	X	--
Total Dissolved Solids	SM 2540C/E	--	--	--	X	X	--
Salinity	SM 2520B	--	--	--	X	X	--
Sulfate	EPA 300.0	--	--	--	X	X	--
pH	EPA 9045	--	--	--	X	X	X
Field Parameters ²		--	--	--	X	X	X

Notes:

ASTM - ASTM International

EPA - United States Environmental Protection Agency

LL - low-level

SPLP - Synthetic Precipitation Leaching Procedure

LEAF - Leaching Environmental Assessment Framework

-- - not analyzed

1. Water #3 will be deionized water made anaerobic by nitrogen sparging and will be used as eluent for leach testing.

2. Field Parameters include pH, redox potential, electrical conductivity, dissolved oxygen, and turbidity to be measured at the time of sample collection (Waters #1 and #2) or prior to leach testing (Water #3)

Aspect Consulting

8/5/2024

V:\230067 West Marginal Way Cleanup Prjct\Deliverables\Treatability Testing WPI\Final\T1 - SS Soil and Water Testing_final

Table 1

Treatability Testing Work Plan

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Table 2. S/S Mix Design Testing

Project No. AS230067A, Seattle, Washington

Mix Properties							Phase 1 - Physical Testing								Phase 2 - Leach Testing											
Design Mix #	Soil #	Total Cement % by mass	Type I/II or IL PC % by mass	Type V PC % by mass	BFS % by mass	Water: Cement Ratio	Grout Testing 0 days	Pocket Penetrometer 1,3, 7 days	UCS Testing (ASTM D2166/D1633)				Moisture Content 28 days	Volumetric Expansion Testing 28 days	Hydraulic Conductivity (ASTM D5084D)			Semi-Dynamic Tank Leaching (EPA 1315M) 28 or 56 days								
									7 days	28 days	28 days Duplicate	56 days			28 days	28 days Duplicate	56 days									
1	1	4	2	0	2	1.25	x	x	x	x				x												
2	1	6	6	0	0	1.25	x	x	x	x				x												
3	1	6	3	0	3	1.25	x	x	x	x				x												
4	1	6	2	0	4	1.25	x	x	x	x				x												
5	1	8	8	0	0	1	x	x	x	x	4 of 8 mixes	Up to 2 contingent	4 of 8 mixes		6 of 8 mixes	2 of 8 mixes	Up to 2 contingent		2 mixes selected based on physical testing results							
6	1	8	2	0	6	1	x	x	x	x											x					
7	1	10	10	0	0	0.85	x	x	x	x											x					
8	1	10	3	0	7	0.85	x	x	x	x											x					
9	2	4	2	0	2	1.25	--	--	--	x				--							--					
10	2	6	6	0	0	1.25	--	--	--	x				--							--					
11	2	6	3	0	3	1.25	--	--	--	x				--							--					
12	2	6	2	0	4	1.25	--	--	--	x				--							--					
13	2	8	8	0	0	1	--	--	--	x	--			--												
14	2	8	2	0	6	1	--	--	--	x	--			--												
15	2	10	10	0	0	0.85	--	--	--	x	--			--												
16	2	10	3	0	7	0.85	--	--	--	x	--			--												
17	3	6	3	0	3	1.25	--	--	x	x	--			x												
18	3	8	2	0	6	1	--	--	x	x	--			x												
19	3	10	3	0	7	0.85	--	--	x	x	--			x												
20	2	6	0	2	4	1.25	--	--	x	x	--			x												
21	2	8	0	2	6	1	--	--	x	x	--			x												
22	2	10	0	3	7	0.85	--	--	x	x	--			x												

Notes:
 ASTM - ASTM International
 BFS - ground-granulated blast furnace slag
 EPA - United States Environmental Protection Agency
 PC - Portland cement
 -- - not tested

Table 3. Column Testing Monitoring Plan

Project No. AS230067A, Seattle, Washington

Column #	Description	Influent	Port 1	Port 2	Port 3	Effluent
	Sampling Frequency¹	Daily¹	Daily¹	Daily¹	Daily¹	Daily¹
1	Control	Total Metals ² , Dissolved Metals, PCP ³ , Anions, Alkalinity, Total Organic Carbon, Ferrous Fe, pH, Eh, DO, SC ⁴	Total and dissolved Arsenic, pH and Eh	Total and dissolved Arsenic, pH and Eh	Total and dissolved Arsenic, pH and Eh	Total Metals ² , Dissolved Metals, PCP ³ , Anions, Alkalinity, Total Organic Carbon, Ferrous Fe, pH, Eh, DO, SC ⁴
2	20 percent ZVI		Total and dissolved Arsenic and Copper, pH and Eh	Total and dissolved Arsenic and Copper, pH and Eh	Total and dissolved Arsenic and Copper, pH and Eh	
3	50 percent ZVI		Total and dissolved Arsenic, pH and Eh	Total and dissolved Arsenic, pH and Eh	Total and dissolved Arsenic, pH and Eh	
4	20 percent ZVI and saline water		Total and dissolved Arsenic, pH and Eh	Total and dissolved Arsenic, pH and Eh	Total and dissolved Arsenic, pH and Eh	

Notes:

1. Sampling frequency is estimated and will be updated based on the groundwater flow velocity estimated and COPC concentrations measured in the Data Gaps Investigation.

2. Total Metals, Dissolved Metals, and Anions analytes listed in Table 4

3. PCP analysis will be conducted at one third of the frequency of other analytes (approximately once per three days)

4. Measurements of pH, Eh, DO, and SC will be collected using a YSI meter.

Eh = oxidation-reduction potential

DO = dissolved oxygen

PCP = pentachlorophenol

SC = specific conductivity

Table 4. Column Analytical Methods

Project No. AS230067A, Seattle, Washington

Sample Matrix	Analytical Parameter	Analytical Method	Sample Container	No. Containers	Field Filtered?	Preservation Requirements	Holding Time
Water	Total Arsenic	EPA 6020B	250-mL polyethylene bottle	1	N	4°C ±2°C, HNO3 pH < 2	6 months
Water	Dissolved Arsenic	EPA 6020B	250-mL polyethylene bottle	1	Y	4°C ±2°C, HNO3 pH < 2	6 months
Water	Pentachlorophenol	SW8270E-SIM	500-mL Amber glass bottle	1	N	4°C ±2°C	7 days
Water	Total Metals (Arsenic, Calcium, Iron, Magnesium, Manganese, Potassium, Sodium)	EPA 6020B	250-mL polyethylene bottle	1	N	4°C ±2°C, HNO3 pH < 2	6 months
Water	Dissolved Metals (Arsenic, Calcium, Iron, Magnesium, Manganese, Potassium, Sodium)	EPA 6020B	250-mL polyethylene bottle	1	Y	4°C ±2°C, HNO3 pH < 2	6 months
Water	Anions (Bromide, Chloride, Fluoride, Nitrate as Nitrogen, Nitrite as Nitrogen, Orthophosphate as phosphate, Sulfate)	EPA 300.0	250-mL polyethylene bottle	1	N	4°C ±2°C	NO3, NO2, PO4 - 48hours; Others - 28 days
Water	Alkalinity	SM2320B	250-mL polyethylene bottle	1	N	4°C ±2°C	28 days
Water	Total Organic Carbon (TOC)	SM5310	250-mL amber glass	1	N	4°C ±2°C, H2SO4 pH < 2	28 days
Water	Ferrous Fe (Fe +2)	SM3500Fe-BM	250-mL amber glass	1	N	4°C ±2°C, HCl pH < 2, avoid headspace	24 hours
Water	Salinity	SM2520B	250-mL polyethylene bottle	1	N	4°C ±2°C	28 days
Water	Total Dissolved Solids	SM2540C/E	250-mL polyethylene bottle	1	N	4°C ±2°C	7 days